UNIVERSITÉ DE MONTRÉAL

AN EMPIRICAL INVESTIGATION OF THE IMPACTS OF COOPERATION TOOLS ON THE PRODUCT DEVELOPMENT PERFORMANCE IN THE AUTOMOTIVE INDUSTRY

GAËL LE HEN
DÉPARTEMENT DE GÉNIE ÉLECTRIQUE
ÉCOLE POLYTECHNIQUE DE MONTRÉAL

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AN EMPIRICAL INVESTIGATION OF THE IMPACTS OF COOPERATION TOOLS ON THE PRODUCT DEVELOPMENT PERFORMANCE IN THE AUTOMOTIVE INDUSTRY

présentée par : LE HEN Gaël
en vue de l'obtention du diplôme de : Philosophiae Doctor
a été dûment acceptée par le jury de l'examen constituée de :

M. BOURGAULT Mario, Ph.D., président
M. LEFEBVRE Louis A., Ph.D., directeur de recherche
Mme. LEFEBVRE Élisabeth, Ph.D.,codirectrice de recherche
M. PÉLLERIN Robert, Ph.D., membre
M. MENDGEN Ralf, Dr.Ing., examinateur externe

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ABSTRACT

Several empirical studies showed that a greater cooperation between the product development stakeholders has a positive impact on the product development performance and on the product's commercial success. Developing products in a cooperative manner may therefore help firms to improve their competitiveness and increase their market shares. Today, the cooperation issue is still at the at the top of manufacturing firms' agenda as they are confronted with an environment where topics such as time to market reduction, cost reduction, development of innovative and differentiated products, integration of a growing number of customers and legal requirements, or the reliance on dispersed teams are more and more present. For all these aforementioned topics, cooperation plays a major role.

The changes in the business and technological environment therefore require a greater level of cooperation and this has a profound impact on people, teams and organisations involved in product development activities: new tasks appear (e.g. plan product dismantling), new competencies are required (e.g. ability to cooperate in a virtual environment), the roles in teams are changing (e.g. supplier as innovation provider) and organisations are confronted with contradictions (e.g. usage of dispersed teams vs. team effectiveness). Since a few years ago, new cooperation technologies such as 3D visualisation, desktop conferencing, or Internet-based applications have emerged and they may help firms to address some of the aforementioned challenges or leverage them to enable new business processes. This study deals with the application of these advanced cooperation tools in product development teams. The main objectives were to find out the benefits of these new technologies and if additional capabilities could be gained (e.g. ability to work in a virtual manner). More precisely, the objectives of this study were to (i) find out how to implement and embed these new technologies in product development teams in an industrial environment, (ii) evaluate the impacts of cooperation tools and some organisational mechanisms on the product development performance, and (iii) examine the factors facilitating the adoption of the cooperation tools.

This study was divided into two main phases. First, advanced cooperation tools facilitating cooperation in virtual and multidisciplinary product development teams were implemented. The implementation consisted in defining and deploying these new cooperation tools and the associated new routines (or work patterns) in product development teams. Four product development teams participated in pilot projects. At the end of this first phase, a conceptual model was defined. In the second phase, a survey was conducted with the members of product development teams that used the collaboration tools to assess and validate the conceptual model. A total of sixty one respondents originating from Bosch and other firms in the German automotive industry participated in the survey. The automotive sector has some interesting characteristics such as heavy reliance on dispersed teams, development of complex products or high competitive pressure and therefore was a good field to study the computer-based cooperation phenomenon in product development teams. This study is also relevant for other manufacturing firms that are taking part in product development projects involving multidisciplinary participants and several organisations.

The first outcome of this study is an evaluation of the benefits of the collaboration tools and of organisational mechanisms. The adoption of CTs can bring benefits for the product development performance (defined as process performance, innovativeness and product and manufacturing performance). The CTs are also appropriate for the current challenges in the automotive industry (e.g. facilitate the work in a virtual environment). The second outcome is the proposition of success factors for the implementation of cooperation tools in product development teams. Some conditions must be fulfilled to facilitate the adoption of the cooperation tools: identify the right team members needing these tools (e.g. virtual environment, performing a lot of discussions) and take specific measures (e.g. training). Finally, several implications for firms, managers and teams wishing to leverage advanced cooperation technologies are suggested. Two main avenues are proposed: promotion of the CTs usage to support cooperation between tier 1 and tier 2 suppliers and a call to better take into account the importance of the product development process improvement.

CONDENSÉ EN FRANÇAIS

L'environnement dans lequel évoluent les entreprises manufacturières et les équipes en charge du développement de nouveaux produits a profondément changé au cours de ces dernières années : réduction du temps de développement, attention portée à une multitude de contraintes dès la phase de conception, développement de produits complexes, omniprésence de différents systèmes d'information, dispersion géographique et organisationnelle des équipes de développement, etc.. Ces changements ont eu un profond impact sur la manière de développer des produits et de nouvelles tâches ont apparues (gestion du cycle de vie), de nouvelles compétences sont requises (capacité à travailler en mode virtuel), les acteurs du cycle de vie produit ont parfois un nouveau rôle (de sous-traitant à « fournisseur d'innovation ») et de nouveaux défis sont à relever (recherche de l'efficacité vs. utilisation d'équipes virtuelles).

Dans ce contexte, la coopération prend une importance toute particulière. Ainsi, elle doit permettre à différentes personnes, organisations, disciplines ou « espaces de connaissance » de travailler ensemble pour répondre aux enjeux mentionnés précédemment. Pour les entreprises, la coopération revêt une importante particulière car un lien existe entre le niveau de coopération et le succès commercial d'un produit (Griffin and Hauser, 1996; Souder, 1988). Néanmoins, cette exigence en matière de coopération requiert la révision des pratiques existantes, l'adoption de nouveaux processus ou de nouveaux outils (notamment au niveau des technologies de l'information).

Les technologies de l'information peuvent (et doivent!) jouer un rôle primordial dans l'amélioration du processus de développement de produit. Ainsi, des outils tels que la téléconférence, des applications basées sur Internet (permettant d'accéder à des données produits, par exemple) ou encore la visualisation de modèles 3D offrent de réelles opportunités pour améliorer les processus existants. Cependant, ces outils restent encore peu utilisés dans le cadre des activités de développement par les entreprises manufacturières.

Cette étude s'intéresse donc à la diffusion et à l'évaluation de ces outils avancés de coopération dans un environnement industriel. La première phase de cette étude à été consacrée à définir le rôle et la place de ces outils dans les équipes de développement, à déterminer l'infrastructure technologique requise et à favoriser l'adoption de ces outils auprès de quelques équipes de développement. Lors de la seconde phase, l'intérêt s'est porté sur l'impact de ces technologies sur le processus de développement de produit et sur l'identification de facteurs de succès. Le secteur automobile présente des caractéristiques intéressantes, telles que l'utilisation d'équipes dispersées et multidisciplinaires ou le développement de produits complexes, et est donc un terrain propice pour l'étude du phénomène de coopération.

Les deux principales conclusions de cette étude sont les suivantes : les technologies utilisées sont matures et offrent de nombreux avantages (influence positive sur la performance du processus de développement de produit, l'innovation et la performance du produit et de la fabrication). Cependant, l'utilisation de ces technologies va souvent de pair avec certains critères : la virtualité des membres de l'équipe, l'existence de différences culturelles, de fréquents besoin de coopérer, la mise en place de mesures pour favoriser la coopération, l'accessibilité des outils et une formation adéquate.

Cette étude offre un nouveau regard sur le phénomène de coopération mais les aspects suivants mériteraient l'attention de nouvelles recherches : comment mieux inclure les partenaires d'affaire en harmonisant certains processus de développement dans l'industrie automobile? Comment améliorer la coopération entre les experts en mécanique, logiciel et électronique? Ou comment acquérir et diffuser les nouvelles pratiques en développement de produit au sein d'une organisation?

CHAPITRE 1 : CONTEXTE DE RECHERCHE

1.1 Environnement d'affaire dans l'industrie automobile

Cette étude se déroule dans le secteur automobile et il est important de définir les enjeux auxquels ce secteur sera confronté à l'avenir. Ainsi, nous serons en mesure d'identifier des pratiques d'affaires pour lesquelles les entreprises doivent posséder des compétences particulières et distinctives et pourrons alors déterminer les investissements nécessaires en matière de technologies de l'information.

De par son importance, le secteur automobile occupe une place primordiale dans l'économie de nombreux pays. Outre les zones traditionnelles de fabrication et de vente que sont l'Europe de l'Ouest, l'Amérique du Nord et le Japon, des zones comme la Chine ou l'Europe de l'Est sont actuellement en pleine croissance. Au cours d'un siècle d'existence, l'industrie d'automobile a connu trois révolutions majeures successives : passage de l'artisanat à la production de masse dans les années 20, puis de la production de masse au « lean manufacturing » sous l'impulsion du modèle japonais et notamment de Toyota. Pour la troisième révolution, plusieurs scénarios se profilent : les constructeurs seront-ils des fournisseurs de mobilité? ce mode de transport tiendra-t-il compte des éléments du développement durable? la complexité croissante des véhicules en feront-elles des ordinateurs sur roues? Le futur sera sans doute une combinaison de ces différents scénarii.

Ce secteur est soumis à de nombreuses contraintes qui influent sur le processus de développement de produit. Les gouvernements encouragent le développement de véhicules plus sécuritaires et plus respectueux de l'environnement (réduction des émissions et amélioration du recyclage). Le marché automobile évolue également, le nombre de modèles proposés s'accroît pour couvrir de nouveaux segments de marché, les véhicules proposés sont plus complexes pour répondre aux besoins de sécurité et de confort des clients. L'origine de cette complexité est l'utilisation massive de la « mécatronique », alliant logiciel embarqué, électronique et mécanique de haute précision. Enfin, ce secteur est marqué par une réduction des temps de cycle (développement et fabrication), une compétition féroce et une surcapacité au niveau mondial. Parallèlement, le besoin en coopération intra- et interentreprises reste encore important.

Pour faire face à ces changements, les constructeurs automobiles se concentrent de plus en plus sur les activités en aval de la chaîne de valeur (le financement de véhicules ou la gestion de flotte, par exemple) qui sont généralement à plus forte valeur ajoutée. Les activités de développement se concentrent sur la définition et le concept de véhicule et sur l'intégration de composantes et de systèmes provenant des sous-traitants. Le rôle des sous-traitants est donc devenu clef dans ce secteur et ceux-ci doivent offrir de la valeur, ils doivent être en mesure de fournir des systèmes ou composantes toujours plus innovants, s'appuyer sur des chaînes d'approvisionnement intégrées, être présent globalement et prendre en compte certains aspects du cycle de vie produit (offrir du support, par exemple). En d'autres mots, les sous-traitants doivent être capables de mettre en place des équipes de développement virtuelles, globales et multidisciplinaires en mesure de développer des produits complexes. Par ailleurs, ces sous-traitants doivent pouvoir s'intégrer avec leurs clients, leurs sous-traitants, réduire le coût et le temps de développement.

Le tableau suivant résume les principales tendances et les actions prises par les constructeurs et les équipementiers :

Tableau 1 – Sommaire des tendances sectorielles de l'automobile

<table>
<tr><th></th><th>Tendances</th><th>Actions des constructeurs</th><th>Actions des équipementiers</th></tr>
<tr><td>Politique</td><td>- Réduction de l'impact environnemental
- Amélioration de la sécurité des véhicules
- Augmentation de la responsabilité des acteurs</td><td rowspan="4">- Concentration sur les activités en aval
- Implications des équipementiers
- Concentration sur l'intégration des véhicules</td><td rowspan="4">- Mise en place d'équipes virtuelles (développement et fabrication à l'échelle mondiale)
- Développement de produits complexes et innovants (différentes disciplines)
- Intégration avec constructeurs, sous-traitants et partenaires
- Réduction temps de cycle et coûts
- Développement de plate-forme modulaire</td></tr>
<tr><td>Technologique</td><td>- Rôle prépondérant de l'électronique
- Produits complexes
- Innovations radicales</td></tr>
<tr><td>Sectoriel</td><td>- Réduction temps de cycle
- Compétition et sur-capacité
- Besoin de coopérer</td></tr>
<tr><td>Marché</td><td>- Réduction des coûts
- Marché de niche</td></tr>
</table>

Cette étude a été principalement conduite au sein de l'entreprise Bosch, le second plus grand équipementier automobile dans le monde en termes de chiffre d'affaires. Cette entreprise est reconnue dans ce secteur pour son leadership technologique (Scholtys et Werres, 2001; Chatterjee, 2001) et sa présence internationale. Par ailleurs, les tendances décrites précédemment sont aussi valables pour cette entreprise. En d'autres mots, cette entreprise constitue un terrain privilégié pour étudier le développement coopératif de produits et son support par des outils avancés de coopération. Outre le secteur automobile, l'entreprise Bosch est présente dans le secteur de l'électroménager, de l'outillage et des équipements industriels (systèmes automatisés).

1.2 Principales pratiques en développement de produit

Au cours des années 80 et 90, les pratiques et les outils utilisés pour le développement de produit ont beaucoup évolués. Traditionnellement, le développement de produit se faisait d'une manière séquentielle en passant de fonction en fonction (marketing puis développement puis production, etc.). Au cours des années 80, des termes tels qu'ingénierie concourante ou simultanée, inspirés par les pratiques des constructeurs automobiles japonais, ont apparus. Ces pratiques visent à paralléliser les activités pour réduire le temps de développement et à prendre en compte un maximum de contraintes du cycle de vie produit. Concrètement, cela s'est traduit par l'adoption de processus de développement (« stage gate ») par les entreprises, l'utilisation d'équipes multi-fonctionnelles, la promotion de la participation des sous-traitants, etc. Actuellement, ces pratiques sont largement diffusées, notamment dans le secteur automobile (Sànchez et Pèrez, 2003; Takieshi, 2001).

Outre ces changements organisationnels, les systèmes d'information ont pris une place importante dans le processus de développement de produit. En effet, l'utilisation de systèmes tels que la CAO (Conception Assistée par Odinateur), les SGDT (Système de Gestion des Données Techniques ou PDM : Product Data Manager), la maquette virtuelle ou la simulation est maintenant devenue commune lors du processus de développement de produit. Ainsi, les produits peuvent maintenant être conçus entièrement en trois dimensions. Cependant, de nombreux acteurs du processus de développement de produit, notamment ceux impliqués dans des activités « avales » telles que les achats ou la production sont exclus de cette chaîne « 3D » et accèdent aux données produits grâce au centenaire dessin 2D (Lang et al., 2002; Boujout et Laureillard, 2002).

1.3 Motivations et objectifs de l'étude

Au cours de la dernière décennie, la maquette virtuelle à joué un rôle important pour les intégrateurs de produits (constructeurs automobiles et aéronautiques) car elle permet de visualiser facilement un produit sans réaliser de prototypes physiques et offre la possibilité de réaliser certaines analyses (ex. : vérification de l'absence de collision). Dans cette étude, l'usage de cette technologie a été détourné (ou « ré-inventé » pour reprendre le terme de Rogers (1995)) de son usage originel. En effet, l'information produit que constituent ces modèles 3D de la maquette numérique peut être facilement accessible aux différents acteurs du cycle de vie, aidé en cela par l'utilisation d'outils de coopération complémentaires. Ainsi, les acheteurs, les planificateurs de production et d'assemblage, l'assurance qualité, les logisticiens, etc. peuvent avoir accès aux données produits (modèles 3D) très tôt et participer ainsi plus activement au processus de développement de produit. La figure suivante présente succinctement l'une des équipes de projet de projet ayant utilisée cette nouvelle génération d'outils de coopération. Cette équipe était en charge du développement d'une nouvelle génération d'alternateur où les différents acteurs du cycle de vie produit devaient collaborer étroitement ensemble (notamment l'ingénierie, la planification de production, les achats, etc.) dans un environnement distribué (Allemagne, Royaume-Uni et Espagne) :

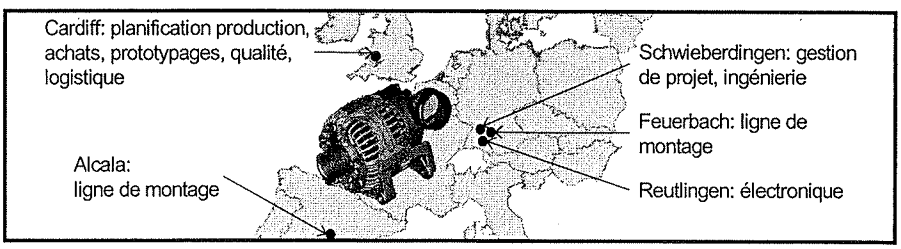


Figure 1 – Exemple de projet de développement

Préalablement à cette étude, plusieurs logiciels de maquette virtuelle et de coopération avaient été testés et le choix s'était porté sur les logiciels « Teamcenter Visualization » (utilisation du format JT) et « Teamcenter Community » (parfois plus connu sous le nom « d'e-Vis ») de l'entreprise UGS. Convaincue que ces technologies permettraient d'améliorer le processus de développement de produit chez Bosch, une petite équipe s'est attelée à la diffusion de ces technologies. En d'autres mots, cette étude est le fruit de près de trois années de travail pour faire aboutir une idée. Pour atteindre l'objectif final, à savoir l'amélioration de la performance du processus de développement de Bosch grâce à l'utilisation de ces nouvelles technologies, il était nécessaire de : (i) connaître la place de cette technologie dans le processus de développement de produit; (ii) déterminer l'infrastructure requise et l'intégration dans le paysage informatique existant; (iii) déterminer la manière d'implanter ces outils au sein d'équipes de développement; (iv) évaluer l'influence de certains facteurs sur l'adoption de cette technologie et (v) connaître enfin l'impact de cette technologie sur la performance du processus de développement de produit. Pour résumer, il s'agit de mieux comprendre l'impact de cette technologie, les prérequis nécessaires à son adoption et les implications futures.

CHAPITRE 2 : CONTEXTE THÉORIQUE DE L'ÉTUDE

Pour atteindre les objectifs définis précédemment, nous allons nous intéresser à la définition de la performance, aux processus de coopération qui existent lors du processus de développement, aux différentes technologies de coopération existantes, et aux mécanismes favorisant l'adoption des outils de coopération.

2.1 Performance du processus de développement de produit

Traditionnellement, la performance du processus de développement de produit est mesuré par l'atteinte des objectifs : temps, coûts et qualité (Gomes et al., 2003). D'autres définitions, plus générales, existent et prennent en compte des facteurs tels que l'acceptation du client, la performance financière, la performance du produit ou d'autres mesures spécifiques à l'entreprise (Griffin and Page, 1993). L'unité d'analyse étant l'individu dans une équipe en charge du développement d'une plate-forme produit, nous devons nous intéresser à des indicateurs plus détaillés et pertinents pour cette étude. Par ailleurs, la prise en compte de critères intangibles doit être inclue dans la mesure de la performance (Gerwin et Barrowman, 2002). Nous allons donc nous attarder sur quelques-uns de ces indicateurs de performance.

Dans l'industrie automobile, l'innovation produit et processus tient une place prépondérante. Premièrement, au niveau des équipes, la notion de créativité, définie comme l'interaction entre différentes personnes et idées, semble importante car elle mène à l'émergence de nouvelles idées (Leenders et al., 2003). Deuxièmement, l'utilisation d'équipes virtuelles est de plus en plus commune mais la virtualité influe sur le comportement et la communication au sein des équipes de développement (McDonough et al., 2001). Ainsi, la qualité du travail d'équipe est souvent utilisée pour mesurer la performance de telles équipes (Edwards and Shridhar, 2003; Huang et al., 2002; Potter and Balthazard, 2002). Enfin, il était nécessaire de tenir compte d'autres indicateurs de performance propres à l'industrie automobile. Outre les critères mentionnés ci-haut, la qualité et la performance de la chaîne d'approvisionnement sont des éléments important dans ce secteur (Von Corswant and Frediksson, 2002).

2.2 Coopération et activités de développement de produit

Dans un contexte marqué par la prise en compte de nombreuses contraintes (fabricabilité, impact environnemental, service, etc.) dès la conception du produit, la coopération, définie comme « le degré auquel les membres d'une équipe travaillent ensemble pour atteindre les objectifs de l'équipe (PDMA, 2003) », est donc de plus en plus nécessaire. De nombreuses études, notamment menées par des psychologues, ont eu pour objectif de définir la manière dont les personnes impliquées dans le processus de développement de produit interagissent et coopèrent entre elles. De manière générale, le développement de produit se déroule d'une manière « itérative » : une ou plusieurs solutions sont proposées, évaluées et une est finalement choisie. La figure suivante présente deux modèles :

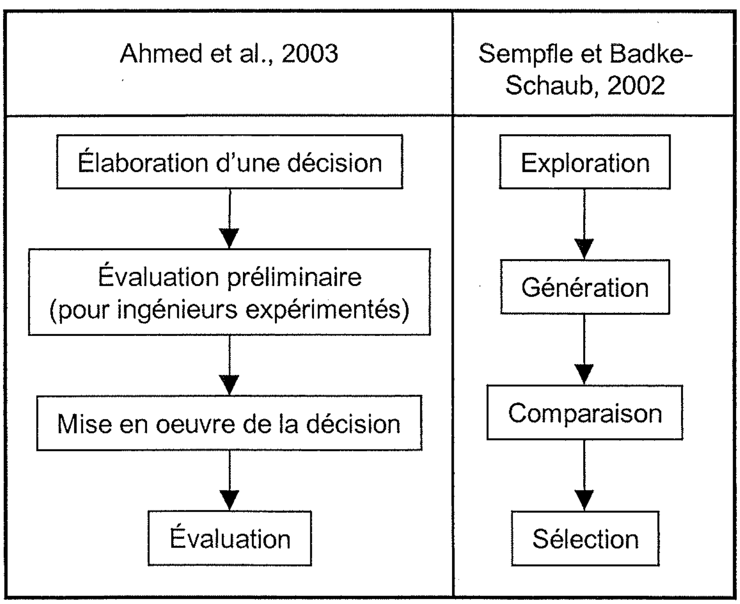


Figure 2 – Modèles de résolution de problèmes

Lors de l'étude de terrain, nous allons chercher à identifier le rôle des nouveaux outils de coopération dans ce processus itératif.

2.3 Définition et impacts des technologies de coopération

Deux types d'outils sont utilisés par les acteurs du processus de développement de produit : les outils individuels et ceux supportant la communication (Kappel et Rubenstein, 1999). Ces derniers peuvent être classés en deux catégories : les outils synchrones permettent une interaction en temps réel et les outils asynchrones permettent une interaction différée. Ainsi, le téléphone et les outils de conférence sont des outils synchrones, le courriel et les répertoires de données sont des outils asynchrones. Lors de cette étude, des outils synchrones et asynchrones seront utilisés.

Au cours de la dernière décennie, quelques chercheurs ont étudié l'impact et les conditions dans lesquelles ils apportent des bénéfices (Allen et Murotake, 1990; Robertson et Allen, 1992; Warkentin et al., 1997; Wierba et al., 2002).

2.4 Mécanismes favorisant l'adoption des technologies de coopération

Certaines études récentes ont montré que l'implantation (ou « l'appropriation ») de ces outils de coopération par les organisations n'est pas une chose aisée (voir paragraphe précédant). Quelques initiatives cherchent à promouvoir l'utilisation d'outils de coopération : le CPFR (Collaborative Planning Forecasting and Replenishment) dans le domaine de la chaîne d'approvisionnement (VICS, 1998), la « simultaneous engineering checklist » de l'association automobile allemande (VDA 4691/2, 2002) et le groupe de travail « maquette virtuelle entre constructeurs et sous-traitants » de l'association des constructeurs automobiles allemands (CAx-AG 2.6.6, 2002). Un point important ressort d'études publiées récemment à ce sujet (Maihora et al., 2001; Mohrman et al., 2003; Majchrzak et al., 2000; Susman et al., 2003) : la mise à disposition de ces outils de coopération n'induit pas automatiquement une meilleure coopération mais des processus utilisant ces outils doivent être établis.

2.5 Synthèse des recherches antérieure

Tableau 2 – Résumé des recherches antérieures et pertinentes pour cette étude

Auteur(s)	Objectifs et contexte de l'étude	Principaux résultats	Contributions	Faiblesses
Ahmed et al., 2003	Observation du processus de résolution de problème dans l'industrie aéronautique (ingénieur débutant vs. ingénieur expérimenté)	Modèle observé pour les ingénieurs expérimentés : élaboration d'une décision, évaluation préliminaire, mise en oeuvre de la décision et évaluation	Observation du processus de décision et de deux points de vue (débutant vs. expérimentés)	Observation dans une seule entreprise et influence des TIC non considérée
Gomes et al., 2003	Enquête (92 gestionnaires de R&D et de produit) sur la relation entre l'intégration fonctionnelle et la performance	Intégration fonctionnelle influence performance produit et opérations Coopération joue un rôle important pour produits innovants	Relation entre la coopération et l'innovation considérée	Influence des TIC non considérée
Gonzáles et Palacios, 2002	Enquête réalisée auprès d'entreprises espagnoles pour évaluer l'impact de nouvelles techniques de développement sur la performance du processus de développement de produit	Impact positif : TIC et techniques manufacturières (ex. : MRP); Impact neutre : ingénierie concourante, « DFMA » et « QFD »; Impact négatif : prototypage rapide	Évaluation empirique de meilleures pratiques d'affaires	Échantillon provenant d'un seul pays
Hauptman et Hirji, 1996	Enquête réalisée sur 50 projets pour évaluer l'impact de l'ingénierie concourante sur la performance du processus de développement de produit	Le succès dépend des éléments suivants : communication bidirectionnelle, régler problèmes en commun, prise de décision en utilisant des informations ambiguës	Évaluation de l'ingénierie concourante, travail d'équipe comme variable dépendante	Influence des TIC non considérée

Auteur(s)	Objectifs et contexte de l'étude	Principaux résultats	Contributions	Faiblesses
Leenders et Wierenga, 2002	Enquête sur l'efficience de 7 mécanismes d'intégration entre R&D et marketing dans l'industrie pharmaceutique	Co-localisation et TIC : mécanismes efficaces d'intégration TIC a un impact positif sur la performance	Influence des TIC considérée	Un seul secteur et seulement relations R&D et marketing
Leenders et al., 2003	Enquête réalisée dans le secteur électronique pour comprendre le phénomène de créativité pour différents niveaux de virtualité (haut vs. bas)	Les éléments stimulsnt la créativité : haute virtualité et innovation incrémentale; rôle non central du gestionnaire; non longévité de l'équipe. Haute virtualité dommageable si tâches complexes et haute créativité requise	Investigation des prérequis de la créativité Influence des TIC considérée	Échantillon provenant d'un seul secteur
Malhotra et al., 2001	Étude de cas identifiant les meilleures pratiques pour l'implantation d'un logiciel de coopération dans le secteur aéronautique	Trois facteurs de succès identifiés : mise en place d'une stratégie globale, décision de profiter de la technologie, modification des processus	Investigation d'outils de coopération dans l'industrie	Échantillon (une étude de cas)
May et Carter, 2001	Étude de cas sur l'utilisation d'outils avancés de coopération pour déterminer leurs impacts	Trois impacts majeurs : amélioration des discussions techniques, meilleure qualité et maturité et réduction temps de cycle	Investigation d'outils avancés dans l'industrie automobile	Échantillon (un seul secteur)
McDonough et al., 1999	Enquête visant à évaluer l'impact de différents mécanismes de communication dans les équipes globales de développement de produit	La formation et la culture influencent la manière de communiquer; la vidéoconférence a une influence négative sur la performance	Investigation de l'impact de différents moyens de communication	Petit échantillon et outils de coopération peu avancés
Mohrman et al., 2003	Évaluation de certaines attitudes et antécédents organisationnels sur les « knowledge outcomes » (« compétences accessibles ») et efficacité organisationnelle auprès de 3596	« knowledge work behavior » ou la manière de mener le travail a un fort impact sur l'efficacité organisationnelle (plus que les mécanismes traditionnels)	Large échantillon Investigation des prérequis du partage de connaissance;	Certaines mesures non validées

Auteur(s)	Objectifs et contexte de l'étude	Principaux résultats	Contributions	Faiblesses
Olson et al., 2001	Enquête visant à évaluer l'impact de l'intégration fonctionnelle (marketing, R&D, opérations) selon les phases du développement de produit	Accroissement de la performance : coopération entre R&D/opérations et R&D/marketing au début; marketing/opérations à la fin	Impact de la coopération selon les phases du développement de produit	Influence des TIC non considérée
Robertson et Allen, 1992	Identification des bénéfices et des prérequis des systèmes CAO dans 10 entreprises	Bénéfices importants si système CAO considéré comme « capital social » par les gestionnaires	Évaluation de l'impact des systèmes CAO sur les organisations	
Sicotte et Langley, 2000	Évaluation de différents mécanismes d'intégration sur la performance dans un centre de recherche corporative	Effets positifs pour : leadership formel, planification et TIC (si haute incertitude et ambiguïté)	Évaluation de l'efficacité de différents mécanismes d'intégration	Échantillon limité à un seul secteur
Stempfle et Badke-Schaub, 2002	Observation du processus de résolution de problèmes dans différentes équipes (étudiants)	Deux activités principales : réflexion (exploration, génération, comparaison et sélection) et processus de groupe (planification du travail, analyse, évaluation, décision, contrôle)	Investigation du processus de résolution de problème; Environnement contrôlé	Influence des TIC non considérée; utilisation d'étudiants
Takieshi, 2002	Enquête visant à déterminer la répartition des tâches et des connaissances entre constructeurs et équipementiers	Projets réguliers : constructeurs doit avoir une « connaissance architecturale » (coordination); Projets innovants : chevauchement entre constructeurs et équipementiers	Investigation de nouveaux aspects de la coopération	Seule industrie automobile japonaise considérée
Wierba et al., 2002	Enquête sur le processus d'implantation et l'impact d'outils de coopération avancé dans l'industrie automobile	Les outils de coopération doivent être supérieurs aux pratiques actuelles; Impact positif sur la performance	Considère l'adoption et l'impact d'outils de coopération	Échantillon (une seule entreprise)

Les principaux éléments ressortant de ces études sont les suivants :

- Secteur automobile : l'utilisation d'équipes virtuelles et multidisciplinaires semble privilégiée pour assurer le développement de nouveaux produits, surtout dans l'automobile. Néanmoins, la gestion de telles équipes se révèle souvent délicate (McDonough et al., 2001; Rognes, 2002; Wierba et al., 2002).

- Le rôle des mécanismes organisationnels et des outils de coopération : au cours des dernières années, de nombreuses études se sont intéressées au rôle des mécanismes organisationnels pour assurer l'intégration ou la coopération au sein des équipes (Dröge et al. 2000; Gonzàles et Palacios, 2002; Leenders and Wierenga, 2002; Sicotte and Langley, 2000, etc). Dernièrement, certaines études ont démontré le rôle prépondérant des technologies de l'information comme moyen « d'intégration » (Leenders and Wierenga, 2002).

- La mesure de la performance du processus de développement de produit : la mesure de la performance du développement de produit doit être adaptée à l'unité d'analyse et prendre en compte des critères intangibles allant au-delà du trio classique que forment le respect des coûts, des délais et de la qualité.

- Activités de développement de produit : le développement de produit est caractérisé par un accroissement des activités de transfert de connaissance entre les différents membres de l'équipe et par la mise en place de boucles itératives. En fait, la prise de décision est au cœur du processus de développement de produit (Ahmed et al., 2003; Robertson and Allen, 1993; Stempfle and Badke-Schaub, 2002).

Certaines pistes de recherche n'ont pas encore été approfondies et nous présentons ici quelques-unes :

- Évaluation des bénéfices d'une nouvelle génération de technologie : l'impact des nouveaux outils de coopération doit être évalué car peu d'études empiriques ne s'intéressent pour l'instant à ce phénomène, pourtant crucial pour les entreprises. De nombreuses études se penchent sur l'impact d'outils relativement « communs » tel que le courriel mais très peu sur des outils plus complexes, mis à part Wierba et al. (2002) ou les travaux de Allen au début des années 90 (Robertson et Allen, 1993).

- Évaluation des mécanismes d'appropriation des outils de coopération : d'un point de vue technique, ces nouveaux outils de coopération fonctionnent d'une manière très satisfaisante. Néanmoins, leur diffusion mérite toute notre attention et il serait donc intéressant de déterminer les facteurs favorisant l'adoption de ces technologies.

- Mesure de la performance : la prise en compte d'éléments intangibles est nécessaire pour la mesure de la performance du processus de développement de produit (travail d'équipe et créativité, notamment).

CHAPITE 3 : CADRE ET STRATÉGIE DE RECHERCHE

3.1 Cadre conceptuel

La performance du développement de produit sera la variable dépendante du modèle et celle-ci sera affectée par un certain nombre d'éléments. Parmi ces éléments on retrouve le contexte de l'équipe, les activités de collaboration (activités réalisées par les personnes impliquées dans le processus de développement de produit) et l'attitude collaborative (planification de la collaboration et les mesures prises pour améliorer la coopération). Par ailleurs, deux autres éléments ont été ajoutés au modèle : le niveau d'utilisation des outils de coopération et de variables liées à l'implantation (qualité des outils, formation et support). Enfin, un certain nombre de variables vont influer sur les relations du modèle. Les variables sont plus précisément décrites dans le tableau 3 (page suivante) et la figure suivante montre le cadre conceptuel suggéré pour cette étude :

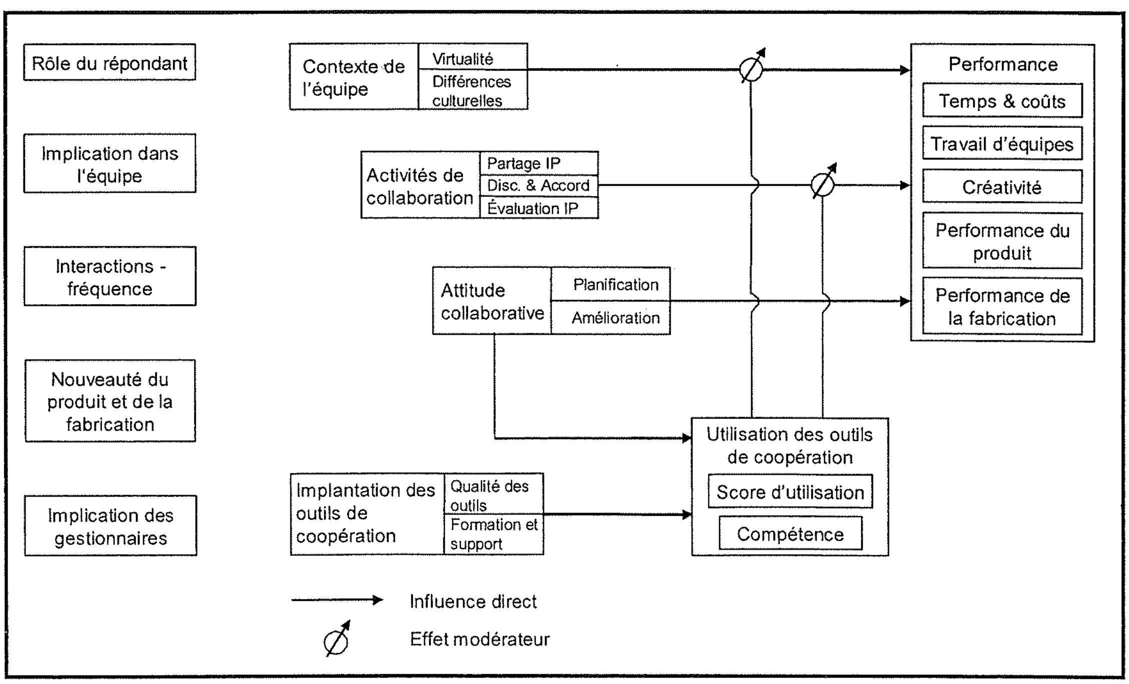


Figure 3 – Cadre conceptuel proposé

3.2 Justification des variables de recherches

Tableau 3 – Résumé des recherches antérieures et pertinentes pour cette étude

Variables	Justification et définition	
Contexte de l'équipe	Les membres des équipes de développement travaillent dans un environnement virtuel et multiculturel et cela devrait influencer la performance du processus de développement de produit	
	Virtualité	La virtualité se manifeste, par exemple, par la difficulté d'avoir des contacts avec les autres membres de l'équipe (Wierba et al., 2002) pour des discussions formelles et informelles
	Différences culturelles	Les équipes actuelles sont composées de membres ayant différentes disciplines (ou formations), langues et habitudes. Ces différences ont une influence sur le flux d'information (Lyles et Salk, 1996) certaines barrières apparaissent (Griffin and Hauser, 1996)
Activités de collaboration	Les membres des équipes de développement traitent de l'information produit (3 activités spécifiques qui seront définies ultérieurement) et cela devrait influencer la performance du processus de développement de produit	
	Partage d'information produit	Des données produits (modèles 3D, par exemple) sont notamment publiées par le département d'ingénierie et accessibles par les différents acteurs du cycle de vie produit
	Évaluation de l'information produit	Ces données produits peuvent être analysées pour trouver des paramètres importants ou être utilisés dans des applications tierces (simulation de fabrication, par exemple)
	Discussions & accords	À partir de l'évaluation de ces données produits, les acteurs du cycle de vie produit peuvent initier des discussions avec le département d'ingénierie (suggestions d'amélioration)

Variables	**Justification et définition**	
Attitude collaborative	Les membres des équipes de développement déterminent la manière de travailler ensemble et améliorent leurs relations. Ces éléments devraient influencer la performance et l'adoption des outils de coopération	
	Planification	Cette activité permet de définir les règles du jeu pour travailler en commun. Mohrmann et al. (2003) définissent cela comme routines ou des procédures communes
	Amélioration	Ce second élément concerne l'amélioration de la coopération par l'assignation de ressources et leur contrôle
Qualité de l'implantation des outils	Les caractéristiques des outils de coopération et certaines actions entreprises durant l'implantation devraient influencer l'adoption des outils de coopération	
	Qualité des outils	Les outils déployés doivent répondre aux besoins des utilisateurs et devraient influencer l'adoption (Delone et MacLean, 2002)
	Formation et support	Ce second élément devrait aussi influencer l'adoption des outils (Robertson et Allen, 1993)
Utilisation des outils de coopération	Cette dimension regroupe les différents outils déployés et sera considérée comme une variable dépendante et indépendante	
	Utilisation des outils	Les outils suivants ont été déployés : partage d'application (« application sharing »), conférence 3D, visualisation, conversion depuis modèles CAO vers maquette virtuelle,
	Compétence	Niveau de compétence des utilisateurs avec les outils de coopération

Variables	**Justification et définition**	
Performance	La variable dépendante du modèle conceptuel	
	Temps & coûts	Cette dimension est extrêmement importante dans le contexte actuel
	Travail d'équipe	La mise en place d'équipes virtuelles s'est traduit par une moindre satisfaction (McDounough et al., 2001, Wierba et al., 2002). Hors, une relation existe entre le travail d'équipe et l'efficience pour des produits innovants (Hoegle et al., 2003)
	Créativité	Le développement de produits complexes requiert l'intégration de différents savoir-faire et la créativité permet de les combiner pour créer de nouvelles solutions (Leenders et la., 2003)
	Performance du produit	Les nouveaux produits doivent avoir un niveau de performance toujours plus élevés (nouvelles fonctions, maintenabilité, coûts,...)
	Performance de la fabrication	La performance de la fabrication est un élément essentiel dans l'industrie automobile (réduction du temps de fabrication, flexibilité,...)

Variables	Justification et définition	
Variables de contrôle	Certaines relations du modèle conceptuel seront influencées par les variables suivantes :	
	Position de l'entreprise	La position de l'entreprise dans la chaîne de développement va influer sur son comportement (VDA 4691/2, 2002)
	Position et tâche du répondant	Le cœur de cette étude est d'améliorer les relations entre les fonctions amonts (conception produit) et avales (planification de production, par exemple). La position va influencer l'attitude du répondant
	Implication dans l'équipe	Une implication au début du processus de développement de produit permet d'avoir une certaine influence sur la conception
	Fréquence des interactions	De fréquentes interactions permettent de transférer des connaissances tacites (Koskinen et Vanharanta, 2002) et devraient mener à de meilleures idées (Leenders et al., 2003)
	Nouveauté produit & fabrication	Un nouveau produit ou processus est caractérisé par un haut niveau d'incertitude quant aux paramètres du produit ou du procédé (Moenaert et Souder, 1990; Sosa et al., 2002).
	Implication des gestionnaires	L'implication des gestionnaires est un facteur de succès clef pour l'adoption de nouvelles pratiques d'affaires

3.3 Propositions de recherche

Le tableau suivant présente les propositions de recherche pour cette étude :

Tableau 4 – Description des propositions de recherche

Propositions		Justifications
P1 – Le contexte de l'équipe va avoir une influence négative sur la performance	P1.1 – la virtualité a un impact négatif sur la performance	McDonough et al. (2001)
	P1.2 – les différences culturelles ont un impact négatif sur la performance	McDonough et al. (1999), Griffin et Hauser (1996)
	P1.3 – l'usage des outils de coopération compense les effets négatifs du contexte	Sosa et al. (2002), Wierba et al. (2002)
P2 – Les activités de collaboration vont avoir un impact positif sur la performance	P2.1 – le partage d'information produit a un impact positif sur la performance	Étude de terrain
	P2.2 – discussions et accords ont un impact positif sur la performance	Étude de terrain
	P2.3 – l'évaluation d'information produit a un impact positif sur la performance	Étude de terrain
	P2.4 – l'usage des outils de coopération va modérer les relations entre activités de collaboration et la performance	Étude de terrain
P3 – L'attitude collaborative va avoir un impact positif sur la performance	P3.1 – la planification de la coopération a un impact positif sur la performance	Mohrmann et al. (2003)
	P3.2 – l'amélioration de la coopération aun impact positif sur la performance	Holland and Plischke (2001)
P4 – L'attitude collaborative va avoir un impact positif sur l'adoption des outils de coopération	P4.1 – la planification de la coopération a un impact positif sur l'adoption des outils de coopération	Susman et al. (2003) et Malhotra et al. (2001
	P4.2 – l'amélioration de la coopération a un impact positif sur l'adoption des outils de coopération	
P5 – Des éléments d'implantation vont influencer l'adoption des outils de coopération	P5.1 – la qualité des outils de coopération va avoir une influence positive sur l'adoption	DeLone et MacLean (2002)
	P5.2 – la formation et le support vont avoir une influence positive sur l'adoption	Robertson et Allen (1992)

3.4 Stratégie de recherche

Cette étude a été divisée en deux phases principales et les objectifs de celles-ci sont décrits dans le tableau ci-dessous. Ces objectifs sont aussi dérivés des éléments du contexte technologique (cf. Chapitre 1).

Tableau 5 – Objectifs de l'étude de terrain et de l'enquête statistique

Objectifs de l'étude de terrain	Objectifs de l'enquête
- Identifier l'usage potentiel des outils de coopération pour les activités de développement de produit (« itérations ») - Intégrer les outils de coopération dans les procédures des équipes (« procédures ») - Implanter les outils de coopération dans les équipes - Définir l'infrastructure requise - Identifier des fonctionnalités supplémentaires	- Évaluer l'impact des outils de coopération - Évaluer les relations entre les éléments du modèle conceptuel

Un point important de la première phase était la nécessité de supprimer les barrières technologiques qui empêchent généralement l'utilisation de ces outils (Sosa et al., 2002; Krishnan et Ulrich, 2001; Wang et al., 2002). Nous voulions avoir une approche « bottom-up » : commencer par de petits projets, accumuler de l'expérience, comprendre les mécanismes de transition, comprendre l'utilisation qui en serait faite et changer les méthodes de travail et concentrer notre effort sur la mise en œuvre de cette technologie et des nouvelles pratiques d'affaires qui en découlent. Cette première phase aurait put être réalisée d'une autre manière (« top down ») : définition d'une méthode prescriptive et son implantation dans un second temps. Néanmoins, compte tenu de la nature du projet (nouvelle technologie et nouvelle pratique d'affaire), la méthode « bottom-up » a été privilégiée.

La seconde phase de ce projet était consacrée à la validation empirique des résultats et à mieux comprendre le rôle et la dynamique de certaines variables. Ces deux phases sont souvent utilisées par d'autres recherches empiriques, la première phase servant à trouver les thèmes importants et la seconde servant à tester ou à confirmer certains mécanismes. La difficulté ici était de créer le terrain pour la seconde phase.

Au début de cette étude, l'équipe de recherche a présenté les outils de coopération dans les différentes unités d'affaires de Bosch et plusieurs gestionnaires de projets ont été intéressés par l'utilisation de ces technologies dans leur projet. Néanmoins, plusieurs critères de sélection ont été définis (notamment après l'échec de certains projets d'implantation) : implication et support des gestionnaires, plate-forme produit où un produit et sa chaîne d'approvisionnement sont développés conjointement, existence de mécanismes organisationnels d'intégration, équipe dispersée, intervention au début du projet et disponibilité de l'infrastructure informatique. Le tableau suivant présente les principales équipes ayant participé à cette recherche :

Tableau 6 – Équipes ayant participé aux activités de recherche

Équipe	Description du produit	Besoin en coopération	Activités de recherche
EIN	Étude de faisabilité pour une génération d'injecteurs diesel	Évaluation de la faisabilité d'une composante par différents experts	Entrevues et groupes témoins; Définition de routines de coopération; Formation et support (six mois); Coopération interne; Participation à l'enquête
DRO	Nouvelle plate-forme de « papillon » pour moteur essence	Pièce critique conçue et fabriquée par un sous-traitant situé à 400km; Fréquentes interactions entre la conception, les achats et le sous-traitant	Entrevues et groupes témoins; Formation et support (six mois); Coopération externe
GEN	Nouvelle plate-forme d'alternateur (configurable, compact, puissant et efficient)	Alternateur et une partie de la ligne d'assemblage conçus en Allemagne; Fabrication, assemblage et achats localisés au Pays de Galles; Produit et opérations développés simultanément	Entrevues et groupes témoins; Définition de routines de coopération; Formation et support (deux années); Coopération interne; Participation à l'enquête
TEE	Nouvelle plate-forme de pompe et gauge multi-carburant	Produit développé entre 4 sites en Allemagne et en Espagne avec deux systèmes CAO; Production et assemblage planifiés en République Tchèque	Formation et support (3 mois); Participation à l'enquête

3.5 Collecte et analyse de données

Lors de cette première phase, la collecte de données a été faite principalement par l'intermédiaire de groupes témoins (« focus groups »). Ces groupes sont souvent utilisés pour les enquêtes de marchés et consistent à réunir certaines personnes pour discuter d'un sujet particulier. Cette méthode offre de nombreux avantages car elle permet d'obtenir de nombreuses données en peu de temps, de stimuler les discussions et débats et est relativement facile à organiser au sein d'une entreprise (Babbie, 1998). Un total de cinq rencontres avec des groupes témoins a été réalisé durant cette étude (les résultats sont disponibles dans la section suivante).

Pour analyser les résultats des groupes témoins et pour guider notre action, nous avons utilisé la théorie ancrée (« grounded theory »). Cette théorie dont les origines se trouvent dans le domaine de la sociologie (Glasser, 1998) consiste à induire des théories à partir des données collectées sur le terrain (les groupes témoins dans notre cas).

Basé sur l'étude de littérature et les résultats des groupes témoins, un questionnaire à été développé et validé par un groupe d'experts (chercheurs et gestionnaires de projets). Ce questionnaire a été distribué à des utilisateurs des outils de coopération dans différentes équipes de développement de Bosch (92 personnes au total) et auprès d'entreprises du secteur automobile utilisant des systèmes analogues. Il a été distribué sous format PDF et pouvait être rempli et renvoyé par les répondants (soit sous forme électronique, soit par la poste).

CHAPITRE 4 : RÉSULTATS ET ANALYSE

4.1 Résultats de l'étude de terrain

La méthode privilégiée pour collecter les données durant cette étude a été l'utilisation de groupes témoins dont un résumé est présenté ci-dessous :

Tableau 7 – Description des groupes témoins

Points abordés → Audience ↓	Usages potentiels des outils de coopération	Bénéfices et barrières	Information produit et flux d'information	Définition de routines de coopération
Fonctions « activités amonts »	✓		✓	
Fonctions « activités avales »	✓		✓	
Membres de l'équipe « EIN »	✓	✓		✓
Membres de l'équipe « DRO »	✓	✓		
Membres de l'équipe « GEN »	✓	✓	✓	✓

Ces groupes témoins ont permis d'aborder chacun des thèmes avec différentes équipes. Ce processus assure une meilleure validité des résultats. Le tableau suivant montre les principaux résultats des deux premiers thèmes (usage potentiel, barrières et bénéfices) :

Tableau 8 – Principaux résultats des groupes témoins

Points abordés	Catégories identifiées et exemples
Usages potentiels des outils de coopération	- Évaluation des données produit selon différents critères (ex. : évaluation de la fabricabilité) - Utilisation des données produits pour planifier les activités avales (ex. : choix d'une séquence assemblage) - Faciliter le travail avec les sous-traitants (ex. : préparation d'une demande de cotation) - Faciliter le travail avec les clients (ex. : explication de changements) - Discussion et accords (ex. : préparation de réunions, discussions de suggestions)

Points abordés	Catégories identifiées et examples
Bénéfices	- Réduction des temps de cycle (ex. : accès rapide aux données produit, tâches réalisées plus rapidement, réactivité, éviter le travail redondant) - Réduction des coûts (ex. : réduction du nombre de prototypes physiques et du nombre de voyages) - Amélioration de la qualité du travail (ex. : réduction du travail à l'aveugle, meilleure planification des opérations) - Amélioration du travail en commun (ex. : plus grande transparence, meilleure compréhension du design, meilleure coordination)
Barrières	- Mauvaise performance technique (ex. : instabilité des logiciels) - Fonctions inappropriées (ex. : inadaptation aux besoins, complexité, difficulté à exporter les modèles 3D) - Mauvaise implantation des outils (ex. : absence de formation, de support et de méthode, sécurité non prise en compte) - Coûts et efforts additionnels (ex. : coûts des licences, gestion et maintien des données)

Ces groupes témoins nous ont permis de définir le flux d'information dans les équipes de développement. À partir du flux d'information et des usages potentiels mentionnés précédemment, une « boucle de coopération » à été déterminée :

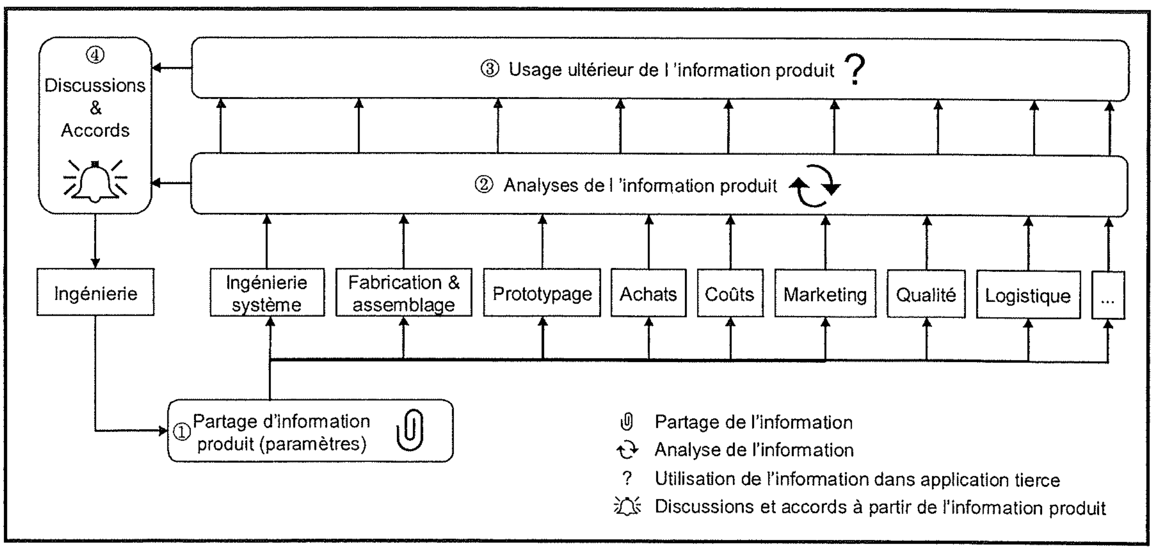


Figure 4 – Boucle de cooperation

Cette boucle comporte quatre éléments principaux. Le partage d'information entre les « fournisseurs d'information » (à savoir les concepteurs de modèles 3D ou « fonctions amonts ») et les « récepteurs d'information » (à savoir les utilisateurs potentiels de ces modèles 3D ou « fonctions avales »). Ces modèles 3D peuvent alors être analysés, c'est à dire que le récepteur peut trouver de l'information produit utile pour effectuer sa tâche (ex : planification de production) ou utiliser cette information dans des applications tierces (simulation, par exemple). Enfin, si le récepteur constate qu'il existe un problème ou une amélioration potentielle, il communique ses suggestions au département de conception. Pour résumer, une boucle de « coopération » se crée, l'information est partagée et les acteurs du cycle de vie produit peuvent être impliqués dans la processus de développement. Quelques auteurs soulignent l'importance de ces « boucles » notamment pour les produits innovants (Debackere, 1999; Lynn, 1996; Eppinger, 2001).

Pour concrétiser l'usage et faciliter l'appropriation et le transfert par les répondants, des routines ont été définies. Ainsi, Allison (1971) suggère que la définition de routines est un élément clef dans une organisation et ceci est notamment vrai dans le processus de développement de produit (Soderquist et Nellore, 2000). Par routines de coopération, nous comprenons des tâches réalisées régulièrement, impliquant plusieurs personnes et pouvant s'appuyer sur des outils de coopération. La figure suivante présente le rôle des routines dans le processus de développement de produit :

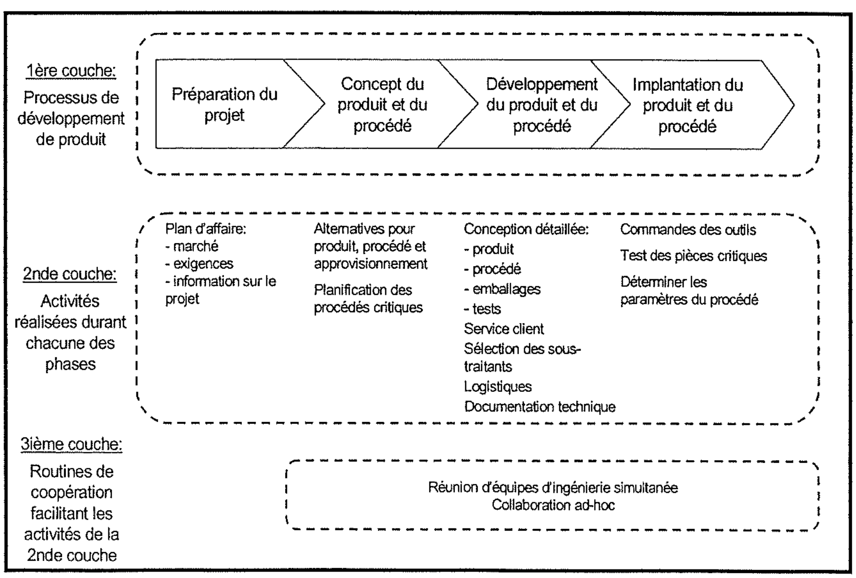


Figure 5 – Place des routines dans le processus de développement de produit

Au cours de cette étude, quelques routines ont été définies : « réunion d'équipe d'ingénierie simultanée », « coopération ad-hoc », « planification de production » et « revue de design» (cette dernière ayant été définie avec le groupe de travail maquette virtuelle entre sous-traitants et constructeurs, CAx-AG 2.6.6 (2002)).

Au cours de l'étude de terrain, une infrastructure technologique a été mise en place pour faciliter le flux d'information au sein des équipes de développement. En d'autres mots, il convenait de fournir les outils nécessaires pour réaliser la boucle de coopération :

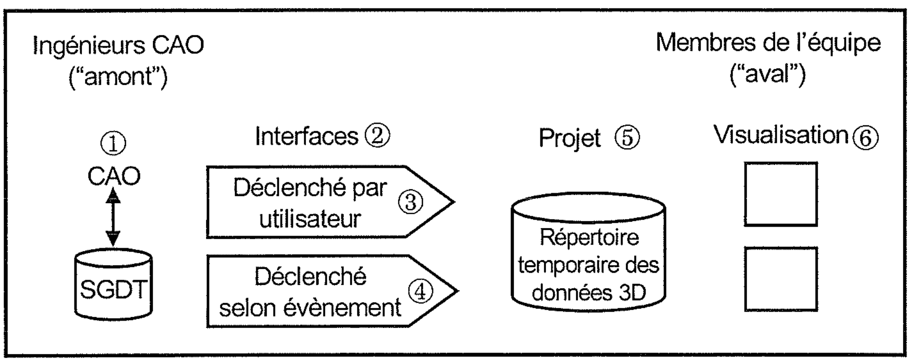


Figure 6 – Processus de conversion des données CAO

L'infrastructure privilégie l'intervention humaine à une conversion automatique (ex. : conversion systématique et journalière de tous les modèles 3D CAO vers la maquette virtuelle). Ainsi, les concepteurs doivent choisir, les modèles CAO 3D devant être exportés (voir points ① et ③ dans la figure). Par exemple, ce concepteur peut choisir d'exporter plusieurs alternatives de design pour demander l'avis à différentes fonctions avales. Le point ④ constitue un cas particulier, les données sont publiées lorsque le design a atteint un certain niveau de maturité (ex. : « quality gate »). Ces données, qui ont un caractère temporaire, sont exportées dans un répertoire de données (⑤). En effet, ce répertoire n'a pas vocation à devenir un système d'archivage et de suivi mais constitue une plate-forme flexible de discussions. Ces données peuvent être visualisées en utilisant des logiciels de visualisation (⑥) ayant différents niveaux de fonctionnalités.

4.2 Résultats de l'enquête

4.2.1 Audience du questionnaire

Le questionnaire a été envoyé à 92 utilisateurs de la plate-forme de coopération chez Bosch et 53 réponses ont été reçues. Ces utilisateurs étaient localisés dans différentes régions allemandes, au Pays de Galles et en République Tchèque. Pour les entreprises externes, le questionnaire a été envoyé à 18 représentants d'entreprises (dans l'industrie automobile allemande) connues pour être utilisatrices de ces technologies. Ces représentants étaient en charge de distribuer les questionnaires au sein d'équipes de développement. Huit questionnaires ont été retournés par ces entreprises. Par ailleurs, le fournisseur de logiciel a été contacté pour distribuer le questionnaire auprès d'autres entreprises : sans succès.

Plusieurs facteurs peuvent expliquer la faiblesse du nombre de réponses, notamment de la part des entreprises extérieures. La pratique des enquêtes par questionnaires est peu répandue en Allemagne. À la suite de plusieurs discussions informelles, il s'est aussi avéré que les outils de coopération sont encore très peu utilisés pour l'usage que nous préconisons, à savoir l'amélioration du travail en commun en utilisant des modèles 3D.

4.2.2 Fiabilité des construits et statistiques descriptives

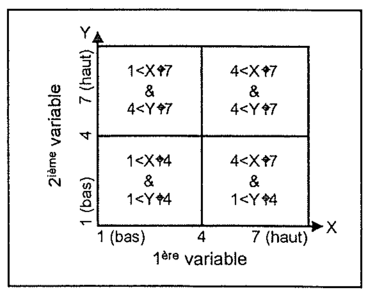
Le tableau suivant (page suivante) présente les α Cronbach, les moyennes et la déviation standard pour les différents construits. Ces construits sont différents de ceux présentés dans le modèle conceptuel. En effet, la valeur de certains α Cronbach était non satisfaisante. Une analyse factorielle a permis de raffiner les construits initiaux. Pour la qualité de l'implantation, trois nouveaux construits ont été définis : utilité des outils, accessibilité des outils (ex. : facilité d'utilisation) et formation. Pour la performance, trois construits ont été retenus : performance du processus de développement de produit (ex. : réduction de temps et de coûts), innovation (ex. : nombre d'alternatives, créativité) et performance du produit et de la fabrication.

Tableau 9 – Analyse univariée et fiabilité des construits

Dimensions	Construits	α Cronbach	Moyenne	Déviation standard
Contexte de l'équipe	Virtualité	.8378	4.63	1.80
	Différences culturelles	.7122	4.00	.098
Activités de collaboration	Partage information produit	.6310	4.59	1.33
	Discussion et accord	.8335	4.97	1.45
	Évaluation info. produit	.8828	4.31	1.90
Attitude collaborative	Planification de la coopération	.7674	4.50	1.22
	Amélioration de la coopération	.7540	2.97	1.27
Qualité de l'implantation	Utilité des outils	.8125	5.54	1.27
	Accessibilité des outils	.7873	4.65	1.18
	Formation	.9138	4.51	1.73
Performance du développement de produit	Performance du processus	.8581	3.94	1.42
	Innovation	.8676	4.36	1.59
	Performance produit et fabrica.	.9376	3.66	1.42

4.2.3 Définition de groupes et analyses bivariées

La seconde phase de l'analyse consiste à identifier des groupes de répondants dont le comportement pourrait se révéler intéressant. Trois méthodes ont été utilisées pour identifier ces groupes : les quadrants, les quartiles et le calcul de cluster. Les quadrants, établis à partir de deux variables (voir figure ci-contre), permettent de facilement définir des groupes. L'analyse par quartile est une méthode permettant de classifier les répondants selon leurs réponses (groupe 1 : 25% des répondants ayant le plus bas score, groupe 2 : les 25 % suivants, etc.). Enfin, l'analyse par cluster se base sur des méthodes mathématiques pour former des groupes (en minimisant la différence au sein d'un groupe et en maximisant la différence entre ces groupes). Pour chacun des groupes identifiés, une analyse bivariée sera conduite. Celle-ci consiste à calculer la moyenne d'une variable par les membres de chacun des groupes. L'échelle de Likert a été conservée pour toutes les variables, sauf pour mesurer l'adoption des outils de coopération. En effet, un score global a été calculé en multipliant le score obtenu par chacun des outils par un indice de



complexité propre à chaque outils. Ce score a été déterminé par des utilisateurs et des experts. Les principaux groupes sont définis dans le tableau suivant:

Tableau 10 – Description des principaux groupes identifiés

Variables	Groupes identifiés	Description
Rôle dans le processus de développement de produit	Gestionnaires de projet	Chef de projet ou membres d'équipe ayant un rôle actif dans les fonctions amont et avale
	Spécialistes amont	Personnes impliquées dans la conception du produit (conception mécanique, par exemple)
	Spécialistes aval	Personnes utilisant les données issues de la conception produit (planification de produit, achats)
	Spécialistes IT	Personnes impliquées dans l'implantation d'outils (provenant essentiellement d'entreprises externes)
Interactions avec partenaires d'affaires	Peu d'interactions avec partenaires d'affaires	Personnes impliquées dans le processus de développement ayant peu d'intéraction avec les clients et les sous-traitants
	Beaucoup d'interaction avec sous-traitants	Personnes impliquées dans le processus de développement ayant beaucoup d'intéraction avec les sous-traitants (pièces et outils)
	Beaucoup d'interaction avec clients	Personnes impliquées dans le processus de développement ayant beaucoup d'intéraction avec les clients
Nouveauté	Produit et processus de fabrication sont nouveaux	La personne impliquée dans le processus de développement estime que le degré de nouveauté du produit et du processus est élevé
	Haut niveau pour produit et bas niveau pour fabrication	La personne impliquée dans le processus de développement estime que le degré de nouveauté du produit est élevé mais pas celui du procédé (fabrication d'un nouveau produit sur une ancienne ligne de production, par exemple)
	Bas niveau pour le produit	La personne estime que le degré d'innovation est faible

Variables	Groupes identifiés	Description
Utilisation des outils de de coopération	Utilisation - Quartiles	Définition de quartiles
	Compétences	Définition de trois groupes (peu, moyennement et très compétent)
Virtualité	Haut niveau de virtualité	Ces personnes estiment que leurs collègues sont géographiquement très dispersés et très difficiles à joindre
	Niveau de virtualité moyen	Ces personnes estiment que leurs collègues sont moyennement dispersés et difficiles à joindre
	Bas niveau de virtualité	Ces personnes estiment que leurs collègues sont géographiquement peu dispersés et faciles à joindre

À partir de ces groupes, des analyses bivariées ont été conduites. Le tableau suivant présente, selon les principales dimensions du modèle conceptuel, le comportement de différents groupes :

Tableau 11 – Comportement des groupes selon les dimensions du modèle conceptuel

Dimensions	Relations avec les groupes
Contexte de l'équipe	- Les groupes suivants sont caractérisés par un haut degré de virtualité : procédés nouveaux, fréquentes interactions avec partenaires d'affaires et haut usage des outils de coopération - Le niveau de virtualité est bas pour les groupes suivants : produit nouveau et planification de coopération
Activités de collaboration	- Les groupes suivants partagent de l'information produit : gestionnaires de projet et beaucoup d'interactions avec les clients - Les groupes suivants sont très engagés dans des activités de coopération (« discussions et accords ») : haut degré de nouveauté du produit - Les groupes suivants sont actifs dans l'évaluation de données produits : beaucoup d'interaction avec sous-traitants et utilisation fréquente les outils de coopération
Attitude collaborative	- La planification de la coopération est une activité pratiquée par les spécialistes amonts, lorsque le niveau d'innovation de la fabrication et le niveau de virtualité sont bas - L'amélioration de la coopération est pratiquée par les répondants ayant beaucoup d'interaction avec les clients et utilisant fréquement les outils de coopération
Utilisation des outils de collaboration	- Les répondants ayant les caractéristiques suivantes utilisent fréquemment les outils de coopération : le gestionnaire est formé et utilise lui-même les outils de coopération, le degré de nouveauté du produit relativement bas, le répondant à le rôle de gestionnaire de projet, travail dans un environnement virtuel avec de grandes différences culturelles et lorsque les outils de coopération sont jugés accessibles
Performance	- La performance du processus est lié avec: un niveau élevé d'implication des gestionnaires, un niveau de nouveauté du produit bas, un haut niveau de virtualité, beaucoup d'interactions avec les partenaires d'affaires et à l'utilisation des outils de coopération - L'innovation est lié avec : l'implication occasionnelle du répondant dans l'équipe (« rôle de consultant »), un haut niveau de virtualité et une fréquente utilisation des outils de coopération - Performance du produit et de la fabrication : beaucoup d'interactions avec les partenaires d'affaires et utilisation des outils de coopération

4.2.4 Test des hypothèses de recherche

La figure suivante présente une version révisée du modèle conceptuel ainsi que les propositions de recherche :

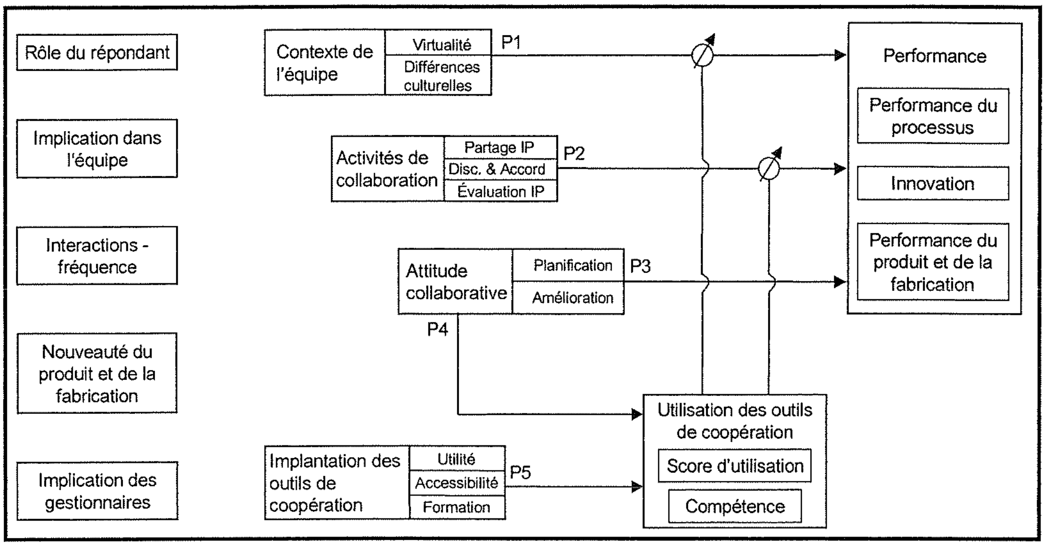


Figure 7 – Résumé des propositions de recherche

Le tableau suivant présente les différentes corrélations entre les variables indépendantes et la performance du processus de développement de produit :

Tableau 12 – Corrélation entre variables dépendantes et indépendantes

		Variables dépendantes		
		Performance du processus	Innovation	Performance du produit et de la fabrication
Variables indépendantes	Virtualité	**.452****	**.329****	.285
	Différences culturelles	**.428****	**.282***	**.429****
	Partage d'information produits	–.114	–.055	–.060
	Discussion et accord	–.012	.101	–.179
	Évaluation de l'information produit	–.004	–.175	.102
	Planification de la coopération	–.007	.026	–.199
	Amélioration de la coopération	.254	**.284***	**.631****
	Score d'utilisation	**.659******	**.556****	**.729******
	Compétence	**.565******	**.366****	**.701******

Le tableau ci-dessous montre les coefficients de corrélation entre certaines variables indépendantes et l'utilisation des outils de coopération ainsi que la compétence :

Tableau 13 – Corrélation entre les variables indépendantes et utilisation des outils

		Variables dépendantes	
		Score d'utilisation	Compétence
Variables indépen-dantes	Planification de la coopération	.083	.018
	Amélioration de la coopération	**.576******	**.370****
	Utilité des outils	.188	.213
	Accessibilité des outils	**.344***	**.341****
	Formation	**.436****	**.356****

À partir de ces résultats, les propositions de recherche peuvent être validées ou non :

Tableau 14 – Test des propositions de recherche : résumé des résultats

Propositions		Résultats
P1	P1.1 – la virtualité a un impact négatif sur la performance	Non soutenue
	P1.2 – les différences culturelles ont un impact négatif sur la performance	Non soutenue
P2	P2.1 – le partage d'information produit a un impact positif sur la performance	Non soutenue
	P2.2 – discussions et accords ont un impact positif sur la performance	Non soutenue
	P2.3 – l'évaluation de l'information produit a un impact positif sur la performance	Non soutenue
P3	P3.1 – la planification de la coopération a un impact positif sur la performance	Non soutenue
	P3.2 – l'amélioration de la coopération a un impact positif sur la performance	Partiellement soutenue
P4	P4.1 – la planification de la coopération a un impact positif sur l'utilisation des outils de coopération	Non soutenue
	P4.2 – l'amélioration de la coopération a un impact positif sur l'utilisation des outils de coopération	Soutenue
P5	P5.1 – l'utilité des outils a un impact positif sur l'utilisation des outils de coopération	Non soutenue
	P5.2 – l'accessibilité des outils a un impact positif sur l'utilisation des outils de coopération	Soutenue
	P5.3 – la formation a un impact positif sur l'utilisation des outils de coopération	Soutenue

Un certain nombre des propositions faites dans le troisième chapitre ne sont pas vérifiées empiriquement. Plusieurs explications peuvent nous aider à comprendre ces résultats. Les effets de la virtualité sont beaucoup discutés dans la littérature et dans les organisations. Pour certains, ces équipes sont requises, pour d'autres, ces équipes ne sont pas aussi performantes que les équipes co-localisées. Nos résultats montrent que la virtualité et les différences culturelles sont corrélées avec la performance et donc que les bénéfices excèdent les inconvénients.

4.2.5 Analyses multivariées

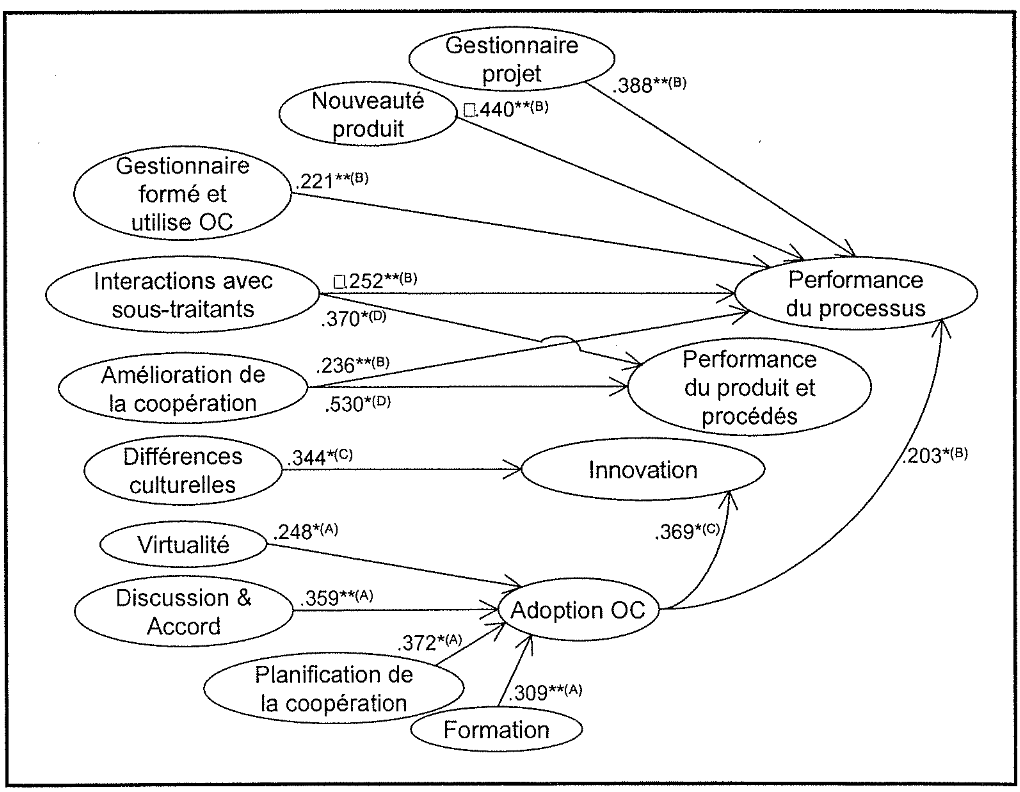
Le but des analyses multivariées est de permettre d'établir la causalité entre deux variables. Un certain nombre de règles doit être respecté pour ce genre d'analyses (notamment la non-collinéarité entre les variables, la normalité des variables et un ratio de 1 à 7 entre le nombre de variables et le nombre de répondants). Un certain nombre de modèles ont été testés et sont présentés dans le tableau suivant :

Tableau 15 – Analyses multivariées : présentation des résultats

Modèles	Variables	β standardisé
Modèle A – Influence des variables sur l'adoption des outils de coopération	Virtualité	.248*
	Discussion et accord	.359**
	Planification de la coopération	–.372**
	Formation	.309**
	R^2	.276
	R^2 ajusté	.198
	SIG.	**
Modèle B – Influence des variables sur la performance du processus	Gestionnaire de projet	.388**
	Interactions avec sous-traitants	–.252**
	Nouveauté produit	–.440**
	Gestionnaire formé et utilisant outils de coopération	.221**
	Amélioration de la coopération	.236*
	Utilisation des outils de coopération	.203*
	R^2	.736
	R^2 ajusté	.660
	SIG.	****

Modèles	Variables	β standardisé
Modèle C – Influence des variables sur l'innovation	Différences culturelles	.344**
	Utilisation des outils de coopération	.369**
	R^2	.302
	R^2 ajusté	.262
	SIG.	**
Modèle D – Influence des variables sur la performance du produit et de la fabrication	Interactions avec sous-traitants	.370**
	Amélioration de la coopération	.530**
	R^2	.423
	R^2 ajusté	.385
	SIG.	****

Ces analyses révèlent les facteurs ayant une influence (positive ou négative) sur la performance du processus de développement de produit et sur l'adoption des outils de coopération. Il est à noter que ces analyses confirment certains résultats obtenus dans les analyses bivariées. Les résultats sont présentés dans la figure suivante :



OC : Outils de Coopération

Figure 8 – Analyses multivariées : résumé des résultats

4.2.6 Analyses supplémentaires

Deux analyses supplémentaires ont été effectuées pour (i) préciser et confirmer les facteurs favorisant l'adoption des outils de coopération et (ii) définir un profil de l'utilisation des outils de coopérations. Les résultats de cette seconde analyse seront présentés ici. Une analyse de cluster a été effectuée sur les trois principaux outils de coopération et trois groupes aux caractéristiques intéressantes ont été identifiés :

Tableau 16 – Analyses supplémentaires : cluster sur le type d'utilisation des outils de coopération

	Groupe 1 $n_1 = 18$	Groupe 2 $n_2 = 14$	Groupe 3 $n_3 = 14$	
	Usage peu fréquent des OC	Visualisation des modèles 3D	Usage équilibré des OC	Test K-W
	Moyenne[1]	Moyenne[1]	Moyenne[1]	
Visualisation de modèles 3D	1.56	**5.36**	3.21	****
Conférences avec modèles 3D	1.28	2.14	**2.29**	**
Partage d'application	1.39	2.21	**4.57**	****

Mesure : Chebyshew, Méthode : Ward
[1]Basé sur l'échelle de Likert (1 = usage rare et 7 = usage très fréquent)

Le premier groupe utilise très peu les différents outils proposés. Le second groupe utilise essentiellement la visualisation de modèles 3D. Enfin, le troisième groupe fait une utilisation relativement équilibrée des différents outils de coopération. Une analyse bivariée à été effectuée en utilisant cette classification (notamment sur l'usage des outils dans 12 mois). Le groupe 2 continuera à se focaliser sur la visualisation des données 3D et le groupe 3, quant à lui, utilisera toujours plus les outils. Ces résultats peuvent être interprétés de la manière suivante : un groupe ne s'intéresse qu'à la visualisation des données produits (la visualisation 3D agirait comme successeur des modèles 2D) et l'autre continuera d'utiliser les différents outils de coopération. Ainsi, ces deux profiles sont parallèles et indépendants et non séquentiels (d'abord visualisation des modèles 3D et utilisation des différents outils de coopération).

CHAPITRE 5 : SYNTHÈSE ET DISCUSSION

5.1 Forces et faiblesses de cette étude

L'intérêt principal de cette étude à été de réaliser une investigation en profondeur d'une nouvelle technologie (la maquette virtuelle), pour un nouvel usage (coopération multidisciplinaire) dans un environnement industriel. Le second intérêt de cette étude est d'avoir suivi des méthodes variées et adaptées au phénomène étudié. Cette approche a permis de concilier les attentes des différents acteurs de cette étude (équipes de développement, personnes en charge d'implanter ces nouvelles technologies et aspects académiques).

Néanmoins, cette étude a plusieurs limites intrinsèques pouvant limiter la généralisation de ces résultats. Premièrement, cette étude s'est entièrement déroulée dans le secteur automobile. Cependant, certains auteurs (Léger, 2003 et Cassivi, 2003) soulignent que ceci est adapté à l'étude de phénomènes exploratoires car le contexte industriel est le même pour tous les répondants. Par ailleurs, nous pensons que ces résultats peuvent être extrapolés dans d'autres secteurs. Deuxièmement, l'échantillon a été relativement limité mais a quand même permis d'identifier différents groupes dont le comportement a été intéressant. Enfin, une partie du modèle conceptuel a été basé sur des variables provenant de l'étude de terrain et non vérifié auparavant. Néanmoins les valeurs des α Cronbach ont confirmé nos choix. Une critique additionnelle peut concerner les éléments du modèle conceptuel dont certains éléments peuvent manquer. Il est cependant illusoire de vouloir un modèle complet (par exemple, Hauser et Zettelmeyer (1996) ont identifié plus de 80 facteurs de succès).

5.2 Rappel des principaux résultats et implications

L'étude de terrain a montré que les outils de coopération sont matures et peuvent être utilisés dans un environnement industriel (ex. : intégration possible avec systèmes CAO). Ces outils répondent aux attentes des utilisateurs et leurs permettent de répondre aux enjeux actuels (virtualisation, complexité, etc.). Le nombre croissant d'équipes de développement utilisant nos technologies témoigne de cet intérêt. Un autre résultat important de cette étude de terrain est l'importance qu'il faut accorder au processus d'implantation de cette technologie car elle ne se « diffuse » pas par elle même mais requiert un accompagnement. La figure suivante montre, en se basant sur l'enquête statistique, les facteurs influençant la performance du développement de produit :

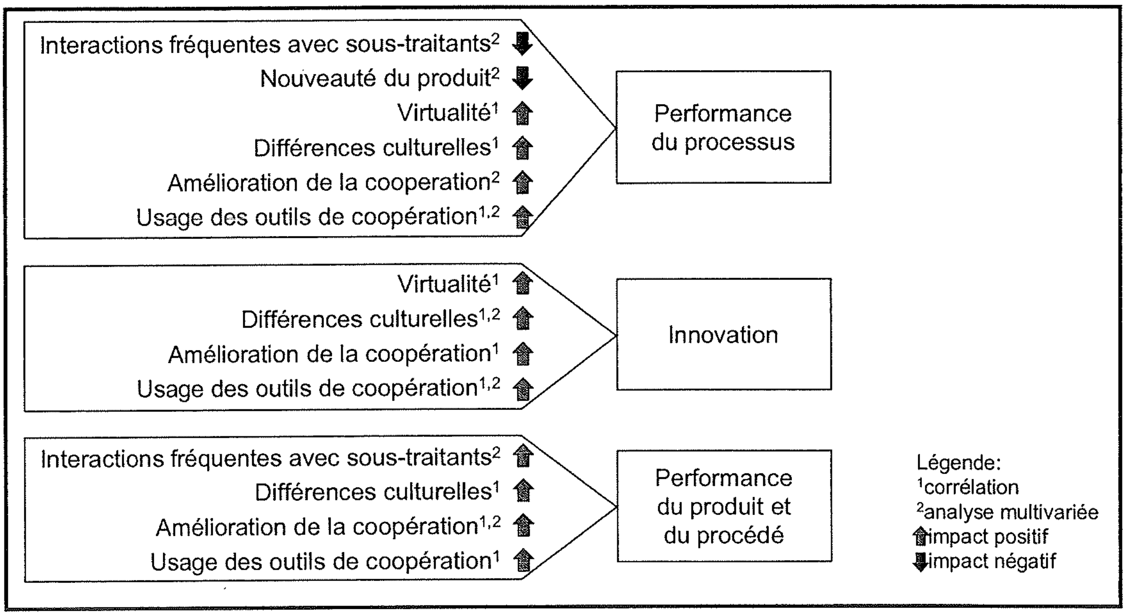


Figure 9 – Analyse statistique : variables influençant la performance

Enfin, la figure suivante montre les facteurs influençant l'adoption des outils de coopération et l'impact sur la performance du développement de produit :

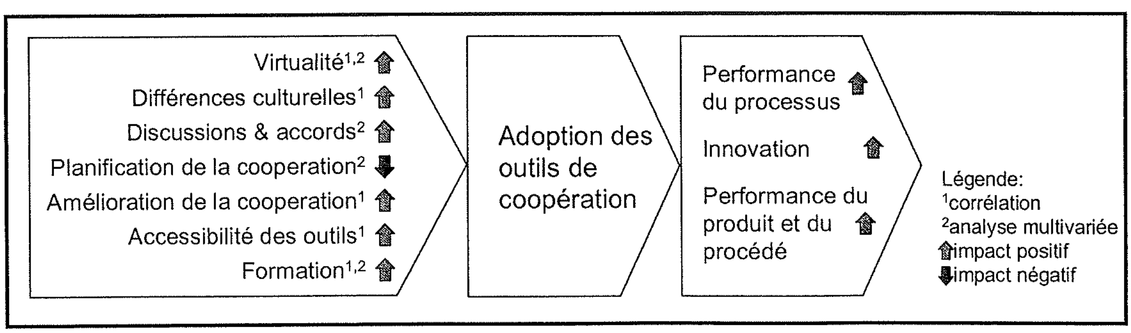


Figure 10 – Analyse statistique : variables influençant l'adoption des outils de coopération

Le tableau suivant résume les principaux résultats et les implications qui en découlent :

Tableau 17 – Implications de certains résultats de l'étude

Principaux résultats	Implications
Le rôle ambigu des sous-traitants : influence positivement la performance du produit et du procédé mais négativement la performance du processus	- Les problèmes de sécurité doivent être résolus afin de faciliter la diffusion des outils de coopérations dans la chaîne de développement (pare-feu, cryptage des données) - Un portail Internet devrait être mis en place pour faciliter la coopération avec les sous-traitants de rang 2 (pour faciliter le flux d'information) - Déterminer le rôle des outils de coopération dans la chaîne de développement et communiquer les meilleures pratiques d'affaires - Définition de mécanismes pour faciliter l'adoption des outils de coopération dans la chaîne de développement (grâce à des recommandations, par exemple)
Influence du contexte sur l'adoption des outils de coopération	- Il est nécessaire d'identifier les équipes pour lesquelles l'usage des outils de coopération apporte un bénéfice substantiel (travail en mode virtuel et coopération active)
Influence de l'amélioration de la coopération et de la qualité de l'implantation sur l'adoption des outils de coopération	- Des ressources doivent être allouées à l'amélioration de la coopération lorsque les outils de coopération sont implantés (séance de réflexion sur les outils) - La coopération doit être récompensée (car tous les acteurs ne profitent pas de la coopération!) - Les outils de coopération doivent demeurer simple d'utilisation - La formation joue un rôle essentiel pour l'appropriation des outils de coopération - Différents concepts de formation doivent être proposés (focus sur la visualisation 3D et sur les outils de coopération) - Les gestionnaires doivent être sensibilisés aux possibilités des outils de coopération, leurs bénéfices et les prérequis (dans le but de les inciter à les implanter) - Un modèle de maturité pourrait être défini (dans le but de les inciter à en évaluer l'impact)

5.3 Futures initiatives de recherche

Certains développement technologiques devraient être entrepris pour améliorer, à l'avenir, la coopération au sein des équipes de développement. Premièrement, le contenu en information du modèle 3D doit être enrichi pour devenir une base de travail au sein des équipes de développement. En effet, le dessin 2D continue de jouer un rôle prépondérant du fait de sa richesse en information (ex. : tolérances) et du fait que ces dessins constituent la base contractuelle pour les relations interentreprises.

Deuxièmement, cette étude s'est focalisée sur la partie « mécanique » d'un produit. Or, les produits actuels font de plus en plus appel à l'électronique et aux logiciels embarqués. Il serait intéressant de comprendre comment la coopération se déroule entre ces différents domaines et quels outils pourraient être utilisés. Par ailleurs, des problèmes liés à la sécurité empêchent parfois une plus grande diffusion des outils de coopération.

D'autres avenues de recherche devraient se focaliser sur des aspects organisationnels et notamment sur l'amélioration du processus de développement de produit qui passe par l'adoption de nouveaux outils et méthodes. Lorsque l'on évoque le terme de « meilleure pratique » ou de « meilleur processus », le Toyota Production System vient rapidement à l'esprit. Au cours de ces deux dernières décennies, ce système a permis à cette entreprise de se hisser comme l'une des entreprises les plus reconnues du secteur automobile. Cette entreprise définit depuis quelques années un Toyota Development System visant à systématiser le processus et promouvoir la coopération (Amasaka, 2002). Une telle initiative est attrayante pour une entreprise souhaitant à acquérir des compétences distinctives dans le domaine du développement de produit.

CONCLUSION

Cette étude a démontré que l'adoption d'outils de coopération représente une réelle opportunité pour les entreprises manufacturières souhaitant améliorer leur processus de développement de produit. À mon avis, le principal enjeu à été l'adoption de ces technologies par les équipes de développement de produit. Pour ce faire, une approche pragmatique conciliant les besoins des équipes et les possibilité des outils de coopération a été adoptée. Cette étude contribue aux connaissances dans le domaine du génie industriel et à la gestion de la technologie. Durant cette étude, j'ai eu de fréquent contacts avec des ingénieurs industriels qui ont eu, grâce à ces nouvelles technologies, la possibilité d'appliquer leur savoir faire et de prendre une part active au processus de développement de produit. De plus, cette étude contribue au domaine de la gestion de la technologie. Cette discipline est apparue en Amérique du Nord lorsque des universitaires et des agences gouvernementales ont conclu que les personnes et les organisations n'étaient pas en mesure de s'adapter aux changements de l'environnement d'affaire et technologique. Au cours de cette étude, nous avons essayé de concilier les aspects technologiques, les personnes et leur manière de travailler. Ainsi, différentes sources universitaires ont été consultées (des psychologues aux spécialistes en technologies de l'information). Par ailleurs, des sources professionnelles ont été consultées, notamment pour déterminer les tendances dans l'industrie automobile. D'un point de vue personnel, j'ai apprécié de pouvoir prendre part à des projets intéressants qui m'ont permis d'implanter une nouvelle technologie dans une organisation – ou ce qui pourrait être aussi appelé la « diffusion de l'innovation ». De plus, ce travail à été réalisé dans l'industrie automobile allemande qui combine différentes caractéristiques intéressantes et développe des produits fascinants : haute exigence technique pour développer des produits qui allient l'émotion, le plaisir de conduire, le respect de l'environnement dans un environnement international. Par ailleurs, cette étude a été conduite à Stuttgart – une sorte de « Motortown » allemande – qui a vu naître l'industrie automobile il y a plus d'un siècle. Cet environnement est encourageant pour l'exploration de nouvelles possibilités et j'espère que cela va continuer ainsi.

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INTRODUCTION

The design of new products is crucial because their major characteristics such as materials, manufacturing processes or ability to satisfy a function are defined almost exclusively during this phase. Ulrich and Pearson (1998) empirically demonstrated that a significant portion of the cost differences results directly from design decisions made early in the product development process (greater impact than local manufacturing economics or variations in plant efficiency). Being strategic, issues related to the development of products are receiving a great attention in the academic literature and numerous studies were published on topics like identification of success factors, investigation of the impact and the effectiveness of business practices, suggestion of prescriptive and descriptive methods, etc.

At the end of the 80´s and beginning of the 90´s, some studies shed a new light on the product development activity and put the emphasis on the crucial role of cooperation (Womack et al., 1991; Wheelwright and Clark, 1992; Clark and Fujimoto, 1991). Since then, numerous empirical studies have demonstrated that a higher level of cooperation or collaboration among product development stakeholders is a critical success factor for product development (Griffin and Hauser, 1996; Souder, 1988). By nature, the development of a product is a collective effort from stakeholders or team members steaming from different disciplines (mechanics, electronics, software, manufacturing, purchasing, etc.) and organisations (suppliers and OEMs) that work together to develop the product and its supply chain. At the team level, problem solving has a tremendous importance: Wheelwright and Clark (1992) asserted that "detailed problem solving is at the core of outstanding development" because team members solve "... engineering problems in a manner that integrates the design of related components, the manufacturing process, and cost management (Takeishi, 2001)". To summarise, product development stakeholders take decisions based on their knowledge and available information. Clark and Fujimoto (1991) compared the product development process to an "information processing system" which "creates, communicates and uses" design information, a final product being the "embodiment of design information".

For this reason, a lot of firms or teams adopted new tools (e.g. Computer Aided Design, Product Data Manager), methods (e.g. Quality Function Deployment, Design for Manufacturing and Assembly) or organisational structures (e.g. cross functional team) aiming at improving and promoting cooperation or decision making during the product development process.

In the same way that electronic commerce reshapes firm activities like procurement or supply chain management, Information and Communication Technologies (ICTs) can redefine and improve how the product development activity is conducted. Some empirical studies demonstrated that the performance of the product development process can be improved by the use of ICTs (Leenders and Wierenga, 2002; McDonough and Kahn, 1996). The information technologies play an important part in the product development (e.g. 3D CAD, PDM) and new technologies (e.g. Internet or visualisation of 3D models) offer opportunities to "revolutionize" it (Krishnan and Ulrich, 2001). Today, the centenarian 2D drawing, face to face meetings, and traditional communications tools (e.g. email, fax and phone) are still the basis for technical discussions. 3D visualisation and other cooperation tools may replace the 2D drawings as a privileged support for communication in the future. The visualisation of 3D models is a promising technology that allows product development stakeholders to access the 3D representation of a product (e.g. dimensions) and other key data associated to the product geometry (e.g. weight) very early in the product development process. These new technologies should enable a greater cooperation among the product development stakeholders by removing communication barriers, the goal being "to connect those who know with those who need to know" (SAP, 2000). The potential benefits of these new cooperation tools are numerous and often cited in professional journals (shorter product development, error reduction, reuse of existing design, better cross functional and organisational cooperation, travel reduction, etc) and known under different acronyms (CPC – Collaborative Product Commerce, E2E – Engineering to Engineering, etc.).

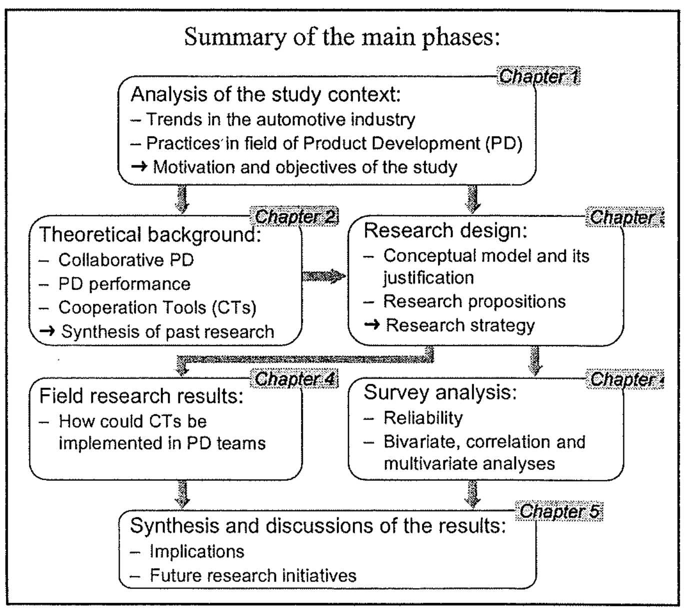
This study was conducted in the automotive sector which is evolving rapidly and has some interesting characteristics: (i) we assist to the transition from "low tech" to "smart" products as the product complexity is increasing due to environmental, safety and driving pleasure requirements, (ii) the model variety is booming to cover new markets, and (iii) time to market and time to customers are being reduced. In addition, the roles of the firms in the automotive value chain are also evolving and the "part makers" are becoming "innovative solution providers" or "full service providers". Actually, suppliers are nowadays responsible for an important part of the design and manufacturing activities and are operating on a global scale. Product development teams in the automotive industry are nowadays dispersed with members from different organisations and different backgrounds. Therefore, it is worthwhile to study the implementation of advanced cooperation tools in this sector. The research has been conducted in Germany by the Robert Bosch GmbH, the second largest automotive supplier world-wide. This company is a leader for the evaluation and research on cooperation technologies in product development teams in this sector along firms like General Motors, Ford, DaimlerChrysler or Siemens.

The author took an active role in the implementation of the cooperation tools (focus groups with product development teams, training, and support of end-users, and participation in working groups in the automotive industry), the design of the questionnaire and the analysis of the results. This study was divided into two main phases. The first phase dealt with the implementation of the cooperation tools in product development teams. Our unit of analysis are team members in charge of the development of product platforms (which are very interesting projects as they deal with the design of a new product and its associated supply chain and require a high level of cooperation). This first phase (or field study) was needed to (i) define how the cooperation tools could be used (or embedded) in product development teams, (ii) define the required IT infrastructure and (iii) identify additional functionalities that could help team members to cooperate better.

During the second phase of the study, a survey was realised to (i) empirically assess the impact of the cooperation tools on the product development performance in teams using the cooperation tools and (ii) find out elements that influence the adoption of the cooperation tools. As a consequence, it was possible to derive implications for managers and persons in charge of the diffusion of the cooperation tools.

This study may contribute to explaining the impact of Internet based development systems on the way which product development activities are performed and the consequences on the product development performance.

The business imperatives in the automotive industry and the main trends in the field of product development will be presented in the first chapter. The main theoretical concepts related to product development performance measurement, the cooperation activities performed during the product development process, the usage of IT-based cooperation tools, the appropriation of cooperation tools, and a synthesis of the past research will be presented in the second chapter. The third chapter presents the conceptual model, the justification of the research variables, the research propositions, the research setting and the data collection strategy. The fourth chapter presents the field research results and the analysis of the survey. The fifth chapter summarises the most important results, presents the practical and theoretical contributions, analyses the strengths and weaknesses of this study, and gives an overview of future research initiatives.



CHAPTER 1: CONTEXT OF THE STUDY

This study is about the improvement of the product development through the usage of new IT technologies. A close link exists between the business strategy and the ICTs strategy as either the ICTs must support a business strategy or new ICTs enables new business practices (Davenport, 1992). Therefore, knowing the challenges facing firms in the automotive value chain, it will be easier to identify the most important activities of the product development process that need to be mastered and which could be supported by the ICT infrastructure. In addition, the identification of relevant technologies that could improve the way a product is developed may procure a competitive advantage for a firm or a sector. The objectives of this chapter are to identify key activities that need to be mastered in the future, present a promising technology and present the research objectives. In the first section, the current and future issues in the automotive sector are presented as well as the strategies adopted by car manufacturers and major suppliers. The second section deals with the main trends in the field of product development and focuses on the organisational aspects, on the role of current information technologies, and the opportunities offered by new technologies. Finally, based on the two previous sections, the motivation and the objectives of the study will be presented in the third section.

1.1. Business environment in the automotive industry

This study being performed in the automotive sector, it is essential to understand its dynamic and its evolution to gain a broad understanding of the challenges and issues that the different actors of the value chain will face in the near future. Here, the focus will be on the product development activity.

To identify the challenges and issues faced by firms in the automotive value chain, the drivers will be presented from different perspectives: political, market, technological and sectorial. Then, the implications for car manufacturers and suppliers and the strategies they adopt will be discussed. Some of the trends described here are also occurring, to a greater or lesser extent, in other sectors (aeronautical, industrial installation, transportation, etc.).

1.1.1. Definition and evolution of the automotive sector

1.1.1.1. The main actors of the automotive sector

In 2002, 58.2 million new vehicles were sold to customers throughout the world. Before they reached the showrooms, hundreds of people from various backgrounds, in different organisations and countries had worked together to develop and manufacture the most complex consumer product. This complexity is due to the fact that a car is made of more than 20,000 parts made from different materials (metals, plastics, textiles, etc.), contains complex components aiming to offer new features (e.g. ESP – Electronic Stability Program) or enhance existing ones (e.g. reduce fuel consumption with injection control). Therefore, the efforts required to develop a new car are high and Ulrich and Eppinger (cited by Veloso and Kumar, 2002) estimated that 10,000 specific and unique parts are developed, 500 people involved, 2.5 million engineering hours needed for a total cost of US $1 billion.

The main life cycle phases are shown in the middle of the following figure, the arrows show where the different players make their contributions:

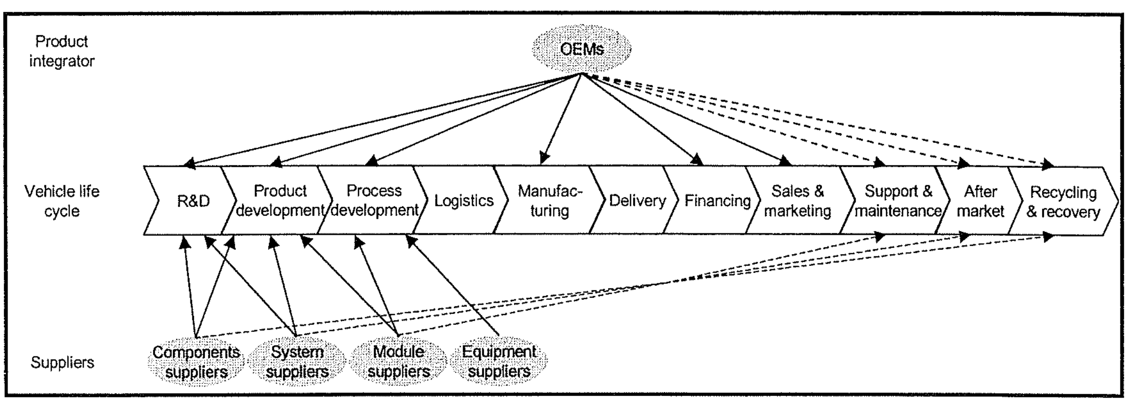


Figure 1.1 – Automotive value chain

This study focuses on the product and process phases of a vehicle life cycle (simplified to "product development" hereafter) and on some actors that contribute to these two phases (namely car makers and major suppliers).

The passenger cars and the commercial vehicles are the two main components of the automotive industry. By the denomination "commercial vehicles", we understand trucks (light and heavy) and busses. It goes without saying that the vehicle manufacturers are the most well known firms in this sector. These firms are responsible for the development and delivery of motor vehicles and are called "vehicle manufacturers", "car manufacturer" or more simply "OEMs" (Origin Equipment Manufacturers). This sector is very concentrated as the number of car makers diminished from 42 in 1970 to 16 in 2000 and the five biggest car manufacturers account for 50% of the vehicles sold in 2002. This sector is dominated by "generalists" that own different brands (e.g. Ford) and cover different segments (e.g. high volume passenger cars, commercial vehicles or sport and luxury). However, some "specialists" (e.g. BMW) remain on the market and cover sport and luxury segments. The figure below shows the 12 biggest OEMs in 2002 (source: Wolz, 2002).

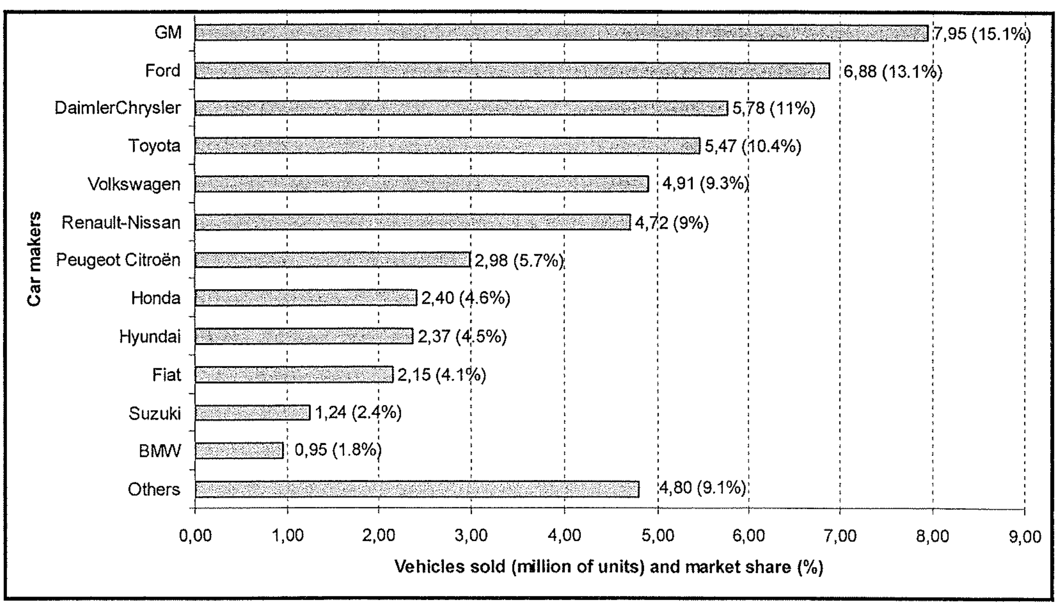


Figure 1.2 – Main vehicle manufacturers

Suppliers are firms whose importance is growing rapidly in the automotive sector. For example, the sales made by German automotive suppliers almost doubled in the last decade, rising from 29.5 billion € in 1992 to 56.6 billion € in 2002, which represents an increase of 91.9% (VDA, 2003). The reasons beyond this phenomenon will be developed later in this chapter.

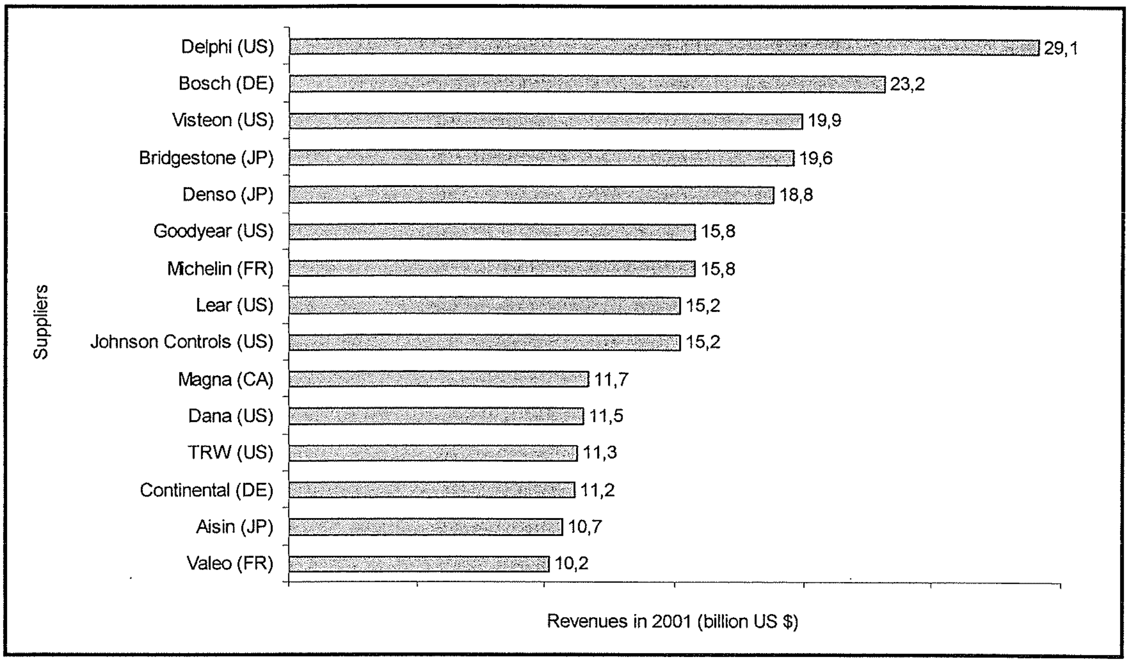


Figure 1.3 – Main automotive suppliers

Source: Bosch Corporate Intranet (2003)

A consolidation phenomenon is also occurring among the automotive suppliers, their number is decreasing while their size is increasing and the main reasons cited by experts are the search for higher capacity (development and manufacturing) and the intense competition. A recent study of Pricewaterhouse Coopers estimated that by the year 2010, 35 global automotive suppliers will remain (instead of 800 today) and that the bargaining power will shift to the suppliers (Automobilwoche, 2002). We will perhaps see the emergence of the "Intel Inside" syndrome in the automotive sector predicted by Fine (1997). The figure above shows the biggest suppliers. Some of them were former OEMs´ internal suppliers until the end of the 90's (Delphi belong to GM, Visteon to Ford and Denso to Toyota). Tire suppliers like Bridgestone, Goodyear or Michelin top among the biggest suppliers. The spectrum of products that suppliers develop and manufacture is very wide, some deliver simple parts other complex sub-systems like engine management or entire interior. The following table shows different classifications found in the literature, explaining the role of the different suppliers:

Table 1.1 – Classification of automotive suppliers

	Classification
German Automotive Association (VDA 4691/2, 2002)	Part suppliers: manufacturing of standard parts or according to detailed specifications from the prime contractor
	Components suppliers: develop and manufacture a component (e.g starter) for the prime contractor
	System suppliers: develop and manufacture coupled complex subassemblies (e.g. injection and motor management) for the prime contractor
	Module suppliers: develop, integrate and manufacture complex subassemblies (e.g. cockpit) for the prime contractor
	Engineering services: provide development services to a prime contractor
	"General" suppliers: are responsible for the development and/or manufacturing of a whole product (e.g. a car)
Laseter and Ramdas (2002)	"critical systems": "highly differentiating / high cost, highly complex systems" (e.g. brake system)
	"hidden components": "less differentiating / low cost / simple components" (e.g. door locks)
	"simple differentiators": "highly differentiating / moderately costly / simple assemblies or components" (e.g. bumper)
	"invisible sub-assemblies": "invisible / moderately costly / moderately complex systems" (e.g. wiring harness)
Schlederer and Sorito (2001)	System partner: develop, integrate, manufacture and deliver components or systems (prototypes and mass manufactured)
	Engineering design supplier: develop and integrate components or systems (prototypes)
	Extended workbench supplier: provide additional development capacity for prime contractors
	Manufacturing partner: manufacture and deliver standard parts
Veloso and Kumar (2002)	Systems integrators: "designing and integrating components ... into modules that are shipped or placed directly by the supplier in the automakers' assembly plants
	Global standardizer – systems manufacturer: "company that sets the standard on a global basis for a component or system. ... capable of design, development and manufacturing of complex systems"
	Component specialist: "... design and manufacture a specific component or subsystem for a given car or platform. ... include "process" specialists"
	Raw material suppliers: "supplies raw materials to the OEMs or suppliers" (steel, polymer, aluminium, etc.)

1.1.1.2. Importance and geographical repartition

The automotive sector holds a very important place in the economy of some countries. In Germany, the automotive industry exported 136 billion € in 2002 (60% of the trade surplus), is one of the largest employers with 763,500 employees (VDA, 2003) and invests heavily in R&D.

The automotive industry used to be concentrated in the "triad", namely Japan, Western Europe and NAFTA but these markets are now mature and saturated. Nowadays, growth opportunities (for sales and production) can be found in Asia and Eastern Europe. For example, China was the 5th largest motor manufacturing country in 2002 (VDA, 2003), rising from the 8th rank in 2001 (VDA, 2002). The following figure shows the distribution (in %) of the automotive production (number of cars) in different regions:

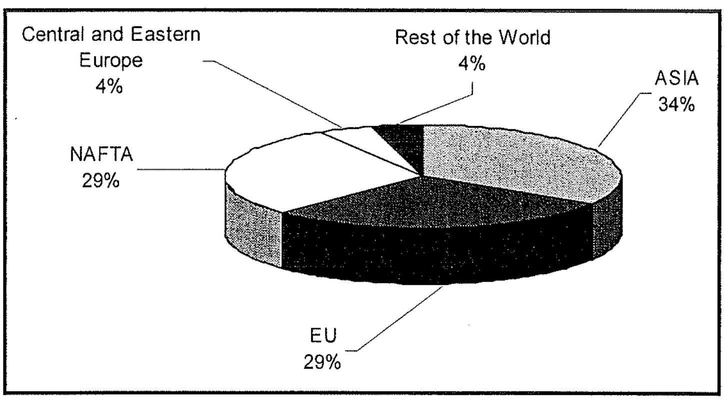


Figure 1.4 – Geographical repartition of the automotive production
Source: VDA 2003

1.1.1.3. (R)evolutions of the automotive sector

The history of the automotive industry began at the end of the nineteenth century and, since then, this sector experienced two major revolutions and another forthcoming.

1st revolution – from craft to mass-production in the 20´s (Womack et al., 1991): at the early days of the automotive industry, cars were built by craftsmen who mastered the entire design and manufacturing process. Cars were therefore unique and customised according to the customers´ needs. Henry Ford developed the mass-production concept whose principles can be summarised by the usage of standard parts to ease the car assembly and the assembly of the car on a line. The Ford T Model appeared in 1908 and was the first car built with standard parts, and, a few years later (1913), the car was built on assembly lines. These practices were rapidly adopted by others manufacturing firms world-wide. However, this mass-production model had several drawbacks: low flexibility, poor quality, low worker motivation.

2nd revolution – from mass-production to lean manufacturing (Womack et al., 1991): Eiji Toyoda and Taichnii Ohno developed the "lean manufacturing" concept and introduced it at Toyota after WWII. Some characteristics of this system are the involvement of employees, just-in-time, collaborative development, or the involvement of suppliers. These practices allowed Japanese car manufacturers to surpass their western counterparts in the 70´s and 80´s in terms of quality or customer orientation. Since then, the actors of automotive value chains in the US and Europe have adopted some of these principles (Sánchez and Pérez, 2003; Takieshi, 2001) which are still part of the dominant design.

Emerging trends – the future of the car industry: mobility providers? a sustainable mode of transportation? computers on wheels?: to tell the future is a difficult and risky exercise but a trend in our society is the move from products to services (Reiskin et al., 2000). One scenario is that car manufacturers will offer a mobility service to their customers: solutions like car sharing, leasing, and other forms of subscriptions are emerging. A second scenario is that cars will become a sustainable mode of transportation and must therefore reduce the environmental impacts during their product life cycle. Whatever the dominant business model adopted by this industry, cars are products that contain complex components and this trend will probably continue as requirements like low fuel consumption, emission reduction, driving pleasure improvement and greater security can not be met without these components (also called "mechatronics" – that is products allying mechanics, software, electronics and hydraulics).

1.1.2. Challenges and drivers in the automotive industry

1.1.2.1. Political drivers

Cars have a great impact on our society. On the one hand it means mobility, freedom and driving pleasure and, on the other hand they have a great impact on the environment. Therefore governments wish to reduce the environmental impacts of this industry, improve safety or increase the liability of firms. These elements will have a profound impact on the product development activity.

Environmental impact reduction: the automotive industry is especially targeted by environmental policy as cars have a great impact on the environment (greenhouse effect, resource depletion, air pollution, noise, etc.) over their whole life cycle (manufacturing, use and end-of-life). Laws are being adopted to further reduce emissions in the US, in Europe, and in other parts of the world. For example, the planned clean-air law in California will further limit greenhouse gas emissions. In Europe, carmakers must reduce average emissions of carbon dioxide from 180 to 140 grams per kilometre by the year 2008. This means a reduction in average fuel consumption from 7.6 to 5.8 litres per 100 kilometres. Besides emission reduction, car recycling must be improved. In Europe, 95 % of the car weight will have to be recycled by 2010 and car makers will have to demonstrate the recyclability of their cars by 2005 and to develop efficient dismantling process (Schöne, 2001). For example, BMW developed a system called "DAISY" (Dismantling Analysis Information System) to assess the recyclability of its cars that takes economical constraints into account (Lefebvre et al., 2000). Other car makers have similar initiatives (for more details see Gaucheron (2001)). Hence, European car owners will be able to give back their old cars free of charge to the car makers which will be responsible for dismantling the cars they manufactured. In the meantime, firms specialised in car dismantling and part reuse are emerging ("reverse distribution channel") in the Netherlands and Denmark (Eusemann, 2002).

Vehicle safety improvement: the number of accident victims decreased in developed countries but their level remains too high. Governments are therefore asking car makers to put more secure vehicles on the market by adding new components (e.g. tire pressure monitoring in the US) or modifying the car design (e.g. pedestrian protection in Europe).

Increasing responsibility: car defects may have fatal consequences and governments want to make manufacturers responsible for their products. The "Tread Act" H.R. 5164 in the US aims at increasing the responsibility of car manufacturers and parts or components having an effect on security must have a 10 year warranty. Hence a manufacturer must inform the NHTSA (National Highway Traffic Safety Administration) within 5 working days if it discovers a security problem affecting a part on a vehicle (no matter where the vehicle was sold).

1.1.2.2. Market drivers

If you take a closer look at a car dealership lot or at a car manufacturer flyer, you will notice that the current vehicle generation is different from the previous generation. The number of models proposed is greater and the vehicles are "smarter".

Increasing product variety: car makers have to develop new vehicles to cover new markets. Currently, several car manufacturers develop (or plan to do it) "cross-over vehicles" allying some elements of a sport utility vehicle, a station wagon and a traditional car. Ford estimates that "a global manufacturer will have to address 300-400 niches to be fully competitive in the next decade" (McDonald, 2002). According to Veloso and Kumar (2002), this trend can by explained by the fact that markets in the triad are mature and saturated and products need to be differentiated. Hence, the number of car models is increasing but the volume per car model is decreasing. The following table shows this evolution for the German market (Diez, 2002):

Table 1.2 – Increase of model variety in Germany

	1980	2000	Evolution (%)
Number of model proposed	160	260	+62.5
Market share per model (%)	0.7	0.39	-44.3

Smarter vehicles: another trend is the growing demand for more comfort, safety and driving pleasure in vehicles. Reaching these objectives is possible through the usage of a growing number of mechatronic components like ABS, ESP, new injection systems, etc.. In addition, these systems enable the reduction of the environmental burden. These features are not only reserved for high-end vehicles but also for mass-manufactured vehicles. The following figure shows the evolution of the car equipment level for vehicles sold in Germany between 1990 and 2000:

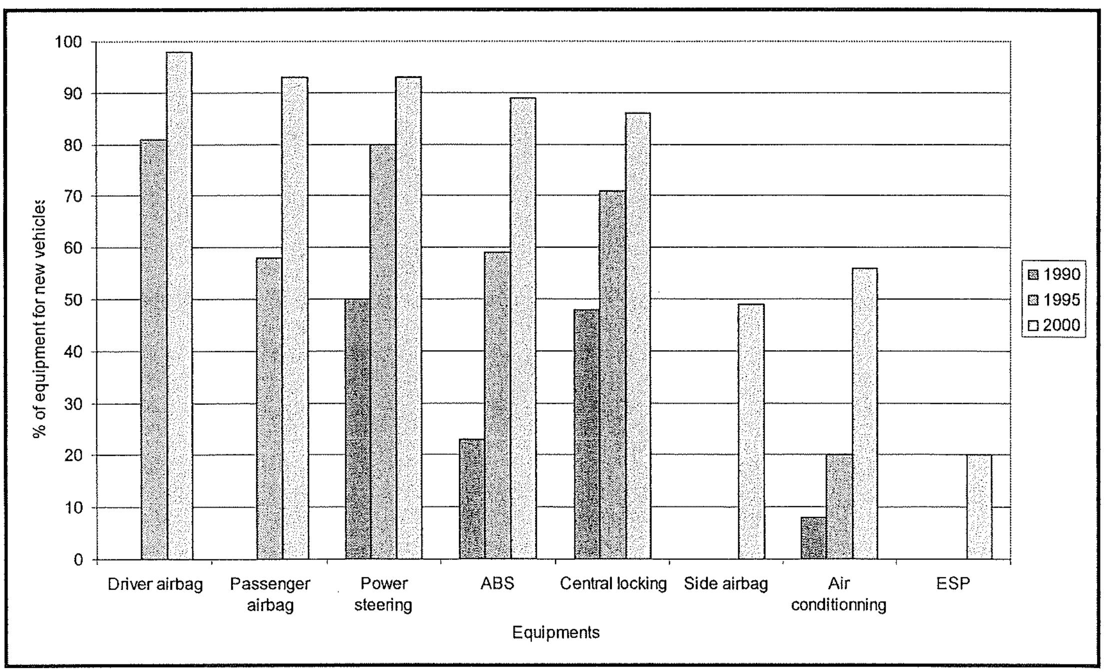


Figure 1.5 – Level of equipment for vehicles sold in Germany

Source: VDA (2002)

Competition and overcapacity: according to a study performed by Accenture, the value per car rose by $5,350 between 1990 and 2000 but the price rose only by $4,200 (benefits of $1,150 for the customer). In other words, smarter cars are delivered but the price does not reflect the additional features. One reason for this phenomenon is the structural overcapacity (20 to 30% in Europe an North America) that drives the price down (The Economist, 2002). This cost pressure is also marked for suppliers as the price reduction are passed on suppliers. The following table shows some price reductions expected by different OEMs from their suppliers:

Table 1.3 – Cost pressure on automotive suppliers

OEMs	Price reduction
Renault	5-8% per year
Toyota	25% over 3 years
German OEMs	13% over 3 years
Ford	5-7% per year

Source: Veloso and Kumar (2002)

1.1.2.3. Technological drivers

The political and market drivers influence the technological driver. The trend to smarter vehicles is characterised by the emergence of new technologies. The automotive industry produces a large number of patents and the R&D expenditures are increasing. In Germany, the R&D expenditures rose from 6.2 billion € to 15 billion between 1992 and 2002 (+142%) (VDA, 2003). The main drivers here are the increasing role of electronic, high precision and complex systems, and the need for breakthrough innovations.

Pervasive computing: electronics and microprocessors were first introduced in the 70's to replace mechanical functions (e.g. electronic injection) or propose new ones controlled through electronics (Ealey and Mercer, 1999). Cars are becoming high-tech products and according to experts, electronic and software will represent 80 to 90% of the innovation. Today, even spark plugs contain electronics. To be precise, the term "mechatronics" should be employed: "Complex products, which consist of mechanical, hydraulic, pneumatic, and electrical components and are controlled by software,..." (Anderl et al, 2000). Another characteristic of these products is their "high poor density" and "small dimension". This phenomenon can also be called "pervasive electronics". The aeronautic industry is also following a similar path as more and more sub-systems contain electronics (e.g. "fly-by-wire"). Nowadays, 40% of the value of high-end vehicles originate from electronics and the trend will continue to rise. The couple electronics & software has been recognised as important by car makers because it differentiates between products (determines vehicle behaviour, safety and comfort) and is at the origin of an increasing number of failures. Another characteristic of products containing electronics is their possibility to be easily customised: a supplier can deliver the same sub-system to all car makers and change only the software.

Entertainment and telematics are also new technologies that are emerging and they may reshape the relationship between end customers and car manufacturers. In the future, applications like on board vehicle diagnostics (problem detection, maintenance need), emergency rescue systems, navigation systems, etc. will probably become common features.

Mechanical complexity: mechanical parts are becoming more and more complex with tighter tolerances, smaller size and long lasting requirements (250,000km). It is a large volume industry and an increasing know-how for design and manufacturing has to be brought together to develop new cars (Volpato and Stocchetti, 2002). An additional factor explaining the complexity of the mechanical design is the fact that the designers are geographically dispersed and belong to different organisations.

Breakthrough innovations: new solutions have to be found to turn cars into a sustainable transportation mode and reduce their environmental impact. In the future, the automotive industry will have to do more than incremental changes to take up with the environmental issue (Niuwenhuis and Wells, 1997) and these new products will require the association of innovative technologies (Magnusson and Berggren, 2001). If successful, the emergence of fuel-cell vehicles could affect the whole automotive industry (manufacturing, support).

1.1.2.4. Sectorial drivers

Finally, some drivers are common for the whole automotive industry. The reduction of cycle time, the need for cooperation and globalisation are the main drivers.

Time pressure: the automotive sector is experiencing a great time pressure: new markets must be filled quickly and a 2 to 3 years development cycle time for a new vehicle is becoming the norm. Naturally, this cycle time reduction is also valid for the suppliers.

Need for cooperation: as a result of outsourcing, cooperation between OEMs and suppliers is increasing and according to the case study of Wognum et al. (2002) "cooperation becomes essential". Indeed, cars have an integrated design or architecture where parts have to be specifically designed to fit together (Ulrich and Eppinger, 2000). For example, a large part of the costs are caused by direct engineered parts which increases the cost of coordination and of change (Novak and Eppinger, 2001). Despite the need for cooperation, May et al. (2000) found out that barriers to communication and cooperation are still numerous in this sector. This is confirmed by recent studies (Hab et al., 2003; CAx-AG 2.6.6, 2002).

Globalisation: the growth opportunities for this sector are outside the "triad" (defined as western Europe, NAFTA and Japan) where the markets are saturated and the production stable. At the same time, production and sales are rising in Eastern Europe, Asia, and in the Mercosur to a lesser extent. In 1992, German car manufacturers produced 5.2 million vehicles in Germany and 1.8 million abroad. In 2002, the figures were 5.5 million (+5.77%) and 4.5 million (+150%), VDA (2003). According to the forecasting of McKinsey (cited by Veloso and Kumar, 2002), the percentage of vehicles sold outside the triad will reach 39% by the year 2010 (from 26% by the year 1999). The globalisation of activities is therefore also occurring in the automotive supply industry. In their survey in the automotive sector, von Corswant and Fredriksson (2002) found out that suppliers in the last decade had plants in 3 times more countries and two times more product development facilities. For example, Bosch expanded its activities outside Germany in the last decade. The percentage of sales made abroad rose by 47%, the investments by 53% and the employees by 46%. The following figure shows the evolution of Bosch in terms of sales, investments and employees:

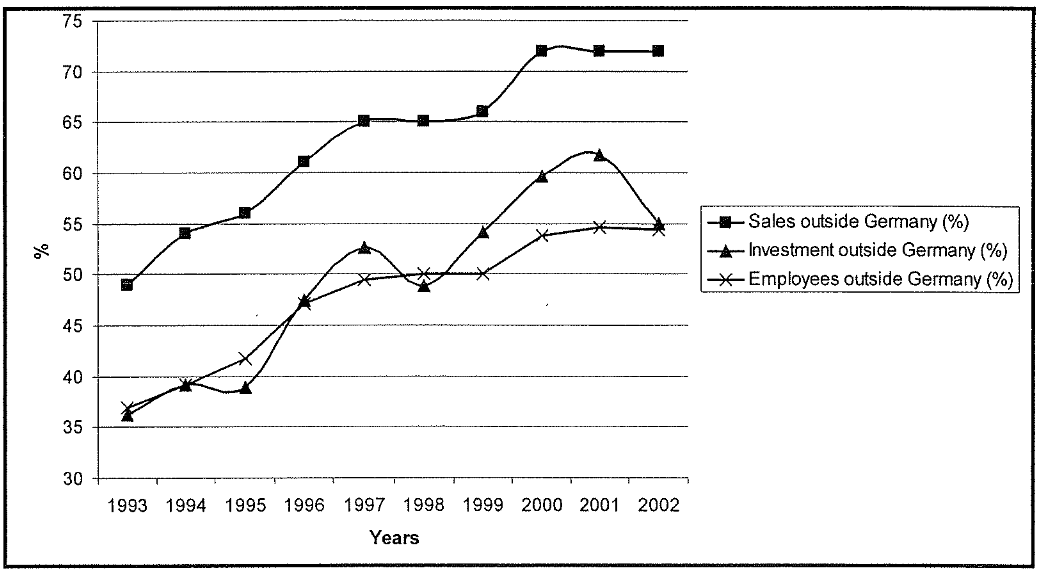


Figure 1.6 – Globalisation of Bosch activities

Source: adapted from the Bosch Geschäftsbericht (2002)

1.1.3. Strategies of the firms

The paragraphs above depicted some elements of the automotive industry environment. Now, we will focus on the consequences of these changes on the different actors of the automotive value chain (namely car manufacturers and suppliers). More precisely, we will take a look at the activities they performed in the value chain and the competencies they need to master in the near future.

1.1.3.1. The new role of car manufacturers

The role of car manufacturers has evolved in the course of the last few years as they focus on downstream activities of the value chain and rely on suppliers to access key sub-systems.

Focus on downstream activities: the way car makers are organised is changing, from vertically integrated firms at the beginning of the 80's to firms focusing on some core activities like branding, styling & concept, product integration, assembly, and services. Their focus is shifting from upstream (e.g. design) to downstream activities (e.g. financing). Of course, car makers still design cars but focus more on the conceptual design (i.e. definition of vehicles for a specific market segment) and the integration of components steaming from key suppliers than on the detailed design of parts.

Car makers develop their activities in the fields of fleet management, financing or even invest in alternative transportation modes. For example, DaimlerChrysler Services plans to finance or lease 50% of cars and 60% of trucks by the year 2006 (Mangold, 2003) and Honda made a major investment in a car sharing company in the US. Von Corswant and Fredikkson (2002), found out that "product related services" were not yet the top priority but their importance increased rapidly in the last decade.

This trend can be explained by the fact that only 20% of the customers' car budget are dedicated to the purchase of the car (Dudenhöffer, 2002) and, according to Mercer Management Consulting, 70% of the potential benefits are generated by downstream activities (Diez, 2002). The spectrum of downstream activities is very large: financing, leasing, insurance, spare parts distribution, services and reparation, rental, fleet management, etc. For some car makers the benefits generated by financial services are greater than the benefits generated by car selling. An analysis of the Deutsche Bank showed that the return on equity (ROE) of the financial services divisions at Volkswagen and PSA between 1999 and 2001 was greater than the average group ROE (Deutsche Bank, 2003). This strategy is also followed by other sectors like the aeronautic industry: Airbus is strengthening its support and diagnostic activities to increase its revenue. In fact, the management of product life cycle offers new business opportunities: "It is widely believed that new economic opportunities exist in the development of product including embedded value at the manufacturing, use and end-of-life as well as any other phase of the product life cycle" (CE-NET Consortium, 2002). In Germany, the term "Extended Product" is emerging: it consists of the bundle of a physical product and its associated accessories or services (Thoben et al., 2001).

Heavy reliance on suppliers: as mentioned earlier the importance of suppliers during the product development phase is growing and there is a shift in the value creation (CAx-AG 2.6.6, 2002; Veloso and Kumar, 2002). Car makers are relying on suppliers to develop or co-develop new technologies and they choose the desired "features" for their cars from their suppliers.

This trend can be explained by several factors. First, no firms have the capabilities and skills required to develop complex products (Fine, 1996) and they need additional capabilities and skills. Therefore the involvement of suppliers is required and Wasti and Liker (1999) found out that "in-house technical capabilities of the suppliers and technological uncertainty of the component were two dominant predictors of supplier involvement". Today suppliers hold a strong know-how in design and manufacturing of key components and OEMs need their participation. Second, outsourcing and concentration on a small number of first tier suppliers should improve profitability (Volpato and Stochetti, 2002). The study of Ragatz et al. (2002) suggests that the implication of suppliers has a positive impact on cost reduction, quality improvement, and cycle time reduction.

It seems that the outsourcing trends have reached a maximum: prevent cars from being a "commodity" as technologies available for high end vehicles are rapidly available in low end vehicles (Ealey and Troyano-Bermúdez, 1996). Hence firms are investing back (e.g. Volkswagen invested in electronics) or limit outsourcing (e.g. Toyota still holds a strong know-how in electronic systems).

Focus on vehicle integration: the two main activities performed by car makers during the product development is the product definition and the product integration (CAx-AG 2.6.6, 2002; Volpato and Stochetti, 2002). Product definition consists of specifying the requirements that a car must fulfil. These products are usually defined within a product "platform" or "product family" that can be defined as "a set of components and subsystems shared across multiple products offered by a firm" (Gonzalez-Zugasti and Otto, 2000). For example, the A platform of Volkswagen is used for the Golf, the Bora/Jetta, the Audi A3, the Audi TT, the Skoda Octavia and the Seat Toledo where brakes, gearbox, chassis elements or motors can be common. This platform represents a volume of 1.2 million units per year (Veloso and Kumar, 2002) and allows to cover new market segments.

BMW defines car integration as the geometrical integration (collision free assembly, enable maintenance, tolerances and ergonomics), the functional integration (vibration, acoustic, electric&electronics, corrosion, comfort and riding) and manufacturing integration (body in white, painting, assembly, logistics) (Kerschbaum and Drozkowski, 2001). To sustain this supplier integration strategy, OEMs must have different competencies. OEMs must possess three "integrative capabilities" (Takeishi, 2001): "architectural knowledge", "integrated problem solving" and "effective internal coordination". In addition, several factors required for a successful cooperation were identified by Von Corswant and Tunalv (2002): "Supplier´s co-operation with other auto manufacturers and own suppliers" ("to remain a competitive partner"); "Coupling between product and product development" (to improve operation, cost, quality); "Pro-active suppliers" (take responsibilities) and a "Co-ordinating auto manufacturer".

To summarise, car makers will focus on downstream activities which correspond to a transformation toward mobility provider and follow the "servicisation" trend. It is there that they add the most value. Hence they leave space for suppliers to develop and deliver new technologies that will fit in their products.

1.1.3.2. Automotive suppliers

The paragraphs above showed the importance of suppliers in the automotive industry and a recent study estimated that the supply sector will experience a 5 to 6% growth per year until 2010 (VDA, 2003). Hence suppliers must become key development partners and, to reach this objective, must work on the three dimensions of innovation: product, process and relational innovations.

Suppliers as key partners for product development: major innovations were developed by suppliers (sometimes in cooperation with car makers) in the last two decades. For example, the ESP (a system preventing car skidding) was developed in cooperation between Bosch and Mercedes-Benz; the common rail diesel injection allowing to increase power and reduce emissions was initially developed by the Elasis company in Italy and further developed by Bosch; an integrated starter-alternator from Valeo allowing noise and emission reductions as well as fuel economy will soon be implemented by a French car maker. Of course this list could be

"Increasingly, it falls to suppliers to develop the truly differentiating aspects of a new vehicle design. As this conflicts with the traditional supplier role – one of being just that, a supplier of OEM specified parts and components – this is creating another situation of conflict. If suppliers develop traction controls, or the electronic stability program which links up with the steering and therefore defines the driving behavior of a car, they make significant contributions to defining the characteristics of a car. This new supplier role is compounded when taking into account the contribution of electronic suppliers: steer by wire, break by wire or magnetic valve control all contribute to how the end-user perceives the handling and character of the car. So if electronics rather than mechanics determine the individuality of a car today, then it may well be the person who writes the software – usually a supplier – and not the OEM engineer who makes the most valuable contribution to the ultimate sale of the car." (Zielke, 2001).

completed by many other examples. Today, car makers expect their suppliers to perform the development of new systems and this trend can be observed in some car makers figures. For example, at Audi, 65 % of the car development is done outside the company in 2000 compared to 31% in 1995 (Schiemenz and Sorito, 2001).

This new role means also new responsibilities. Suppliers must deliver a product without major defects and are responsible for changing the product if a defect is found. Recently, DaimlerChrysler AG announced that all its suppliers will be "...financially responsible for recall and warranty problems caused by their work (Dow Jones, 2002)". Until now, only suppliers of critical parts (e.g. axles) were bound with this kind of contract.

Innovation providers: in order to become the key partners in product development, suppliers must demonstrate their abilities and develop system competencies to combine subsystems together (Volpato and Stocchetti, 2002). These new products (or products of the future) are required to answer challenges arising from the requirements identified previously (environmental, comfort, economy). For example, Michelin and Bosch announced a long term strategic partnership for the development and manufacturing of advanced vehicle dynamics management systems that offer improved safety and mobility by optimising the coupling between tire and electronic vehicle control technologies. Cornet et al. (2001) call it the merger of "complementary players". This path is followed by suppliers which try to deliver value-added car sub-systems (components, systems or modules). The products of the future need the merge of different know-hows.

Process innovators: most automotive related products are mass-produced, meaning that several million units are produced per year with a high quality standard. Two additional criteria steaming from the drivers identified previously must be fulfilled: cycle time reduction (for ramp-up and for the production) and cost effectiveness. Hence a strong know-how in manufacturing process and logistics are required to be competitive in this sector.

In the past, a pre-development phase existed which allowed to gain a design, manufacturing and delivery experience. Car makers had only to "pick-up" and slightly modify the sub-system. Nowadays, the development cycle (from the idea to the first unit produced) is shorter and in some cases sub-systems are even developed during the development of a car. This leaves less time for "end of the pipe" optimisation.

Besides the time pressure, the cost pressure is the second element that forces suppliers to innovate in terms of process. Currently, innovative and complex products are demanded by car makers but a strong competition among global suppliers prevents them from reaping the benefits of innovation that require huge investments in R&D and manufacturing operations (Frankfurter Allgemeine Zeitung, 2002). The price remains low and more innovation must be delivered at the same price.

Global suppliers are therefore seeking to reduce production cycle times and deliver cost effective innovations. For von Corswalt and Tulnav (2002), the "coupling between product and product development" is an important factor for the success of cooperation projects between a supplier and an OEM. Based on case studies in American and Japanese firms in the 80´s and 90´s, Fine (1996) showed that a strong "manufacturing process" know how has an impact on items like manufacturability (equipment capabilities are known), process tailoring, ramp-up facilitation, better specifications for purchased tooling, better control of the maintenance (improve run time), and provide unique capabilities (everyone can access standard machines but not special ones).

Relational innovators: nowadays, automotive suppliers must operate with development centers and manufacturing facilities spread around the world. It is not rare to have a sale representative in the US managing a project for a Japanese car manufacturer with the application being done in Japan, the development in Germany and the assembly operations being planned in Mexico or in Eastern Europe.

In this context and to support this strategy, suppliers must remove cooperation barriers, the goal being to put the best supply chain as "the competition in the future will be supply chain to supply chain, not company to company" (Schorr, 1998). In the case of tier one suppliers, the integration with tier 2 suppliers allows them to access design and manufacturing know-how and facilitates the design and the management of an effective supply chain. No figures exist but tier one suppliers like Bosch are outsourcing a large part of manufacturing and design activities (80% in some projects). Integration with customers must also be facilitated so they can integrate innovations steaming from suppliers.

To remain competitive in the world automotive industry, suppliers must demonstrate their ability to create and deliver innovative products. In concrete terms this could mean:

(i) design high precision mechanics with a high content of electronics and software;

(ii) deliver high volume and high variety and cost effective products;

(iii) facilitate cooperation with dispersed partners (competition between supply chains);

(iv) reduce product development cycle time, and integrate product life cycle issues.

One way to reach this objective is to promote and facilitate cooperation during the product development process. Therefore, a supplier like Bosch must not only devote resources for R&D but also develop "best in class" product development activities where cooperation tasks have a great importance. Suppliers must have distinctive capabilities to develop products in the new environment.

The following table summarises the drivers and actions for car manufacturers and suppliers:

Table 1.4 – Summary of the sectorial drivers and actions

<table>
<tr><th></th><th>Drivers</th><th>Actions – OEMS</th><th>Actions – Suppliers</th></tr>
<tr><td>Political</td><td>- Reduce environmental impact
- Improve vehicle safety
- Increase responsibility</td><td rowspan="4">- Focus on downstream activities
- Reliance on suppliers
- Focus on vehicle integration</td><td rowspan="4">- Set-up global virtual teams (global scale development and manufacturing)
- Development of complex and innovative products (different disciplines)
- Integration with customers, suppliers and partners
- Reduce time and costs
- Develop modular and flexible product platform</td></tr>
<tr><td>Technological</td><td>- Pervasive computing
- Product complexity
- Breakthrough innovations</td></tr>
<tr><td>Sectorial</td><td>- Time pressure
- Competition and over-capacity
- Need for cooperation</td></tr>
<tr><td>Market</td><td>- Cost reduction
- Niche market</td></tr>
</table>

1.1.3.3. The case of Bosch

This study was mainly conducted at the Robert Bosch GmbH and some general information on this company will be presented here. Bosch, the second largest automotive supplier world-wide, is known as a significant innovator in the automotive industry and Mr. Pischetsrieder (CEO of the Volkswagen group) said that "without Bosch, the German automotive industry would not have reached its leadership position in the world" (Scholtys and Werres, 2001). In the automotive sector, Bosch is present in the braking systems (e.g. ABS, ESP, brake by wire, brake assistant), gasoline systems (e.g. injection, intake modules), diesel systems (e.g. common rail), energy systems (e.g. alternator, electronic energy management, wipers) and car multimedia (e.g. navigation systems, radio). These business units represent almost 2/3 of the revenue (23 billion €). Bosch has business units in the other sectors like power tools, industrial automation, household appliances and security systems.

For its automotive part, Bosch wishes to enhance its position as systems and components supplier which means being able to develop complete systems for car makers. To maintain and strengthen its leadership as innovative partner in this sector, Bosch invested 8% of the revenue of the automotive sector in R&D (1.9 billion €) in the year 2001: 18.500 engineers, scientists and technicians were developing new technologies or products and 2050 patents have been registered in the year 2000. The rating Agency Standard & Poor´s mentioned that Bosch has a good financial profile (AA) due to its capability to deliver products that are less sensible to price fall than those of many of its competitors (Handelsblatt, 2002).

> "A lot of suppliers are producing differentiating technologies. Bosch, for example, has been able to build up distinctive capabilities as concerns automotive electronics like engine management or driving dynamics systems. Innovation standstill from suppliers seems less of an option at the moment, but the final outcome of the supplier fate is by no means settled yet" (Chatterjee, 2001)

To remain competitive in the future, Bosch defined several objectives:

(i) Develop innovative solutions: new functions have to be developed and they require a greater cooperation between business units (or partners). Therefore, multidisciplinary cooperation will be required to develop ever more complex products;

(ii) International expansion: growth opportunities for Bosch lie outside Western Europe (Eastern Europe, North America, Asia). Plants, development centers, partners, suppliers and customers will be dispersed across the world and virtual teams will become the norm;

(iii) Reduce time to market and ramp-up: being able to put new innovations on the market quickly is key to success (manufacturing capabilities and high volume are important in this sector). The quick planning of effective supply chains will be required and a tight cooperation between product and process development will be needed;

(iv) Develop cost effective solutions: while product complexity increases, product costs must remain low (due to competitive pressure). Therefore investments must be reduced by 30% (optimised manufacturing equipment, usage of production across several product generations);

1.2. Main trends in product development practices

The objective of this second section is to present the organisational mechanisms and the technologies adopted by firms to improve their product development process. These practices and tools have been used for almost a decade and it is now possible to evaluate their real impact. The following topics will be investigated: (i) the transition from the traditional product development approach to the concurrent engineering approach, (ii) the limits of organisational mechanisms, (iii) the contribution of current software and (iv) the areas of improvement as well as the opportunities offered by new technologies.

1.2.1. Organisational mechanisms

1.2.1.1. From the traditional approach to concurrent engineering

Product development can be defined as the period elapsed between the first idea of a product and the first physical unit produced. During this period the product characteristics are determined to meet requirements to fulfil its role during its physical life cycle. In addition, the whole infrastructure that allows the product to be manufactured has to be designed and implemented.

Here, we will look at the historical evolution of "product development". A characteristic of the mass manufacturing era was the creation of separated functional organisations (design, production, marketing to name a few). The traditional approach to design products was to pass "the design" (i.e. information related to the product, such as specifications, drawings, prototypes) between the different functions (or silos): marketing, then design, then manufacturing and so on.

This organisational (and often geographical) division favoured the presence of barriers between functions: "over time these groups grow apart, each expert at their own function, but less aware of the other's contribution. As integration and communication between these critical functions decreases, their ability to combine skills to develop and produce successful products decreases. The firm suffers." (Griffin and Hauser, 1996). The traditional approach had therefore numerous weaknesses: long development cycle time, poor design quality, costly, lack of flexibility, low worker motivation (Ehrlenspiel, 1995).

At the end of the 80's, it was clear that the organisation of the product development activity had a tremendous importance and that the Japanese practices were superior to the traditional approach used by western firms. The way activities are performed at the operational level is important and Clark et al. (1987) stressed the importance of firms behaviour (especially at the factory level) in explaining productivity and product quality differences. So, firms redefined the way they developed new products by adopting the "concurrent engineering" paradigm inspired by the Japanese practices (Caputo and Zirpoli, 2002). Several definitions of concurrent engineering exist:

1. The US Department of Defense defined concurrent engineering as: "a systemic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements" (Institute for Defense Analysis, 1988).

2. Whitney (1996), "CE is a method of product development which utilizes all of the relevant information in making each decision" citing Clausing (1996).

3. For Luczak and Eversheim (1999), simultaneous engineering and concurrent engineering aim at defining a product development process where the design of the product and the manufacturing operations are parallel allowing participants to take earlier and better decisions.

To operationalise concurrent engineering, firms reviewed their "organisational structure" and adopted new mechanisms that are described in the following table:

Table 1.5 – Organisational mechanisms enabling cooperation

Organisational mechanisms	**Description**
Stage gate model	This model, initiated by Cooper (1994), consists in breaking down the product development process in several phases (usually: project planning, conceptual design, detailed design, testing and refinement, and production ramp-up) and checking the conformance of the project between the phases through design review (or quality gates).
Cross functional team	To build a cross functional team means to "...assemble a team of individuals from various functions for the duration of the development process and to allocate among them the task of making subsets of decisions." (Krishnan et Ulrich, 2001). The background variety of the team members bring different perspectives and "helps project team members to understand the design process more quickly and fully from a variety of perspectives, and thus it improves design process performance. Moreover, the increased information helps the team to catch downstream problems such as manufacturing difficulties or market mismatches before they happen, when these problems are generally smaller and easier to fix" (Brown and Eisenhardt, 1995).
Early supplier involvement	The early supplier integration into the product development process has long been recognized to have positive effects (Clark and Fujimoto, 1991)
Front loading	"front loading" aims at taking better decisions at the early phase of the product creation (Thomke and Fujimoto, 2000). The rational behind this practice is that changes can be easily made during the early phase. Later in the design, changes are more costly.
Dedicated personnel	"Liaison personnel are not members of any functional piece of an organization, but rather people who are capable and prepared to address issues that span functional boundaries" (Smith, 1997). An approval process can be put in place where the design must be approved by the functional department (Smith, 1997).
	Functional representative: "... people representing each functional area meet regularly (typically weekly) to discuss items that are of boundary-spanning or general interest with regard to a development project" (Smith, 1997).
	Guest engineers: engineers of extern firms working on the customer site. This practice is widespread in the automotive industry (Lewis et al., 2001)

To summarise, firms are organising their product development activities to parallelise and overlap tasks (especially design and manufacturing) to insure that downstream constraints are taken into account. These practices are also widespread in the automotive sector and each firm developed a specific model (MDS at DaimlerChrylser; Quality Assurance Plan at Bosch). In a survey on firm practices, Griffin (1997) found that about two thirds of the firms adopted cross functional teams – this figure rises to 85% for innovative products. In another survey of 80 Swedish SMEs conducted during the autumn 2001, Rundquist and Chibba (2002) discovered that "60% of the best firms use a cross-functional third generation model" (defined as: stage gate model and activities overlapping).

1.2.1.2. Limits of organisational mechanisms

Following the "lean paradigm" and the identification of best practices (e.g. stage gate, supplier involvement), firms transformed the way they were developing products. Since then, numerous studies have evaluated empirically the impacts of the new practices. Cooper (1999), a well known author in the field of product development and innovation, published a provocative article on the "invisible success factors in product innovation" because firms "...have failed to heed the messages and continue to repeat the same mistakes." Among the two main problems, we retrieve the definition and execution of the product development process (through stage gate), the limits of cross functional teams and the resource allocations.

> Success factors (Cooper, 1999):
> - Solid up-front work
> - Voice of the customer
> - Product advantage
> - Sharp, stable, and early product definition
> - A well-planned, adequately resourced, and proficiently executed launch
> - Tough go/kill decision points or gates– funnels, not tunnels"
> - Accountable, dedicated, supported cross functional teams with strong leaders
> - An international orientation

(i) Product development process and the stage gate: this practice is well adopted and documented in the literature but some authors found out that its implementation can be problematic. Gomes et al. (2003) found out that such a model is appropriate for "routine innovations" not for highly innovative products. A lot of difficulties are caused by a model which is ill defined and badly applied. For Cooper (1999), the main "blocker" is the fact that the model is sometimes irrelevant and that competencies failed to execute it in an appropriate manner. Firms should therefore focus on the way the model is applied (Engwall et al., 2002).

(ii) Cross functional teams: the usage of cross functional teams is related to a higher project success (McDonough, 2000) but working in such an environment (different backgrounds, frequent design changes) is not easy and can lead in some cases to burn-out (Crawford, 1992, cited by Gerwin and Barrowman, 2002).

(iii) Resource allocation: time scarcity and the fact that too many projects are performed are major causes of failures identified by Cooper (1999). In addition, too much constraints such as time pressure may lead to inferior design and Van Looy et al. (2002) showed it can endanger the "knowledge creation process".

1.2.2. The omnipresence of Information and Cooperation Technologies

These organisational mechanisms rely on or are associated with the use of ICTs. Product development is based on the processing of information and computers have therefore been used in this field for a long time. Reserved for scientific calculation at the beginning, computers are now one of the main tools used by engineers and they play a crucial role in the product development process to store ideas and support communication (McMahon and Browne, 1998).

1.2.2.1. Virtual Product Development

In the last decade, major product integrators especially in the automotive and space & aeronautics sectors developed their products in a virtual environment with the help of sophisticated tools (3D CAD systems, simulation tools, PDM, etc.). This virtual environment helped them to perform their integrative work. The Product Development Management Association defined virtual product development as: "paperless product development. All design and analysis is computer-based" (PDMA, 2003). Spur and Krause (1997) defined the virtual product development as: (i) a virtual product model (i.e. computer-based, such as CAD) and, (ii) whose aim is to support every task during the product creation process (i.e. support the work of the product development process participants). The following figure illustrates this concept:

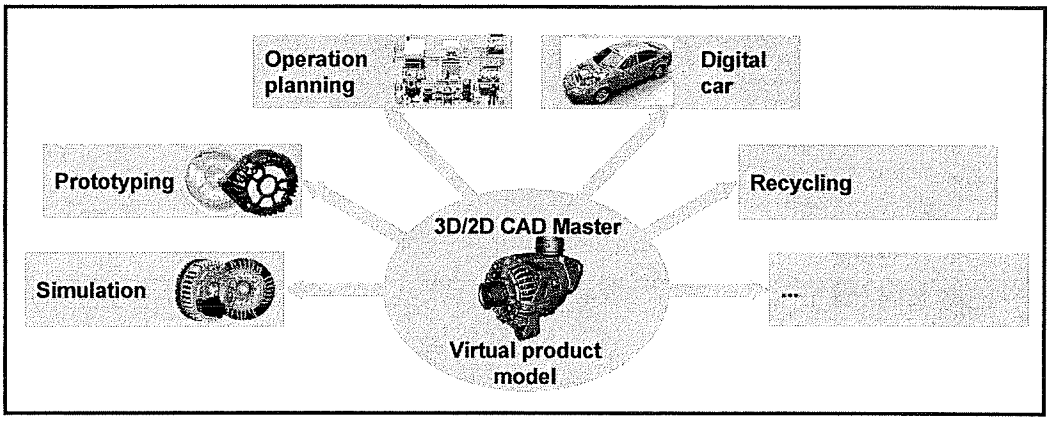


Figure 1.7 – Virtual product creation

Source: adapted from Spur and Krause (1997)

To create a virtual product development environment, firms adopted new tools and integrated them:

(i) 3D modelling: firms replaced the drawing boards by 2D drafting systems and then moved to 3D modelling. 3D CAD systems allow to create (or "to model") the geometry of a part in 3D dimensions (McMahon and Browne, 1998). The 3D models play an important role as they impact product functions, manufacturing and assembly operations, costs, maintainability, etc. Therefore, product geometry ("3D model") is a design representation that is widely used. Nowadays most of the advanced firms use solid 3D modelling software but these systems are highly specialised and expensive (McMahon and Browne, 1998).

(ii) 3D process chain: firms invested massively in the integration of 3D CAD systems with CAE/CAM systems to create seamless "3D models pipeline" along their internal product development chain. To assess the properties of the 3D models created, CAE and simulation software are used to perform qualitative and quantitative predictions (Spur and Krause, 1997). 3D models can also be further used by manufacturing equipment such as a CNC machines to directly produce parts or to create tools and moulds. This process is known as CAD/CAM. Since a few years, a new software generation allows to simulate manufacturing operations in a virtual manner and is known as "virtual manufacturing".

(iii) Data management: to manage the 3D models, firms implemented PDMs whose aim is to store and maintain information on the product (Abramovici et al., 1997). A PDM system can manage the 3D CAD models, 2D drawings or NC programs. As a consequence, each member of the product development team can access product information and be involved in the product development process (Spur and Krause, 1997).

1.2.2.2. The emergence of the digital mock-up

Some product integrators in the aeronautic and automotive industry were interested in visualising an entire product in three dimensions. However, due to the complexity of the 3D CAD models and the limited power processing capacity of computers, the visualisation of a whole car or plane was impossible. The solution was to create a "digital mock-up" (DMU) where 3D CAD models are converted into a "light weight" format that only shows the external envelope of the 3D models. More complex and ambitious definitions exist: the European research project AIT (Advanced Information Technology) has defined DMU as "A realistic computer simulation of a product with the capability of all required functionality from design/engineering, manufacturing and product service environment which is used as a platform for product and process development, for communication and decision from a first conceptual layout up to maintenance and product recycling" (AIT, 1999). The usage of the DMU has been popularised by the development of the Boeing 777 where the DMU allowed engineers to create a virtual plane and to check the fit between the parts and components. This is the classical example of DMU usage in the industry. DMU is also a visualisation tool that allows non CAD users to access 3D models (otherwise, they need to be trained and use a complex and costly 3D CAD software). The DMU technology helps team members to access 3D models very early in the design process and facilitate the sharing of design information. This "non-traditional" usage of DMU is the base of this study. Non CAD users can perform actions like measurement, mark-up, explosion, cross section, PMI[1] visualisation, clearance and disassembly operations. The following figure illustrates some of these functionalities (Source: Bosch internal sources):

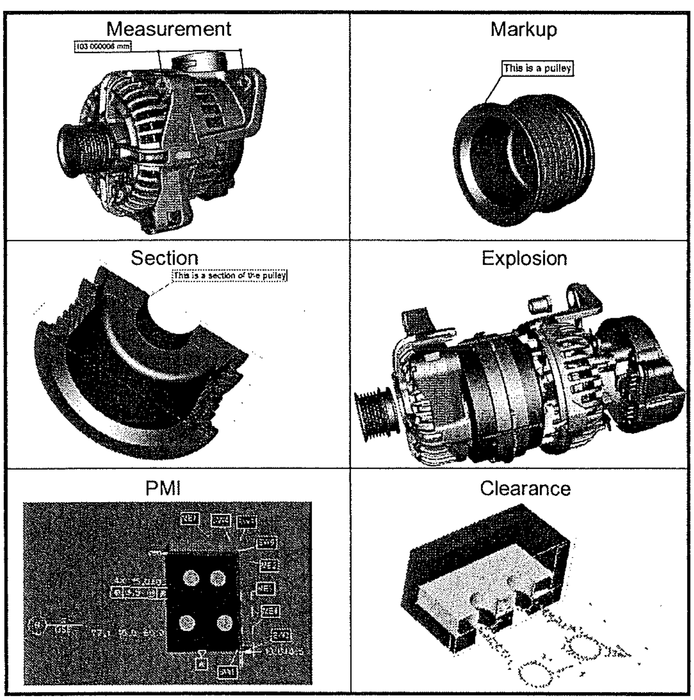


Figure 1.8 – Functionalities offered by the Digital Mock-Up

[1] Product and Manufacturing Information (e.g. tolerances, surfaces)

1.2.2.3. Limits of current software solutions

(i) <u>The limits of the software integration:</u> as mentioned earlier, firms integrated some of their systems (3D CAD, PDM, CAE) to create a "3D pipeline". However integration is not an easy task because incompatibilities (operation systems, data formats, etc.) prevent a seamless integration between all applications. The current situation is still characterised by "islands of information systems" and by an increase of the effort to manage product data into different information systems. This situation has also profound consequences on the daily work of engineers. For example, a study performed at EADS in Germany showed that engineers are spending less and less time on "creative work" whereas the time spent to use information systems is growing (Valnion, 2002). In addition, firms in the automotive supply chain frequently exchange 3D models but it is a cumbersome process. Several "neutral" formats exist (e.g. STEP) but due to their limitations to transfer the content richness of a proprietary format, their usage is limited. A study showed that the US automotive industry loses one billion US$ per year with problems due to incompatibility between CAD systems (Brunnermeier and Martin, 1999).

(ii) <u>Limited cooperation offered by the 3D pipeline:</u> 3D CAD systems offer few functionalities to support cooperation (Bocheneck and Ragusa, 2003). The exchange is limited to similar specialists (e.g. product designers) not for a multidisciplinary cooperation. 3D models capture only explicit knowledge not tacit knowledge (Mascitelli, 2000). 3D models are the end result of a design process but we do not know what was the design rationale or which alternatives were examined. PDMs were supposed to support cooperation among the product development teams. However, these systems failed to support cooperation as they "are not well suited for the support of distributed development activities, as they focus on homogenous IT system environments."

(Abramovici et al., 1998). In numerous firms, the access to the PDM is reserved to the CAD engineers to access 3D CAD models.

(iii) The coexistence of 3D and 2D: product development team members "outside the 3D pipeline" still rely on 2D drawings (Lang et al., 2002; Boujut and Laureillard, 2002) to access critical product data. 2D drawings contain a lot of crucial technical product information but are available later than 3D models and are not as easy to understand. Functions like system engineering, purchasing, prototyping, manufacturing and assembly planning, logistics, sales and marketing have therefore a limited access to the product information. Indeed, they have to wait until the 2D drawings are derived from the 3D CAD models. Henderson (1999) studied how engineers were working and found that engineers often refer to graphic information to communicate (2D drawings, pictures, 3D models, sketches). The following figure shows the evolution of tools supporting the technical communication:

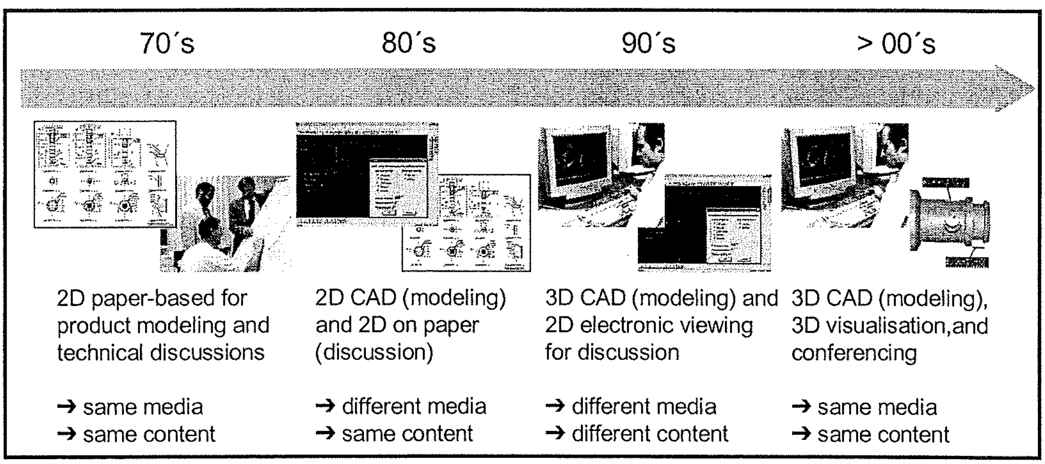


Figure 1.9 – Evolution of technical communication

In the past, the PDM systems were implemented because the product information was difficult to retrieve and some studies found out that engineers spend 30% of their time looking for data. Since then, the debate in firms is often dominated by "data integrators". However, a difference exists between software integration and cooperation: sending data from one computer to another does not mean a high level of cooperation (Luczak and Eversheim, 1999). Of course, integration is required to avoid the errors of the past but issues like communication flow, problem solving and decision making are the key for the product development process and should be more taken into account.

1.3. Motivation and objectives of the study

Based on the two previous sections, it is possible to conclude that some important issues are challenging the current practices in the field of product development: intense competitive pressure (time, costs), the dispersion of product development team (geographical and organisational), the development of complex product and processes (knowledge intensive tasks), and unsatisfying software tools to support cooperation. This section will present the motivation and the objectives of this study.

Prior to this study, several improvement potentials were identified in Bosch product development teams. Like in other firms (mentioned earlier), design engineers use CAD systems (UG, Pro/E, CATIA, IDEAS, etc.) to create 3D models but these models are almost exclusively used in design and prototyping departments. The other actors still rely on 2D drawings to access the product information.

Beyond the fact that 3D models and 2D drawing co-exist, people involved in product development activities use different applications. Indeed, the members of the product development teams sometimes stem from different divisions which are working with different tools (CAD, CAE, PDM) which are sometimes not compatible. Of course, a first solution could be to integrate together the different software systems. However, this integration is not realistic as it can be a cumbersome and lengthy process and has to be done for each new partner. Choosing applications coming from one software provider could be the second solution. However, choosing the same application is unlikely as no single application offers the best performance for all functions. To summarise, this heterogeneous IT infrastructure prevents members in the short term from using the same applications and cooperating.

The current media to support technical communication without travelling are email, phone and fax. These systems are not designed for graphic intensive communication required by engineers and the usage of advanced computer-based cooperation tools is limited. Formal Engineering Change Orders (ECO) exist, but like in other firms are cumbersome to fill (Loch et al., 2001) and are not well suited during the early phase of the design process. In other words, no common cooperation platform is available to support technical communication. So, team members (or "non CAD users") have to travel frequently or use inappropriate communication tools to get information and solve problems.

The DMU technology and associated cooperation tools offer some functionalities that could help teams to overcome the aforementioned communication barriers. Prior to this study, several types of DMU software have been extensively tested and the JT format has been chosen. This format offers the following advantages: exact geometry, CAD independent, widely used by customers (e.g. GM, Ford) as well as competitors (e.g. Siemens). In addition, the DMU solution can leverage the large investments made in CAD and PDM systems during the last decade as it is a complementary tool. This technology has the potential to help product development teams in their daily tasks (close cooperation, overcome physical and temporal barriers, etc.).

The research team – in which the author was embedded – was committed to the diffusion of this new technology inside Bosch. The lack of such teams (or "champions") may explain the low adoption of CTs in firms (Bajwa et al., 2003). The research team was confronted, among other things, to the following questions and issues:

(i) Place and positioning of the cooperation tools in the product development process: the basic idea of this study was to use the digital mock-up (DMU) to improve information sharing and collaboration in teams. Therefore, it was required to understand how this technology could be used or embedded in the product development process. More precisely it would be interesting to know for activities of the product development process can this technology contribute and how will the work pattern change;

(ii) Place and positioning of the cooperation tools against other technologies: many systems are already used by team members such as data management applications (e.g. PDM, other data-bases) or specific applications (e.g. CAD, CAM). Cooperation tools cannot work alone and a concept must be developed to integrate cooperation tools with existing IT systems;

(iii) Identify the benefits of the cooperation tools: these tools should ultimately bring benefits and new capabilities for the organisations that adopt them. To be precise, it would be interesting to know which category of benefits can be obtained and for whom;

(iv) Implications and prerequisites for the usage of cooperation tools: these tools offer new opportunities for improvement but which factors need to be taken into account to insure the adoption? Which new competencies are required?

(v) Additional factors: identification of new software functionalities to improve cooperation and the definition of new research avenues;

The goal of the thesis was to tackle the aforementioned issues. Usually, a research team at Bosch mostly pays attention to the first three issues – the second issue or "the technological focus" being the most important (data format, software functionalities, integration with other software, etc.). Therefore, this thesis complements "the technological focus" by investigating more deeply some of the issues (mainly the first issue) or by studying new issues (especially the fourth issue dealing with the prequisites for the adoption of the cooperation tools). The following chapter will focus on the theories underlying some of these issues (namely the product development performance – issue # 3, the cooperation and the product development activities – issue # 1, the definition and the impacts of cooperation technologies – issue # 2 and the enablers for cooperation technologies – issue # 4).

CHAPTER 2 : THEORETICAL BACKGROUND

This chapter is composed of five sections and deals with the main theoretical concepts that will be used later in this study. The objective of this study is to improve the product development process and we will take a look at the different definitions of product development performance in the first section. The cooperation tools will modify the information flow and the work patterns in product development teams. Several studies on the work and tasks performed by team members will be presented in the second section. Topics related to the usage and the impact of cooperation technologies are reviewed in the third section. The fourth section presents some industrial initiatives whose aim is to facilitate the appropriation or implementation of cooperation tools. Finally, the most important results of previous empirical studies will be summarised and the implications for future research will be presented in the fifth section.

2.1. Performance of the product development

Product development is an important activity for a manufacturing firm as the launch of successful products is essential for the short and long-term success of a firm and its stakeholders (Ulrich and Eppinger, 2000). In addition, product development impacts productivity, costs and customer choices (Clark et al., 1987). Without successful products on the market, a firm cannot survive, improve its profitability or win new markets. Therefore the monitoring and measurement of the product development performance is of tremendous importance for organisations (Driva et al., 2000). The measurement of the product development performance is an important but arduous exercise. For example, even if intangible benefits must be considered (Gerwin and

> "In the social, managerial, and behavioral environments and sciences, the phenomenon under consideration is much less precise [than physical science]. In most instances the phenomenon of interest is in the form of a process, or at least a set of events. What we don't know about such phenomena – and sometimes what we find so difficult to measure – is precisely that which we wish to measure (Geisler, 2000, p35)"

Barrowman, 2002), they can be difficult to measure in an appropriate manner (e.g. flexibility).

Before assessing the impact of cooperation tools on the product development performance, we had to define the notion of performance. Driva et al. (2000) conducted a survey and found "that companies are using basic time, cost and quality measures, whereas academics would like to see increased use of customer-related measures at the design and development stages". In addition, the set of performance indicators depends on the context or the unit of analysis (project level vs. firm level).

In the literature, the term "performance" is often used as a dependant variable but the concept of performance is multidimensional. Several definitions of performance will be defined and presented in the following paragraphs. First, the "classical" or holistic perspective which emphasises the product market success and the meeting of targets will be presented. Then, additional dimensions relevant for this study will be presented: innovation, virtual teams and some specific to the automotive industry .

2.1.1. The classical performance perspective

In the 90´s, the Product Development Management Association set-up a task force in charge of defining "measures of product development success and failure". It came up with the following results:

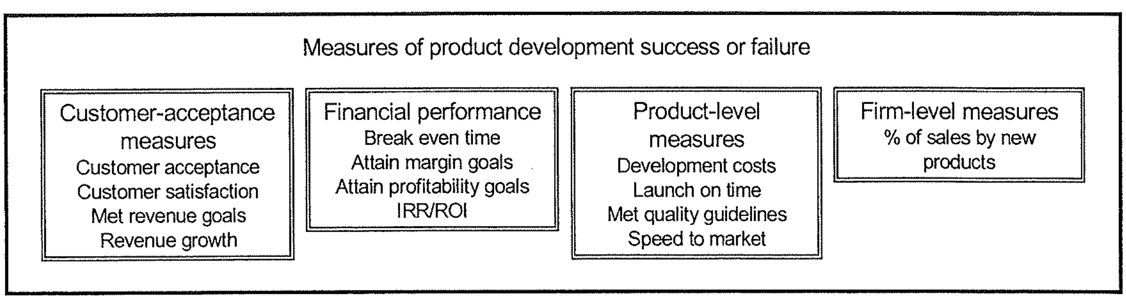


Figure 2.1 – Definition of the product development success

Source: Griffin and Page (1993)

In the literature, a great deal of studies refer to this initiative to define the product development performance (Driva et al., 2000; Gonzáles and Palacios, 2002; O'Donnell and Duffy, 2002; Olson et al., 2001; Souder et al., 1998). To gain a better understanding of the performance measurement sets used in previous studies, the following table lists different measures used in empirical studies in the field of product development.

Table 2.1 – Performance measurement of product development process

Author(s), date	**Objective and context of the study**	**Definition of product development performance – dependent variable**
Dröge et al., 2000	Impact of practices (e.g. supplier closeness). Automotive sector	- Product development time reduction (or time to market) - Product introduction time reduction (or time to customer)
Gomes et al., 2003	Impact of "functional integration". Several sectors	Outcome measure: product development time and cost and product quality
Gonzáles and Palacios, 2002	Impact of "product development techniques". Spanish firms	Product success: market share, success rate, launching frequency, percentage of new products (< 3 years), and customer satisfaction
Hauptman and Hirji, 1996	Impact of process concurrency. Various sectors and countries	Project outcomes: "Team satisfaction", "Project cost and schedule", and "Product cost and quality"
Leenders and Wierenga, 2002	Effectiveness of seven integration mechanisms (R&D and marketing). Pharmaceutical sector.	New product performance: "Speed of the decision-making process, quality of the decision-making process, product development speed, commitment to translating decisions into actions, cost efficiency, and ability to react to new opportunity"
McDonough et al., 1999	Impact of communication mechanisms (e.g. email). Various sectors and countries	Product design team performance: overall team performance, overall team satisfaction, quality of the product, and efficiency of the process
McDonough, 2000	Identification of factors explaining teams success	Project performance: time to market, on budget, product quality, and team member satisfaction
Olson et al., 2001	Impact of functional integration (R&D, marketing and operations)	Effectiveness: quality of the product, management satisfaction, and commercial success (target); Efficiency: on budget and on time
Sicotte and Langley, 2000	Impact of different integration mechanisms (e.g. formal leadership). One research centre	Project performance: product and process met quality standards, technical outcomes met expectations, on schedule, all tasks were accomplished, on budget (± 10 %), goals achieved, and product's profitability exceeded
Souder et al., 1998	Impact of integration under "technical and market uncertainty"	NPD effectiveness: NPD cycle time, prototype development proficiency, design change frequency, R&D technical effectiveness, R&D commercialization effectiveness, product launch proficiency, and market forecast accuracy

Author(s), date	Objective and context of the study	Definition of product development performance – dependent variable
Swink, 2000	Impact of integration and top management support	Product design performance: development time, design quality, and financial performance
Takieshi, 2002	Assess the impacts of knowledge and task partitioning between car makers and supplier	Component design quality: performance (simplicity, innovativeness, weight, etc.), cost, quality (durability, manufacturability, etc.), and structural and functional coordination between components

The above studies focused on the project or product development process. Some studies focus on the achievement of objectives such as quality, costs and delays (Gomes et al., 2003; McDonough, 2000, Olson et al., 2001; Sicotte and Langley, 2000 and Swink, 2000). Other studies integrate the outcome of the product development process like "component design quality" which includes manufacturability and functional performance (Takieshi, 2002). Finally, some authors include additional factors like market aspects (Gonzáles and Palacios, 2002; Olson et al., 2001), team satisfaction (Hauptman and Hirji, 1996; McDonough et al., 1999; McDonough, 2000), decision making (Leenders and Wierenga, 2002). To summarise, some studies look at the output of the product development process (product costs, quality, manufacturability, market shares) and other studies open the "black-box" to include factors like decision making or team satisfaction.

2.1.2. The innovation perspective

To survive, firms must offer new products on the market or use new processes because "... innovation is a central determinant of longer-run success and failure for manufacturing firms." (Utterback, 1994). Rogers (1995) defined innovation as "an idea, a practice, or an object perceived as new by an individual or a unit of adoption". As mentioned in the first chapter, this is especially true for the automotive sector.

In the literature, innovation is measured according to criteria like number of patents, R&D expenditures or the number of qualified engineers and scientists. In the field of product development, the level of innovation - measured by product and process level of newness – is commonly used as mediating variable (see Swink, 2000 or Takieshi, 2002).

While these criteria can be used by a firm, a sector or a country, other measures have to be defined for a team or for people. What would be interesting to know for teams is the antecedents that lead to the development of more innovative products or processes. It is usually admitted that the processing information (or interactions) in the team leads to new ideas. For example, a study performed at the MIT showed that 80% of the ideas arise trough personal contacts and discussions (cited in Luczak and Eversheim, 1999). In other words, the new ideas about a product or a process (i.e. how to design or improve it) appear during discussions. Leenders et al. (2003) call these discussions creativity and defined it as the ability to "combine and integrate input from multiple NPD team members".

2.1.3. The virtual team perspective

Virtual teams are more and more commonly used for the development of products. The first empirical evaluations have been published. Allen (1977) established that communication between people decreases sharply when the distance increases. The virtuality changes the interactions between team members whereas collocation "can reinforce social similarity, shared values and expectations" (McDonough et al., 2001). It makes virtual teams more difficult to manage and leads to paradoxical situations as upper management promotes global and virtual teams and team managers prefer collocated teams (Rognes, 2002). Therefore, the measure of the performance of virtual teams is very specific.

The following table lists some measures used in empirical studies to assess the performance of these teams:

Table 2.2 – Measurement of virtual team performance

Author(s), date	**Objective and context of the study**	**Definition of virtual team performance**
Edwards and Shridhar, 2003	Impacts of the usage of virtual teams in the software industry	Virtual team meeting outcome: "learning effectiveness", "quality of projects", "virtual team project experience", "effect on software engineering process"
Huang et al., 2002	Impacts of a "group support system". Performed with students	Process of virtual team building: team cohesion, commitment, and collaboration climate; Outcome of virtual team building: perceived decision quality and the number of decision alternatives generated
Montoya-Weiss et al., 2001	Impact of "conflict management behavior", "coordination mechanism", and "process structure". Students (Japan, US)	Virtual team performance (based on Diehl and Stroebe, 1987): range of relevant issues, decisions well structured, and the decision rationale explored issues deeply
Potter and Balthazard, 2002	Examination of "interaction styles" in virtual and traditional teams. MBA students	Objective performance: team error, gain, and synergy; Process performance: solution acceptance, satisfaction, and perceived efficiency
Wierba et al., 2002	Impact of collaboration tools on a dispersed product development team by an automotive supplier	Performance of distributed teams: difficult scheduling common meeting times, difficult finding co-workers, receive timely information about changes in plans, frequency of delays, and the average length of delays

One of the major challenges for virtual teams is to maintain a good teamwork. This capacity is therefore used as performance criteria (Edwards and Shridhar, 2003; Huang et al., 2002; Potter and Balthazard, 2002). A second aspect of the virtual team performance is the quality of work such as learning (Edwards and Shridhar, 2003) and the quality of the decisions (Huang et al., 2002; Montoya-Weiss et al., 2001).

2.1.4. The automotive perspective

As this study is performed in the automotive sector, it would be interesting to find out performance criteria that are important and relevant for this sector. Some empirical studies were performed with firms or product development teams in this sector and the following table gives an overview of these studies:

Table 2.3 – Product development performance measurement in the automotive industry

Author(s), date	**Objective and context of the study**	**Definition of product development performance in the automotive industry**
Dröge et al., 2000	See Table 2.1 – Performance measurement of product development process	
Evans and Jukes, 2000	Exploratory study on "co-development" improvement. Automotive industry in UK	Objectives: product development time reduction (-30%), product development cost reduction (-40%), and part costs reduction (-30%)
May and Carter, 2001	Case study investigating usage of ICTs in "the automotive engineering supply chain"	"Impact on the product introduction process": improvement of technical discussions, quality (earlier maturity), "time savings"
Takeishi, 2002	See Table 2.1 – Performance measurement of product development process	
Von Corswant and Fredriksson, 2002	Identification of performance criteria used in the automotive industry	Key performance criteria (for suppliers): delivery precision, quality, product costs, product innovation, development time, development costs, product related services, and customised products Key performance criteria (for car manufacturers): quality, product costs, development time, delivery precision, development costs, product innovation, product related services, and customised products

We retrieve similar performance measurement criteria identified in the preceding paragraphs (Evans and Jukes, 2000). However, the study of Von Corswant shows that the ability of suppliers to deploy a performing supply chain is important (from the OEMs perspective). Indeed, the three first criteria are related to the delivery precision, the quality, and the product costs.

2.2. Cooperation and product development activities

Today, the development of products is a joint effort done by people from different disciplines or fields spread along the product life cycle (engineering, manufacturing, marketing, procurement, support, dismantling, etc.) that bring their respective knowledge together. Product life cycle issues are important and the topics related to "Product Lifecycle Management" (PLM) will be first presented. Then, the way team members work together (i.e. to perform PLM) will be presented.

2.2.1. Product life cycle management

The acronym PLM has been well known and diffused for several years and refers to both a business strategy and software tools. This new paradigm stems from business practices and environmental standards that strain/force firms to take the life cycle of their products into account. The IT infrastructure provides the tools for managing the life cycle of products.

The ISO standard 14040 forces firms to manage the life cycle of their products and to reduce the environmental impact of products (i.e. "from cradle to grave"). The European Union released a "greenpaper" on the Integrated Product Policy that calls for action to minimise environmental impacts of products (IPP, 2001). As mentioned in the first chapter, the automotive industry is especially targeted by the current and future legislation.

Besides legal pressures, the management of product life cycle represents business opportunities. The Gartner Group defines PLM as "Guiding products from concept through retirement to deliver the greatest business value to an enterprise and its trading partners" (Halpern, 2002). This trend is also exemplified by the term "servicizing" (Reiskin et al., 2000) which means that firms are no longer selling products but services (e.g. a mobility service instead of a car). Suppliers are developing a "field service concept" during the product development process. For example, a field service concept encompasses (i) instructions for performing a diagnostic and the maintenance, (ii) the development of specific tools for dismantling and repairing the product, (iii) costs analysis (when to repair, when to change), (iv) definition of the supply chain for spare parts, etc.. Managing the life cycle of products is therefore becoming a key issue for firms.

Managing the product life cycle begins from the outset, i.e. from the design phase. In the engineering management literature and especially the system engineering literature, the term "Design for X" is often used, X being a life cycle phase that needs to be optimised during the product development phase. The following figure shows different requirements:

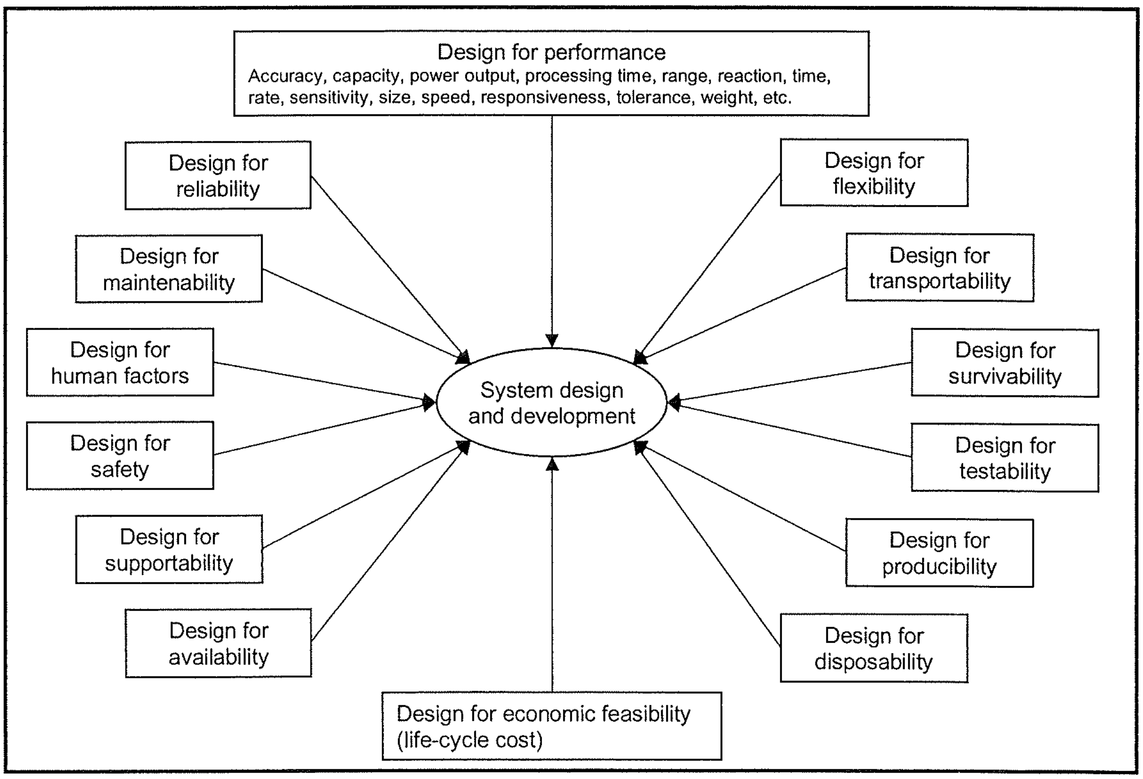


Figure 2.2 – Design for X

Source: Blanchard (1991)

The optimisation of the different life cycle phases requires the input from different product development stakeholders. It is the base of practices such as concurrent engineering where "manufacturing and functional design constraints need to be considered simultaneously (Smith, 1997)". Today, product development is seen as a knowledge sharing experience (Mohrman et al., 2003). To summarise, "communication is an important part of the engineering work..." (Robertson and Allen, 1993). Cooperation during the product design is therefore required and the ability to solve problems in an integrated manner or holistic view.

2.2.2. Activities underlying the product development activity

Several empirical studies were conducted to find out how product development stakeholders were working together (i.e. ability to solve problems, define common solutions). The following table presents the results of several empirical studies:

Table 2.4 – Summary of studies in the field of product life cycle orientation

Authors, date	**Objectives and context of the study**	**Definition of product development activities**
Ahmed et al., 2003	Observation of problem solving pattern of novice and experienced engineers in the aeronautic industry	Observed patterns: - generation of a decision - preliminary evaluation (experienced designers) - implementation of the decision - evaluation of the decision
Ehrlenspiel, 1995	Proposition of a systemic problem solving model in product development	Proposition of a 6 steps model: Steps 1 & 2: analysis and formulation of the problem Steps 3 & 4: development of solutions and analysis Steps 5 & 6: ranking of the solutions and choice
Crabtree et al., 1997	Observation of activities performed by team members in the aeronautic industry	Activities performed: - problem solving and thinking - documentation - support and consulting - planning and negotiation
Lefebvre and Lefebvre, 2001	Observation of activities performed by firms in various sectors	Activities performed during the product development: - transfer data to customers and suppliers - integrate product development software - simultaneous engineering with suppliers - on-line collaboration with suppliers and customers
Stempfle and Badke-Schaub, 2002	Observation of problem solving activities in product development teams	Problem solving activities: - "thinking operations" (exploration, generation, comparison and selection) - "group process" (work planning, analysis, evaluation, decision, control) - "content"

Authors, date	Objectives and context of the study	Definition of product development activities
Ullman, 2002	Propositions for the improvement of CAD tools	Two components of problem solving (based on Newell and Simon, 1972): - "internal human problem solving environment" (long and short term memory) - "external environment" (information, communication, procedures)

Several of these studies identified characteristics of work patterns that occur in product development teams. More precisely, team members perform activities like searching and transfer of information, proposition of design alternatives, and evaluation of alternatives (Ahmed et al., 2003; Clark et al., 1997; Stempfle and Badke-Schaub, 2002). To perform these activities, people switch between individual and group tasks (Olson and Olson, 1999; Stempfle and Badke-Schaub, 2002).

2.3. Definition and impacts of cooperation technologies

As mentioned in the first chapter, the role of ICTs in product development has grown during the last decades. ICTs or "hard technologies" (McDonough and Kahn, 1996) are nowadays considered as practices that facilitate integration (like organisational mechanisms, see the literature review of Nihitilä (1999) and Sicotte and Langley (2000)).

Kappel and Rubenstein (1999) distinguished two kinds of tools involved in the product development, the first kind supporting specific design tasks ("engineers working independently") and the second supporting interactions between product design stakeholders ("engineer working with his engineering colleagues and with others who influence the design"). These cooperation technologies can be classified in two main categories: asynchronous and synchronous technologies. The first one is a real time (same time) interaction between two (or more) people while the second can be called "off-line" (not at the same time). We find here a similar classification as for work in product development processes (switch between individual and group work).

The following table (on the next page) presents some empirical studies on the usage of cooperation tools ("hard technologies") in the field of product development (with a focus on CAD, web-based tools).

Numerous studies investigated the use of "traditional" or "all purpose" cooperation technologies (i.e. email, phone, fax). Cooperation tools have a positive impact under certain circumstances: give an advantage to the adopters (Wierba et al., 2002), are used for communication purposes (Robertson and Allen, 1993), for structured work (Allen and Murotake, 1990), when time and language barriers prevent the usage of synchronous tools (Sosa et al., 2002), when "relational links" exist – namely cohesiveness, group interaction and satisfaction (Warkentin et al., 1997). This latter point shows also that organisational integration mechanisms are important to get benefits from cooperation tools.

Table 2.5 – Summary of studies evaluating the impact of cooperation technologies

Authors, date	**Objectives and context of the study**	**Main results**
Allen and Murotake, 1990	Identify the usage and the benefits of computer aided tools in "two U.S. electronics firms"	Benefits: usage for "structured work"; Pitfalls: usage for "less structured work" leads to less innovative solutions
Bajwa et al., 2003	Survey on the usage of electronic collaboration tools in the U.S. and Australia	Tool usage (decreasing): e-mail, teleconferencing, videoconferencing, dataconferenicng, proprietary groupware, web-based tools and electronic meeting
Bochenek and Ragusa, 2001	Identify the best visualisation support for design review	Problem detection and solving: HMD and CRT were better than stereoscopic glasses
McDonough et al., 1999	Impact on the performance of various cooperation tools on the performance. Global team managers in various sectors and firms	Positive impact: phone; Negative impact: videoconference; No impact: fax, email, teleconference, face-to-face meetings, mail, company data-bases
Ocker and Overbaum, 1999	Comparison asynchronous tools/face-to-face meetings. Survey on students	Similar effectiveness but a lower satisfaction for asynchronous meetings
Robertson and Allen, 1992	Identify when computer-aided design systems have the greatest impact. Interviews, various sector	Greatest benefits: when managers "...view the systems as enabling improvement in social capital..."
Robertson and Allen, 1993	Impact of computer-aided design systems on the performance. Two manufacturing companies	Impact on "engineering work" performance: communication, design and then analysis
Sosa et al., 2002	Investigation of the usage of communication tools in virtual teams. Telecommunication sector	Usage of asynchronous tools: preferred when the distance between the partners is long or different mother tongue. Otherwise face-to-face meetings and phone calls.

Authors, date	Objectives and context of the study	Main results
Warkentin et al., 1997	Comparison of collocated teams and virtual teams (using a web-based "asynchronous conference system")	Impact of the asynchronous tool: less performance, less satisfaction. Crucial role of "relational links"
Wierba et al, 2002	Adoption of collaboration tools on a dispersed product development team at an automotive supplier	Adoption: when collaboration tools have a significant advantage (trade off with the effort to learn a new tool)

2.4. Enablers for cooperation technologies

To improve the way they were organising their product development process, firms adopted several practices in the last two decades: stage gate, cross functional team, approval process, liaison personnel and guest engineers, more face-to-face communication, collocation, meeting between functional representatives, supplier integration, design structure matrix (Smith, 1997; Leenders and Wierenga, 2002, Dyer, 1996; Eppinger, 2001). These mechanisms ensure that upstream and downstream activities are coordinated and that cooperation occurs. The work of people involved in product design activities must be organised in a way to facilitate the exchange of information ("coupled tasks", Clark and Fujimoto (1991)) and coordinate their efforts (Kappel and Rubenstein, 1999).

However, the implementation of software-based collaboration tools represents a new challenge for product development teams and their members. In the last few years, some methodologies aiming at improving cooperation and the usage of advanced collaboration tools were set-up in the field of procurement and product development. These industrial initiatives as well as academic studies will be presented in this section.

2.4.1. Industrial initiatives

2.4.1.1. Collaborative Planning, Forecasting, and Replenishment (CPFR)

The "CPFR is a method that enables companies to do collaborative forecasting with other members of a virtual organization" (Cassivi, 2003) is appropriate for the fields of procurement and supply chain management. This methodology "attempts to coordinate the various activities including production and purchase planning, demand forecasting and inventory replenishment between supply chain trading partners" (Fliedner, 2003).

The CPFR method consists of three major processes (VICS, 1998):

1. Planning (front-end agreement, joint business plan);
2. Forecasting (sales-forecast collaboration, order-forecast collaboration);
3. Replenishment (order generation);

The "rules of the game" are determined in the first process (metrics, common objectives, management support, joint business plan, business information). Cassivi (2003) empirically investigated the influence of cooperation planning on the supply chain performance and demonstrated its positive influence (especially on intangible benefits).

2.4.1.2 Simultaneous Engineering Checklist

In the field of product development, the German Automotive Association developed the Simultaneous Engineering Checklist recommendation (VDA 4961, 1998). The VDA published a first checklist in 1998 to improve cooperation in development projects in the German automotive sector. The goal was to plan cooperation from the project outset. This recommendation is one of the 50 recommendations of the VDA and has been developed by a working group of the "VDA CAD/CAM working committee" which regroups representatives of German firms operating in the automotive sector. At the VDA, this kind of working group must develop recommendations that are "specific and detailed, support different kind of situation in the application, applicable at the working level" (VDA 4691/2, 2002).

The recommendation focuses on "data logistics" ("Datenlogistik") which is defined as the "deployment of computer aided and information technology to support and carry out inter firm simultaneous engineering processes" (VDA 4691/2, 2002). It is also viewed as a basis for intra-firm agreements on " methods and standards" (BMW, 2002). Hence, this checklist facilitates the definition of "standardised working methods and processes" that lead to a reduction of data transfer problems in cross-organisational projects. This recommendation is also used by some OEMs to improve internal cooperation. A second version of the Simultaneous Engineering Checklist describes several cooperation models between different firms in the automotive sector: engineering services, part providers, component providers, module providers, system providers, and "general suppliers" ("Generalunternehmer" or "all purpose company"). Depending on the firm position in the value chain, the cooperation pattern (or model) differs. The cooperation models describe the characteristics of the partners, the art of integration (i.e. geometrical integration, functional integration, manufacturing integration and level of integration) and the kind of information that is exchanged between the partners. The following figure shows the example of a cooperation model between a prime contractor and a component supplier:

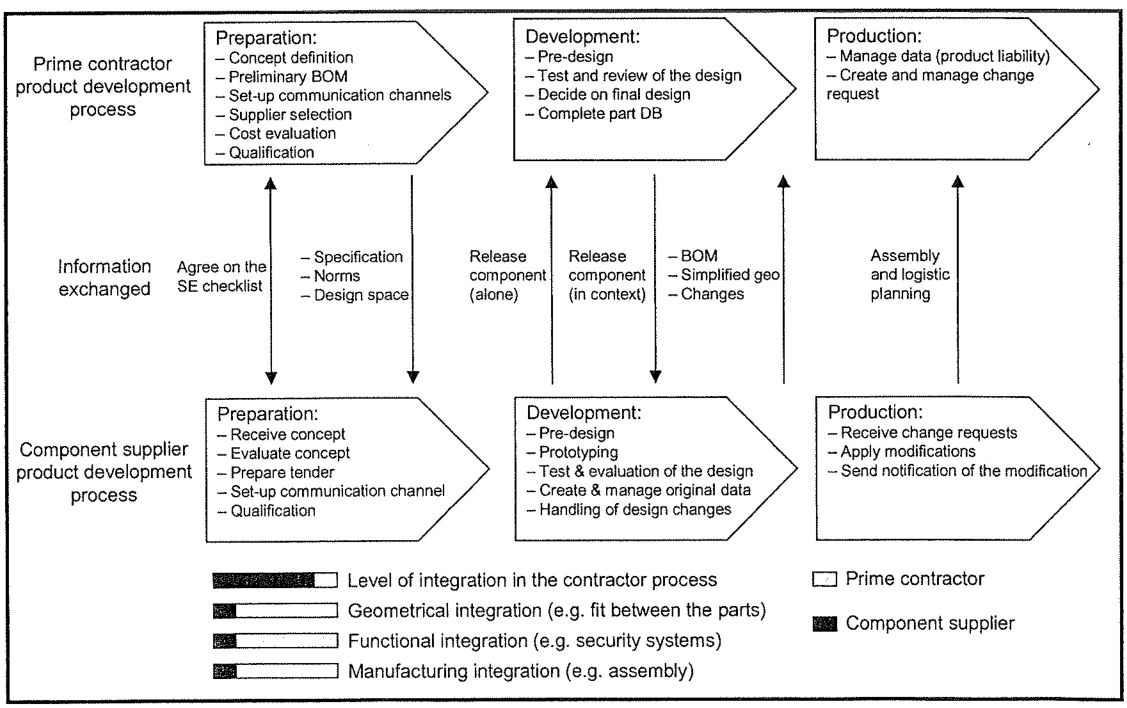


Figure 2.3 – VDA Checklist: example of a cooperation model
Source: adapted and translated from Holland and Plischke (2001)

The application of these six cooperation models should bring the following benefits: reduce errors and rework in projects, cost reduction, promote common work, create transparency in processes, stimulate the improvement of the cooperation processes, help partners for internal as well as external deployment, provide approaches to shape cooperation work in joint project, and help the deployment of the first recommendation.

2.4.1.3. The DMU with suppliers working group

The usage of DMU is widespread in the automotive industry and the German vehicle manufacturers set up a working group to investigate the usage of the DMU between car makers and their suppliers. This working group was composed of experts of car development originating from Audi, BMW, Bosch, Porsche, DaimlerChrysler and Volkswagen. Designing a homogenous (or "standardised") environment between car makers and suppliers is difficult and the working group proposed the concept of a "process tool box".

The tool box contains different processes (e.g. design review) that can be adopted by firms to facilitate their communication and cooperation. The processes can be used independently or in combination. The figure describe the concept of the process tool-box where different process elements are available (above) and combined to form a process (below) that can be described in details in the form of an ARIS model (for more details, see 3.4.2.5).

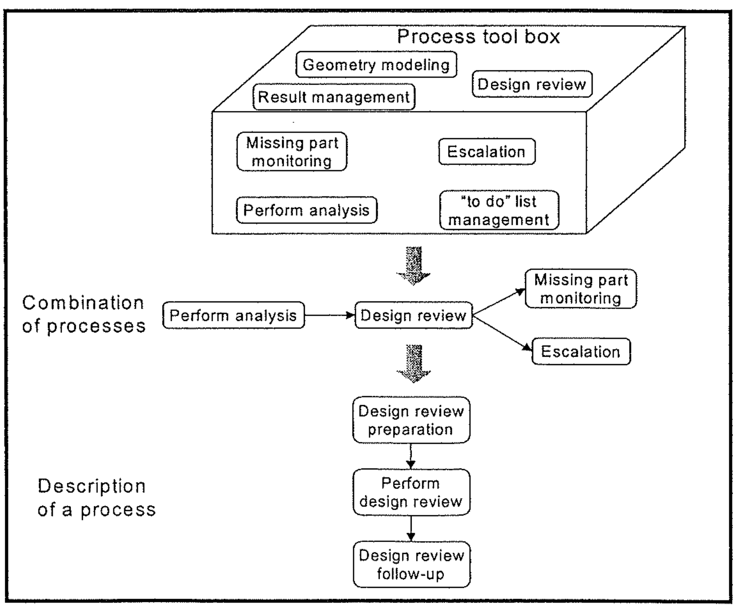


Figure 2.4 – DMU with suppliers: the process tool box

This concept is powerful and the processes can be supported by advanced cooperation tools (CAx-AG 2.6.6, 2002). Hence cooperation processes or cooperation routines could be diffused or used in the automotive industry.

In fact, this initiative was inline with other initiatives in the field of organisational processes. For example, Malone et al. (1999) noticed that organisations were facing the following dilemma: ambitious improvement programs are initiated but "they provide too little guidance about what the improved organization might look like in particular situations. They hold out the promise of innovation, but lack the details needed to accomplish it." To solve this problem, they designed a "handbook of organizational processes" that allows organisations to:

- "redesign existing business processes";
- "invent new processes (especially those that take advantage of information technology)";
- "organize and share knowledge about organizational practices";

The emergence of cooperation tools changes (or should change) the way people are working. The aforementioned initiatives (CPFR, VDA) are aimed at enabling the benefits associated to the collaboration tools or new ways of working.

2.4.2 Appropriation of cooperation and tools

The adoption of new cooperation tools in the field of product development represents a challenge for teams and firms. In the last few years, some studies were performed on the adoption or appropriation of these new tools (see table on the next page).

The industrial initiatives and many authors stress the importance of planning and improving cooperation. Mohrman et al. (2003) conclude that it is more important "to emphasize the way the work is carried out, rather than programs and particular approaches to managing knowledge". Cooperation is not a phenomenon that occurs automatically between the members of a dispersed and cross-organisational product development team even if cooperation tools are available. Several authors (Hacker and Kleiner (1996), Jarwenpaa and Staples (2000), Malhotra et al. (2001), and Mohrman et al. (2003)) and the aforementioned industrial initiatives showed that the establishment of processes is required to use the cooperation tools. In other words, cooperation tools bring benefits only if a new work pattern is defined. To be successful, teams must determine and practice new rules or routines.

Table 2.6 – Summary of studies investigating the appropriation of cooperation tools

Authors	**Objectives and context of the study**	**Main results**
Malhotra et al. (2001)	Identification of factors explaining the success of a virtual team that used a collaboration tool (NexpriseTM). Case study at Boeing Rocketdyne	Factors identified: - "<u>Strategy-Setting:</u> Establishing an umbrella agreement in advance of team formation" - "<u>Technology Use:</u> Using collaborative technology not only to collaborate but also to manage knowledge" - "<u>Work Restructuring:</u> Restructure work processes without changing the core creative needs of the team"
Mohrman et al. (2003)	Impact of "attitudes" on the knowledge transfer effectiveness. Various sectors	"<u>knowledge work behaviors</u> ... contribute significantly to knowledge outcomes" rather than traditional mechanisms (e.g. IT and rewards). "knowledge work behavior" is composed of "system performance", "systematic process", "knowledge linking", and "trying new approaches". The usage of systematic processes plays the most important role.
O'Sullivan (2003)	Examination of the "work patterns" in a large development project in the aeronautic industry	"standardized work processess" defined very early in the project (e.g workflow, deliverables, coordination memo, meeting preparation) by the prime contractor. Integration facilitated: "... reduced the range of possible interpretations of the timing and content of work outputs and allowed unfamiliar individuals drawn from widely varying organizational contexts to form accurate and convergent expectations about each other's design work."
Susman et al. (2003)	Identification of model helping teams to implement cooperation tools. Based on the work of Majchrzak et al. (2000) who observed that tools create "misalignements among the pre-existing organizational environment, groups and technology structures". Theoretical work	"conceptual model of the technology appropriation process": - "generation of misalignments - interpreting and experiencing misaligments - recognizing differences in interpretations of misaligments - reconciling different interpretations and reaching agreement about appropriations"

2.5. Synthesis of past research

A rich and vast literature exists in the field of cooperation and product development. The studies privileged had the following characteristics: team or team member as unit of analysis, related to “mechanical engineering”, the investigations of new practices or tools and found in journals with “peer review”. Numerous papers were published on the impacts of “practices” on the product development performance. Practices being defined by tools (e.g. information systems), organisational mechanisms (e.g. new form of team organisation) or methodologies (e.g. Quality Function Deployment). These empirical studies investigated different dimensions of the product development performance (e.g. costs, delay, quality, teamwork, etc.) and were conducted under different project circumstances (e.g. uncertainty), sectors and countries. Other studies had a more explorative goal and observed the work pattern of teams in different circumstances (e.g. critical situations) or the implementation of new tools.

Some of the studies mentioned in this chapter will be presented in detail in Table 2.7 followed by the contributions and weaknesses of the empirical studies in Table 2.8. Finally, the main elements of the past research will be summarised as well as the implications for future research.

Table 2.7 – Summary of studies relevant for this research

Authors, date	**Research strategy**	**Data collection**	**Organisations**	**Respondents**	**Type of evidence**	**Objectives of the studies**	**Main results and conclusions**
Ahmed et al., 2003	"observational study"	Observation, interview, discourse analyses	aeronautics industry	12 design engineers (6 novices, 6 with experience)	Coding: thought, action, pattern, design strategy and general activity	Observation of problem solving pattern (novice and experienced engineers)	Observed patterns: - generation of a decision - preliminary evaluation (experienced designers) - implementation of the decision - evaluation of the decision
Gomes et al., 2003	Survey	Questionnaire	40 British and Dutch firms in various sectors	92 R&D and product development managers	- PDP (time to market, costs, product quality) - Functional integration	"...relationships between performance ... and functional integration under different conditions of project uncertainty..."	- Functional integration influence product and process performance - Collaboration plays an important role in the case of highly innovative products - The NPD depends of the type of products
Gonzáles and Palacios, 2002	Survey	Questionnaire	54 Spanish firms in (electronic and transportation equipment)	R&D, manufacturing and marketing executives	- "new product success" - "new development techniques"	Assess the impact of "new development techniques" on the "product success"	Positive impact: IT and "manufacturing technique" No impact: "Concurrent engineering, DFMA, QFD" Negative impact: rapid prototyping
Hauptman and Hirji, 1996	Survey	Questionnaire	50 projects in various 14 firms and countries	Project leaders, R&D and manufacturing representatives	- "Project Outcomes" - "Degree of Concurrency in the CE Process"	Assess the impact of concurrent engineering on the product development performance	Success affected by: "two way communication, overlapping problem solving, readiness to make decisions on the basis of uncertain and ambiguous information, and readiness to release uncertain and ambiguous information"

Authors, date	Research strategy	Data collection	Organisations	Respondents	Type of evidence	Ojectives of the studies	Main results and conclusions
Leenders and Wierenga, 2002	Survey	Question-naire	148 pharmaceuti-cal firms	Senior managers (R&D, marketing)	- "new product performance" - 7 integration mechanisms	Assess the effectiveness of seven integration mechanisms (between R&D and marketing)	- Collocation and ICTs are effective integration mechanism - ICTs have a positive effect on performance
Leenders et al., 2003	Survey	Question-naire	11 firms in the electronics sector	243 product development team members	- "team level creativity" - Communication frequency - Centralization of communication	Understand how to enhance creativity (high and low virtuality)	Creativity fostered: high level of virtuality possible when incremental innovation; complex task and high creativity: high virtuality unproductive; less central of virtual leader better for creativity; creativity decreases with the team longevity
Malhotra et al., 2001	Case study (10 months period)	Observatio n, panel, interviews	2 firms in the space industry	8 team participants	Process adaptation, how were barriers overcome, how was integration ensured, how can knowledge storage and retrieval be improved	"identify successful managerial practices and develop recommendations for managers responsible for	Success factors: "strategy setting" ("umbrella agreement"), "technology use" ("to collaborate but also to manage knowledge"), "work restructuring" (modify work process)
May and Carter, 2001	Case study (2 years period)	Proforma sheets, observatio n, interviews	Automotive industry (4 European countries)	40 engineers	"nature of the collaborative sessions", impacts on the product development process and on the firm	Investigation of the usage of Information and Cooperation Technology	"Impact on the product introduction process": improvement of technical discussions, quality (earlier maturity), "time savings"

Authors, date	**Research strategy**	**Data collection**	**Organisati ons**	**Respondents**	**Type of evidence**	**Ojectives of the studies**	**Main results and conclusions**
McDonough et al., 1999	"explora-tory investiga-tion"	Interviews and question-naire	22 projects in 10 firms	"global new product managers or new product team leaders"	- Product design team performance - Technologies	Assess the impact of various communication mechanisms on the "Global New Product Development Team"	- Background and origin influence the way people communicated - Videoconferencing negatively impact team performance
Mohrman et al., 2003	Structural equation model	Question-naire	10 firms	3596 scientists and engineers	- "Knowledge work behavior" - Outcome ("knowledge", "employee", "organizational")	Assess the impact of "knowledge work behavior"	"knowledge work behavior" has a significant influence on the knowledge outcome (traditional mechanisms have a limited impact). Therefore, the work the work is done is crucial
Olson et al., 2001	Survey	Interviews, question-naire	34 projects, 9 firms	Projects leaders and functional representatives	- Project performance - Cooperation between marketing, R&D and operation	Assess the impact of functional integration on the product development performance	Performance increases when: cooperation between R&D/operation and R&D/marketing at the beginning, R&D/operation and Mar-keting/operation in the late stages
Robertson and Allen, 1992	Explora-tory study	Interviews	10 firms	Design engineers, managers, support personnel	- Manager perspective on the CAD systems - Performance	Identify the benefits and their prerequisites	CAD are seen by managers as: "physical capital", "human capital", or "social capital". The latest bring the most benefits

Authors, date	Research strategy	Data collection	Organisations	Respondents	Type of evidence	Ojectives of the studies	Main results and conclusions
Sicotte and Langley, 2000	Survey	Questionnaire, Interview	121 R&D projects in a large corporate research centre	Researchers (1 success / 1 failure)	- Project performance, "information processing context", "integration mechanisms", "communication effectiveness"	Assess the impact of integration mechanisms on the "project performance"	Effect on performance: "Formal leadership": positive "planning and process specification": positive ICTs: low (higher when high uncertainty and equivocality)
Stempfle and Badke-Schaub, 2002	Observatio n	Analysis of the team communication	3 teams composed of students in engineering	4 to 6 students per team	Communicative acts: "analysis of the frequencies", "process analysis - steps", "transitions"	Observation of problem solving activities in product development teams	<u>Problem solving activities:</u> "thinking operations" (exploration, generation, comparison and selection) "group process" (work planning, analysis, evaluation, decision, control) "content"
Takieshi, 2002	Survey	Question-naire Interview	Nine Japanese automotive suppliers (45 cases)	Project managers	- Performance: "component design performance" - Knowledge and task partitioning	Determine the level of tasks and knowledge partitioning between OEMs and suppliers	Regular projects: OEMs must have "architectural knowledge" Innovative projects: overlap between OEMs and suppliers
Wierba et al., 2002	Survey	Interview, question-naires	An US automotive supplier	50 members of a product development team	- Performance - "receptivity to new collaboration tool" usage of collaboration tools"	Assess the impacts and the implementation challenges of a collaboration tool	"collaborative tools must be clearly superior to existing practices" Has a positive impact on performance

The following table presents the contributions and weaknesses of the past research according to several criteria: topic and objective, sample, method, factors not considered, organisations:

Table 2.8 – Synthesis of past research

Authors, date	Contributions	Weaknesses
Ahmed et al., 2003	- Observation of design work (problem solving pattern) - Two points of view (novice and experienced engineers)	- Sample (one firm) - Influence of ICTs not considered enough
Gomes et al., 2003	- Consider the relationship between cooperation and product innovation	- Influence of ICTs not considered
Gonzáles and Palacios, 2002	- Empirical assessment of "best practices"	- Sample (one country)
Hauptman and Hirji, 1996	- Assessment of concurrent engineering - Teamwork as a dependant variable - Various sectors and countries	- Role of ICTs not considered
Leenders and Wierenga, 2002	- Investigation of the impact of ICTs on performance	- Sample (one sector) - Only the R&D/marketing interface considered
Leenders et al., 2003	- Investigation of the prerequisites for creativity improvement in product development teams - ICTs considered	- Sample (one sector)
Malhotra et al., 2001	- Investigate the adoption of an advanced cooperation tool in an industrial environment	- Sample (one case)
May and Carter, 2001	- Investigate the usage and impacts of advanced cooperation tools in the automotive industry	- Sample (one sector)
McDonough et al., 1999	- Investigate the impacts of different communication tools	- Low-end cooperation tools (stand: 1995) - Small sample

Authors, date	Contributions	Weaknesses
Mohrman et al., 2003	- Investigate prerequisites to share knowledge - Large sample	- Untested measures
Olson et al., 2001	- Investigate the impact of cooperation during the different phases of the product development	- Role of ICTs not considered
Robertson and Allen, 1992	- Assess the impacts of CAD systems in organisations	
Sicotte and Langley, 2000	- Assess the effectiveness of different integration mechanisms	- Sample (one R&D center)
Stempfle and Badke-Schaub, 2002	- Empirical investigation of the problem solving process in engineering - Controlled environment	- Role of ICTs not considered - Utilisation of students (novice engineers)
Takieshi, 2002	- Investigate new cooperation aspects (knowledge sharing) between OEMs and suppliers	- Only Japanese automotive industry considered
Wierba et al., 2002	- Consider the adoption and impact of cooperation tools on team performance	- Sample (one firm)

2.5.1. Important elements of past research

From the preceding studies we can draw some conclusions:

1. Automotive sector: firms and especially suppliers must act globally, deliver innovative products, and keep prices low. The adoption of virtual and multidisciplinary teams seems privileged for the development of new product platform. **The usage of virtual teams makes sense but the management of this kind of team is arduous.** Lower satisfaction (team leaders and team members) and effectiveness (e.g. time) are too often the characteristics of virtual teams (McDonough et al., 2001; Rognes, 2002; Wierba et al., 2002);

2. The role of organisational mechanisms and ICTs: numerous studies assess the impacts of practices or organisational structure adopted by firms (Dröge et al. 2000; Gonzàles et Palacios, 2002; Leenders and Wierenga, 2002; Sicotte and Langley, 2000, etc.). The usage of ICTs is in some cases an effective means to facilitate cooperation in the product development team. However, **a prerequisite for the adoption of collaboration tools is that team members or organisations work together.** Indeed these tools modify the work behaviour;

3. Product development performance measurement: the notion of performance is broad, for some authors targets must be met (Sicotte and Langley, 2000; McDonough, 2000; Olson et al., 2001; etc.), improved (Sanchez and Perez, 2003; Dröge et al., 2000; Ragatz et al., 2002; etc.) or a mix (Takeishi, 2002). Some studies focus on sector specific performance (Leenders and Wierenga (2002) in the pharmaceutical industry; Dröge et al. (2000) in the automotive sector). **A set of specific indicators must therefore be defined (especially for intangibles factors)**;

4. Product development activities: decision making is at the heart of the product development process and is described in some studies (Ahmed et al., 2003; Robertson and Allen, 1993; Stempfle and Badke-Schaub, 2002). Some studies suggest problem solving models (e.g. Ehrlenspiel, 1995). **Today, product development is characterised by an increase of knowledge transfer and cooperation activities.**

2.5.2. Implications for this research

The results of the literature review also show that some topics should be further investigated to complement the existing knowledge. This study will try to fill some of the identified gaps:

1. Toward the assessment of the benefits of a new generation of technology: Krishnan and Ulrich (2001) suggest to "explore" the benefits in greater detail and especially want to "understand the situations in which advancements in information technology are likely to change the established wisdom about how to effectively manage product development." Since the work of T. Allen, few studies have been conducted on the impact of new development technologies. For example, very few empirical studies investigated the usage of "visual collaboration tools" or Internet-based tools in product development. This can be explained by the fact that these new tools are not widespread. The motivation and objectives of this study (see paragraph 1.3) are in line with the conclusions of Krishnan and Ulrich (2001). Hence, this research deals with the place and positioning of the cooperation tools in the product development process as well as the benefits of these tools;

2. Assess diffusion mechanisms of the cooperation technologies: the adoption of such technologies is challenging and few studies proposed models for their implementation (e.g. VDA). Therefore it would be interesting to know how to implement these new tools? what are the success factors for the diffusion? or what are the barriers? Furthermore new competencies and attitudes required by the members of product development teams have to be identified. This result confirms the importance of identifying the prerequisites for a successful usage as one of the objectives of this study (see paragraph 1.3);

3. Performance measurement: "The 'optimal' set of performance measures is very situation-dependent" (Driva et al., 2000) and intangible benefits must be investigated. Therefore, some new performance indicators – beyond the traditional cost, quality and time indicators – will be investigated in this study.

CHAPTER 3 : RESEARCH DESIGN AND STRATEGY

This chapter is composed of four sections and aims at presenting the conceptual model and the methodological aspects of this study. First, the main elements of the conceptual model will be described. Then, the research variables used in the conceptual model will be justified in the second section. The research propositions will be presented in the third section. Finally, the research strategy and the methodological elements will be described in the fourth section.

3.1 Conceptual model

The main elements of the conceptual model will be depicted here. The **product development performance** is the dependant variable of the conceptual model. Other elements will directly influence the performance and will be considered as the independent variables. Namely, the **team setting** (or team environment that characterised the respondents), the **collaboration activities** (or the activities performed by the respondents) and the **collaborative behaviour** (or the planning and improvement of cooperation in the teams) are the independent variables. Two other elements are included in the model: the quality of the cooperation tool **implementation** and the **usage of the cooperation tools**. Hence, we will be able to investigate if the implementation of cooperation tools influences some of the relationships between the dependent and the independent variables. Finally, the latest element contains some control variables.

The following figure shows the proposed conceptual model and some of the main relationships between the different elements:

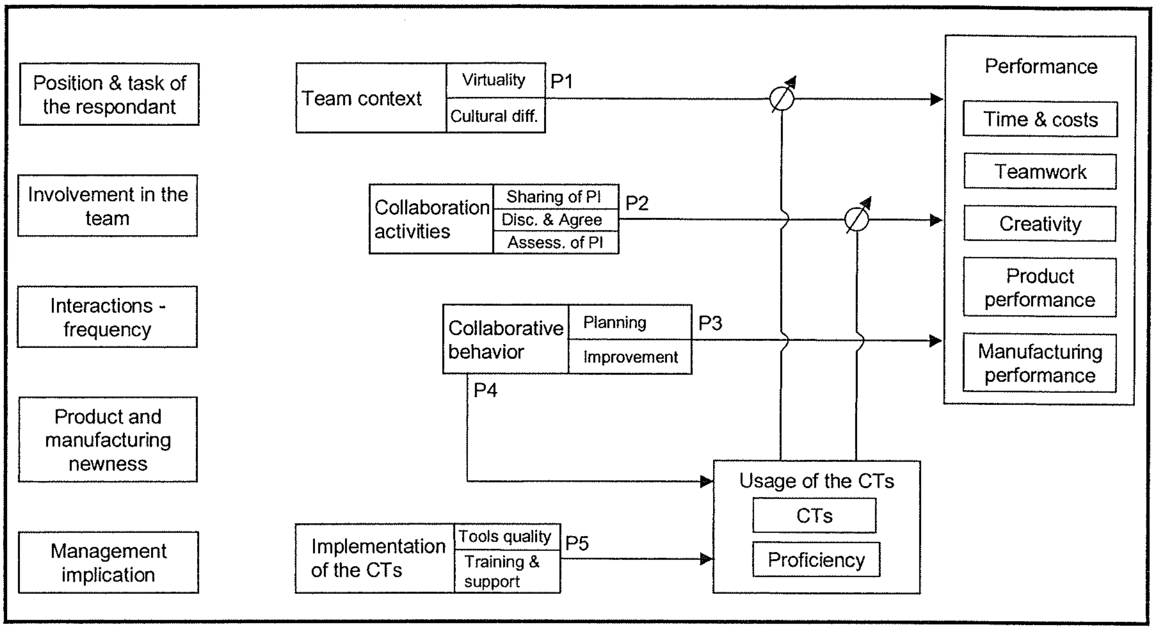


Figure 3.1 – Proposed conceptual model

The elements of the conceptual model will be described in more detail in the following paragraphs:

(i) Team context: nowadays, team members are confronted with numerous challenges. For example, team members are working at different locations which increases the level of virtuality and cultural differences exist because teams are multidisciplinary and assemble people from different countries. This element will influence the product development performance;

(ii) Collaboration activities (or product development activities): people involved in the product development process are performing different activities related to the processing of product information. Namely they are sharing product information (e.g. inform colleagues about changes), discuss and agree with other team members and perform their dedicated task using product information (e.g. design an assembly line). These three activities will be justified later in this chapter. Due to changes in the environment the importance of these activities is growing (as the field study shows). The three activities will be linked to the product development performance as a greater processing of product information among the team members will influence the product development performance;

(iii) Collaborative behaviour (or cooperation planning and improvement): this element deals with the way team members plan their cooperative work and improve their relationships. In other words, they establish the rules of the game to work together. A collaborative behaviour will influence the product development performance and the usage of cooperation tools;

(iv) Product development performance: this element will be considered as the dependant variable for this study and contains different dimensions of the product development performance (i.e. the process performance, the product performance and the manufacturing performance);

(v) Quality of the implementation: the way the cooperation tools are implemented (e.g. appropriate training) and the characteristics of the tools (e.g. userfriendliness) will influence the level of the CTs usage;

(vi) Usage of cooperation tools: several advanced cooperation tools were deployed in product development teams during the field study. These tools should streamline and facilitate the flow of product information between product development team members. The tool usage will influence some relationships of the conceptual model. Namely, between the team setting, the collaboration activities the collaborative behaviour and the product development performance;

(vii) Control variables: items like the position held by the team member in the product development chain, the level of implication in the team, the interactions with colleagues and other firms, the product and the manufacturing newness as well as the management implication will influence some relationships in the conceptual model;

3.2. Justification of the research variables

The research variables and the constructs selected for this study are described and justified in this section. Mentzer and Kahn (1995) defined constructs as "abstract, nonobservable concepts that represent different components of a theory" and are "designed for a special scientific purpose, generally to organize knowledge and direct research in an attempt to describe or explain some aspect of nature."

3.2.1 Team context

This element contains constructs that characterise the current team environment, namely: the dispersion, the degree of innovation and newness and the cultural issue.

(i) Virtuality: one of the challenges related to the usage of virtual teams is the difficulty to reach colleagues (Wierba et al., 2002). Colleagues who are travelling frequently, working at different location or in a different time zone are difficult to reach. This situation makes formal and informal discussions more difficult;

(ii) Cultural differences: an other aspect of current product development teams is the variety of their members. Teams are not only composed of people from different disciplines but also with different languages or habits. Edwards and Sridhar (2003) call it "cultural differences" and cite examples like "work ethic, work hours, preferred method of communication, revering hierarchy, individualism versus collectivism and concern for quality". In the field of product development, Griffin and Hauser (1996) identified some barriers that prevent product development team members form communicating: personality, cultural thought worlds, language, organisational responsibilities, and physical barriers. Hence cultural differences may affect the product development process because they influence the information flow and the learning process (Lyles and Salk, 1996). In other words, cultural differences are a factor that can influence the behaviour of the team members;

3.2.2. Collaboration activities

The second element of the conceptual model deals with the activities performed during the product development process. Several work patterns and problem solving patterns were found in the literature. The following figure shows two of them:

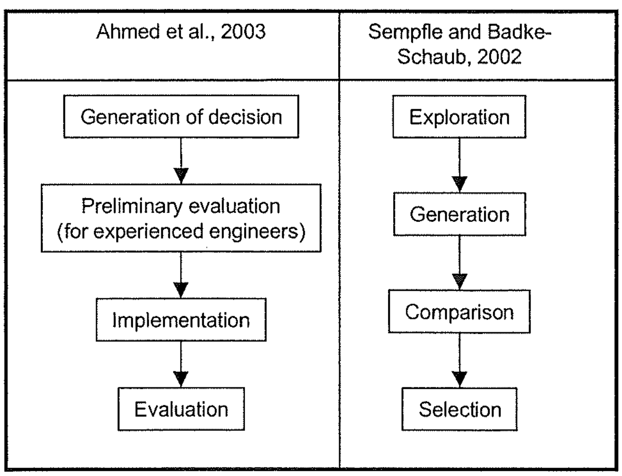


Figure 3.2 – Problem solving patterns

These patterns follow a kind of "iteration" or "loop" principle: solutions to a problem are proposed, the solutions are tested or evaluated and finally a solution is chosen. This solution is usually not the "best" but rather the most "satisfying" solution (Stempfle and Badke-Schaub, 2002). This is consistent with the seminal work of Simon (1945). Some authors stressed the importance of this "loop" in the product development process. Debackere (1999) introduced the notion of "experimental design" that is allowed by the information asymmetry reduction (difference between information available and needed), the interpretation asymmetry reduction (difference in the interpretation of information). Eppinger (2001), presented a project management tool that enhances "learning loops" by focusing on "the information flows of a project rather than its work flows". Such an iterative process can also be applied for higher level processes. For example, Lynn et al. (1996) suggest that the "process of probing and learning" has a tremendous importance for "discontinuous innovations" and "firms enter an initial market with an early version of the product, learn from the experience, modify the product and marketing approach based on what they learned, and then try again". In fact, product development can also be viewed "as a knowledge enterprise" and the ability to create and share the knowledge determines the success on the marketplace (Mohrmann et al. (2003).

During the field study, several focus groups were organised with several product development teams to determine the information flow and find out how the collaboration tools could be implemented (more information on the teams and the results of the focus groups are presented later in this chapter and in Chapter 4). The following figure shows the process of 3D model sharing or what we call a "cooperation loop":

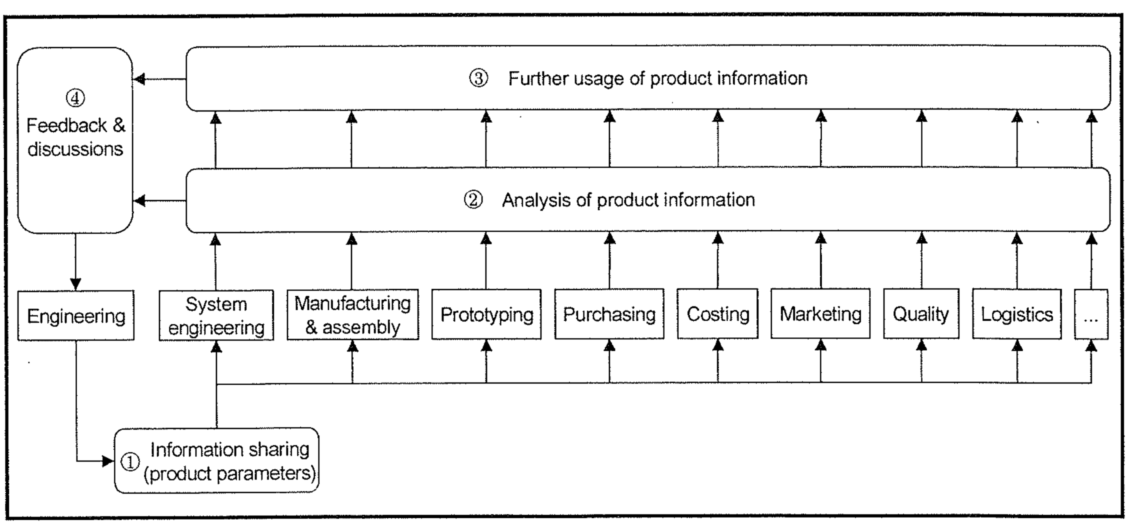


Figure 3.3 – Focus group results: the cooperation loop

This model is made of four blocks that are described in the following paragraphs:

(i) Information sharing (①): first, the "data creators" (i.e. CAD engineers) publish product information (i.e. 3D models) that is relevant for a wide spectrum of disciplines (or downstream activities);

(ii) Analysis and further usage of product information (②,③): once published, these data are used by downstream activities for two purposes. First, team members look for product information that is relevant for them – called "analysis". For example, a purchaser wishing to get the volume and the weight of a part to estimate its price. Second, the product information can be used into a third application – called "further usage". For example, the 3D models can be used to simulate the product assembly process;

(iii) Cooperation (④): finally, once the team members analysed the product information or used into a third application, they are able to give their feedback and initiate discussions. For example, they can detect problems, add new requirements or propose solutions to a problem. These topics are discussed with other team members and actions are defined. At this stage, CAD engineers implement the proposed actions. Then, the process is restarted when modified or new product information is published;

To summarise, product development teams are performing iterative information processing loops: the data creators publish product information and the data consumers give their feedback on the product information.

3.2.3. Collaborative behaviour

Several initiatives in different fields were set-up to better understand how to grasp the benefits of advanced cooperation tools. In supply chain management, the CPFR initiative proposes a three stages model (planning, forecasting and replenishment) to streamline procurement activities between the different levels of suppliers (tier 1, tier 2, tier 3). This model presents the activities that have to be performed by supply chain partners to improve their ability to cooperate.

Other initiatives exist in the field of product development. The Capability Maturity Model (CMM) developed by the Software Engineering Institute of the Carnegie Mellon University presents a model for the development of software. This model is particularly known for its 5 maturity levels that an organisation can reach. The goal is to determine for each stage which capabilities an organisation must have and propose ways to improve its software development capabilities. Based on this well-known model the MICADO Association (Mission pour l'Infographie, la Conception Assistée et le Design par Ordinateur) proposed a maturity model to assess the cooperative capability of a firm (MICADO, 2004). This model also proposes best practices and technologies to improve the cooperative capability of a firm. Unfortunately, this model was not complete and could not be used for this study.

Finally, the German automotive industry association (VDA) proposed several cooperation models between OEMs and different kinds of suppliers (presented in the second chapter). The VDA also published a procedure (or line of actions) that described the different steps to be followed to facilitate the adoption of the cooperation models. This procedure can be simplified into two main elements: the planning of cooperation (step 1 to 5) and the monitoring and implementation of cooperation (stage 6).

For this study, a two steps model was derived from the CPFR and VDA models. The first step deals with cooperation planning and the second step with cooperation improvement and monitoring:

(i) <u>Cooperation planning:</u> is an important constituent of cooperation as the rules must be defined at the forefront of the project. It encompasses activities like the definition of how information will be distributed and exchanged in the team and the definition of common work procedures or routines ("systematic processes" according to Mohrmann et al. (2003));

(ii) Cooperation improvement: the second element is the improvement of cooperation through measures aiming at assigning resources and monitor cooperation;

The following figure shows the CPFR model, the VDA model and the model defined for this study:

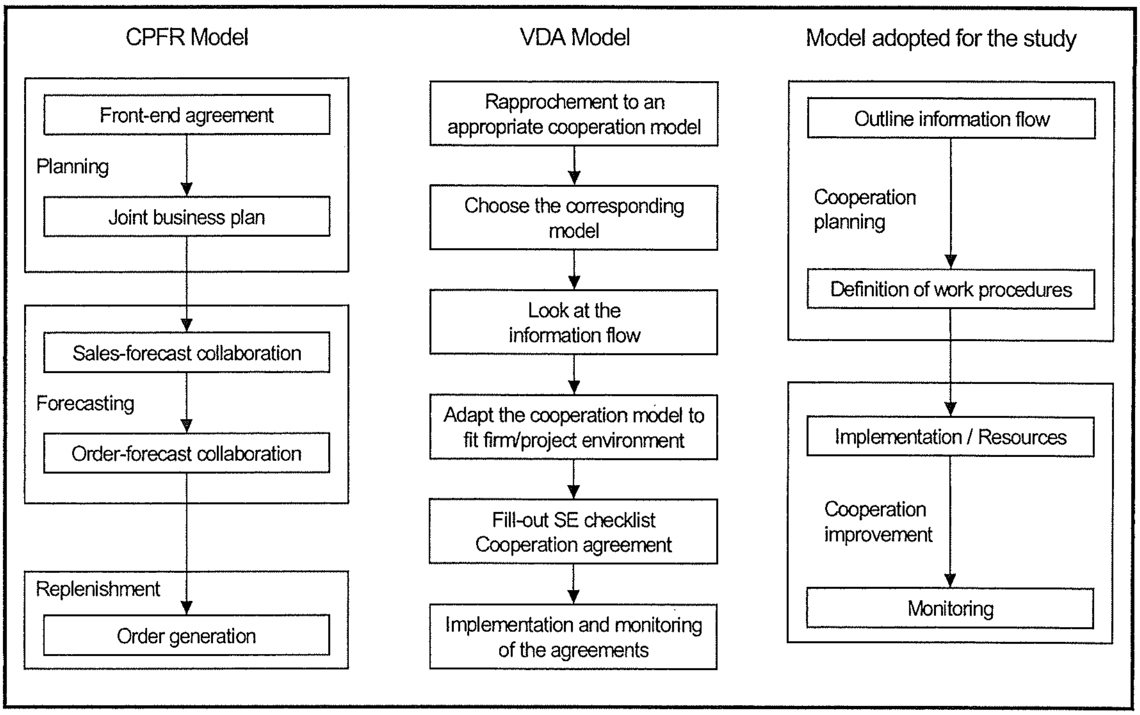


Figure 3.4 – VDA checklist: the cooperation planning model

Sources: VICS (1998), Holland and Plischke (2001)

3.2.4. Product development performance

The product development performance is often used as dependant variable in the literature (see Chapter 2). However, several constraints prevent us from using some performance indicators. First, strategic objectives (e.g. market share) are very interesting but out of scope because they are not applicable for this study. Indeed, the unit of analysis (i.e. mainly team members, few managers or team leaders) were involved in projects that were still under development and no post-mortem analyses were possible. Therefore, it was required to choose indicators relevant for the participants, for the stage of the projects (e.g. under development) and aligned with the requirements of the automotive sector.

In this study, we distinguished between the performance of the process itself and the output of the process. By process performance, we understand the input (time and expenditures), the quality of the teamwork and the creativity level. For the output, the manufacturing performance and the product performance will be considered. The following figure illustrates this concept:

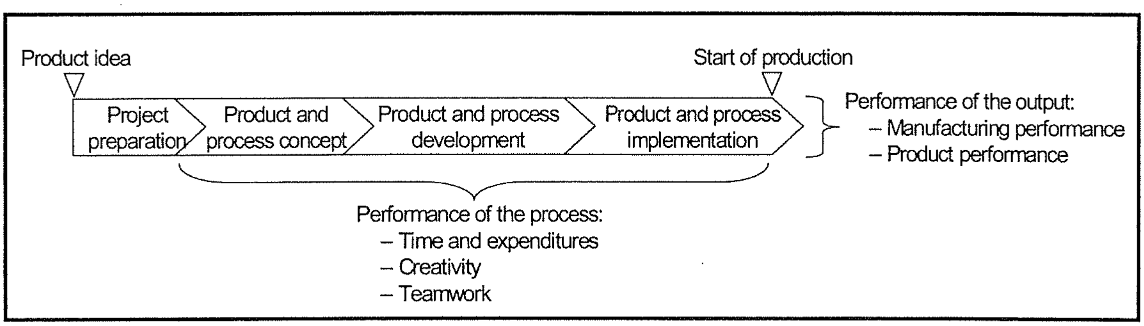


Figure 3.5 – The scope of product development performance

3.2.4.1. Time and expenditures

In the current business environment, the time dimension has an extreme importance. The denomination "velocity" is also used. Hadaya et al. (2000) defined it as "the optimal speed at which physical and virtual interactions must take place in order to reach the market at the customer's desired place and time (Magretta, 1998a, 1998b)".

(i) <u>Velocity:</u> time to market reduction – or being the first to develop a new product – are major issues for firms in the automotive industry. For example, car makers must quickly fill out new market segments or suppliers must quickly propose their innovative systems or components. Several reasons explain the need to increase the velocity: firms having a "first to market" strategy can charge premium prices; "fast followers" may quickly imitate products. Of course, this reduction may endanger other outcomes ("knowledge creation process" – Van Looy et al., 2002; "tradeoffs against other development objectives" and "costs of organisational changes" – Smith, 1999; "technologically inferiors products" – Karlsson and Åhlström, 1999). At the project level, this means that team members should be able to perform their task faster. A project manager said during the field study that "you only have 3 months to propose a concept for an OEM. Even if you propose a better one but you need 6 months to propose it, you are out of business". Another aspect of the time dimension is the reactivity. The importance of reactivity was found in the focus groups performed during the field study: team members must quickly react to internal and external requests. For example, during the study an OEM wanted to know if it was possible to integrate an interesting feature of a new product in development in an existing product. Such a request has to be answered very quickly;

(ii) Development expenditures: in their survey von Corswant and Fredriksson (2002) found out that development costs were an increasing concern for suppliers (6th position). The extensive usage of virtual teams implies frequent travels and additional costs without speaking of the unpleasant personal consequences for team members. These travels are required to exchange information or perform meetings. The changes that occur during the product development are a second source of costs. On one hand, changes are required to improve the product, on the other hand changes are costly, especially when a change occurs late in the product development phase. In fact, maturity plays an important role in the product development process ("time to mature") because later changes are reduced (Monell and Piland, 2000). The term "front loading" is also used in the literature (Thomke and Fujimoto, 2000) and aims at taking better decisions at the early phase of the product development process to avoid later changes;

3.2.4.2. Teamwork

International expansion and globalisation are a leitmotiv for many firms and lead to the usage of virtual teams. However it is admitted in the literature that – besides additional costs – the management of this kind of team is not an easy task and their usage is often related to a lower satisfaction or effectiveness (McDonough et al., 2001; Wierba et al., 2002). Hoegle et al. (2003) made the link between teamwork and innovation by demonstrating that "there is a positive relationship between teamwork quality and team efficiency" for the development of innovative products. In fact, the importance of the teamwork can be explained by the fact that "more cohesive teams generally arrive at better decisions" (Evans and Dion, 1991 cited by Huang et al., 2002). Finally, several team members mentioned during the field study that the lack of product information (or "information asymmetry") in the team was impeding the teamwork. To summarise, a better teamwork should promote discussions and lead to a better decision quality. Therefore "teamwork" was selected as the second construct of the product development performance.

3.2.4.3. Creativity

> "... team creativity requires teams to combine and integrate input from multiple NPD team members. Through effective communication, building on the knowledge of the various team members, teams facilitate the exchange of information and create new knowledge and insights. To achieve innovation there must be ideas and these initially appear from among individuals in the team. A new idea dies unless it finds a breeding place. Developing, refining, testing, selecting, and in the end implementing these ideas further rests on interaction among the team members. Creativity does not happen inside people's heads, but in interaction (Csikszentmihalyi, 1996)."
> Source: Leenders et al. (2003)

The development of new and complex products is nowadays a prerequisite for many firms. This is the case in the automotive industry where new products combine high precision mechanics, electronics and software and are manu-factured in a very high number. Product innovation was ranked 4th in the survey of von

Corswant and Fredriksson (2002). This complexity requires the integration of the know-how of the different product life cycle actors and creativity takes an important place (see text box on the right side). However, the definition and the role of creativity is still the object of numerous discussions (Leenders et al., 2003; Kappel and Rubenstein, 1999): creativity is either exhibited through new products or through interactions in a social system. The second aspect will be privileged in this study and will be the third construct of the performance dimension.

3.2.4.4. Manufacturing performance

The three first constructs dealt with the product development process. From here, the focus will be on the output of this process. Manufacturing and supply chain issues are important in the automotive sector. For example, delivery precision was ranked first in the study of von Corswant and Fredriksson (2002). This topic is relevant for this study because the development of a new product platform implies the design of new manufacturing machines and assembly lines. Cooperation allows to take manufacturing constraints into account early in the product development process and develop simultaneously the product and the manufacturing operations. One aspect of the manufacturing performance is the ability to improve the operations themselves. For example, cycle time reduction and manufacturability improvement can be considered as measures for the improvement of the operations. A second aspect of the manufacturing performance is related to the reduction of investments. One of the Bosch corporate objectives is to reduce investments to deliver cost effective products. The flexibility is also essential in our context: it is nowadays common for firms in the automotive sector to set up flexible assembly and manufacturing lines able to produce several product generations or a high product variety.

3.2.4.5. Product performance

The last construct deals with the performance of the product. New products must have superior performance than the preceding generations. The product performance can be defined in several dimensions. First, a product must fulfil the function for which it has been designed (e.g. a component must satisfy requirements like emissions, consumption, power output, weight, etc.). Besides the technical performance, life cycle aspects are also important in the current environment. For example, the maintainability or the durability need to be considered from the beginning. Finally, costs aspects are primordial in the automotive sector (3rd ranks in the survey of von Corswant and Frediksson (2002)).

3.2.5. Quality of the tool implementation

This study deals with the implementation of new cooperation tools. By quality of the implementation, I understand the factors that influence the use of the cooperation tools. Numerous software implementations failed and a vast literature emerged on this topic. For example, DeLone and Maclean (2002) proposed an information success model. A first version was published in 1992 and the model was validated and enhanced since then. The dimensions information quality, system quality and service quality influence the user satisfaction and the system usage, which to its turn, may lead to benefits. The latest version of the model is presented here:

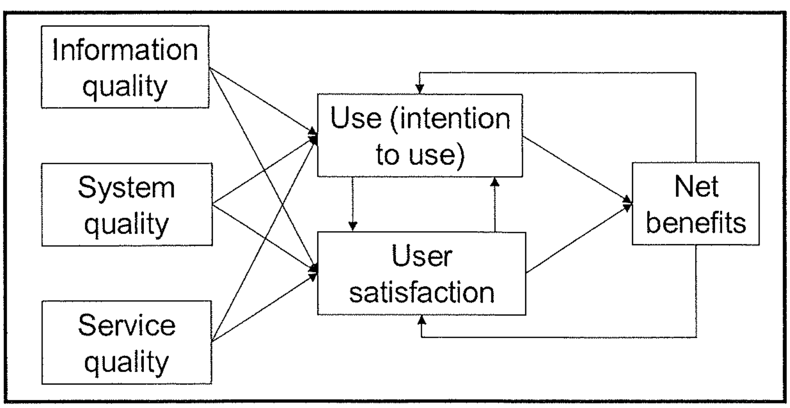


Figure 3.6 – The DeLone & McLean information system success model
Source: DeLone and McLean (2002)

Today, the interest of numerous papers is on the success factors for the implementation of ERP or e-commerce solutions. Studies in the field of IS adoption in the product development domain remain scarce (or not known to the author). An exception is the work of Robertson and Allen (1992) that identified some factors influencing the usage of 3D CAD systems. Three enablers were identified: "basic enablers" ("training", "support", etc.), "human support enablers" (e.g. "managerial understanding of CAD systems"), and "coordination enablers" (e.g. "required use of CAD").

To summarise, the quality of the system, the training and support are important elements for the implementation success. Therefore, these three constructs have been selected for this study.

3.2.6. Cooperation tools investigated

As mentioned in the first chapter, this study was conducted to assess the ability of CTs (especially the visualisation of 3D models) to facilitate technical communication and thereby improve cooperation. During this study, synchronous tools (namely application sharing and 3D conferencing) and asynchronous tools (visualisation) were investigated and deployed. In addition, some future tools will be presented. These tools will be described hereafter.

(i) Application sharing: is a software allowing to share a specific application (e.g. Microsoft Word) or the entire desktop between different PCs. During an application sharing, the conference participants can visualise the application of one participant and the application can be controlled by the different participants. From a technological point of view, the "content of a screen" is sent from one PC to the other PCs which requires a high bandwidth (preventing the usage of "graphic intensive applications"). Therefore, application sharing is suitable for applications like Microsoft Word or Excel. Otherwise, the performance is bad due to a high latency. The most known application sharing software are NetMeeting from Microsoft, WebEx, Interwise or Centra. The following figure illustrates how two team members can discuss the minute of a design review by using an application sharing software:

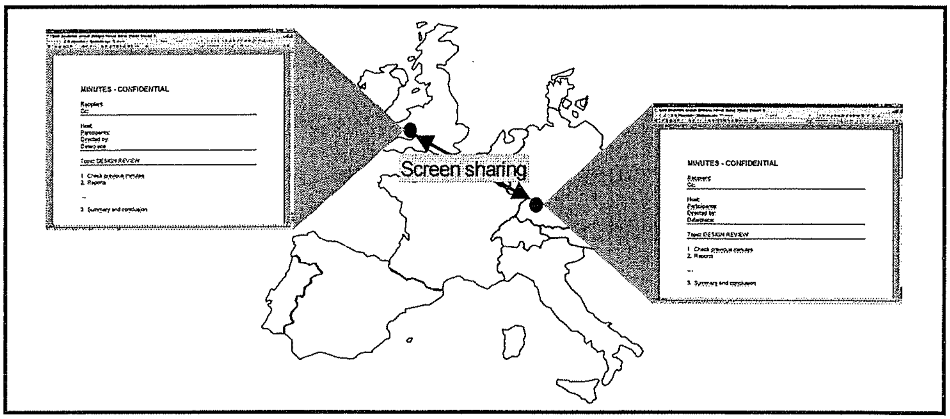


Figure 3.7 – Application sharing: working principles

(ii) 3D conferencing: the purpose of this second cooperation tool is the same as for an application sharing (namely, common visualisation) but the technology behind is different. A 3D conferencing uses a command sharing principle where only the commands are exchanged between the applications. This means that the content of a screen does not have to be transmitted from on PC to the other PCs. This mode of conferencing is therefore appropriate for a "graphic intensive" application like the visualisation of 3D models. Indeed, once the 3D models are downloaded on the different PCs, only commands like rotation, zoom, etc. are exchanged. As a consequence, the required bandwidth is high at the beginning of the conference (to download the 3D models) but low during the conference as only commands are exchanged. It enables quasi-real time interactions between the participants of the 3D conference. The following figure (on the next page) illustrates a situation where two product development team participants discuss a technical issue using 3D models (the functionalities that could be used during the working session are the same as for viewing):

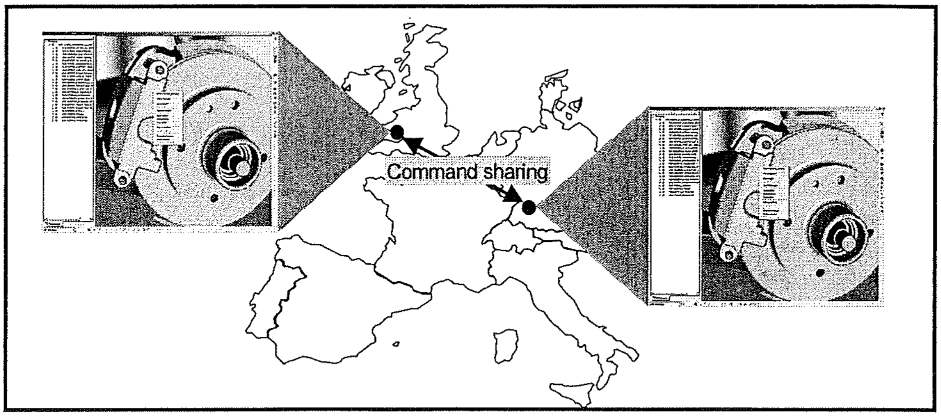


Figure 3.8 – 3D Conferencing: working principles

(iii) Viewing: the 3D models published for the product development teams were saved in a web-based data repository. The team members can visualise the 3D models in the DMU format using a dedicated viewer. Different versions of the viewer exist and offer a wide scope of functionalities, from the simplest viewer with a few functions (measurement, mark-up or redlining) up to an advanced viewer with additional functions (cross-section, product explosion, comparison of parts, etc.). This data repository was only accessible to the product development team members (access protected through a password);

(iv) Conversion from 3D CAD models to the DMU: the native 3D CAD models had to be converted into the DMU format (JT). An interface was used by CAD design engineers wishing to export data. This interface allows the extraction of the 3D CAD data from the EDM[2] system, the conversion of the 3D CAD data into the DMU format and the export of these converted data onto the web-based data repository system (described above). The conversion process can be triggered in different manners. The first alternative was "user driven", i.e. the CAD engineer select with his CAD/EDM systems the data he wishes to export. This process is very flexible and was privileged during this study. The second

[2] Engineering Data Manager where CAD 3D models are saved and managed

proposed alternative consists in automating this export process. For example, a time triggered (e.g. every night) or event triggered could be used (e.g. new revision or new step in the product development process is reached). The following figure shows the export of the 3D data from the EDM/CAD to the project area (that can be then visualised by the team members):

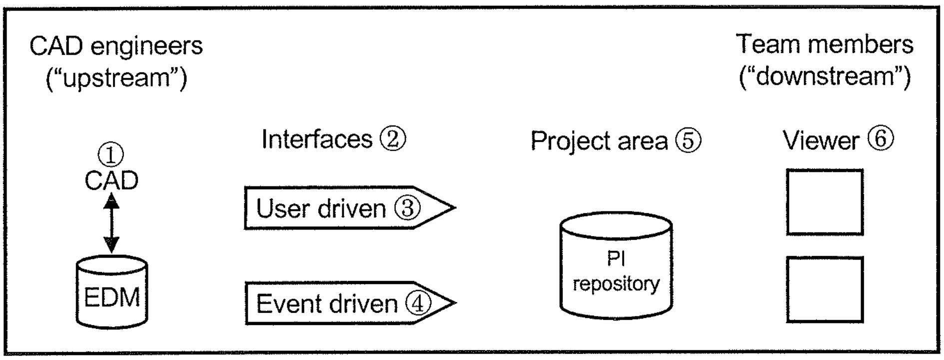


Figure 3.9 – Conversion 3D CAD to DMU

During the field study, several cooperation tools that could improve cooperation were identified. The ideas came from research projects or from the monitoring of other solutions:

(v) <u>Issue manager:</u> allows a participant to document and describe a problem or an improvement on a 3D model using the viewer functionalities (measurement, mark-ups, etc.). This suggestion could be saved on a web server where it is available for other team members. Hence, it builds the base for discussions in an asynchronous manner. This functionality would be similar to the discussion lists that exist on the Internet but would offer specific functionalities to facilitate the work of product development teams using 3D models. The following figure (on the next page) shows the concept:

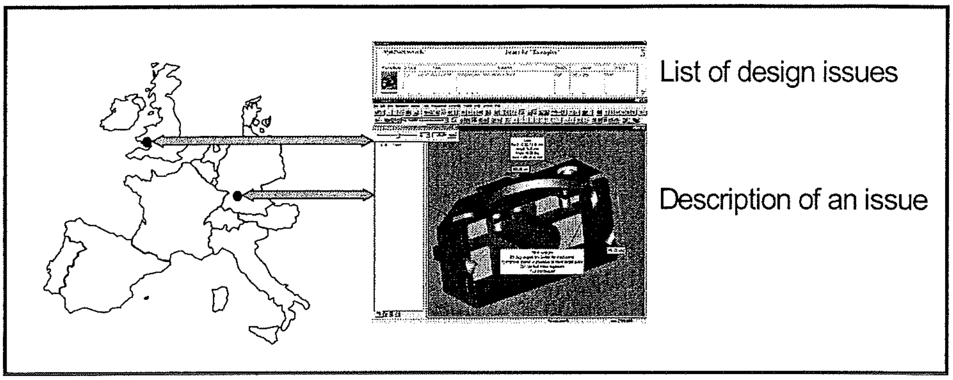


Figure 3.10 – Issue manager description

(vi) Iteration manager: should communicate the changes that occur in the 3D CAD models and help the non CAD users to be informed about the changes (Claassen, 2002). With the issue and iteration managers the cooperation loop could be closed by enabling changes to be communicated and facilitate the feed-back from product development stakeholders. The following figure shows the prototype of an issue manager:

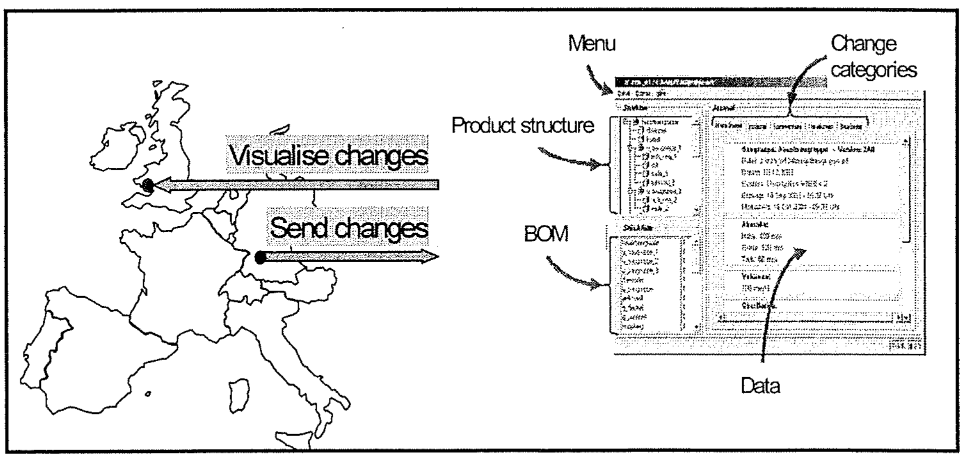


Figure 3.11 – Iteration manager
Source: adapted from Claassen (2002)

(vii) Clearance and assembly tool: the functionalities offered by the viewer can be expanded. For example a clearance and assembly tool could help a team member to check the clearance between parts (i.e. space between parts) or simulate the assembly or disassembly of a product;

3.2.7. Control variables

During the field study and in the literature review we identified several additional variables that may influence the relationships in the model conceptual: the position of the respondent in the product development chain, its involvement in the product development team and the interactions with colleagues.

(iii) Firm position: depending on its position in the product development chain, the need for cooperation is different. The VDA model (VDA 4691/2, 2002) presents the nature of the relationships for six cooperation cases:

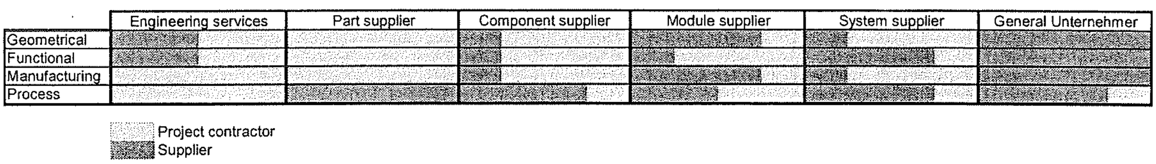


Figure 3.12 – Nature of the relationships between a contractor and its suppliers

Hence, a component supplier (e.g. a starter) is responsible for the development process of the component (simplified by "Process" in the figure above). The project contractor (or product integrator) will focus on the integration of the component in vehicle: geometry (e.g. collision or tolerance analysis), function and manufacturing (e.g. assembly of the starter in the motor). The relationships are different for a system supplier (e.g. braking system) which has more responsibility, especially for the functional integration. The responsibility during the product development is high for component, module, system and general suppliers;

(iv) Team member position: the heart of this study is to promote the cooperation between upstream (e.g. product design) and downstream activities (e.g.

manufacturing planning) by facilitating the sharing of product information. The position of the stakeholder in the team will have an influence on its behaviour;

(v) Involvement in the team: has an influence on the product development process. In fact, an early involvement allows a team member to better influence the design of the product or of a process. Once the design reached a certain level of maturity changes are less frequent. Some studies observed the influence of the involvement timing of project partners or functions in the product development process. Von Corswant and Tunalv (2002) identified the "timing of involvement of suppliers" as a success factor for the involvement of suppliers in a vehicle development project;

(vi) Interactions: are seen in the management literature as one means for transferring tacit knowledge (Koskinen and Vanharanta, 2002) – the other being "internalisation" through learning. For Leenders et al. (2003) "interaction is expected to lead to more and better new ideas" (citing West, 1990);

(vii) Degree of innovation and newness: the degree of newness of the design or the level of experience will influence the behaviour of the team member. A characteristic of new design is its high degree of uncertainty (Moenaert and Souder, 1990) that can be defined as the "the absence of critical and stable information" (Sosa et al., 2002). The need for cooperation is greater for new products because a lot of parameters are unknown;

(viii) Management implication: It is widely admitted that management support is a key antecedent for the success factors of organisational changes or the adoption of new practices. Robertson and Allen (1992) found that "managerial understanding of CAD systems" was a key enabler;

3.3. Research propositions

The research propositions will be presented in this section. The relationships between the different elements of the conceptual model are based on the literature review, the observations made during the field study and the research objectives. The relationships that will be investigated are presented in the following figure:

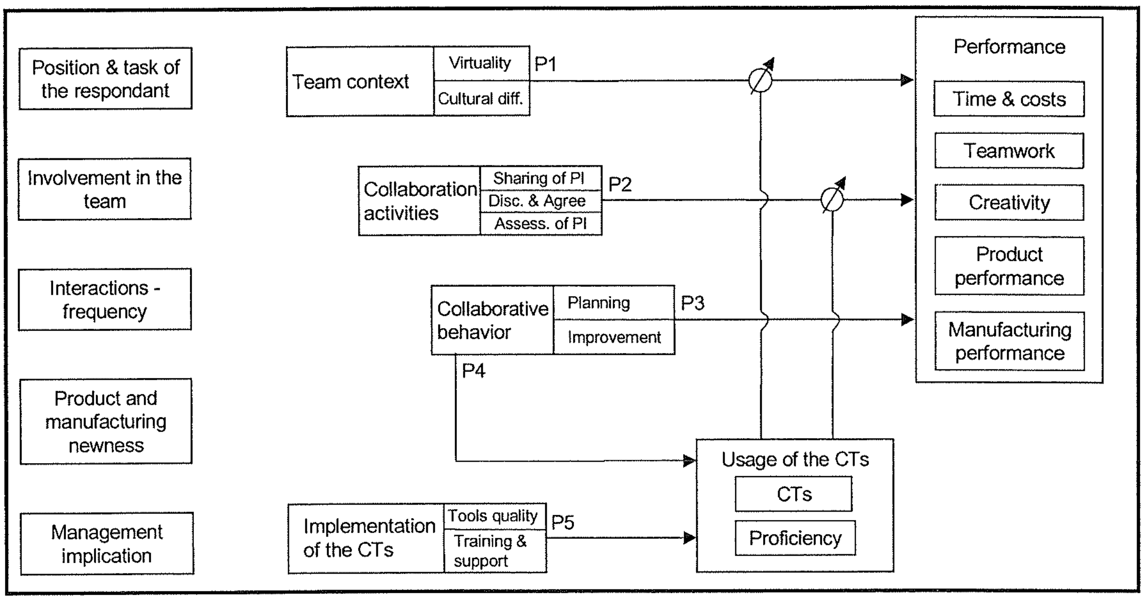


Figure 3.13 – Research propositions

P1: The team context will have a negative impact on the performance. Today, teams are working in a virtual environment and cultural differences exist. These constructs will have a negative impact on the product development performance. However, the usage of cooperation tools and a cooperative behaviour should help team members to compensate the negative effect of the team context. More precisely:

> **P1.1 – Virtuality has a negative impact on the performance.** McDonough et al. (2001) showed that global teams were less performing than virtual and collocated teams. In their paper, a virtual team had the following characteristics: "moderate level of physical proximity and [...] culturally similar";

P1.2 – Cultural differences have a negative impact on the performance. For McDonough et al. (1999), global or virtual teams often exhibit cultural differences (e.g different backgrounds or languages) which can lead to a lower performance (Griffin and Hauser, 1996);

P1.3 – The usage of cooperation tools compensates the negative effects of the team context. Sosa et al. (2002) showed that a "high degree of team interdependence, strong organisational bonds, and use of electronic based communication media" can mitigate the team dispersion. However, the discussion is not closed. As Ocker and Overbaum (1999) found out that the usage of an asynchronous computer conferencing system was related to a lower satisfaction. In addition, Wierba et al. (2002) cite results of previous studies showing that the usage of "computer-mediated communication" was related to: greater time to perform tasks, less effectiveness and more frustrations. The real impacts of different tools have to be investigated;

P2: Collaboration activities will have a positive impact on the performance. Product development is an information processing activity (Clark and Fujimoto, 1991; Sicotte and Langley, 2001). Information processing means that product information has to be shared within the team, it has to be analysed and evaluated as well as discussed (for a more detailed description of these activities, please refer to the paragraphs 2.2.2 and 3.2.2). More precisely:

P2.1 – Product information sharing has a positive impact on the performance. The ability to share product information with colleagues in the team should have a positive impact on the product development performance. Clark and Fujimoto (1991) identified product information sharing as one important factor for the success of the product development process. ;

P2.2 – Discussion and agreement has a positive impact on the performance. As mentioned earlier, the input of the different product life cycle actors is needed. These actors therefore have to discuss in order to find a satisfying solution. In other words, they solve problems and several authors insist on the importance of this element (Wheelwright and Clark, 1992; Takieshi, 2001). Hence, this collaboration activity should be related to a greater performance;

P2.3 – Analysis of product information has a positive impact on the performance. In her paper on "virtual prototyping", D'Adderio (2001) insists on the need of the "downstream" team members to analyse the product information (i.e. 3D models). These analyses help them to start and perform their work and should be related to an increase of the product development performance;

P2.4 – The usage of cooperation tools will moderate the relationships between collaboration activities and the performance. The impact of the three collaboration activities should be greater on the product development performance when a team member makes greater use of the cooperation tools. Indeed, these tools may facilitate the sharing of important product information and the ability of the team members to cooperate;

P3: Collaborative behaviour will have a positive impact on the performance. When team members discuss about how they will work together and when resources are allocated for the improvement of cooperation, we might expect a positive impact on different elements of the conceptual model. More precisely:

P3.1 and P3.2 – Cooperation planning and cooperation improvement will have a positive influence on the performance. In his case studies conducted in the automotive industry, MacDuffie (1997) showed that appropriate "organisational structures", "common language" or "process standardization" were important to solve problems. More recently, O'Sullivan (2003) showed that the "imposition of administrative standards" lead to a better integration;

P4: Collaborative behaviour will have a positive impact on the usage of cooperation tools. For the same reasons that a collaborative behaviour should improve the performance, we might expect that these activities will improve the adoption of the cooperation tools. More precisely:

P4.1 and P4.2 – Cooperation planning and cooperation improvement will have a positive influence on the adoption of cooperation tools. According to Susman et al. (2003), new cooperation tools generate "misalignment" which need to be mastered by the team. For Malhotra et al. (2001), the success of the implementation of cooperation tools was related to "formulation of appropriate inter-organizational strategy and structuring of conducive inter-organizational work processes and dramatic reassessments of current business contracts, practices and processes";

P5: Some elements will influence the adoption of the cooperation tools. If these tools have a positive impact on the performance, their usage has to be promoted and we need to find the elements that favour their usage. In other words, we need to identify the antecedents of team members that use the tools. More precisely:

P5.1 – The quality of the cooperation tools will have a positive influence on their usage. In their model on information system success, DeLone and Maclean (2002) place information quality and system quality as antecedents for the use of systems and the user satisfaction. Robertson and Allen (1992) identified enablers for the adoption of 3D CAD systems. Among the basic enablers they found "fast hardware and efficient software" and "ease of use and usefulness";

P5.2 – An appropriate training and support will have a positive influence on the usage of cooperation tools. In their paper on the new role of IT departments in the organisation, Markus and Benjamin (1996) identified training as a factor that influences the success of a new IT project. In their study, Robertson and Allen (1992) found that "good training" and "good support" were important for the adoption of 3D CAD systems;

3.4. Research strategy

The objectives of this section are to present the two main phases of the study and the methodological elements that were required to support these two phases.

3.4.1. Presentation and justification of the research strategy

This study was divided up into two phases for several reasons: the focus of the first phase was the implementation of the cooperation tools in product development teams in the Bosch development chain; the goal of the second phase was to realise a survey with team members to empirically validate the results of the first phase. The research strategy or more precisely the "relationship between these two phases" is explained in the following figure:

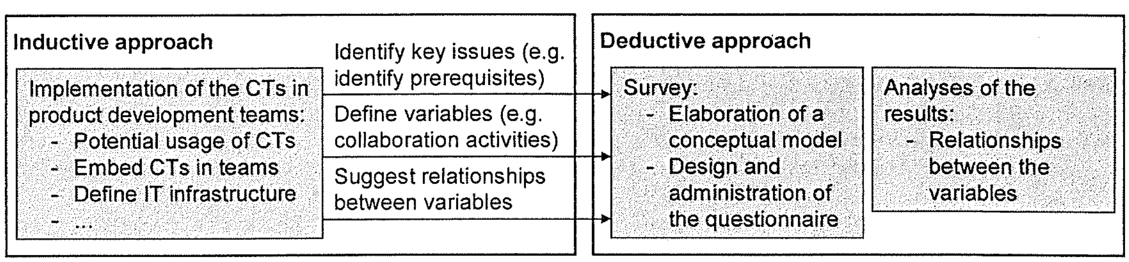


Figure 3.14 – Relationships between the research phases

To summarise, the field study allowed us to find the relevant issues and to propose solutions; the survey allowed us to test and confirm the proposed solutions and conduct further analysis. Such a strategy is useful to investigate new phenomena. For example, Debreceny et al. (2002) applied this two phases model to find out e-commerce inhibitors. In fact, this approach is consistent with the model ("validity network schema") of Brinberg and McGrath (1985) that defined a three stages research process: "prestudy stage", "central stage" and "follow-up stage". The prestudy stage corresponds to the first phase of this study (analysis of existing results and findings in the substantive, conceptual and methodological domains). The privileged research path for the second stage (or central stage) is the "theoretical path" that consists in defining a set of propositions by combining the conceptual and substantive domains and testing them by applying elements from the methodological domain.

3.4.2. Field study

3.4.2.1. Objectives and research activities

Numerous studies evaluated the impacts of "low end" cooperation tools (e.g. email) but rarely the impact of "high end" CTs like those that were evaluated. The underlying reason is the existence of IT barriers that prevent the use of such advanced tools (Sosa et al., 2002; Krishnan and Ulrich, 2001; Wang et al., 2002). Therefore, their assessment on a large basis is not available. So, the first goal of the research team at Bosch was to remove these barriers and "coach" some product development teams in order to facilitate the implementation of the technology. To achieve this objective the following activities had to be conducted:

(i) Define the potential usage of the cooperation tools in product development activities: at the beginning of the study we had to understand where the 3D models could be used as a work basis. More precisely, we had to investigate for whom the tools where relevant in the development chain. In addition, we needed to understand how the cooperation tools modify the information flow in product development teams. In other words, the goal was to get a picture of the role and the limitations of the cooperation tools ("potential usage");

(ii) Embed cooperation tools in team procedures: organisational routines are an important component of any organisation (Allison and Zelikow, 1999; Nobuo, 1998; Winter 2000). Therefore, the second activity was to define new work patterns or routines. Hence it was possible to embed the cooperation tools in the daily working procedures of the team members;

(iii) Implement cooperation tools in teams: training and support activities were proposed to insure the adoption of the cooperation tools in some product teams;

(iv) Define required IT infrastructure: the cooperation tools are no stand alone applications and have to be integrated with existing applications used by product development team members. We had to investigate how to integrate the tools together;

(v) Identify additional functionalities: this field work allowed us to identify functionalities that were missing and that could help team members to better cooperate in the future;

To perform the aforementioned activities, data from the field had to be collected and analysed.

3.4.2.2 Data collection method – Focus groups

Focus groups were used to collect the data from product development team members for the first phase. The data collected were analysed and contributed to the implementation of the collaboration tools at Bosch (an input for the grounded theory process).

Focus groups appeared in the 1930's and have been used for market research (Gibbs, 1997). Powell and Single (1996) defined it as "a group of individuals selected and assembled by researchers to discuss and comment on, from personal experience, the topic that is the subject of the research". This method presents two main advantages:

(i) Effectiveness: this method allows to get a large amount of data in a shorter time period and is considered as "low cost" (Babbie, 1998);

(ii) Richness of the data: the second advantage of the method is the richness of the data collected. Indeed, it is a "... socially oriented research method capturing real-life data in a social environment" (Babbie, 1998) which "draws upon respondents' attitudes, feelings, beliefs, experiences and reactions" (Gibbs, 1997);

As a consequence, such a method is appropriate to obtain background information about a topic and is therefore very useful for preliminary stages. In addition, it allows the evaluation of hypotheses or to check the validity from different perspectives (Babbie, 1998). During the focus groups, we also observed that this method promoted the emergence of new ideas and the development of creative concepts.

However, this method has several weaknesses. Babbie (1998) cites several weaknesses or pitfalls: more difficult to control groups than individuals; the moderator must have specific competencies; the discussions must be lead in constructive manner; the data can be difficult to analyse; the groups can be very different and it can be difficult to assemble the participants. To summarise, the first difficulty is to get the right people in the groups and animate the discussions. The second difficulty being the analyses of the results.

At Bosch, the term "workshop" is used and it is an usual procedure for the employees. A typical workshop takes place in the following way: presentation of the subject (e.g. purpose of the meeting, background information or a live demonstration) and explanation of the different topics that will be discussed. The participants write their ideas or keywords on small cardboards (10x20cm) and the cards are displayed on a board. If the meaning is not clear or if additional ideas emerged, a discussion takes place between the participants and the moderator. Finally, the ideas related to one topic are clustered to let emerge categories. In addition, a researcher records the idea expressed by the participants as explanations are sometimes given later or new ideas appear which are not necessarily written down. As the researchers closely cooperate with end-users, additional interviews can be performed to investigate further topics and gather additional data. Hence, we were able to insure that the weaknesses cited on the previous page could be overcome: the focus groups being performed inside the company, it was less difficult to find the right persons and the animators were certified to perform this task.

The contact with end users was very fruitful and several authors stressed its importance in the field of product development process. Eppinger (2001) stated that "you cannot rely on what your company's managers tell you: they are usually not the people doing the work, and they may have an interest in justifying existing or outdated processes". Helper (2000) stressed the point that end users can better describe the challenges and problems they are facing. In this study, several focus groups (or workshops to use the Bosch vocabulary) were organised with different product development teams where different functions were represented (system engineering, design, sales and marketing, manufacturing and assembly planning, prototyping, purchasing, product costing, quality). Focus groups participants were asked to discuss the following topics:

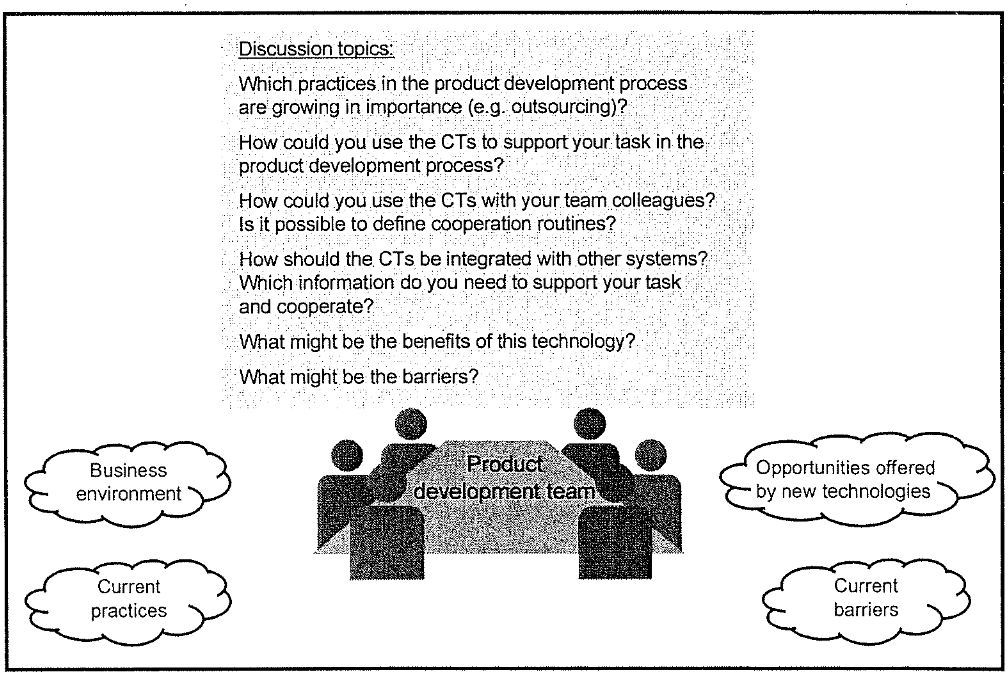


Figure 3.15 – Topics discussed in the focus groups

3.4.2.3. The grounded theory

The grounded theory methodology represents an interesting and appropriate approach to generate new theories ("understand what is going on"). This methodology has been developed by Glasser and Strauss in the 1960's in the sociology domain and is now applied in new fields such as management (Glasser, 1998). This method is both inductive and deductive. The data generated from the field ("observations") are used to induce theory (analysis and conceptualisation). Deduction is used to determine where the next data collection ("observations") must occur. Therefore, this method is appropriate when "current perspectives are inadequate" (Eisenhardt et al., 1989). For Glasser (1998), the grounded theory presents advantages like a fit between the theory and the substantive area and a high flexibility because the theory is modifiable as new data emerge. Hence, this methodology is relevant for people in the substantive field because it is "well-suited to discovering the participants' problem" (Glasser, 1998). The following figure shows the main research activities that we retrieve in the grounded theory method:

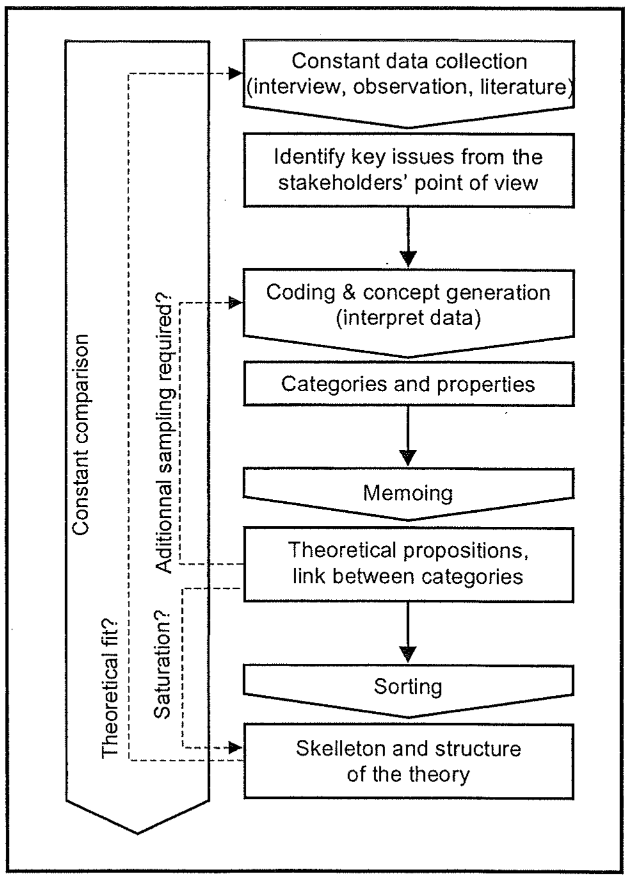


Figure 3.16 – The grounded theory process

Even if this methodology "attains levels of rigour and validity that would stand comparison with well-established quantitative ones" (Bryant, 2002), this methodology is still the object of frequent critics. Eisenhardt et al. (1989) cite two main drawbacks: the theory generated can be too complex (by trying to capture everything) and have a low level of generality ("narrow and idiosyncratic theories"). However, this methodology was used in several studies related to the field of product development or information systems:

Table 4.1 – Summary of studies using the grounded theory

Author(s), date	Goal of the study and usage of the grounded theory
Debreceny et al., 2002	Investigation of the e-commerce inhibitors. "Grounded Theory most accurately describes the adjustment process that ensued as at successive stages of the research we came to a better understanding of the implications of the data for theory construction."
Jassawalla and Sashittal, 1998	Identification of factors increasing the level of cooperation. Usage of the GT "to understand how the information and ideas flowed between participants... and how NPD activities were organized in high-technology firms"

The contribution of the grounded theory for the project was to analyse the data collected in the focus groups to identify the key issues. The second contribution was to help us to propose solutions that fit with product development team requirements (IT infrastructure, implementation method). In addition, we were able to determine the new topics that had to be investigated in the subsequent focus groups.

3.4.2.4. Selection of product development teams

Several teams were selected or expressed their wish to participate in the field study and later in the survey. We wanted to get teams that were confronted to the current environment in the automotive industry (dispersion, product and process complexity, etc.). Urban and Von Hippel (1988) stressed the importance of fulfilling the needs of the customers of tomorrow. Therefore, teams having the following profiles were privileged:

(i) Project manager implications and support: the management attention is often cited as a success factor for the implementation of new technologies or practices (McDonough, 2000) because their commitment and the allocation of resources is essential. In addition, the Business Units IT specialists must help and facilitate the implementation;

(ii) The product developed in a new "platform project": the development of a new product platform has a great importance for manufacturers as it implies the development of a new product with new features, new manufacturing and assembly operations and the development of a new supply chain. Therefore, different disciplines must work together and a certain degree of uncertainty and innovation exist in the project. Besides the platform project, three other kinds of projects are performed at Bosch: *R&D project* (e.g. define new functions), *variant development* (improvement or variant of a platform) and *application project* (a product platform or a variant is modified to fit with the customers' requirements);

(iii) Existence of organisational integration mechanisms: the product development must show a certain degree of integration. Cooperation tools cannot replace other mechanisms, they rather complement them and are one of the integration mechanisms (Nihitilä, 1999);

(iv) Dispersed team: some members of the team must be dispersed as the proposed technology makes more sense if the team participants are dispersed;

(v) Early project phase: this phase is crucial as a lot of decisions requiring different knowledge are taken in the early phase;

(vi) IT infrastructure available: some interfaces were needed to use the cooperation tools in an effective manner. In addition, some special authorisations were needed (e.g. usage of the cooperation tools via the Internet);

These criteria are extremely important. Several pilot projects were initiated at the beginning of the study but failed because some of the criteria were not fulfilled. A failure means that end users did not attempt to adopt or use the CTs. Hence, a first pilot project was abandoned because the team structure was not clear and the involvement of the project manager was lacking. A second project was cancelled as the team experienced some technical problems and therefore concentrated its resources on other topics. Finally, a third project was cancelled because the IT infrastructure was not mature at that time. However, these failures allowed us to complete the list above and therefore improve our way of implementing the cooperation tools.

The following table describes the different product development teams that participated to the focus groups and the subsequent implementation of the cooperation tools:

Table 3.2 – Description of the teams involved in the study

Team name	**Product description**	**Need for cooperation**	**Research activities**
EIN	New injector generation for a diesel injection system	Feasibility study (very early stage) between experts from development, sample shops, quality and, operation planing. Not a dispersed team, located in the Stuttgart area.	One focus group. Definition of org. routines ("meeting" and "manufacturing planning"). Training provided for users. Follow up over a six months period. Focus on internal cooperation. Participation in the survey
DRO	New throttle valve platform for gasoline engines	A critical part is developed and manufactured by a supplier located 400 km away from the plant and the development centre. Discussions between purchasing and supplier (design assessment, product costing)	Interviews and one focus group. Test and evaluation of the technology provided by a dedicated electronic marketplace. Follow up over a six months period. Focus on external cooperation

Team name	Product description	Need for cooperation	Research activities
GEN	More efficient and powerful, and easily customisable new generator platform	Manufacturing and assembly operations are planned in the UK. The product and the assembly line are designed in Germany. Need to develop simultaneously the product and the operation processes	Interviews and three focus groups. Definition of org. routines ("ad-hoc collaboration" and "SE team meeting"). Training provided for users. Follow up over a two years period. Focus on internal cooperation. Participation in the survey
TEE	New generation of "demand controlled fuel-supply"	Product developed between 4 different locations in Germany and Spain using different CAD systems. Manufacturing operations planned in the Czech Republic	Training, follow-up over a 3 months period. Participation in the survey

3.4.2.5. ARIS methodology

One aspect of this study was to identify and describe routines in which cooperation tools can be used. The ARIS methodology was used to represent the routines. ARIS (**Ar**chitektur integrierter **I**nformations**s**ysteme) was developed at the university of Saarbrücken and enables organisations to describe the business processes and how they can be performed using information systems. The following figure shows the different "views" required to describe a business process according to the ARIS methodology (source: ARIS Handbook, 2000):

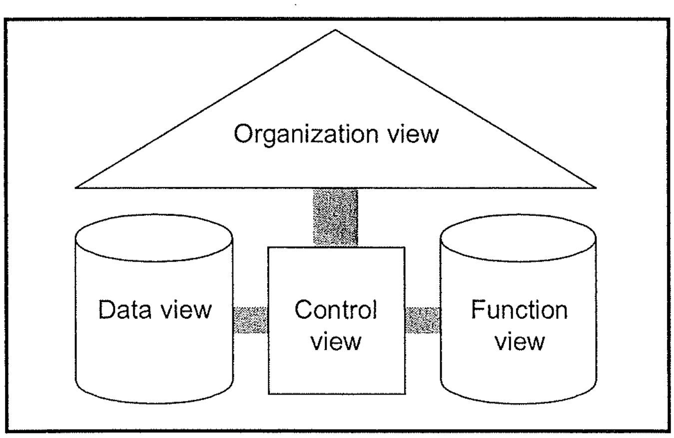


Figure 3.17 – Description of the ARIS Methodology

3.4.3. Survey

The field study ensured that the cooperation tools were diffused in some teams for a defined purpose. In addition, it was possible to identify key issues and derive the elements and constructs of the conceptual model. In order to empirically assess the impacts of the new product development practices enabled by the cooperation tools and evaluate the importance of some relationships, it had been decided to realise a survey.

Based on the literature review and on the results of the field study, a questionnaire has been designed. The questionnaire has been reviewed by project managers and R&D managers to assess its relevance and check if respondents could understand and answer the questions. Several iterations were performed to improve the questionnaire. The detailed questionnaire as well the theoretical validation are available in APPENDIX 1, APPENDIX 2, APPENDIX 3 and APPENDIX 4. In addition, the questionnaire has been checked by a member of the "Betriebsrat" (workers council) to ensure that no questions were threatening employees.

An initial objective was to diffuse the questionnaire in Bosch product development teams and other teams in the German automotive industry. Therefore, the questionnaire was sent to several key IT managers or researchers that were involved in the evaluation and implementation of similar tools in external firms. These key persons were asked to distribute the questionnaire to product development team members using the cooperation tools. These key persons were members of working groups of the German Automotive Industry. In addition, the software provider of the cooperation tools was contacted to distribute the questionnaire to other customers world-wide.

The questionnaire has been distributed electronically to the respondents in a PDF format. The respondents could either fill in and print the questionnaire or print the questionnaire and fill it in by hand. The questionnaires distributed inside Bosch were returned via the internal post and the questionnaires distributed outside Bosch were received by post. This process guaranteed the anonymity of the responses.

CHAPTER 4 : RESULTS AND ANALYSIS

This chapter is composed of two sections. The first one presents the main results of the field research: the focus groups results and the role of the CTs in the product information flow. The results of the survey are presented in the second section – that is the descriptive, bivariate and multivariate analysis.

4.1. Field research results

This first section presents the way the CTs were implemented in product development teams. The first objective of the field research was to understand how the CTs could be used in product development teams or more ambitiously "how to develop the best practices of tomorrow". Indeed, as mentioned in the first chapter, the classical usage of the DMU was not appropriate for Bosch. The new – and promising – usage had to be investigated. Therefore, several focus groups were performed to collect the issues related to the usage of CTs within multidisciplinary and distributed product development teams. The most important topic investigated in the focus groups was to determine the potential usage of the CTs in the product development process (to support development task) and their role in the product development teams information flow (to support cooperation). In addition, the focus groups allowed us to explore issues related to the implementation such as the potential benefits, the barriers or the definition of "cooperation routines". Based on these results, the cooperation tools have been implemented in several product development teams. Other outcomes of the first phase are not presented here: training documentation, detailed description of work procedures in teams, detailed description of the technological infrastructure, process or steps to implement the technologies in teams.

In this section, the results of the focus groups will be first presented (benefits, barriers and the potential usage). Based on these results, a model – the "cooperation loop" – describing the role and the place of the CTs in the information flow will be presented.

Finally, several cooperation routines (an attempt to turn the CTs into processes) will be described.

4.1.1 Focus groups results

The participants of the focus groups came from different development teams (presented in Table 3.2), backgrounds (upstream and downstream activities) and allowed us to cover various topics related to the implementation of the CTs in the product development process. The following table describes the focus groups that were performed during the study:

Table 4.1 – Description of the focus groups

Audience	Topics covered
Various persons with different functions working in plants (downstream activities)	- Which product information is needed by plants representatives - Identification of tasks in the product development process that are important and could be supported by the cooperation tools
Various persons with different functions working in engineering (upstream activities)	- Which product information is needed by engineering representatives - Identification of tasks in the product development process that are important and could be supported by the cooperation tools
Members from the GEN team	- Identification of the relationships between the different functions ("métiers") to gain an overview of the work pattern and information flow in the team - Definition of two cooperation routines (ad-hoc collaboration and SE team meeting) - Definition of the main functionalities of an interface between CAD and the cooperation tools
Members from the DRO team	- Identification of the role of the CTs for the cooperation with a tier 2 supplier - Identification of the potential benefits - Identification of potential barriers
Members from the EIN team	- Definition of one routine (manufacturing process planning) - Identification of the potential benefits - Identification of potential barriers
External firms using similar CTs	- Current and future usage of the cooperation tools in the firms

The focus groups allowed us to verify if similar patterns were observed in the different teams, improving therefore the generalisability of the results. By using one of the grounded theory principles ("additional sampling"), we were able to investigate new issues discovered in a preceding focus group. Finally, the results of the focus groups allowed us to perform additional analysis like the definition of the cooperation loop and of cooperation routines or the development of an appropriate technological infrastructure. The results of the focus groups are organised around topics and are presented in the following tables.

4.1.1.1. Potential benefits

To justify the implementation of the CTs, we first had to find their potential benefits for product development teams. The following table shows the potential benefits cited by the participants of different focus groups:

Table 4.2 – Focus groups: potential benefits of cooperation tools

Topic: benefits from the usage of cooperation tools	
Categories	**Examples**
Cycle time reduction	- Quicker and earlier access to product information (solve problems earlier by performing analysis earlier) - Less time necessary for engineering departments to prepare product information for downstream activities and less interruptions - Less time necessary to perform some downstream tasks - Quicker reaction to new information, events or problems - Less discussions or consultations required because it is easier to work independently - Less iterations and recursions - Prevent unnecessary labour and costs due to misunderstanding
Cost reduction[3]	- Less physical prototypes - Less travel required by performing meetings online

[3] The examples cited in the category "cycle time reduction" imply also a cost reduction but are not repeated in the category "cost reduction"

Topic: benefits from the usage of cooperation tools	
Categories	**Examples**
Improvement of the quality of work	- Reduce "blind" work due to the lack of product information - Better planning of downstream activities through a better understanding of the design (e.g. cost estimation of design and changes, CNC, assembly, manufacturing) - Improved design of the product (e.g. better manufacturability)
Teamwork improvement	- More transparent decisions and less misunderstanding - Better understanding of the design (less information asymmetry) - Better internal communication (better informed about changes) - Better coordination between team members - Work independently (without disturbing design engineers)

Team members expect from the usage of the CTs a reduction of cycle times and of the development costs (the two dimensions being related). Indeed, product information can be quickly and easily available to each member in the team and bring benefits such as quicker reaction to changes or the ability to perform some tasks faster. Another advantage of the usage of the CTs is the potential improvement of the work quality due to a better planning of the work (e.g. better planning of the manufacturing operations) and access to information in a richer format (e.g. 3D models are easier to understand than 2D drawings). Finally, the usage of the cooperation tools may lead to a better teamwork by improving, for example, the quality of the decisions because the team members are more informed about the design of a product.

Our work confirms the results of other studies that identified the benefits of CTs. May and Carter (2001) report the benefits provided by the usage of ICTs in a research project in the automotive sector. Three categories of benefits were defined: "Collaborative engineering discussions" (e.g. ability to perform effective technical discussions), "Product quality" (especially the maturity that is reached earlier) and the "Time to market". Some consulting firms realised surveys to determine the ROI (Return on Investment) of new ICTs for the product development process. For example, CIMdata (2003) investigated the benefits of "collaborative product design".

According to them, benefits can be obtained for engineering costs (by reducing travel costs and time), manufacturing costs (less changes being required), time to market reduction and product quality (e.g. less recall).

4.1.1.2. Barriers and inhibitors

During the first implementation of the CTs in a team, we noticed that the tools were not used much. Therefore, prior to the implementation of the CTs in a second team, we asked the participants of a focus group to identify potential barriers preventing the usage of the CTs. The results are presented in the following table (on the next page):

Table 4.3 – Focus groups: barriers and inhibitors

Topic: barriers and inhibitors preventing the usage of cooperation tools	
Categories	**Examples**
Bad technical performance	- Slow performance - Unstable systems - Complex connection for suppliers
Inappropriate functionalities	- Functionalities supporting cooperation are missing - Complex to use - Obsolete 3D models (i.e. not up to date) - Difficulty to export 3D models
Wrong system implementation	- Missing support and training - Time effort for the training – the shorter the better - No discipline and method - Information leakage and security problem (e.g. not allowed usage or product data theft) - Not enough distance between the partners (usage of cooperation tools is not necessary)
Costs	- Costs for licences - Additional costs for suppliers
Additional efforts	- Project care - Maintain product information up to date

Team members fear that the CTs may not work well or do not provide the right functionalities to cooperate. In addition, the CTs must work well and be stable – new systems have often the reputation to be unstable. An important element deals with the quality of the CTs implementation: team members need coaching (e.g. through training or the development of methods) and must be informed about the limits of the CTs (e.g. security issues). Finally, the usage of cooperation tools implied additional costs and required additional care (e.g. to maintain and update production information) which can be seen as a barrier. At this point, we can make an additional and interesting remark: the lack of manager involvement was not cited as a potential barrier.

Our results are confirmed by those of DeLone and MacLean (2002) who show that information quality, system quality and service quality are the antecedents for the usage of an IT system. It is to note that the costs of CTs appeared to be an issue. However, during the pilot projects only minimal costs were imputed to the departments as the projects were mainly financed by the Corporate Research division.

4.1.1.3. Potential usage of the CTs

As mentioned earlier in this study, we wanted to embed the CTs in the daily tasks of product development team members. Focus group participants were therefore asked to think about the potential usage of the CTs based on the classification by Kappel and Rubenstein (1999): for individual and group tasks. The following table shows some potential usage of CTs:

Table 4.4 – Focus groups: potential usage of cooperation tools

Topic: potential usage of cooperation tools in product development teams	
Categories	**Examples**
Use the product information to assess the design according to different criteria	- Ability to fulfil the function - Manufacturability - Measurement (for quality control) - Packaging and logistical issues - Costs of the proposed design

Topic: potential usage of cooperation tools in product development teams	
Categories	**Examples**
Use the product information to plan downstream activities	- Consider and define different concepts for operations (e.g. the sequence of operation or which manufacturing techniques can be used to manufacture a part) - Design of the assembly and manufacturing processes, instrumentation (for quality control), CNC program and tooling - Illustration for shop floor instructions and training of workers
Support work with suppliers	- Assess the capabilities required by a supplier to manufacture a part or a tool - Prepare request for quotations (e.g. concept for a function, tooling) and other documentation for suppliers (information about changes) - Assess and discuss the design proposed by a supplier
Support work with customers	- Agree on "geometrical" interfaces (where the system or component will fit in the vehicle, check collisions) - Plan subsequent handling (e.g. how the system or component will be mounted on the vehicle) - Discuss and explain changes (suppliers to OEMs, OEMs to suppliers)
Integration into third application	- Further usage of 3D models to simulate CNC program, assembly and manufacturing line
Discussion and agreement (internal, suppliers, customers)	- Prepare meetings and improvement suggestions - Clarify issues (e.g. manufacturability with supplier) - Collect requirements (internal, customers and suppliers) - Discuss improvement proposed by downstream activities - Prepare and define common solutions - Document design review and discussions

The results confirm the high potential offered by the usage of the CTs because they can be used for a wide scope of tasks in the product development process. They also confirm the importance of the 3D models in the product development process. The participants noted that some of these tasks were becoming important in the current business context. For example, the higher level of outsourcing for custom parts implies a greater cooperation with suppliers (e.g. provide product data to suppliers, get the feedback from suppliers, etc.).

4.1.1.4. Characteristics of the product information flow

In the previous section, some potential usage for the CTs were identified. A premise was the availability of product information to perform these tasks. Therefore, we investigated in a focus group how the 3D models could be shared in a product development team. Product information (or 3D models) can be classified into three main categories (draft, with status and released). The three categories are displayed in the following figure:

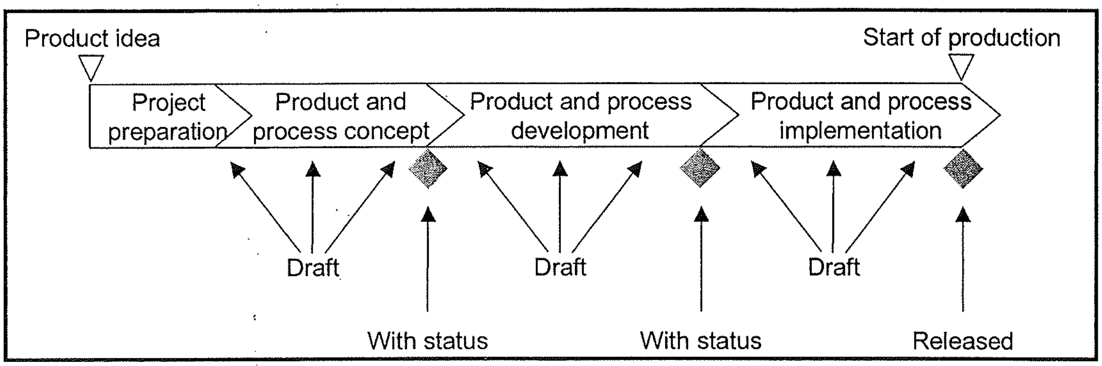


Figure 4.1 – Status of the product information

(i) <u>3D models in work (or draft):</u> this status refers to 3D models prepared by the design engineers who want to propose design alternatives or develop preliminary solutions. These 3D models are further detailed and enriched based on the comments from other team members. For us, the 3D models having this status are essential: at this point in the product development process, a lot of creative work has to be done and decisions that will influence the product life cycle are taken;

(ii) <u>3D models with status:</u> these 3D models are published before each stage of the stage gate model. These data have a higher level of stability and represent the solution that has been chosen during the "creative part" of the design. Being more stable, these data can be used by downstream activities. For example, the tooling or physical prototypes can be ordered if the design has reached a particular stage;

(iii) Released 3D models are the 3D models of products being manufactured in serial production. At the stage of our study, these data are less interesting because few modifications are possible and their is a limited need for cooperation;

An additional topic of interest was to understand how the product information is shared in a multidisciplinary context. For Ullman (2002), team members are sharing various information related to the 3D models: materials, manufacturing and assembly, cost, requirements, issues and plans and design intent. This information goes beyond the fit, form and function of the 3D models. Therefore, we asked representatives from engineering departments ("upstream") and from plants ("downstream") to describe how they process product information and which product information they need. The following figure (on the next page), summarises the results of this focus group.

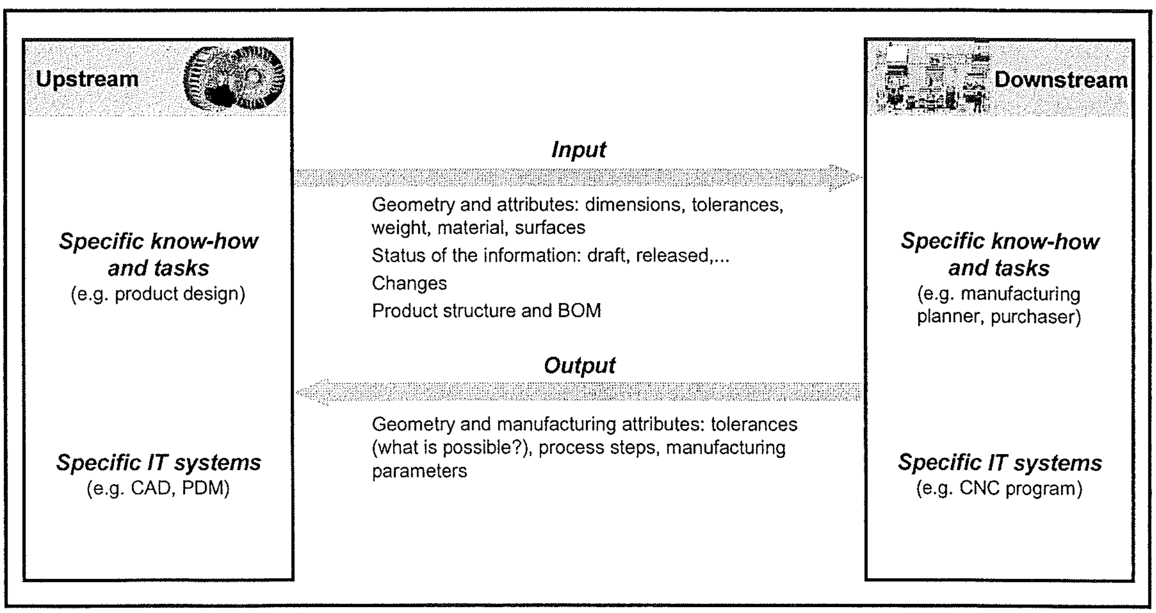


Figure 4.2 – Product information exchanged between team members

Based on the previous results, a taxonomy was defined to illustrate the communication between design engineers and other product life cycle stakeholders:

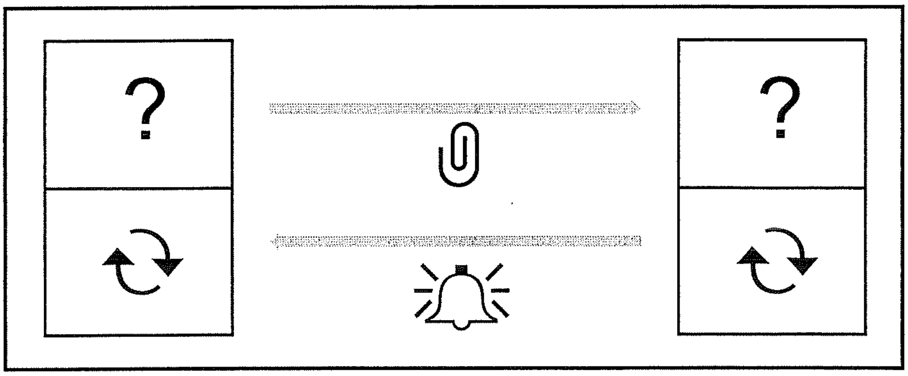


Figure 4.3 – Taxonomy of information exchanged between team members

Four symbols were used: ? is the specific task performed by the stakeholders; 📎 is the information exchanged; 🔄 is the information system used by the stakeholders and 🔔 is the feedback of the stakeholder. Based on this taxonomy, two cooperation scenario examples were build:

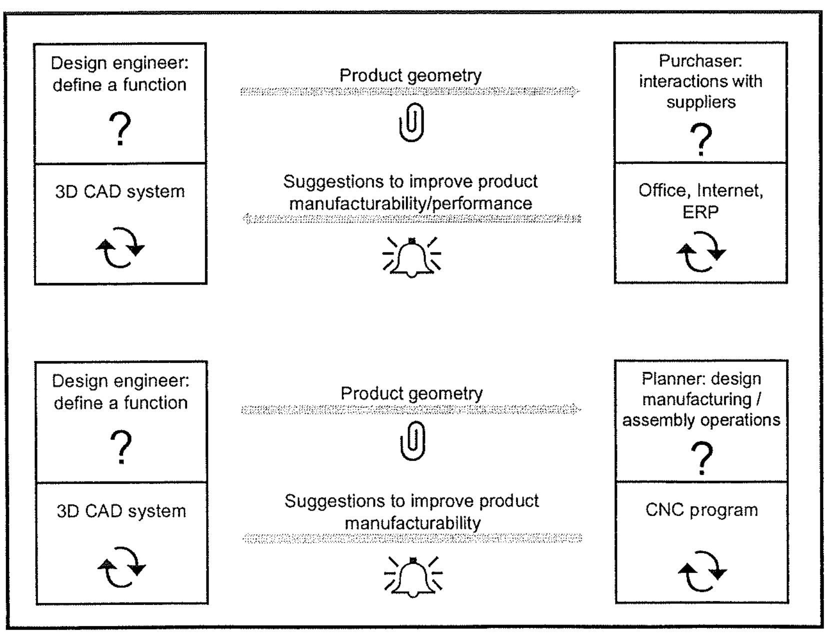


Figure 4.4 – Example of cooperation scenario

4.1.2. Cooperation loop

The results of the focus groups gave us a detailed picture of the product information flow in product development teams and of the potential usage of the CTs (for individual and group tasks). Therefore, we were able to develop a model that illustrates the processing of product information in a product development team. This model is called "cooperation loop" and was presented in the third chapter.

This model helped us to (i) clarify how the product information is flowing between the upstream and downstream activities and to (ii) determine the role of the different CTs in the information flow.

The cooperation loop is presented in the following figure. The rounded boxes show the information processing activities (namely, product information sharing, analysis of the product information, the further usage of product information and discussion and agreement). The flow of product information is represented by the arrows. The different functions involved during the product development process are in the square boxes.

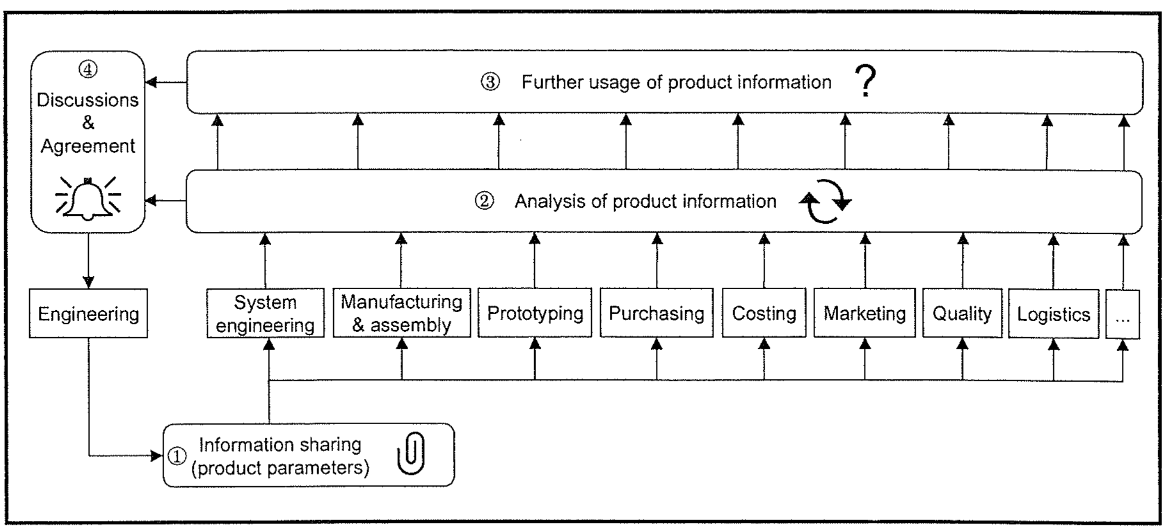


Figure 4.5 – Cooperation loop

This model was called "cooperation loop" because the product information (e.g. 3D models) is generated by the engineering departments, used by the downstream activities which also give their feedback to the engineering department. Of course, this loop restarts once the engineering departments process the feedback and publish new product information. The model was defined after the first two focus groups and was confirmed during a focus group with representatives of the GEN team.

This model can be compared to the work of Stempfle and Badke-Schaube (2002) that observed how product development teams were solving problems. They found two patterns for problem solving:

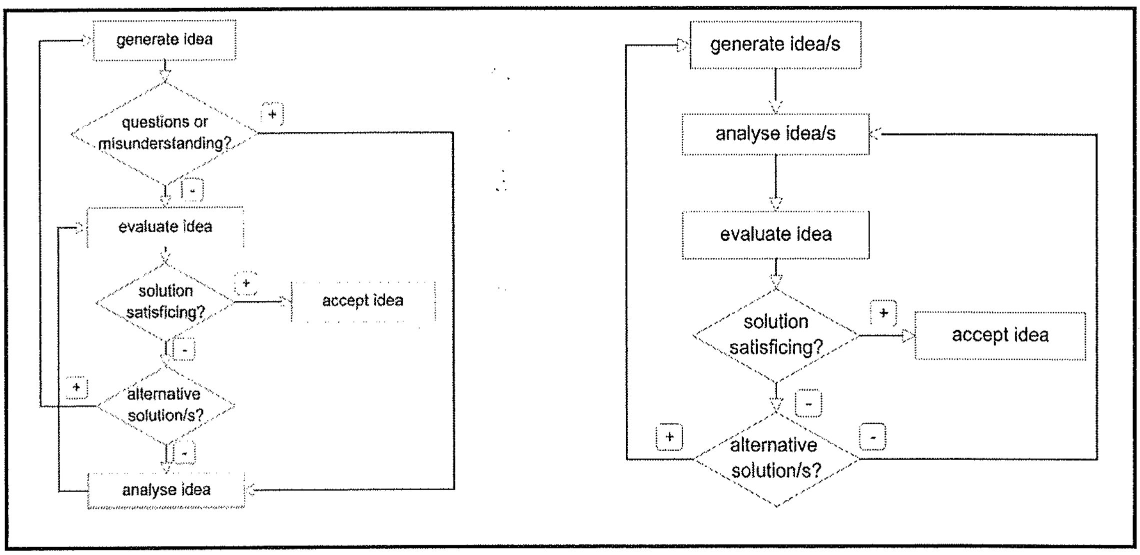


Figure 4.6 – Problem solving patterns
Source: Stempfle and Badke-Schaube (2002)

The first problem solving pattern (on the left side of the figure) is more appropriate for "well-defined problems" than the second pattern. For the authors, the first pattern has the following advantages: shorter time to take decisions, focus on one idea (no dispersion) and the analyses to be performed are simple. The authors suggest the usage of the second pattern for complex problems. Such problems have a higher level of uncertainty and equivocality. Sicotte and Langley (2000) defined uncertainty as "the absence of answers to well-defined questions" and equivocality as "a deeper level of ambiguity and confusion concerning the nature of the questions asked".

Their models have some similarities with our model: ideas are generated (in our case 3D models), analysed and evaluated. If no satisfying solution is proposed, additional ideas have to be found. However, some differences exist: the disciplines are not represented, no discrimination between group and individual tasks (our model has a specific activity that deals with cooperation – a group task). Now, each activity of the processing information cooperation loop will be described in more detail: definition of the activity, presentation of the results of other studies and the description of the solution that was adopted for the implementation.

4.1.2.1. Sharing of product information

The sharing of product information is the first step of the cooperation loop. Data creators have to "share" or "publish" relevant product information for their team colleagues. Hameri and Nihtilä (1997) call it "disseminating information".

The sharing of product information is a topic that raised a lot of issues during the focus groups and the subsequent discussions: who has access to which product information? where must the data be saved? when has the product information to be published? or how frequently? how do you deal with product information that is not mature ("in work")? For example, a manufacturing planner does not need to be informed about every change made in the 3D CAD models but rather know how to deal with draft 3D models submitted for an ad-hoc comment. In other words, we had to propose a solution that goes beyond an automatic transfer of product information from one system into another.

Terwiesch et al. (2001), performed a case study on engineering changes by a car manufacturer and proposed three patterns for the sharing of product information:

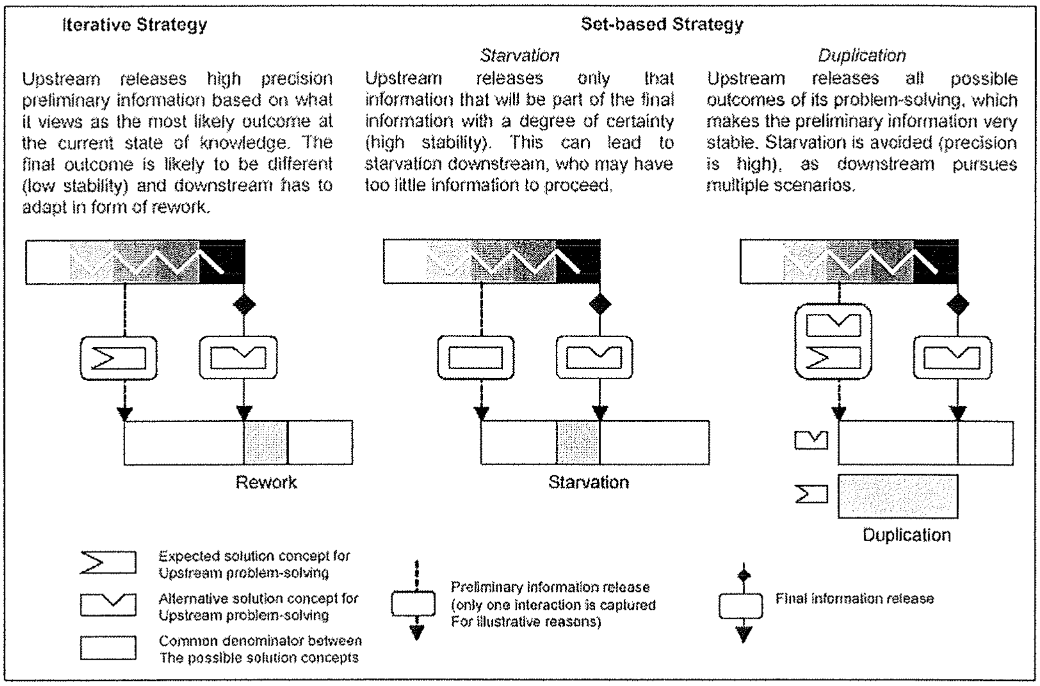


Figure 4.7 – Information sharing strategies

Source: Terwiesch et al. (2001)

The "iterative strategy" implies that people involved in downstream activities must accept rework if changes occurs. The "duplication strategy" implies that people involved in upstream activities release a wide spectrum of information (alternatives) so that people involved downstream activities can plan several alternatives. The "starvation strategy" is positioned between the two previous strategies: upstream activities share only product parameters that are considered as stable.

To solve this problem of data sharing during the implementation of CTs, two categories of data were differentiated in the pilot project: "released data" and "data for cooperation". The released data are the 3D models that are approved at each stage of the gate model. The data are relatively stable and such strategy is similar to the "starvation strategy" proposed by Terwiesch et al. (2001). Under "data for cooperation", we understand the data that have a temporary character. For example, a data creator can propose different design alternatives to get the feedback of some downstream disciplines. Here, we are more in a "duplication strategy". This solution was developed during a focus group with the GEN team and adopted later by other teams. The goal was to identify a simple structure so that team members can find the relevant data and their context. Based on these concepts, it was possible to define a simple data structure model that was implemented in the data repository. The following figure shows the proposed solution:

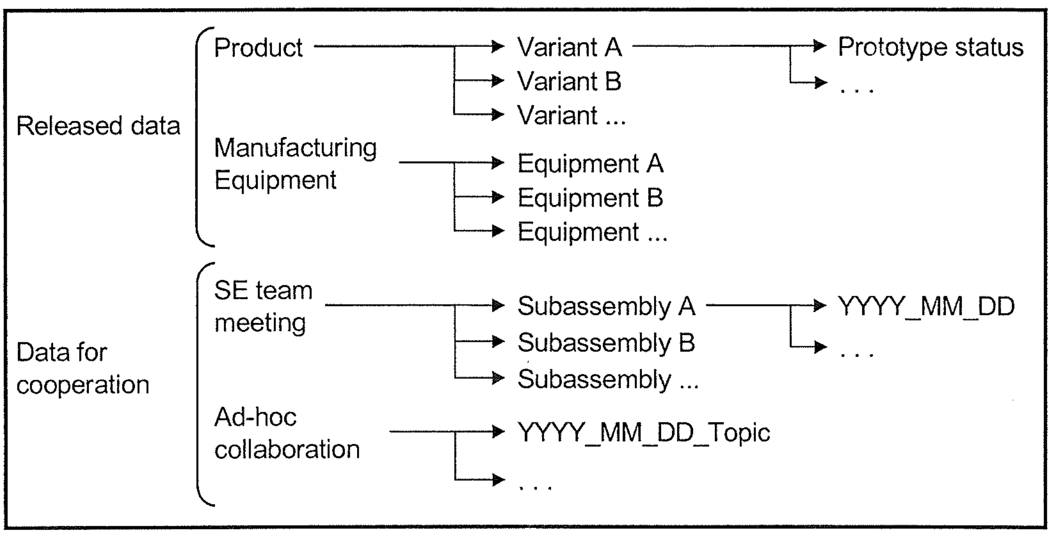


Figure 4.8 – Structure of the data repository

In the figure above, the 3D models of the different variants of the product were published for the different stages of the stage gate model (namely A, B, C, and D). The same could occur for the 3D models of the manufacturing equipment (assembly lines, tooling, etc.). For the "data for cooperation" two sub-categories were identified: SE[4] team meeting and ad-hoc collaboration (two cooperation routines that will be described in more details later). The category "SE team meeting" is divided into the main product sub-assemblies.

[4] Simultaneous Engineering

4.1.2.2. Assessment and further usage of product information

The 3D models contain critical parameters that are relevant for the tasks that product development stakeholders have to perform. As mentioned earlier, 3D models are of tremendous importance for manufacturing and assembly operations (e.g. definition of the manufacturing steps, define assembly sequence, tooling and machine layout, etc.). First, a team member analyses these critical parameters to evaluate their impacts on his tasks, the goal being to evaluate the consequences of the design choices. The critical parameters that were changed (e.g. dimensions) have also to be identified. It is what we call "assessment of product information". Second, the team member can start a design activity using the product parameters or use it for simulation purposes in a third application (quantitative and qualitative predictions, optimisation, improve decisions, etc.). This is what we call "further usage of product information".

For example, a purchaser is interested in getting the weight of a part (as it greatly influences its price) – this is what we call "assessment" or "analysis of the product information". In a second time, the purchaser can prepare a RFQ that includes a geometrical description of the part – this is what we call "further usage of product information".

Several authors stressed the role of experimentation in the design of products (e.g. D'Adderio, 2001 or Debackere, 1999). For them, the availability of product information (available earlier and easier to understand) in a digital form is another form of experimentation. To perform their analyses, product development team members can use a viewer (described in the third chapter).

4.1.2.3. Cooperation and agreement

During the preceding phase, team members can discover improvement potential related to the product geometry (i.e. improvement of the manufacturability). Therefore, 3D models can be used by team members for discussion and agreement purposes.

The CTs should facilitate the problem solving and decision making process in product development teams. Focus groups' participants defined four sub-activities under this process: prepare alternatives, collect requirements and suggestions, discuss and reach agreement and document discussions.

It appeared that cooperation occurs in a synchronous and asynchronous manner as team participants need time to describe a potential problem and prepare possible solutions which are then discussed "on-line". These results are confirmed by the research conducted by Olson and Olson (1999) on group work which showed that "individuals move between individual tasks, coordination, and real time clarification of goal" (quoted by Wierba et al., 2002).

Besides the use of a viewer for individual work, this activity can be performed online by using a 3D conference or an application sharing (for office documents).

4.1.3. Cooperation routines

An important objective of the field study was to embed the cooperation tools in the daily tasks of the product development team members. The adoption of CTs by end users is not easy and does not occur automatically (Wierba et al., 2002, Sicotte et al., 1998, Susman et al., 2003). The CTs change the traditional working pattern and we thought it important to describe "situations" where team members could use the tools. Our objective was to facilitate the appropriation of the CTs by the team members through the definition of so-called "cooperation routines".

4.1.3.1. Role of routines in organisations and in the product development process

For some authors, organisational routines are an important component of any organisation. Allison (1971) quoted that the goal of an organisation is "to have a mission, to create special capabilities linked to operational objectives oriented toward performance of specific tasks, and reliance on associated routines." By "routine"

Nobuo (1998) understands "as a system of interlocking, reciprocally-triggered sequences of skilled actions stored in a form of procedural memory." However, some debates exist on the definition of routines (Becker, 2003) – which call them "recurrent interaction pattern".

Routines are essential because they bring specific capabilities to organisations. Winter (2000) quoted that "An organizational capability is a high level routine (or collection of routines) that, together with its implementing input flows, confers upon an organization's management a set of decision options for producing significant outputs of a particular type." Nobuo (1998) cites another benefit: "the persistence of pattern of this system survives a replacement of its elementary individual memory". In our field of interest – that is the implementation of new information systems in the product development process – Soderquist and Nellore (2000) "concluded that when implementing information systems to support operational development work, it is essential to ground the system specification in clearly identified user needs that reflect the double nature of product engineering, namely the continuous interplay between routines and cognitive processes." Another argument justifying the definition and the usage of routines is the recognition that the product development process is unpredictable and rigid workflow systems are not appropriate (Chung et al., 2003; Krause et al., 2002).

The importance of the routines also appeared to be obvious during the implementation of the cooperation tools. Despite training, support and integration efforts, the usage of the cooperation tools remained low. One of the explanations was that these tools were not embedded in the daily activities (or routines) of the team members. Based on this observation and on the insights of the literature, it was decided to define cooperation routines with end users. These routines were also tought to the team members during the training sessions. By "cooperation routines", I understand tasks or activities that occur on a regular basis between different product development team members and where cooperation tools can provide substantial advantages. The routines defined are not intended for individual tasks. For example, design reviews are conducted on a regular basis in product development teams and various topics such as the product geometry are discussed. The place of the cooperation routine is described in the following figure. The main product development phases are displayed on the 1st layer. During each of these phases, specific activities have to be performed (2nd layer in the figure). Finally, cooperation routines (3rd layer) can facilitate the operationalisation of the specific activities of the 2nd layer:

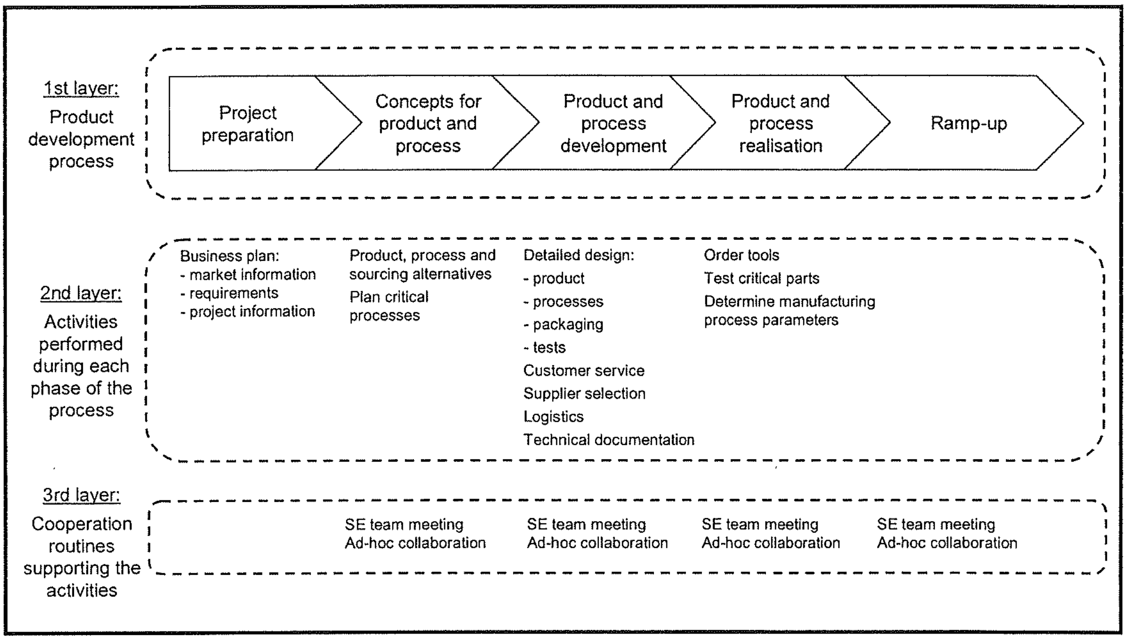


Figure 4.9 – Place of the cooperation routines in the product development process

Some examples of cooperation routines are presented in the following paragraphs.

4.1.3.2. Design Review

Design reviews are activities that occur frequently in the product development process. Blanchard (1991) distinguishes the formal "design review" (e.g. at the end of a project phase) from the "informal day-to-day review and evaluation". In the automotive industry, three kinds of design reviews exists (Schiemenz and Sorito, 2001): for the board of directors where the focus is on the product and its market segment, for a vehicle project where aspects like costs and schedule are monitored and "functional integration" where topics like function, geometry and manufacturing are discussed. The latter kind corresponds to the design review where CTs can be employed.

The routine presented here was elaborated by the working group "DMU with suppliers" (see 2.4.1.3.) and can be defined as "an agreement between OEM and supplier designers. The results presented there come from previous processes and deal with the modification of the product geometry. The relevant 3D models (including design alternatives) are presented and discussed. The results of a design review are agreed measures that solve a problem (change request, escalation, etc.)." This routine can be divided into three phases: preparation, execution, and follow-up (see illustration on the right side). Huang and Jiang (2002) present a similar design review process with five steps: "preparation, download, view comments and submit comments, common form and private form, discussion and make conclusion". During the preparation phase, the scope of the analysis will be defined (e.g. collision analysis), the required data prepared (e.g. 3D models), the discussion topics prioritised (the topics with higher priority will be selected), the people involved invited and informed. One of the critical elements is the "to do list", a list that summarises the problems to be solved. The second phase of the design review deals with the realisation of the design review itself. For each topic identified in the preparation phase, the results of the analyses are presented and critical subjects discussed. At the end of the discussion, solutions are proposed and tasks assigned to the designers. In the last phase of the design review, the "to do list" is updated and the measures (actions) documented.

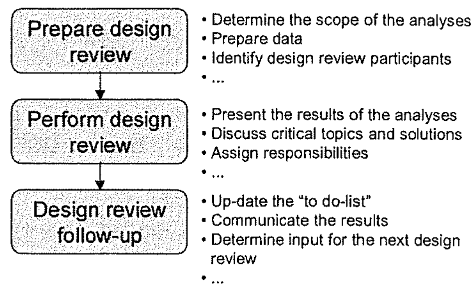


Figure 4.10 – Main steps of a design review
Source: Cax-AG 2.6.6 (2002)

Some cooperation tools were used to simulate this routine in a cross-organisational setting (i.e. including firewalls). A summary of the results is available in the reference CAx-AG 2.6.6 (2002).

4.1.3.3. SE Team meeting

An SE Team meeting is a variant of the design review described above. This meeting is organised on a regular basis (every 6 to 8 weeks) by an SE team leader of a sub-system and various topics are discussed with the representatives from different disciplines (e.g. purchasing, manufacturing, controlling). For example, five SE teams exist in the GEN project (rotor, stator, regulator, rectifier and final assembly) with representatives from different disciplines (design, purchasing, manufacturing, etc.). Technical issues related to the product geometry are regularly discussed in this kind of meeting.

Like the design review, this routine can be divided into three main phases. In the first phase, the SE team leader determines the technical issues that will be discussed and communicates them to the appropriate team members. Technical issues stem from various sources: previous design review (e.g. an issue identified during a discussion), project management (e.g. mandatory analyses have to be performed to comply with development regulations) or system engineering (e.g. the test results suggest that the product could be improved). In addition, the engineering department is asked to prepare the 3D models that will be discussed during the meeting. In our case, the preparation of the 3D models means their conversion from the 3D CAD system into the DMU format and their transfer into the data repository. In the second phase, the technical issues are discussed and the results of the discussions documented. This phase can be performed in a face-to-face meeting or on-line by using a synchronous cooperation tool like a 3D conference. During the last phase, the SE team leader defines the actions to be taken (e.g. changes of the product geometry) and sends the results to the SE team. At the beginning of the product development process the changes can be incorporated in an informal manner. Once the process has reached a certain maturity (beginning with product and process implementation phase), an ECR (Engineering Change Request) must be filled in. Otherwise, if no solution can be found, an escalation process may be triggered.

4.1.3.4. Ad-hoc collaboration

The two preceding routines had a formal character. In this routine, two or more team members must quickly discuss a technical issue related to the geometry. This routine is more difficult to describe and one of the key users that participated in the definition of this routine quoted: "it is difficult to describe a chaotic and dynamic phenomenon". However, as mentioned earlier, the heart of the product development process is the decision making in an uncertain environment. Ad-hoc collaboration is especially important for multidisciplinary and dispersed teams under time pressure as it enables two or more product design team members to discuss a technical problem.

To ease the understanding, this routine was also divided into three phases like the two previous examples. In the first phase a team member identifies a problem or has a suggestion and triggers a discussion. The problems or suggestions appear mostly in the "physical space" (e.g. a manufacturing planner discovers a default in a prototype).

In the second phase, the appropriate colleagues have to be identified (who can help to solve the problem) and informed (by sharing the appropriate product information such as 3D models, sketches, 2D drawings, etc.). The technical issue is discussed and documented in the second phase. The results of this process are various: feedback (validation, estimation, assessment), an additional issue for a subsequent SE team meeting, change product geometry with the 3D CAD system (during the early phase), or trigger an ECR (formal change process).

4.1.4. Summary of the field study

Several objectives for the field research were defined in the third chapter: (i) define the potential usage of the CTs in product development activities, (ii) embed the CTs in team procedures, (iii) implement the CTs in teams, (iv) define the IT architecture and (v) the identification of additional functionalities. At the end of this field study, some general comments can be made on the achieved results:

(i) Technical feasibility and maturity of the CTs: the software available on the market can now be considered as mature and the sharing of 3D models is therefore possible from a technical point of view. In addition, we showed that the CTs can be integrated in the existing IT landscape (with CAD and PDM systems);

(ii) Appropriate for current challenges in the automotive industry: the CTs were used in different pilot projects for the development of some product platforms. These tools were used for different purposes (e.g. analysis of product information, team meeting or ad-hoc discussions) and embedded in the team procedure. We got a positive feedback from the different participants of the pilot projects. As an evidence of the success of the CTs, an increasing number of virtual teams are today using these tools. Therefore, we assume that CTs are important to overcome the current and the future challenges of the automotive industry. More precisely, the CTs help team members to overcome the geographical dispersion while avoiding travels, work with different CAD systems, reduce some product and manufacturing costs, reach the maturity quicker, support discussion and cooperation. In addition, some team members begin to use 3D models instead of 2D drawings as a privileged means to access the product information;

(iii) The main challenge lies in the introduction: the CTs are mature and can bring some substantial benefits to the product development teams. However, our experience showed that the main challenge is the implementation (or diffusion) of new tools and new practices. First, we confirm the observations of Wierba et al. (2002) and Sussman et al. (2003) who demonstrated that organisational changes are required to grasp the benefits of the CTs (especially in the form of an "appropriation process"). The CTs do not spread themselves and the implementation of the CTs must be coached in teams. The survey will shed a new light on this topic because the factors influencing the adoption will be identified;

To summarise, the field study demonstrated the usefulness of the CTs for product development teams and provided some insights about their implementation. The willingness of new teams to use the CTs is a sign of success.

4.2. Survey results

The results of the survey will be presented in this section. First, we will examine how the questionnaire was administrated in the firms and give some information about the context. Second, the reliability of the constructs will be evaluated. Third, the characteristics of the respondents will be presented in the part dedicated to the descriptive analyses. The definition of distinctive groups (or profiles) is also a result of these analyses. Fourth, based on these groups, some bivariate analyses will be presented. Finally, the test of the hypotheses as well as additional analyses will be presented.

4.2.1. Audience of the questionnaire

The questionnaire was sent electronically to 92 members of product development teams registered on the cooperation server of Bosch. After a few weeks, a follow-up action was set up to increase the answer rate. The researcher individually visited potential respondents in the Stuttgart area. For respondents outside the Stuttgart area (i.e. located in other German regions, in Great Britain and in the Czech Republic), a paper-based questionnaire was sent with a letter mentioning the objectives of the study. This follow up action allowed us to increase the number of respondents to 53. For the external firms, the questionnaire was sent to 18 representatives that were responsible for the distribution of the questionnaire in product development teams in their firms. Eight questionnaires were returned from external respondents. Hence, we get a total of 61 questionnaires which corresponds to an answer rate of 55.5% (considering the 18 representatives as potential respondents). More returned questionnaires were expected, especially from external firms. The software provider was also asked to identify additional firms that were using these CTs. Despite multiple discussions, the software provider was not able to convince any additional firms to participate in the survey. Several reasons may explain this situation:

(i) Usage of survey uncommon: in this field, the realisation of such a survey is not widespread in Germany. We can also speculate that the respondents had concerns about the evaluation of the results. Indeed, the firms were contacted through Bosch and were perhaps afraid to reveal internal strengths or weaknesses;

(ii) Cooperation tools at an evaluation stage: numerous firms contacted in the German automotive industry are still evaluating the CTs (i.e. the CTs are rarely used in product development teams). This fact was confirmed through formal and informal contacts. Today, firms focus on integration issues (e.g. integration of some CTs with SAP prior to their roll-out) or do not use these technologies for the same purpose ("traditional DMU" vs. multidisciplinary cooperation, like mentioned in the first chapter);

4.2.2. Reliability of the constructs

The alpha Cronbach are considered as an appropriate measure and well spread method to measure the reliability of the constructs. More precisely, this coefficient measures how well the different items (or questions) are linked. A bad coefficient indicates that they are not only measuring one phenomenon. To be valid, the value of this coefficient should be greater than 0.70 (Nunnally, 1978).

The coefficients were computed but some of the values of the initial constructs (presented in the third chapter) did not satisfy the criteria mentioned above. Therefore, some factorial analyses were performed to find if the constructs contained several dimensions. These analyses allowed us to refine the calculation of some alpha Cronbach coefficients:

(i) Quality of the implementation: after a factorial analysis, the two initial constructs quality of the tools ($\alpha = 0.5782$) and training & support ($\alpha = 0.6731$) were split up into three dimensions: tools' usefulness (i.e. usefulness of the CTs and of the 3D models), tools' accessibility (i.e. CTs user friendliness and easiness to get support) and training (i.e. if the training provided information about the basic features of the CTs and what job-related tasks CTs were good for solving);

(ii) Product development performance: after a factorial analysis, the five initial constructs time & costs ($\alpha = 0.8581$), teamwork ($\alpha = 0.8568$), creativity ($\alpha = 0.8676$), manufacturing performance ($\alpha = 0.9539$) and product performance ($\alpha = 0.8739$) could be regrouped into three main constructs: process performance (or the old constructs "time & costs"), innovativeness (that bundles the following items: more issues explored, more alternatives generated and more creative alternatives) and product and manufacturing performance (meaning that the performance of the product and the process are linked);

Initially, the variable "collaboration activities" was made of four constructs ("sharing of product information", "discussion and agreement", "further usage of product information" and "assessment of product information"). Two of the constructs were problematic because the criteria mentioned above were not respected. First, the "sharing of production information" had an alpha Cronbach value of .6310. However, due to its importance for the researcher, it had been decided to keep this construct for subsequent analyses. For exploratory studies, an alpha Cronbach of .60 is accepted (Devellis, 1991). Second, the construct "further usage of product information" (made of two items) had an alpha Cronbach value of .6297. Being less important for us, this construct will be ignored for the subsequent analyses. The values of the alpha Cronbach used for this study are presented in the following table:

Table 4.5 – Reliability of the constructs

Dimensions	**Constructs**	**Alpha Cronbach**
Team context	Virtuality	0.8378
	Cultural differences	0.7122
Collaboration activities	Sharing of product information	0.6310
	Discussion and agreement	0.8335
	Assessment of product information	0.8828
Collaborative behaviour	Cooperation planning	0.7674
	Cooperation improvement	0.7540
Quality of the implementation	Tools' usefulness	0.8125
	Tools' accessibility	0.7873
	Training	0.9138
Product development performance	Process performance	0.8581
	Innovativeness	0.8676
	Product and manufacturing performance	0.9376

More detailed results that include the mean and the standard deviation are available in the following appendices: APPENDIX 5 (dependent variables) and APPENDIX 6 (independent variables). From now on, we will use the term "variable" instead of "construct".

4.2.3. Descriptive analyses and group building

The output of these analyses is twofold: on the one hand the description of the basic features of the data and on the other hand the building of groups or "profiles" that characterise different respondents (e.g. which respondents are working in a virtual environment vs. those who are working in a collocated manner). The mean and the standard deviation will be used to describe the basic features of the data. A standard deviation shows the dispersion of the results around the mean. If the distribution is normal (or "bell-shaped"), then 70% of the respondents belong to the distance defined by "mean – standard deviation" and "mean + standard deviation". In other words, a high standard deviation suggests that the respondents answered very differently. To perform the classification of the respondents, quadrants were built (see figure on the right side). This method allows to easily recognise groups and this feature explains its great diffusion in the industry. However, not being statistical, the data are "forced" to belong to one quadrant or another. The usage of quadrants must therefore be considered as a first attempt to classify the data.

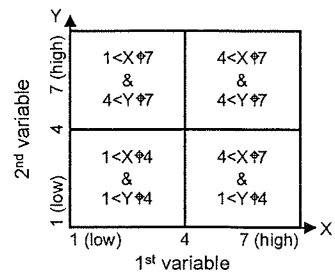


Figure 4.11– Bivariate analysis: quadrants building

4.2.3.1. Position of the firms and of the respondent in the product development process

The respondents were asked to give the role of their firm or business unit in the automotive value chain. The vast majority of the respondents (90%) were involved in the development of components. This is due to the fact that Bosch respondents (87% of the total) were developing components for OEMs. The rest of the

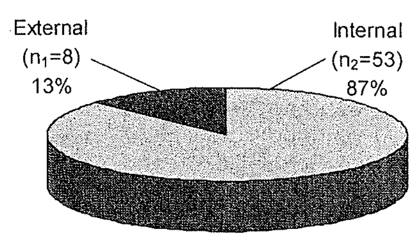


Figure 4.12 – Univariate analysis: distribution of respondents (internal vs. external)

respondents (n = 6) were distributed as follows: OEM (n = 1), module supplier (n = 1), module and system supplier (n = 1), system supplier (n = 2), and system and component supplier (n = 1). The distribution between internal and external respondents is shown in the figure above. The respondents were also asked to describe their role(s) in the product development process. The results are presented in the following table:

Table 4.6 – Univariate analysis: the role of the respondents in the product development process

Role(s) of the respondents	Mean[1]	S.D. [2]
System engineering	2.44	2.02
Product design ("mechanics")	3.56	2.61
Product design ("electronics")	1.80	1.55
Process design (manufacturing)	2.79	2.21
Process design (assembly)	2.66	2.04
Controlling (costing)	1.95	1.66
Purchasing	1.51	1.14
Prototyping	1.87	1.72
Testing	2.11	1.72
Quality	1.77	1.40
Sales and marketing	1.38	1.07
Logistics	1.25	0.85
Application	1.92	1.64
Team manager	2.31	2.33
Other	2.61	3.34

[1]Based on a Likert scale (where 1 = play this role very little and 7 = play this role very much)
[2]Standard Deviation

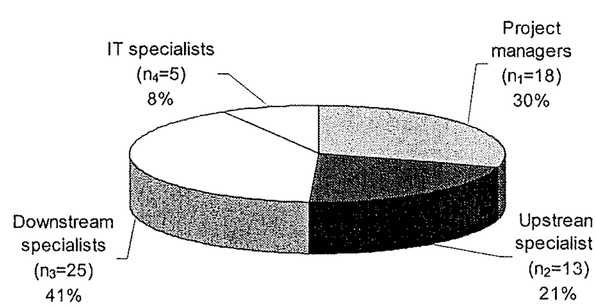


Figure 4.13 – Univariate analysis: distribution of the respondents according to their role in the development process

The respondents had the possibility to select several roles, which explains the low level of the mean. In the field "others", the respondents had the opportunity to specify their role in the organisation: some of the respondents were responsible for the improvement or the implementation of such technologies (5 answers). Others (6 answers) specify their tasks in the product development process (e.g. team management, responsible for the design, manufacturing planning, etc.). To facilitate the subsequent analyses, some of the tasks were regrouped. The results were therefore coded and four mutually exclusive categories emerged (see figure on the preceding page): the "***project managers***" are team leaders, project managers or team members having both a role in upstream and downstream functions; the "***upstream specialists***" are team members involved in upstream functions (mostly mechanical design); the "***downstream specialists***" are team members involved in downstream functions (e.g. manufacturing planning, purchasing); finally, "***IT specialists***" are people in charge of the implementation of CTs (they were mostly respondents of external firms);

4.2.3.2. Behaviour of the control variables

The focus of the following paragraphs will be to characterise the behaviour of the control variables.

a) Involvement in the team

To qualify their level of involvement in the product development team, the respondents were asked to rate: the timing of their involvement (involved early in the project vs. involved late in the project) and the effort (time spent working on the project). The respondents were very much involved in the projects (mean = 5.09 and 5.40 respectively). This relatively high mean suggests that the projects conducted in the different firms that participated in the survey are stable.

Table 4.7 – Univariate analysis: involvement in the development team

	Mean[1]	S.D.[2]
Involvement in the project	5.09	1.93
Time spent on the project	5.40	1.67

[1]Based on a Likert scale (where 1= low and 7 = high)
[2]Standard Deviation

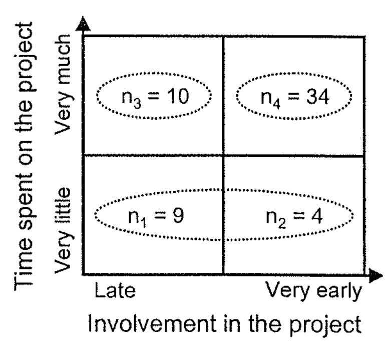


Figure 4.14 – Bivariate analysis: typologies of the involvement in the development team

The quadrant shows (see the figure above) that a large group of respondents ($n_4 = 34$) was involved early in the project and spent a lot of time working on it. This group will be called "***high involvement***" in subsequent analyses. A second group ($n_3 = 10$, "***late involvement***") regroups team members that were involved late but spent much time working on the project. Finally, a third group ($n_1+n_2 = 13$, "***occasional involvement***") spent a small part of their time working on the project. We assume that they were either working on other projects or had hierarchical responsibilities.

b) Interactions with the business partners (OEMs and suppliers)

The frequency of the respondents' interactions with suppliers and customers will be examined. The respondents had much more interaction with suppliers (mean = 3.69) than with customers (mean = 2.62). Such results can be explained by the fact that we had to do with product platforms – i.e. the tier 1 supplier takes the responsibility for developing a product alone and proposes it to customers once a certain level of maturity is reached. In addition, frequent interactions with suppliers are required because a large part of the development and manufacturing work is done by tier 2 suppliers (e.g. part suppliers, tooling suppliers or engineering services).

Table 4.8 – Univariate analyses: interactions' frequency with business partners

	Mean(1)	S.D.(2)
Frequency of the interactions with suppliers	3.69	1.76
Frequency of the interactions with OEMs	2.62	1.77

(1)Based on a Likert scale (where 1= low and 7 = high)
(2)Standard Deviation

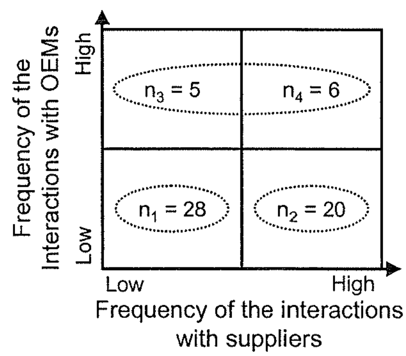


Figure 4.15 – Bivariate analyses: typologies of interactions with external partners

The observation of the quadrant allows us to draw some conclusions: the largest group ($n_1 = 28$) has "***few interactions with business partners***". A second group ($n_2 = 20$) has "***frequent interactions with suppliers***" (and few with customers). Finally, a third group ($n_3+n_4 = 11$) is constituted by team members having "***frequent interactions with OEMs***" (with both a high and low level of interactions with the suppliers).

c) Interactions with colleagues

We also asked the respondents to specify how frequently they interact with their colleagues inside their organisations, people having the same task and people having a different task in the product development team. A consensus exists for the interactions with colleagues inside their organisation (mean = 6.19 and Standard Deviation = 1.06).

For the interactions with people having the same or a different task, four groups could be built (see quadrant below). A large group (n_4 = 26) has frequent interactions with both people having the same task and a different task and can be called "***frequent interactions with all team members***". A second group (n_2 = 14), the "***discipline focused***", has a high level of interaction with the team members having the same discipline. A small group (n_3 = 8), the "***multidisciplinary***", has more interactions with team members having a different than with people having the same task. Finally, a small group (n_1=11, 19%) has few interactions at all and will be called the "***few interactions with other team members***".

Table 4.9 – Univariate analysis: interactions' frequency with other team members

	Mean(1)	S.D.(2)
Frequency of the interactions with team members having the same task	5.12	1.22
Frequency of the interactions with team members having a different task	4.80	1.26

(1)based on a Likert scale (where 1= low and 7 = high)
(2)Standard Deviation

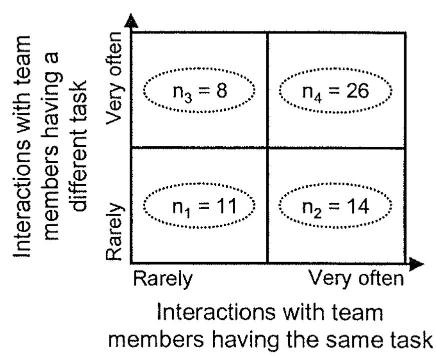


Figure 4.16 – Bivariate analysis: typologies of interactions with other team members

d) Product and manufacturing newness

The level of newness was measured through the assessment by the respondents of the product and the manufacturing newness. The product newness was rated higher than the process newness (mean 5.5 vs. 5.1).

Three major groups emerged from the quadrant (next page): the first group (n_4 = 28, "***high product and manufacturing newness***") characterises projects needing innovation on both dimensions. The second group (n_2 = 21, "***high product newness and low manufacturing newness***") can be explained by the fact that the automotive industry tries to deliver innovative products using existing manufacturing and assembly equipment to reduce the investment while improving the flexibility. Finally, the last group ($n_1+n_3 = 9$, "***low product newness***") assembles the respondents working on projects with low product newness.

Table 4.10 – Univariate analysis: product and manufacturing newness

	Mean(1)	**S.D.**(2)
Product newness	5.52	1.31
Manufacturing newness	5.06	1.16

(1)Based on a Likert scale (where 1= low and 7 = high)
(2)Standard Deviation

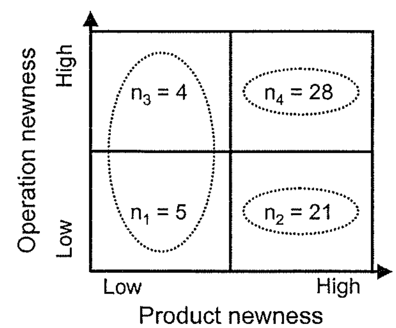


Figure 4.17 – Bivariate analysis: typologies of product and manufacturing newness

e) Management implication

The implication of management is an essential ingredient for the adoption of new practices. Therefore, the respondents were asked to rate the implication of their manager or team leader in the usage of the CTs: (i) if they were trained and used the CTs and (ii) if the capabilities and limits of the CTs were known.

Table 4.11 – Univariate analysis: implication of the managers

	Mean(1)	**S.D.**(2)
Manager trained and uses CTs	3.49	1.75
Manager understands capabilities and limits of CTs	4.05	1.70

(1)Based on a Likert scale (where 1= low and 7 = high)
(2)Standard Deviation

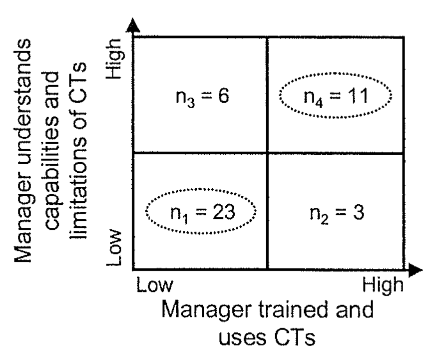


Figure 4.18 – Bivariate analysis: typologies of manager implication

The means are relatively low (3.49 and 4.05) and a large group of the respondents answered with N/A[5] (n = 17 and n = 15). A high level of N/A suggests that the topic "CTs" was not discussed between employees and their managers (e.g. usage of CTs as a means to reduce travel costs or improve cooperation). We can also speculate that such a question is a sensible topic and that respondents were reluctant to judge their team leader or manager.

Two groups were chosen from the quadrant: a large group (n_1 = 23) has "***less implicated managers***" than a second group (n_4 = 11, "***highly implicated managers***") which is characterised by a high level of management implication on both dimensions.

4.2.3.3. Usage of the cooperation tools and the proficiency

a) Usage of the proposed cooperation tools

An essential element of this study was the evaluation of the level of CTs usage. Therefore, the respondents were asked to rate their usage of the CTs (currently and in 12 months) and their willingness to use additional CTs. Besides the usage of CTs, a "complexity score" for the different tools was created. Several researchers and key users were asked to rate the level of complexity of the different CTs (on a scale from 1 to 10).The results are summarised in the following table (on the next page):

---

[5] Not Answered

Table 4.12 – Univariate analysis: usage of the available cooperation tools and complexity score

Cooperation tools	Mean[1]		S.D. [2]		Complexity score[3]	
	Currently	In 12 months	Currently	In 12 months	Currently	In 12 months
Visualisation of 3D models	3.29	3.96	1.86	1.66	4.50	3.50
Conferencing with 3D models	1.88	2.76	1.13	1.69	5.17	5.00
Application sharing	2.73	3.00	1.85	1.94	4.50	4.25
Publication of 3D models	2.32	2.86	1.74	1.87	5.00	4.50

(1)Based on a Likert scale (where 1= low usage and 7 = high usage)
(2)Standard Deviation
(3)Complexity of CTs usage (rated by researchers and key users – a detailed description is available in the text)

A first impression is that the usage is currently relatively low as all the results are below the mean of the scale (4 on a scale from 1 to 7). For the existing CTs, the most used tool is the visualisation of 3D models (mean = 3.29), followed by application sharing (mean = 2.73), the conversion from 3D CAD models to the DMU format (mean = 2.32) and finally the 3D conferencing (mean = 1.88). For the planned usage – that is in 12 months – the ranking remains the same but the progression of 3D conferencing is high: + 47% (publication of 3D models: +23%, visualisation of 3D models: + 20%, application sharing: + 10%). The 3D conferencing was rated as the most complex CT. Indeed, a 3D conference combines the complexity of the 3D visualisation with the work in a virtual environment. To simplify the subsequent analyses, it was decided to create a "cooperation tools usage score" that measures the level of CTs usage for each respondent. This score was computed as follows:

Formula 4.1 – Calculus of the CTs usage score

$$CTs\ usage\ score = 4.50 \times \begin{bmatrix} visualisation \\ of\ 3D\ models \end{bmatrix} + 5.17 \times \begin{bmatrix} conferencing \\ with\ 3D\ models \end{bmatrix} + 4.50 \times \begin{bmatrix} application \\ sharing \end{bmatrix} + 5.00 \times \begin{bmatrix} publication \\ of\ 3D\ models \end{bmatrix}$$

For each respondent a score was computed. The minimum score was 5 and the maximum score was 100. To build groups, a cumulative percentage curve was built:

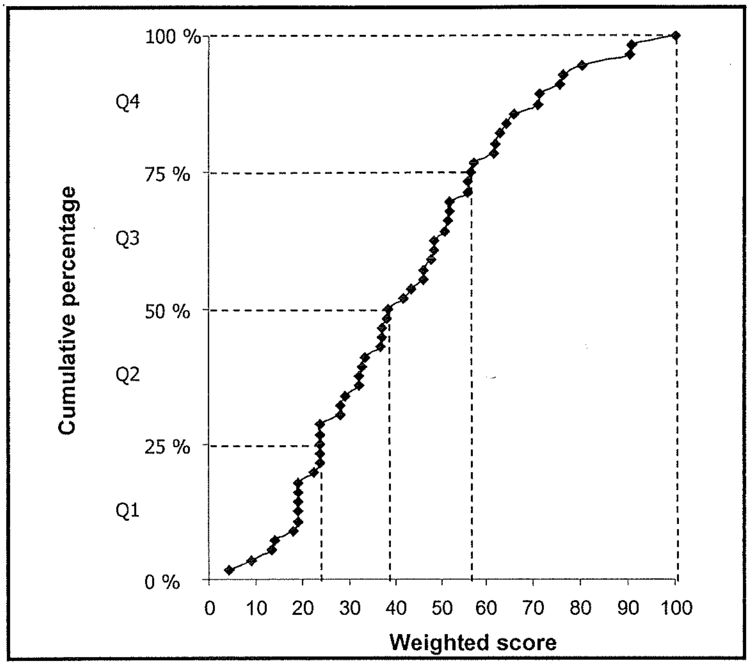


Figure 4.19 – Bivariate analysis: cumulative percentage of the CTs usage score

The weighted scores were ranked (in growing order) and are in the abscissa of the preceding figure. The ordinate shows the percentage of respondents (100% corresponding to the 56 respondents that answered this item).

Four groups were defined for subsequent analyses: "*Q1*" (the first quartile or the 25 % of the respondents that used the CTs at least – a score between 4 and 24), "*Q2*" (the second quartile with respondents that have a score between 24 and 38), "*Q3*"(the third quartile or 25% for a score between 38 and 57) and "*Q4*" (the quartile that regroups 25% of the respondents that achieved the best score).

b) Usage of the proposed cooperation tools

The additional CTs – issue manager, iteration manager and disassembly tools – have a high potential, especially the clearance and assembly tools that allow to perform more complex analyses on the 3D models. However, we can also speculate that the respondents prefer to use not yet existing tools than existing tools.

Table 4.13 – Univariate analysis: usage of the suggested cooperation tools

Cooperation tools	**Mean**[1]	**S.D.**[2]
Issue manager	4.10	1.71
Iteration manager	4.76	1.73
Clearance & assembly	5.09	1.76

[1]Based on a Likert scale (where 1= low usage and 7 = high usage)
[2]Standard Deviation

c) Proficiency with the cooperation tools

Finally, the respondents should estimate their level of proficiency with the CTs. The mean was relatively low (3.63) and the standard deviation was relatively high (1.67). This result indicates that some respondents were very proficient whereas others were less proficient.

The following figure shows the distribution of the respondents' answers concerning their proficiency. We decided to split the sample up into three groups: a first group (n1 = 16) has a "**very low proficiency**" (those who answered 1 & 2). The second and largest group (n2 = 33) has a "**moderate proficiency**". Finally, a small group (n3 = 7) of respondents considered themselves as "**highly proficient**". These three groups are illustrated in the following figure:

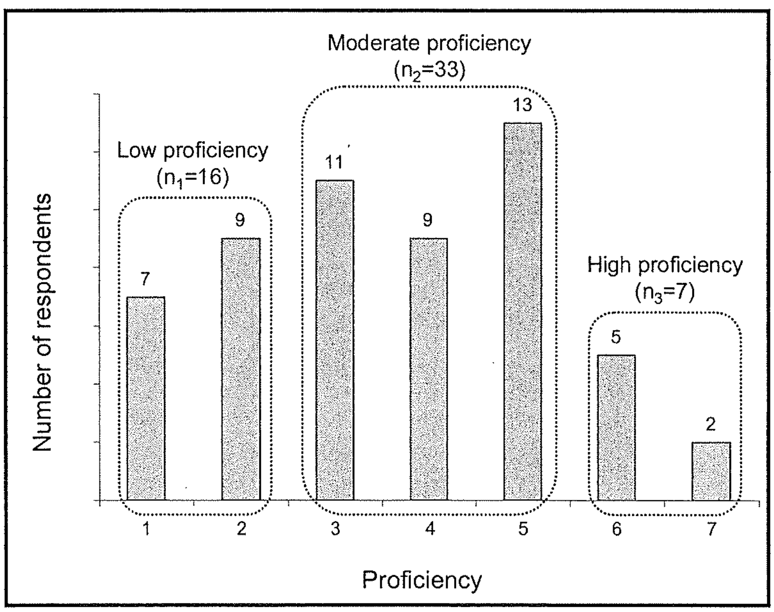


Figure 4.20 – Univariate analysis: distribution of the CTs proficiency

4.2.3.4. Independent and dependent variables

The following table presents the univariate analysis of the independent and dependent variables:

Table 4.14 – Univariate analysis: independent and dependent variables

Dimensions	Variables	Mean[1]	S.D.[2]
Team context	Virtuality	4.63	1.80
	Cultural differences	4.00	.98
Collaboration activities	Sharing of product information	4.59	1.33
	Discussion and agreement	4.97	1.45
	Assessment of product information	4.31	1.90
Collaborative behaviour	Cooperation planning	4.50	1.22
	Cooperation improvement	2.97	1.27
Quality of the implementation	Tools' usefulness	5.54	1.27
	Tools' accessibility	4.65	1.18
	Training	4.51	1.73
Product development performance	Process performance	3.94	1.42
	Innovativeness	4.36	1.59
	Product and manufacturing performance	3.66	1.42

[1]Based on a Likert scale (where 1= low or disagree and 7 = high or agree)
[2]Standard Deviation

Several conclusions can be drawn from the preceding table:

(i) Team context: a high level of virtuality (4.63) combined with a high standard deviation (1.80) indicates that some respondents work in a highly virtual environment whereas others are working in a collocated manner. This confirms observations made during the field research: some people are closely working together (e.g. upstream specialists) while others are working with colleagues at different locations. A quadrant was also built for this topic and three groups emerged: "***low virtuality***", "***moderate virtuality***" (high geographical dispersion but no problem to reach colleagues) and "***high virtuality***" (high geographical dispersion and problems to reach colleagues). A detailed description is available in APPENDIX 16;

(ii) Collaboration activities: this dimension refers to the activities performed by the team members during the product development process and was made of three variables: sharing of product information, discussion and agreement, and assessment of product information. Discussion and agreement was rated higher (mean = 4.97) than the two other variables. This can be explained by the fact that the current context is characterised by a high degree of cooperation between the product development team members. The assessment of product information exhibits a high standard deviation (1.90) indicating that some team members perform this kind of activity more often than others;

(iii) Collaborative behaviour: two variables constituted this dimension: cooperation planning and cooperation improvement. Cooperation planning has a higher mean (4.50) than cooperation improvement (2.97). We can speculate that teams invest resources in the planning of their common work but that less actions are taken to improve cooperation afterwards.

(iv) Quality of the implementation: this dimension contains variables that represent factors that could influence the adoption of the CTs: tools' usefulness, tools' accessibility and training. The tools were judged very useful by the respondents (mean = 5.54). However, the accessibility of the tools and the training obtained more moderate scores (mean = 4.65 and 4.51 respectively). In addition, the standard deviation is high for the training (1.73). Hence, the training was not well performed for all team members;

(v) Product development performance: finally, the respondents were asked to evaluate the impact of intense sharing of product information and cooperation during the product development process. On two items of the questionnaire a consensus was reached: teamwork satisfaction (mean = 4.79, standard deviation = 1.56) and information asymmetry reduction (mean = 4.75, standard deviation = 1.51). The results show that the greatest benefit lies in innovativeness (i.e.

exploration of more issues, generation of more alternatives and a better creativity), before the performance of the product development process (i.e. delays and costs reduction) and finally for the product and manufacturing performance. It is to notice that the mean of the "process performance" and "product and manufacturing performance" is relatively low. In addition, the number of N/A was sometimes high, reflecting the difficulty for the respondents to assess the benefits of cooperation while the projects were still in development.

4.2.3.5. Summary of the univariate analyses

From the univariate analyses, we conclude that:

(i) The constructs had a good reliability and exhibit some interesting features: except for "sharing of product information", the alpha Cronbach were greater than 0.70. The factorial analyses allowed us to refine some constructs. First, the constructs "product performance" and "process performance" could be regrouped into one construct. Second, the constructs belonging to "quality of the CTs implementation" were refined and a new interesting construct (the accessibility of the CTs) emerged from the data analysis, completing the other constructs (namely, tools' usefulness and training). We can conclude that the results of the survey are robust;

(ii) Interesting sample: several groups with distinctive characteristics or behaviour could be identified. These results indicate that the sample is coherent with the reality of the product development teams. For example, team members with different roles are represented in the sample (project managers, upstream and downstream specialists), different interaction patterns with business partners exist, etc.;

All the groups identified during the univariate analyses are presented in the following figure:

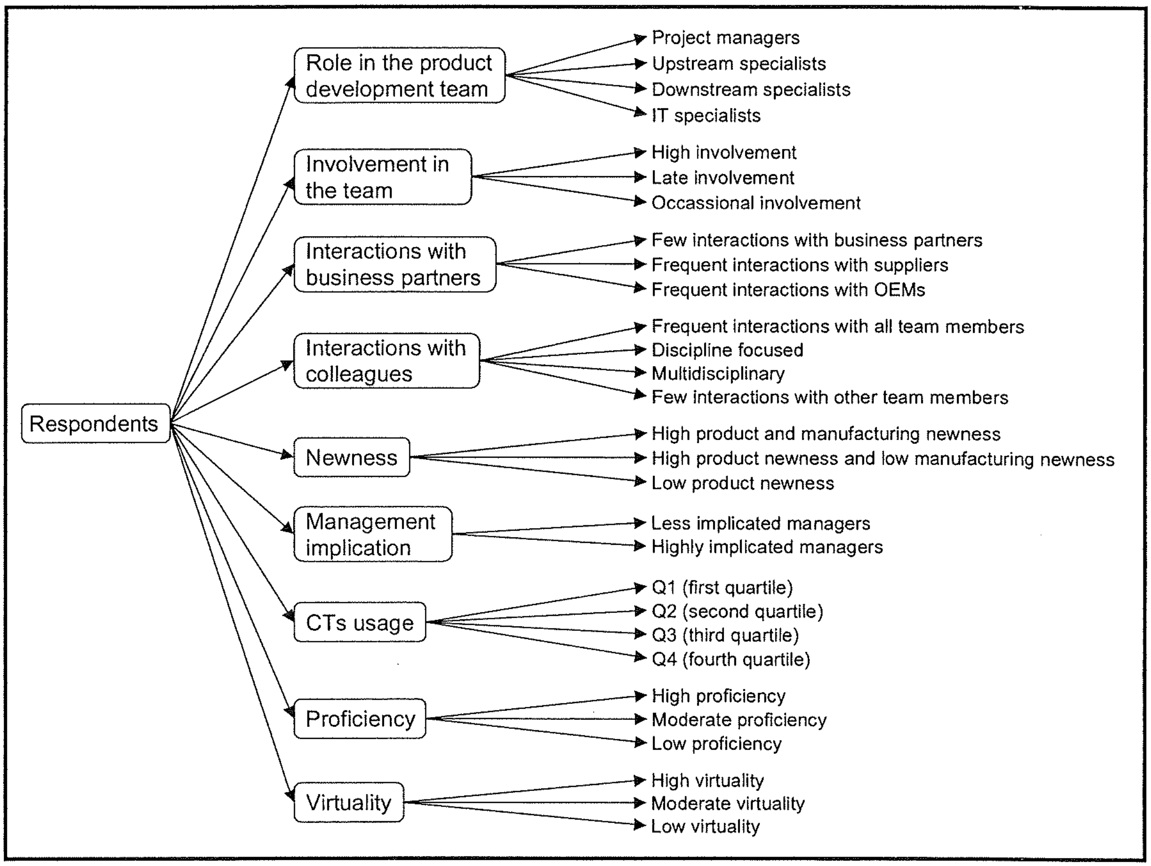


Figure 4.21 – A priori groups retained from the descriptive analyses

The next part will be dedicated to the bivariate analyses where the behaviour of the different groups against the other research variables will be presented.

4..2.4. Bivariate analyses

The goal of such an analysis is to first explore the associations between the groups (or profiles) identified previously and the other variables (control, independent and dependent).

The table (on the right side) shows how the results are presented. The results can be interpreted as follows: "$mean_{1i}$" is the average result achieved by the "$group_1$" for the "$variable_i$" (or construct).

Table 4.15 – Interactions between research variables

	$group_1$ ($n = r_1$)	$group_2$ ($n = r_2$)	test
$variable_i$	$mean_{1i}$	$mean_{2i}$	p
$variable_j$	$mean_{1j}$	$mean_{2j}$	p

Except for the CTs usage score (a computed score that bundles all the CTs), all the other scales were based on a Likert scale (1 to 7). The figure in brackets ($n = r_1$ and $n = r_2$) indicates the number of respondents belonging to the group. In the "test" column, p is a coefficient calculated to assess the significance of the result. In the case of two groups, the Mann-Whitney test is used (M-W test), otherwise the Krushall-Wallis test is used (K-W test). A p value inferior to .10 is considered as significant (i.e. there is a significant difference between the groups). In the tables, the value of p will be replaced by * (* when $p <.10$, ** when $p < .05$, ***when $p < .001$ and **** when $p < .0001$).

The heart of the bivariate analyses is to grasp and compare the behaviour of different groups. Some groups were defined in the previous part but, as mentioned earlier, the proposed classification is not perfect (the data necessarily belong to one group or another). However, a statistical technique, more known as "cluster analysis", allows to build more homogenous groups. A cluster analysis builds groups by maximising the differences between the groups and minimising the differences within a group. The following principles will guide our action to perform the bivariate:

(i) First step: the bivariate analyses will be performed on the a priori groups;

(ii) Second step: if the results are not satisfying and the topic important, a cluster analysis will be performed. Based on these new groups, an additional bivariate analysis will be presented. Three topics were considered as important: the product and manufacturing newness, the frequency of interactions with business partners and the virtuality;

(iii) Third step: the bivariate analyses can also be performed on individual variables. For example, it is possible to compare the respondents that assessed a variable high (e.g. greater than the mean) vs. the respondents that assessed a variable low (e.g. lower than the mean). Such an analysis will also be performed in some particular cases;

Traditionally, bivariate analyses are performed on the control variables. In our case, we were also interested in performing a bivariate analysis on the moderating variables (CTs usage score and the proficiency). Hence, a total of twenty one bivariate analyses will be presented in the following paragraphs. The following figure summarises the analyses that will be presented:

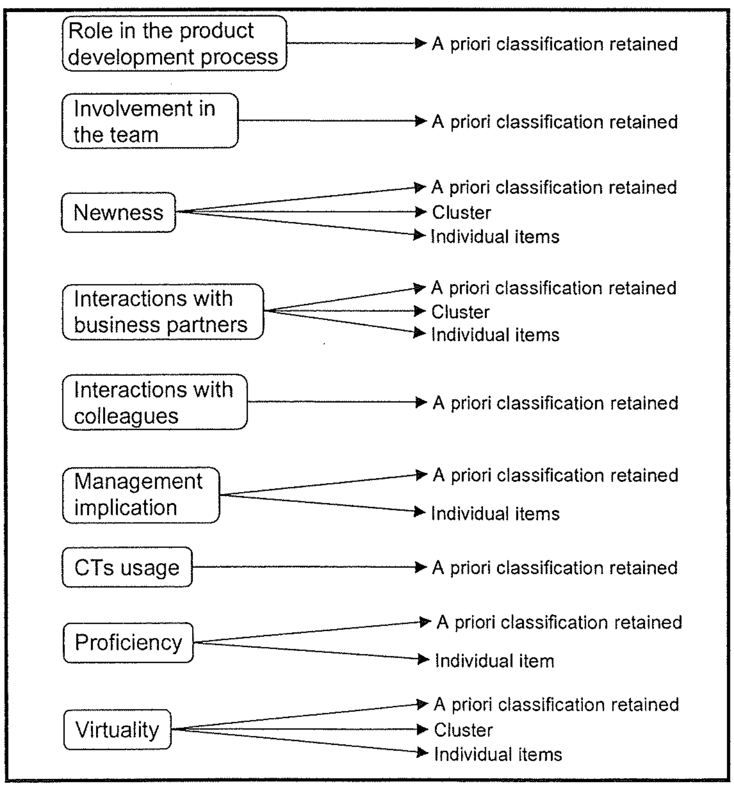


Figure 4.22 – Summary of the bivariate analyses performed

4.2.4.1. Influence of the role in the product development process

Our first interest was to find out the differences existing between the four different roles in the product development process (project managers, upstream specialists, downstream specialists and IT specialists):

Table 4.16 – Bivariate analysis: the influence of the role played in the product development process on the other research variables

	Project managers (n_1 = 18)	Upstream specialists (n_2 = 13)	Downstream specialists (n_3 = 25)	IT specialists (n_4 = 5)	K-W test
Control variables					
Timing of involv. in the team	5.71	4.77	4.67	5.60	NS
Time spent in the team	5.76	5.77	4.95	4.50	NS
Interactions with OEMs	2.59	2.31	2.43	4.50	NS
Interactions with suppliers	4.29	3.31	3.42	4.50	NS
Interactions with "same tasks"	**5.41**	4.54	5.38	4.75	*
Interactions with "diff. tasks"	**5.18**	3.92	5.08	4.25	**
Product newness	5.29	6.08	5.32	6.00	NS
Manufacturing newness	**5.25**	4.14	5.05	5.80	*
Manager trained & uses CTs	3.46	**4.33**	2.89	5.67	**
Manager understands CTs capa.	4.07	4.71	3.53	5.67	NS
Team context					
Virtuality	4.78	3.88	4.67	5.50	NS
Cultural differences	3.86	3.87	3.92	5.04	NS
Collaboration activities					
Sharing of PI	**5.33**	4.10	4.39	4.33	**
Discussion and agreement	5.38	5.06	4.61	5.19	NS
Assessment of PI	4.82	4.27	3.86	5.22	NS
Collaborative behaviour					
Cooperation planning	4.73	**5.10**	3.93	4.53	**
Cooperation improvement	3.18	3.25	2.50	3.57	NS
Implementation of the CTs					
Tools' usefulness	5.73	4.88	5.63	6.38	NS
Tools' accessibility	4.43	4.36	4.79	5.38	NS
Training	**5.32**	3.71	4.33	5.50	*
Usage of the CTs					
CTs usage score	**57**	39	39	79	**
Proficiency	**4.25**	2.75	3.36	5.20	**
Product development performance					
Process performance	**4.34**	3.30	3.66	5.25	*
Innovativeness	**4.36**	4.04	4.15	6.17	*
Product & manuf. perf.	**4.30**	2.67	3.07	6.08	***

*p<.10, **p<.05, ***p<.001, ****p<.0001; except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or high).

A first general conclusion can be drawn from the results: the persons in charge of the implementation of the CTs ("IT specialists") rated some variables much higher than those actually involved in product development activities (especially CTs usage and performance). We can speculate that they overestimate the usage of the CTS and the benefits from a cooperation increase. However, some interesting conclusions can be drawn from the other results:

(i) Interactions with colleagues: project managers and downstream specialists have more frequent interactions with colleagues having the same task (or a different one) than the upstream specialists. We can conclude that the specificity of their role forces them to have more interactions with their colleagues (e.g. to discuss a topic such as manufacturability where different disciplines are intervening);

(ii) Managers are trained and use the CTs: people involved in downstream activities rated this item much lower (mean = 2.89) than the project managers (mean = 3.46) or the upstream specialists (mean = 4.33). These figures indicate that the managers in plants are less trained and use less the CTs. Additional efforts should be made to enhance the usage of the CTs and the training by the managers or team leaders in the plants;

(iii) Sharing of product information: project managers share much more information (mean = 5.33) than the downstream specialists (mean = 4.39) or the upstream specialists (mean = 4.10). This situation can be explained by their "horizontal role" in the product development process as they either manage a team regrouping upstream and downstream specialists or have a role in upstream and downstream functions. This result is coherent with their greater interaction with colleagues;

(iv) Cooperation planning: the downstream specialists get the lowest score (mean = 3.93) for this variable. It can be concluded that they are less involved in the planning of how the product information is shared in the team. Upstream specialists that practised simultaneous engineering and used IT systems (e.g. PDM) rated this item higher (mean = 5.10). We can either speculate that the information flow is defined by the engineering departments (traditionally, they manage and are responsible for the product information) or that downstream functions are less integrated in the product information flow (see chapter 1);

(v) CTs usage score and proficiency: the project managers used the CTs more (score = 57) than the two other groups (score = 39). This fact can be linked to their need to share more product information with the other team members and their greater need to interact. The project managers are also more proficient (mean = 4.25) than downstream specialists (mean = 3.36) and far more than upstream specialists (mean = 2.75). Some elements can explain why the upstream specialists are less proficient than the two other groups: they received less training than the others (mean = 3.71 vs. 5.32 for the project managers and 4.33 for the downstream specialists) or they did not need to use the CTs as much because they have access to the product information using their 3D CAD and PDM systems;

(vi) Performance: the most significant result refers to the product and manufacturing performance where the project managers get the most benefit from a better cooperation (mean = 4.30), before the downstream specialists (mean = 3.07) and the upstream specialists (mean = 2.67). The same pattern is observed for the two other dimensions of the performance: the project managers have the most benefit. Some explanations can be suggested to interpret these results. Due to their particular position in the product development process the project managers ("horizontal role") directly profit from an increase of cooperation between the different roles in the development team. The downstream specialists also get some benefits from the access to product information and cooperation. However, the upstream specialists are getting less benefits from cooperation or it even has a rather negative effect on performance (mean = 3.30, 4.04 and 2.67) if we assume that the average is 4.00. These results confirm some of the observations made during the field study. First, upstream specialists see less benefits because they already have access to the product information. Second, the use of "simultaneous engineering" with the other product life cycle stakeholders changes the nature of their work: they must take various comments into account, they are interrupted to provide information for other functions, their work is commented, etc.. Hence, some roles do not benefit from an increase of cooperation;

4.2.4.2. Influence of the involvement in the team

Three kinds of involvement in the product development team were identified: high involvement (persons involved early who spent a lot of time), late involvement and the occasional involvement (persons involved early but are not spending a lot of time). The influences on the other variables are presented in the following table:

Table 4.17 – Bivariate analysis: the influence of the involvement in the team on the other research variables

	High involvement ($n_4 = 34$)	Late involvement ($n_3 = 10$)	Occasional involvement ($n_1 + n_2 = 18$)	K-W test
Control variables				
Interactions with OEMs	**2.94**	1.60	2.82	*
Interactions with suppliers	3.94	3.10	4.08	NS
Interactions with "same tasks"	5.24	5.40	4.67	NS
Interactions with "different tasks"	5.00	4.40	4.67	NS
Product newness	5.76	5.00	4.91	NS
Manufacturing newness	5.17	4.89	4.60	NS
Manager trained & uses CTs	3.52	4.29	3.00	NS
Manager understands CTs capa.	4.13	3.00	4.50	NS
Team context				
Virtuality	4.81	4.25	4.29	NS
Cultural differences	3.92	3.87	3.98	NS
Collaboration activities				
Sharing of PI	**5.18**	3.88	3.79	**
Discussion and agreement	5.15	5.55	4.56	NS
Assessment of PI	4.79	3.70	4,33	NS
Collaboration behaviour				
Cooperation planning	4.77	4.22	4.54	NS
Cooperation improvement	2.97	3.32	3.13	NS
Implementation of the CTs				
Tools' usefulness	5.74	4.10	**6.08**	**
Tools' accessibility	4.48	4.63	5.13	NS
Training	4.80	3.95	4.88	NS
Usage of the CTs				
CTs usage score	49	45	53	NS
Proficiency	3.70	3.20	4.08	NS
Product development performance				
Process performance	3.85	3.98	4.31	NS
Innovativeness	3.81	4.89	**5.22**	**
Product & manufacturing perfor.	3.54	3.67	4.07	NS

*p<.10, **p<.05, ***p<.001, ****p<.0001; except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or high).

(i) Tools' usefulness: the team members involved occasionaly found the CTs very useful (mean = 6.08). They only spend a small part of their time working on the projects and we can speculate that the CTs allow them to easily find the appropriate product information or better cooperate with the other team members. The late involved rated the usefulness (4.10) of the CTs lower. Being involved late in the product development process means that less changes are possible (cancelling therefore one of the CTs' strengths – that is the ability to support cooperation and discussions about improvement). In addition, the product information (in the form of 2D drawings) is completed, which was not the case in the early phase (where only 3D models are available). Therefore, the usefulness of the CTs appeared low for the late involved;

(ii) Innovativeness: team members involved occasionally think that a better cooperation improves the level of innovation (mean = 5.22). We can speculate that a better cooperation and sharing of product information allows them to investigate additional issues and propose new alternatives. However, highly involved team members, rated this item much lower (mean = 3.81);

4.2.4.3. Influence of the product and manufacturing newness

The "newness" was split up into three categories: high newness in terms of product and manufacturing, high product and low manufacturing newness and low product newness. The analysis (in the following table) will help us to investigate the influence of the newness on the other variables.

Table 4.18 – Bivariate analysis: the influence of the product and manufacturing newness on the other research variables

	High product & manufacturing newness ($n_4 = 28$)	High product & low manufacturing newness ($n_2 = 21$)	Low product newness ($n_1 + n_3 = 9$)	K-W test
Control variables				
Timing of involv. in the team	5.88	4.76	4.22	NS
Time spent in the team	**5.84**	5.05	4.78	*
Interactions with OEMs	2.48	2.90	2.50	NS
Interactions with suppliers	3.59	3.52	4.56	NS
Interactions with "same tasks"	5.30	4.95	4.89	NS
Interactions with "diff. tasks"	4.96	4.76	4.89	NS
Manager trained & uses CTs	3.47	3.50	3.50	NS
Manager understands CTs capa.	3.94	4.29	3.38	NS
Team context				
Virtuality	4.98	4.00	**5.33**	*
Cultural differences	4.10	3.78	4.31	NS
Collaboration activities				
Sharing of PI	5.03	4.26	4.28	NS
Discussion and agreement	5.06	5.14	4.47	NS
Assessment of PI	4.83	3.87	4.29	NS
Collaborative behaviour				
Cooperation planning	4.78	4,39	4.53	NS
Cooperation improvement	2.89	3.13	2.89	NS
Implementation of the CTs				
Tools' usefulness	5.88	5.25	5.11	NS
Tools' accessibility	4.43	4.96	5.00	NS
Training	4.75	4.08	4.94	NS
Usage of the CTs				
CTs usage score	49	47	52	NS
Proficiency	3.60	3.29	4.50	NS
Product development performance				
Process performance	3.44	3.95	**5.09**	**
Innovativeness	4.16	4,46	4.58	NS
Product & manuf. perfor.	3.83	3.33	3.61	NS

*p<.10, **p<.05, ***p<.001, ****p<.0001, except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or high).

The following differences could be found in the analysis:

(i) Time spent in the team: people involved in highly innovative projects spent more time working on the projects (mean = 5.84). We can speculate that new and innovative projects need more time to be developed and that the turn-over is low in this kind of team;

(ii) Virtuality: the virtuality is relatively high (mean = 5.33) for low product newness. An explanation can be found in the fact that "old products" are often manufactured in lower cost countries or by suppliers which increase the virtuality level;

(iii) Performance: the process performance is lower (mean = 3.44) for highly innovative products and manufacturing than for the two other categories. An increased cooperation may bring a better process performance only for less innovative products. For the other dimensions, no significant differences were found;

As mentioned in the first chapter, the importance of newness (or "innovation") is crucial in the automotive industry. Thus, an additional analysis was made to further investigate this issue. The relative lack of interesting results was perhaps due to the classification proposed with the quadrant in Figure 4.17. Therefore, three new groups were defined using a cluster analysis (see APPENDIX 7). Three groups were identified: moderate product and moderate manufacturing newness (n_1 = 17), high product and high manufacturing newness (n_2 = 12) and high product newness and low manufacturing newness (n_3 = 20). It is to be noticed that the last two groups are very similar to the typology retained initially for the analysis. Based on these groups, a bivariate analysis was performed (see APPENDIX 8). No interesting results about the influence of these new groups on the other research variables could be gained from this additional analysis.

This topic was further investigated by observing the two variables separately. The first analysis deals with the product newness (APPENDIX 9) and the second with the manufacturing newness (APPENDIX 10). The average was used to divide the variables up into two groups. These analyses allowed to gain new insights about the product newness:

(iv) Discussion and agreement: this cooperation activity is more performed when the product has a higher newness level (mean = 5.14 vs. 4.65 for a lower product newness). This result confirms our observation: a great deal of cooperation is needed when the product is new;

The investigation of the manufacturing newness also delivered interesting results:

(v) Interactions with colleagues: they are more numerous when the manufacturing process is new (mean = 5.65 vs. 4.97 for interactions with different tasks and mean = 5.29 vs.4.70 for interactions with the same tasks). Hence, manufacturing newness in some way also leads to a kind of greater cooperation with colleagues;

(vi) Virtuality: when the manufacturing process is new, the virtuality is slightly higher (mean = 5.11 vs. 4.61 for lower manufacturing newness). This pattern is the opposite of the pattern observed for the product newness (where the newness is low when the virtuality is high). Therefore, we can speculate that the development of new manufacturing processes requires the implication of different disciplines (see point (v)) which also increases the level of virtuality;

(vii) Tools' usefulness: when the manufacturing newness is higher, the tools are perceived as more useful (mean = 6.00 vs. 5.25 for lower manufacturing newness). This perceived usefulness demonstrates that the CTs are interesting for team members involved in the development of new manufacturing process. This result is also in line with the points (v) and (vi): frequent interactions and the virtuality make them assess the usefulness higher;

4.2.4.4. Influence of the interactions with business partners (OEMs and suppliers)

Three interaction patterns with business partners were identified: few interactions with the business partners, frequent interactions with the suppliers and frequent interactions with the OEMs. Based on the typology presented in Figure 4.15, a bivariate analysis was performed (see APPENDIX 11). The results were not very instructive: no significant interrelations were found. Thus, like for the influence of the product and manufacturing newness, a cluster analysis was performed to check if the group building was appropriate. The result of this cluster analysis is presented in the following table:

Table 4.19 – Cluster analysis: frequency of the interactions with suppliers and OEMs

	Group 1 $n_1 = 18$	Group 2 $n_2 = 24$	Group 3 $n_3 = 16$	
	Moderate interactions with suppliers & high interactions with OEMs	High interactions with suppliers & low interactions with OEMs	Low interactions with OEMs and suppliers	K-W test
Interactions with suppliers	3.78	**5.08**	1.69	****
Interactions with OEMs	**4.83**	1.79	1.38	****

Measure: Chebyshew, Method: Ward
[1]Based on Likert scales where 1 = very low interactions and 7 = very high interactions

Three groups emerged from the analysis: moderate interactions with suppliers and high interactions with customers; high interactions with suppliers and very low interactions with OEMs; and, very low interactions with business partners. The three groups are very similar to the classification proposed initially (especially Group 2 and Group 3). Based on these new groups a bivariate analysis was performed (see table presented on the next page). This analysis brought more interesting results:

(i) Interactions with "different tasks": team members having frequent interactions with suppliers have more frequent interactions with people having a different task in the product development process (mean = 5.42 vs. 4.56 and 4.13 for the two other categories). We can conclude that the relationship with the suppliers implies to deal with different disciplines (e.g. purchasing, quality, manufacturing, etc.);

Table 4.20 – Bivariate analysis: the influence of the interactions with OEMs and suppliers on the other research variables

	Moderate interactions with suppliers & high interactions with OEMs ($n_1 = 18$)	High interactions with suppliers & low interactions with OEMs ($n_2 = 24$)	Low interactions with OEMs & suppliers ($n_3 = 16$)	K-W test
Control variables				
Timing of involv. in the team	6.00	4.96	4.46	NS
Time spent in the team	5.59	5.61	5.00	NS
Interactions with "same tasks"	5.17	5.29	4.94	NS
Interactions with "diff. tasks"	4.56	**5.42**	4.13	**
Product newness	5.53	5.09	**6.20**	*
Manufacturing newness	4.86	5.14	5.21	NS
Manager trained & uses CTs	3.46	3.43	3.17	NS
Manager understand CTs capa.	4.23	3.71	4.38	NS
Team context				
Virtuality	5.03	**5.19**	3.40	*
Cultural differences	**4.16**	4.13	2.94	**
Collaboration activities				
Sharing of PI	**5.16**	4.59	4.12	*
Discussion and agreement	4.81	5.41	4.54	NS
Assessment of PI	4.49	4.73	3.52	NS
Collaborative behaviour				
Cooperation planning	4.60	4.51	4.15	NS
Cooperation improvement	**3.57**	2.95	2.33	**
Implementation of the CTs				
Tools' usefulness	**6.28**	5.29	5.31	**
Tools' accessibility	4.84	4.52	4.29	NS
Training	4.20	4.86	4.00	NS
Usage of the CTs				
CTs usage score	37	32	23	NS
Proficiency	**4.38**	3.61	2.73	**
Product development performance				
Process performance	**4.39**	4.12	2.90	**
Innovativeness	4.91	4.30	3.67	NS
Product & manufacturing perfor.	**4.25**	3.44	2.22	**

*p<.10, **p<.05, ***p<.001, ****p<.0001, Except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or high).

(ii) Product newness: the product newness is slightly greater for team members having few interactions with business partners (mean = 6.20). An explanation could be that innovative products are mainly developed internally. Team members having frequent interactions with suppliers judge the product newness lower than the others (mean = 5.09). Our argument can be repeated: "old products" are outsourced and suppliers are involved in the development process for less sophisticated parts. Customers are involved for more sophisticated products;

(iii) Virtuality and cultural differences: they are greater when the team members have frequent interactions with suppliers or with customers. Suppliers and customers are located in other regions or countries and have probably different working habits (or cultural differences) which can explain this result;

(iv) Cooperation improvement: the actions taken to improve cooperation are greater with people having frequent interactions with OEMs (mean = 3.57 vs. 2.95 and 2.33). This result emphasises the fact that suppliers are making an effort to improve their relationship with their customers;

(v) Tools' usefulness: team members having frequent interaction with OEMs found the CTs very useful (mean = 6.28). Several explanations can explain this result. First, the "3D culture" is established when dealing with customers (i.e. 3D CAD models are already the base to share product information with them). Hence, the usefulness of CTs is perhaps more clear for these team members (i.e. the opportunities offered by a more appropriate tool). Second, this result can be related to the fact that they are sharing much more product information (mean = 5.16 vs. 4.59 and 4.12 for the two other categories) and need appropriate tools to communicate;

(vi) CTs usage and proficiency: the results are not statistically significant but team members having frequent interaction with OEMs and suppliers use the CTs more often. For the proficiency, team members having frequent interactions with business partners are more proficient. This is especially true for team members having frequent interactions with customers (4.38 vs. 3.61 and 2.73). We can speculate that they used to use 3D CAD modelling software and that the CTs are easy for them to master;

(vii) Product development performance: team members having frequent interactions with business partners get the most benefits from an increase of cooperation. We can speculate on the explanation of these results: cooperation really brings benefits for the team members or respondents having more frequent interactions and therefore practising cooperation are better able to assess the benefits;

To summarise, we can speculate that people having frequent interactions with business partners are working apart, process more product information are keen to use CTs than the other and see more benefits from cooperation. A third analysis was conducted on this topic. Two groups were defined for the two items (interactions' frequency with suppliers and OEMs): lower than the mean and greater than the mean. The bivariate analyses are available in APPENDIX 12 and APPENDIX 13. Some additional results were obtained from these two analyses:

(viii) Managers understand the capabilities of the CTs: this is the case for team members having frequent interactions with customers (mean = 4.39 vs. 3.71). As mentioned earlier, the usage of ICT is frequent when dealing with customers. Therefore, the managers are perhaps more aware of the capabilities of these new tools;

(ix) Assessment of product information: more product information is assessed by people having frequent interactions with suppliers (mean = 4.83 vs. 3.78). This result confirms an observation made during the field study: the internal product information is assessed and the critical parameters are transmitted to the suppliers (e.g. key dimensions or changes) or external product information is assessed by internal experts (e.g. assess the manufacturability or the fit with the other parts);

4.2.4.5. Influence of the interactions with colleagues

Four groups were defined and their influence on the other research variables is presented in the following table:

Table 4.21 – Bivariate analysis: the influence of the interactions with colleagues on the other research variables

	Few interactions with other team members ($n_1 = 11$)	Discipline focused ($n_2 = 14$)	Multidisciplinary ($n_3 = 8$)	Frequent interactions with all team members ($n_4 = 26$)	K-W test
Control variables					
Timing of involv. in the team	5.40	5.00	5.14	5.16	NS
Time spent in the team	5.90	5.23	5.33	5.32	NS
Interactions with OEMs	2.73	2.43	2.71	2.65	NS
Interactions with suppliers	3.91	2.57	3.38	4.31	**
Product newness	5.50	5.62	5.29	5.52	NS
Manufacturing newness	4.50	5.00	5.00	5.24	NS
Manager trained & uses CTs	3.57	3.44	4.83	3.05	NS
Manager understands CTs cap.	4.50	4.40	**5.33**	3.26	**
Team context					
Virtuality	**5.36**	3.50	5.00	4.96	*
Cultural differences	4.09	3.73	4.04	3.75	NS
Collaboration activities					
Sharing of PI	4.60	4.31	4.40	4.83	NS
Discussion and agreement	4.68	4.54	4.54	5.43	NS
Assessment of PI	4.42	4.10	4.67	4.38	NS
Collaborative behaviour					
Cooperation planning	4.70	4.65	4.35	4.30	NS
Cooperation improvement	3.27	3.50	2.73	2.77	NS
Implementation of the CTs					
Tools' usefulness	4.86	5.64	6.25	5.69	NS
Tools' accessibility	4.40	4.85	5.14	4.38	NS
Training	4.32	3.81	5.36	4.59	NS
Usage of the CTs					
CTs usage score	35	30	12	37	NS
Proficiency	3.30	3.93	2.75	3.83	NS
Product development performance					
Process performance	3.70	3.90	4.54	3.79	NS
Innovativeness	3.67	4.53	4.22	4.64	NS
Product & manuf. perf.	3.17	3.96	3.26	3.33	NS

*p<.10, **p<.05, ***p<.001, ****p<.0001, except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or high).

(i) Interactions with suppliers: they are more numerous for team members having "frequent interactions with all team members" (i.e. both with the same discipline and other disciplines). This confirms the fact that the interactions with suppliers are multidisciplinary by nature;

(ii) Manager understands the capabilities of the CTs: this item was rated high by team members belonging to the "multidisciplinary" category (i.e. frequent interactions with people having a different discipline and few with people having the same discipline). We can suppose that the managers of these team members understand the unique characteristics of the tools better;

(iii) Virtuality: the virtuality is globally higher for team members that do not belong to the "discipline focused" category (mean = 3.50 vs. 5.36, 5.00 and 4.96 for the three other categories). Hence, as soon as the multidisciplinarity is increasing, the virtuality increases as well;

4.2.4.6. Influence of the managers' implication

The management implication was measured through two items: the manager is trained and uses the CTs and the manager understands the capabilities of the CTs. Two groups were distinguished: high level (on both dimensions) and low level (on both dimensions). Their influence is presented in the following table:

Table 4.22 – Bivariate analysis: the influence of the management implication on the other research variables

	Low level ($n_1 = 23$)	High level ($n_4 = 11$)	M-W test
Control variables			
Timing of involvement in the team	5.00	5.73	NS
Time spent in the team	5.05	5.70	NS
Interactions with OEMs	2.39	2.80	NS
Interactions with suppliers	4.09	4.00	NS
Interactions with "same tasks"	**5.35**	4.55	**
Interactions with "different tasks"	5.04	4.45	NS
Product newness	5.22	5.75	NS
Manufacturing newness	4.74	5.11	NS
Team context			
Virtuality	4.86	5.36	NS
Cultural differences	3.98	4.30	NS
Collaboration activities			
Sharing of PI	4.85	4.33	NS
Discussion and agreement	5.05	4.98	NS
Assessment of PI	3.98	**5.33**	*
Collaborative behaviour			
Cooperation planning	4.51	4.26	NS
Cooperation improvement	3.19	3.21	NS
Implementation of the CTs			
Tools' usefulness	5.35	**6.00**	*
Tools' accessibility	4.65	4.90	NS
Training	4.33	**5.40**	**
Usage of the CTs			
CTs usage score	31	42	NS
Proficiency	3.86	4.27	NS
Product development performance			
Process performance	3.82	**4.68**	*
Innovativeness	4.62	4.67	NS
Product and manufacturing perfor.	3.63	3.97	NS

*p<.10, **p<.05, ***p<.001, ****p<.0001, except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or high).

Two main results can be drawn from this analysis:

(i) Tools' usefulness: the CTs were perceived as slightly more useful when the managers were more implicated (mean = 6.00 vs. 5.35). We can speculate that the implication has a positive impact on the perceived usefulness;

(ii) Training of the respondents: respondents having managers that are more implied are more trained than the others (mean = 5.33 and 3.98). This result can be explained by the fact that the implementation of the CTs was well performed (i.e. the team members and their managers participated in the training sessions);

Like for some of the preceding analyses, an additional bivariate analysis was performed using an other classification (see APPENDIX 14). An additional result on the usage of the CTs and the proficiency was obtained:

(iii) CTs' usage and proficiency: respondents having a manager who was trained and used the CTs were themselves using more frequently the CTs. Hence, they achieved a CT usage score of 59. In addition, they were also more proficient;

To summarise, the management implication influences or is related with the variables dealing with the quality of the implementation (tools' usefulness and training) and the usage of the CTs.

4.2.4.7. Influence of CTs usage

Until now, the bivariate analyses focused on the control variables. The following analyses will present the influence of some moderating and independent variables on the other research variables. First, the influence of the CTs' usage (Q1, Q2, Q3 and Q4) will be presented in the following table:

Table 4.23 – Bivariate analysis: the influence of the CTs usage level on the other research variables

	Q1 ($n_1 = 14$)	Q2 ($n_2 = 14$)	Q3 ($n_3 = 14$)	Q4 ($n_4 = 14$)	K-W test
Control variables					
Timing of involv. in the team	4.38	4.69	5.85	5.14	NS
Time spent in the team	4.82	5.85	5.62	5.07	NS
Interactions with OEMs	2.38	1.57	**3.31**	3.08	**
Interactions with suppliers	3.23	3.57	3.43	4.62	NS
Interactions with "same tasks"	5.31	5.00	4.86	5.46	NS
Interactions with "diff. tasks"	5.00	4.64	4.79	4.69	NS
Product newness	5.64	6.00	5.43	4.86	NS
Manufacturing newness	5.33	4.77	4.77	5.33	NS
Manager trained & uses CTs	2.25	3.29	3.54	**4.36**	*
Manager understands CTs capa.	4.56	4.00	3.85	3.91	NS
Team context					
Virtuality	3.07	4.82	5.00	**5.36**	**
Cultural differences	3.30	3.51	4.15	**4.49**	**
Collaboration activities					
Sharing of PI	4.27	4.19	4.92	4.57	NS
Discussion and agreement	5.15	4.67	4.73	5.21	NS
Assessment of PI	3.18	4.74	**4.95**	4.42	*
Collaborative behaviour					
Cooperation planning	4.21	4.17	4.95	4.62	NS
Cooperation improvement	3.06	2.25	3.13	**3.75**	**
Implementation of the CTs					
Tools' usefulness	5.86	5.07	5.79	5.73	NS
Tools' accessibility	4.69	4.21	4.39	5.15	NS
Training	3.86	4.08	4.79	5.38	NS
Usage of the CTs					
Proficiency	2.67	2.69	3.93	**5.43**	****
Product development performance					
Process performance	3.20	3.19	4.04	**4.97**	**
Innovativeness	4.03	3.37	4.35	**5.53**	**
Product & manuf. perf.	2.57	2.56	3.07	**4.61**	**

*p<.10, **p<.05, ***p<.001, ****p<.0001, except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or high).

Some of the significant relationships in the preceding table were already presented in the bivariate analyses on the control variables. Namely, the interactions with OEMs and the fact that the manager uses and is trained on the CTs (related to a higher usage of the CTs). However, some new relationships were discovered:

(i) Virtuality and cultural differences: the greater the usage of the CTs, the greater the virtuality (mean = 5.36 for Q4, 5.00 for Q3, 4.82 for Q3 vs. 3.07 for Q1) and the cultural differences (mean = 4.49 for Q4 and 4.15 for Q3 vs. 3.51 for Q2 and 3.30 for Q1). This result confirms the importance of the CTs for team members working in a high virtual context and with a high cultural differences. Hence, we can conclude that CTs are appropriate for the current and future challenges in product development teams. An additional interpretation can be made: the cultural difference does not limit the usage of the CTs (can even promote it because it is easier to perform a technical discussion with the help of 3D models);

(ii) Cooperation improvement: this result is difficult to interpret (mean = 3.75 for Q4, 3.13 for Q3, 2.25 for Q2 and 3.06 for Q1), however this variable is slightly higher rated when the CTs' usage is high. We can assume that actions taken to improve cooperation can facilitate the adoption of the CTs;

(iii) Product development performance: the greater the usage of the CTs, the greater the benefits perceived from an increase of cooperation and product information sharing. This is an encouraging result! The greatest benefits lie in the innovativeness (mean = 5.53 for Q4), before the process performance (mean = 4.97 for Q4) and product and manufacturing performance (mean = 4.61 for Q4);

Therefore, the usage of the CTs is related with the variables of the team context, the collaborative behaviour and influence the product development performance. Some of the results can be difficult to interpret and we will get back on them in a part dedicated to additional analyses.

4.2.4.8. Influence of the proficiency level

The behaviour of the different groups will be presented in the following table:

Table 4.24 – Bivariate analysis: the influence of the level of proficiency on the other research variables

	Low proficiency ($n_1 = 16$)	Moderate proficiency ($n_2 = 33$)	High proficiency ($n_3 = 7$)	K-W test
Control variables				
Timing of involvement in the team	4.79	5.13	5.57	NS
Time spent in the team	6.00	4.90	5.71	NS
Interactions with OEMs	2.25	2.45	3.43	NS
Interactions with suppliers	2.81	**4.00**	**4.00**	*
Interactions with “same tasks”	4.63	5.13	**6.00**	**
Interactions with “different tasks”	4.81	4.75	4.71	NS
Product newness	5.81	5.48	4.86	NS
Manufacturing newness	5.00	5.11	5.00	NS
Manager trained & uses CTs	3.25	3.58	3.83	NS
Manager understands CTs capa.	4.78	3.93	4.00	NS
Team context				
Virtuality	4.03	4.77	5.50	NS
Cultural differences	3.61	4.02	4.19	NS
Collaboration activities				
Sharing of PI	4.59	4.48	4.87	NS
Discussion and agreement	4.86	5.03	4.79	NS
Assessment of PI	4.45	4.14	5.17	NS
Collaborative behaviour				
Cooperation planning	4.55	4.39	4.67	NS
Cooperation improvement	2.46	3.11	**3.67**	*
Implementation of the CTs				
Tools’ usefulness	5.34	5.67	6.14	NS
Tools’ accessibility	4.27	4.48	**5.29**	*
Training	3.96	4.52	5.42	NS
Usage of the CTs				
CTs usage score	19	35	**62**	**
Product development performance				
Process performance	3.01	3.98	**5.29**	**
Innovativeness	3.79	4.65	5.39	NS
Product & manuf. perfor.	2.22	3.60	**4.79**	**

*p<.10, **p<.05, ***p<.001, ****p<.0001, except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or high).

Several results are already known from previous bivariate analyses (the influence of the interactions with business partners on the proficiency and of the interactions with team members having the same task). However, the level of proficiency has an influence on some other research variables:

(i) Cooperation improvement: like for the influence of the CTs' usage, the most proficient team members were those having the highest score for cooperation improvement (mean = 3.67 for high proficiency vs. 2.46 for low proficiency);

(ii) Accessibility of the CTs: the respondents that were using the CTs more often (moderate and high) rated the accessibility higher. Even if statistically not significant, the other components of this dimension (namely: "tools' usefulness" and "training") are also higher for the most proficient team members. We can speculate that this dimension positively influences the proficiency of the team members;

(iii) Performance: the most proficient users achieved the best score on two variables of the product development performance dimension (process performance and product and manufacturing performance). This confirms our impression that the usage of CTs and the proficiency positively influence the product development process

An additional bivariate analysis was performed using the mean to split the sample (see APPENDIX 15). This analysis confirmed the importance of some relationships found in the analyses on the CTs usage and on the proficiency: the role of cooperation improvement, the role of the tools' accessibility and the impact on the product development performance.

4.2.4.9. Influence of the virtuality

First, a bivariate analysis was performed using the three groups identified in the part dedicated to the group building. The results are presented in the following table:

Table 4.25 – Bivariate analysis: the influence of the virtuality on the other research variables

	High virtuality ($n_4 = 22$)	Moderate virtuality ($n_2 = 20$)	Low virtuality ($n_1 = 17$)	K-W test
Control variables				
Timing of involvement in the team	5.60	5.00	4.50	NS
Time spent in the team	5.84	5.25	5.00	NS
Interactions with OEMs	3.00	2.50	2.20	NS
Interactions with suppliers	3.77	**4.75**	2.33	****
Interactions with "same tasks"	4.82	5.25	5.53	NS
Interactions with "different tasks"	4.68	4.90	4.80	NS
Product newness	5.58	4.80	**6.27**	**
Manufacturing newness	5.43	4.80	4.77	NS
Manager trained & uses CTs	**4.50**	3.22	2.25	**
Manager understands CTs capa.	4.40	3.50	4.56	NS
Team context				
Cultural differences	**4.45**	4.11	3.24	**
Collaboration activities				
Sharing of PI	4.74	4.71	4.21	NS
Discussion and agreement	4.95	4.74	5.33	NS
Assessment of PI	4.38	4.75	3.69	NS
Collaborative behaviour				
Cooperation planning	4.31	4.50	4.72	NS
Cooperation improvement	2.62	3.25	2.93	NS
Implementation of the CTs				
Tools' usefulness	5.79	5.55	5.23	NS
Tools' accessibility	4.75	4.79	4.27	NS
Training	4.35	4.91	4.19	NS
Usage of the CTs				
CTs usage score	52	52	37	NS
Proficiency	3.80	3.90	3.20	NS
Product development performance				
Process performance	**4.33**	4.24	2.62	**
Innovativeness	4.56	4.60	3.76	NS
Product & manuf. perfor.	3.68	4.02	1.75	NS

*p<.10, **p<.05, ***p<.001, ****p<.0001, except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or high).

The analysis confirms some of the results found previously: higher virtuality when frequent interactions with business partners, the virtuality is low when the product newness is low and the virtuality increases where there are greater cultural differences. However, the virtuality influences some additional research variables:

(i) Managers trained and use the CTs: in a highly virtual context, the managers are trained and make a more frequent use of the CTs (4.50 for high virtuality vs. 3.22 for moderate virtuality and 2.25 for low virtuality). This result confirms some of our observations: some managers are relying on the CTs to virtually perform meetings and discussions with colleagues;

(ii) Product development performance: despite a higher virtuality, the team members found that the increased sharing of the product information and cooperation bring benefits for the process performance (mean = 4.33 for high and 4.24 for moderate vs. 2.62 for low virtuality);

To refine the results, a cluster analysis was performed on the two items of this dimension (geographical dispersion and difficulty to reach colleagues). The result of this cluster analysis is presented in APPENDIX 17 and the result of the bivariate analysis in APPENDIX 18. This analysis confirmed the preceding results but also allows to clarify two issues:

(iii) Cooperation planning: lower for high virtuality (mean = 3.77) than for moderate (4.47) and low virtuality (5.29). This result is difficult to interpret. However, we can speculate that for team members working in a highly virtual environment cooperation planning is not practised;

(iv) Product development performance: significant for process performance and for product and manufacturing performance. However, this analysis moderate the preceding result because the higher benefits are for moderate virtuality (mean = 4.19 vs. 3.83 for the high virtuality in the first analysis);

Third, a bivariate analysis was performed with the geographical dispersion (presented in APPENDIX 19) and for the difficulty to reach colleagues (presented in APPENDIX 20). The following comments could be added to the preceding points:

(v) CTs usage score: the score was higher for people being geographically dispersed (score = 55 vs. 36). This result suggests that dispersion incites people to make a more frequent usage of the CTs;

4.2.4.10. Summary of the bivariate analyses

The preceding bivariate analyses allowed us to gain a better understanding of the behaviour of the different groups or profiles identified (the groups were mainly based on the control variables). In this summary, the link or relationships between the different dimensions of the conceptual model and the groups will be presented. For example, the following table shows the groups working in a highly virtual environment and where cultural differences are high:

Table 4.26 – Bivariate analysis: summary of the factors influencing the team context

Team context dimension		**Relationships with the groups**
Virtuality	Cultural differences	Comments
↗		There is a higher virtuality when the team member assesses the **manufacturing newness high**. However, this trend is contrary for the product newness: high virtuality for **low product newness**
↗		There is a higher virtuality and cultural differences when the team member has **frequent interactions with business partners** (OEMs & suppliers)
↗		The **cooperation planning actions are lower** when the virtuality is high
↗	↗	The team member is making a **greater usage of the CTs** when high virtuality or cultural differences exists

Virtuality is first related to some control variables. The newness and the interactions with business partners are related with the virtuality. Second, it is interesting to note that cooperation planning is not practised in a high virtual environment. Finally, a link exists between the team context and the adoption of the cooperation tools.

The second table (on the next page) presents the groups related to the collaboration activity dimension. The sharing of product information is made by team members processing a lot of product information (e.g. project managers, frequent interactions with OEMs). Discussion & agreement (i.e. the second activity of the cooperation loop) is performed in the case of innovative products and by team members having frequent interactions with colleagues having a different task. The main results are presented in the following table:

Table 4.27 – Bivariate analysis: summary of the factors influencing the collaboration activities

Collaboration activities			Relationships with the groups
Sharing of PI	Discussion & agreement	Assessment of PI	Comments
➚			The team member having the role of the **project manager** in the product development process is sharing more product information
➚			**Highly involved** team member is sharing more product information than the late involved and the team members occasionally involved
➚			Team member having **frequent interactions with OEMs** are sharing more product information
	➚		Team member involved in the development of **innovative products** perform more discussion & agreement activities
	➚		Team member having frequent **interactions with colleagues having a different task** perform more discussion & agreement activities
		➚	Team member having **frequent interactions with suppliers** are assessing more product information
		➚	Team member assessing product information are making a **more frequent usage of CTs**

The third table summarises the groups that are involved in the collaborative behaviour:

Table 4.28 – Bivariate analysis: summary of the factors influencing the collaborative behaviour

Collaborative behaviour		**Relationships with the groups**
Cooperation planning	Cooperation improvement	Comments
↗		The team member has the role of an **upstream specialist** in the product development process
↗		The process developed has a **low manufacturing newness** level
↗		The team member is working in a **low virtual environment**
	↗	The team member has **frequent interactions with OEMs**
	↗	The team member is making a **more frequent usage of the CTs and is more proficient**
↗	↗	The team member has a **low level of interaction with colleagues having different tasks**

Cooperation planning (i.e. activities performed in the team to plan the flow of information and define processes) is done by team members having particular characteristics (e.g. upstream specialists or low virtual environment). Hence, cooperation planning is only performed by people not having the typical profile of the current environment.

The groups related to a higher usage of the CTs and the proficiency are summarised in the following table:

Table 4.29 – Bivariate analysis: summary of the factors influencing the adoption of the cooperation tools

Cooperation tools		**Relationships with the groups**
Proficiency	CTs usage	Comments
↗		Highly proficient team members have **high interactions with OEMs.**
↗		The team member having **frequent interactions with other team members having the same task** are proficient
↗		The team member that **received a training** are more proficient than the others
↗	↗	When the team member **has a manager who is trained and uses the CTs,** he is more proficient and makes a greater usage of the CTs
↗	↗	When the team member is involved in the development of a **low product newness** he is more proficient and makes a greater usage of the CTs
↗	↗	The team member has the role of **project manager**
↗	↗	The team member is **working in a virtual environment** and the **cultural differences are high**
↗	↗	The team member is working in a team where **initiatives are taken to improve cooperation**
↗	↗	The team member assesses the **CTs accessible**

Some of the control variables are related to a higher usage (high need to process product information). The team context is also important: virtuality enhances the usage of the CTs. Even cultural differences are related to a higher usage of the CTs (this also means that cultural differences do not prevent team members from using CTs). Among the other independent variables, the cooperation improvement seems linked to a better adoption. Finally, two other elements seem to facilitate the adoption: accessibility of the tools and the training.

Finally, the last part of this summary focuses on the product development performance. The main factors related to the three variables of this dimension are listed in the following table:

Table 4.30 – Bivariate analysis: summary of the factors influencing the product development performance

Product development performance			Relationships with the groups
Process perf.	Innovativeness	Product & manuf. perf.	Comments
↗			The level of management implication is higher
↗			The product developed has a low newness level
	↗		The team member is occasionally involved in the product development process
	↗		The team member has frequent interactions with other team members having the same task
↗	↗		The team member is working in a high virtual environment and the cultural differences are high
↗		↗	The team member has high interaction with suppliers and high interaction with OEMs
↗	↗	↗	The team member having the role of project manager in the team assesses the performance better (on the three variables)
↗	↗	↗	Team members are using the CTs and are proficient

This table allows us to define a profile of team members profiting from cooperation: they are working in an environment that promotes the usage of CTs (e.g. management implication) for particular project characteristics (lower product newness, virtuality, frequent interactions) and of the role and art of involvement in the product development team (project manager, occasional involvement).

4.2.5. Correlation analyses between the independent variables

This small part deals exclusively with the correlation between the independent variables. The correlation between independent and dependent variables (or research proposition testing) will be presented in the next part.

The aim of a correlation analysis is to test if the variables are going in the same direction (i.e. when the first variable is growing, the second is also growing). The Pearson formula was used to calculate the correlation coefficient. This coefficient has a value between -1 and +1. A correlation does not prove the causation of one variable on the other.

The correlation coefficients between the different independent variables are presented in the following table:

Table 4.31 – Correlation coefficients between the independent variables

Virtuality	Virtual.								
Cultural differences	**.662********	Cultural diff.							
Sharing of PI	.164	.077	Sharing of PI						
Discussion and agreement	-.046	-.196	**.393****	Dis. & agree.					
Assessment of PI	.062	.107	.197	**.301****	Ass. of PI				
Cooperation planning	-.183	.009	.093	**.376****	**.551********	Coop. plan.			
Cooperation improvement	-.070	**.354****	.225	.143	.147	**.323****	Coop. improv.		
Tools' usefulness	.162	.000	.156	-.200	.048	-.035	.070	Tools usef.	
Tools' accessibility	.203	.244	-.157	**-.292***	-.259	-.176	.178	-.014	Tools acc.
Training	.064	.266*	.259*	.135	.356**	.234	**.343****	.252*	**.313****

Pearson correlation coefficients
Level of significance one-tailed: * p<.10, ** p<.05, *** p<.001, **** p<.0001

The main results (positive or negative correlation in bold in the table) will be discussed now:

(i) Correlation between virtuality and cultural differences (.662****): team members working in a virtual environment are also working in an environment where cultural differences are high. Virtuality is highly related to cultural differences. For example, we learned from the bivariate analyses that virtuality is related to more frequent interactions with business partners;

(ii) Correlation between cultural differences and cooperation improvement (.354**): cooperation improvement are the actions or measures taken in the product development team to enhance cooperation. This item is correlated with the cultural differences. This can be a sign that cultural differences are recognised and that specific actions are taken to mitigate the effect of them;

(iii) Correlation between the elements of the collaboration activities dimension: discussion & agreement is correlated with sharing of product information (.393**) and assessment of product information (.301**). These results suggest that there is a logical link between these collaboration activities;

(iv) Correlation between discussion and agreement and cooperation planning (.376**): discussion and agreement are activities performed by team members when cooperating with other team members. These activities require the processing of product information (e.g. collect requirement or preparation of alternatives). Hence, this result can be explained by the fact that the team members performing the collaboration activities also need to design how the product information will be shared between the team members;

(v) Correlation between discussion and agreement and tools' accessibility (–.292*): team members performing the activities that were just described above find the tools difficult to access (i.e. not user friendly or difficulty to get support).

Several reasons can be suggested to explain this result: the tools are perhaps difficult to use for team members cooperating a lot? Or they do not bring the appropriate functionalities to cooperate;

(vi) Correlation between assessment of product information and cooperation planning (.551****): this result shows that team members assessing product information probably define how product information must be shared between the team members. The same explanation as the point (iv) can be proposes to justify this result;

(vii) Correlation between cooperation planning and cooperation improvement (.323**): the two variables of the collaborative behaviour dimension are correlated. Hence, actions taken to plan cooperation (e.g. how to share product information and define cooperation processes) are linked with the actions aiming at improving cooperation;

(viii) Correlation between cooperation improvement and training (.343**): such a result can be interpreted by the fact that some team members are working in "well organised teams" where an effort is made to train people and improve cooperation;

(ix) Correlation between tools' accessibility and training: we can speculate that the training facilitates the accessibility of the tools;

To summarise, some of the independent variables are highly correlated (virtuality with cultural differences and assessment of product information with cooperation planning) and will be thus mutually excluded for the multivariate analyses. These analyses allowed us to explore some new and interesting links between the research variables ((ii), (vi) and (viii)). The next part will also present correlation analyses but will focus on the relationships between independent and dependent variables.

4.2.6. Research propositions testing

Now, the objective is to test the research propositions defined in the third chapter. First, the conceptual model and the research propositions will be summarised. Then, the research propositions will be tested using different statistical methods.

4.2.6.1. Presentation of the conceptual model and of the statistical methods

The following figure reminds of the research propositions presented in the third chapter. The two main elements of this model are: the influence of independent variables on the product development performance (P1, P2, P3) and the impact on the usage of CTs (P4, P5). Afterwards, the moderating effect between independent variables and variables will be presented.

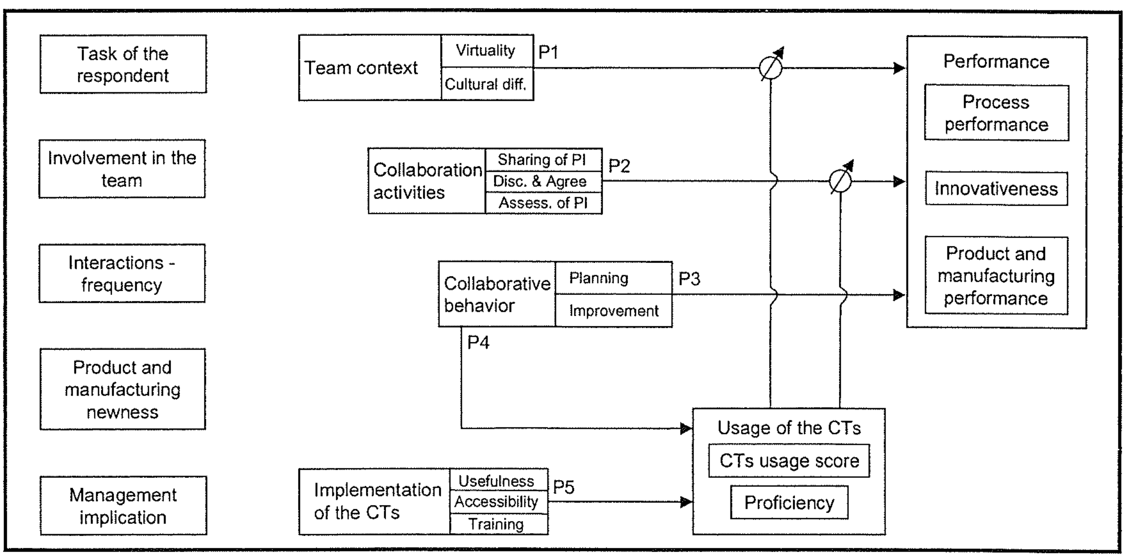


Figure 4.23 – Research propositions

Two statistical methods will be used to test these propositions. First, the correlation analyses will be used to check the direct effect between two variables. Second, linear regressions will be used to determine the factors responsible for the variance of an input variable. The main difference between the regressions analyses and the correlation is the demonstration of the causality of one or several phenomena on another.

A regression works as follows:

(i) An equation is proposed where Y is the dependant variable and X the independent variable (or input). The following figure shows a simple example:

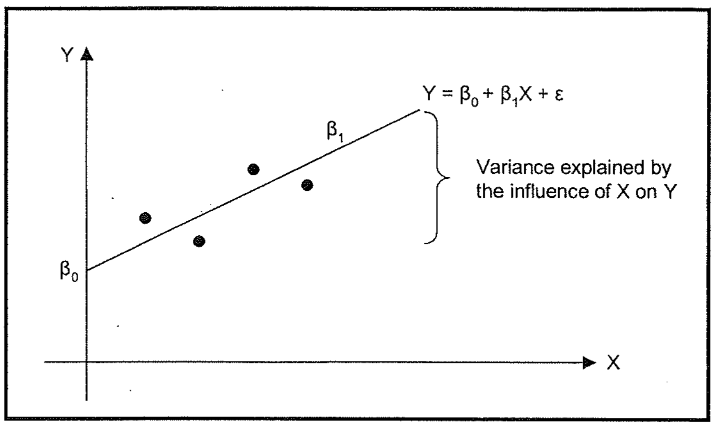


Figure 4.24 – Principles of a linear regression

(ii) The analyses deliver three results: (i) the percentage of variance – or the "Adjusted R^2" – explained by the input variables, (ii) the direction of the influence (positive or negative) which will be noted "β" in the analyses and (iii) the level of signification of the regression. The analyses will be of type "enter stepwise" where the elements are entered one after the other.

Some rules must be respected when making regressions:

(i) <u>Low collinearity:</u> the correlation between the independent variables must be low. Hence, some independent variables will be excluded from the linear regressions (e.g. virtuality and cultural differences are highly correlated (.662****): they will not be entered together in a regression analysis). The correlation coefficients are presented in (APPENDIX 21);

(ii) Normality of the variables: the variables must be normal (measured by the Kurtosis or Sknewness coefficients). The value of these coefficients (see

Appendix 22) were correct;

(iii) Appropriate number of respondents: the following ratio must be respected: number of respondents = 7 x number of dependent and independent variables in the regression model;

A variant of linear regression "moderated regression" will also be used to assess the moderating effect of the CTs usage between the independent and dependent variables. The proposed equation is different: $Y = \beta_0 + \beta_1 X + \beta_2 MOD + \beta_3 XMOD + \varepsilon$. The interaction term β3 provides an indication of the presence or absence of an interaction effect of MOD between X and Y. Hence, it is possible to compare the impact of X on Y for different levels of MOD. For example, we will assess the moderating influence of the CTs usage between the independent and dependent variables. In other words, the effectivity (when > 0) and or ineffectivity (when < 0) of the interaction term will be known. Such analyses were conducted but delivered not interesting and significant results (for the proposals P1.3 and P2.4). The limited size of the sample can explain this phenomenon.

4.2.6.2. Relationships between the independent variables and the product development performance

A small reminder: to define the product development performance, the respondents were asked to assess the impact of a better cooperation on this dimension.

a) Relationships between the team context and the product development performance

The initial thought was that the current team environment had a negative impact on the product development performance. For example, virtuality should lead to a lower process performance (measuring through delays and costs). The following table presents the correlation coefficients between the two variables of the team context dimension (virtuality and cultural differences) and the three variables of the performance dimension:

Table 4.32 – Correlation coefficients: influence of the team context on the performance

	Process performance	Innovativeness	Product & manufacturing performance
Virtuality	.452**	.329**	.285
Cultural differences	.428**	.282*	.429**

Pearson correlation coefficient
Level of significance one-tailed: * p<.10, ** p<.05, *** p<.001, **** p<.0001

P1.1 – Virtuality has a negative impact on the performance:

This proposal is not supported. Process performance and innovativeness are correlated with the virtuality. Thus, these results strengthen the need to adopt virtual teams as the performance is not affected (except product and manufacturing performance, positive but not significant). Hence, virtuality allows a better access to resources and competencies in the team.

P1.2 – Cultural differences have a negative impact on the performance:

This proposal is not supported as the cultural differences are positively correlated with the three variables of the performance dimension (especially process performance and product and manufacturing performance). The cultural differences defined as the "variety" in the team (mother tongue, professional background, etc.). The same explanation can be suggested: the diversity improves the performance.

To summarise, these results tend to support the advocates of virtual teams. However, additional analyses are required to understand in which circumstances the team members have a greater benefit of cooperation. Additional analyses will be performed to see if other variables can also help to understand this situation. Indeed, other research variables may also influence the performance or mitigate the effect of the virtuality and of the cultural differences.

b) Relationships between the collaboration activities and the product development performance

During the field study, a cooperation loop was defined whose three main components are: sharing of product information, discussion and agreement and assessment of product information. It was suggested that these three elements were positively influencing the product development process.

The following table presents the correlation coefficients between the variables:

Table 4.33 – Correlation coefficients: influence of the collaboration activities on the performance

	Process performance	Innovativeness	Product & manufacturing performance
Sharing of product information	–.114	–.055	–.060
Discussion and agreement	–.012	.101	–.179
Assessment of product information	.004	–.175	.102

Pearson correlation coefficient
Level of significance one-tailed: * p<.10, ** p<.05, *** p<.001, **** p<.0001

The three proposals are not verified. P2.1 (Sharing of PI has a positive impact on the performance), P2.2 (Discussion and agreement has a positive impact on the performance) and P2.3 (PI analysis has a positive impact on the performance). The activities performed during the product development process are not related to the performance. Additional analyses will have to be performed to assess the role of these three activities on the other variables (e.g. CTs usage).

c) Relationships between the collaborative behaviour and the product development performance

The collaborative behaviour (or the actions taken to plan and improve cooperation) should have a positive impact on the product development performance. As to product development stakeholders working in a team where such actions are taken, they should assess the product development performance better. The following table (on the next page) presents the correlation coefficient between the two variables of the collaborative behaviour dimension and the three variables of the performance dimensions:

Table 4.34 – Correlation coefficients: influence of the collaborative behaviour on the performance

	Process performance	Innovativeness	Product & manufacturing performance
Cooperation planning	–.007	.026	–.199
Cooperation improvement	.254	.284*	.631**

Pearson correlation coefficient
Level of significance one-tailed: * p<.10, ** p<.05, *** p<.001, **** p<.0001

P3.1 – Cooperation planning will have a positive influence on the performance:

This proposal is not verified. The planning of the information flow and the definition of common processes between the team members have no impact on the product development performance. The results of the bivariate analyses showed us the profiles of the team members performing cooperation planning activities: upstream and low virtuality. In fact, it is also the team members that were profiting from a cooperation increase. Hence, cooperation is not performed by team members working in a virtual environment and do not influence the performance.

P3.2 – Cooperation improvement will have a positive influence on the performance:

This proposal is partially supported. The actions taken to improve cooperation have a positive impact on the innovativeness and much more on the product and manufacturing performance (the impact on process performance is positive but not significant). Cooperation improvement seems to be an essential element to explain the product development performance.

d) Miscellaneous effects

Finally, the correlation analyses reveal an interesting additional result: the usage of CTs is highly correlated with the product development performance. The results are presented in the following table:

Table 4.35 – Correlation coefficients: influence of the CTs usage on the performance

	Process performance	Innovativeness	Product & manufac-turing performance
CTs usage score	.659****	.556**	.729****
Proficiency	.565****	.366**	.701****

Pearson correlation coefficient
Level of significance one-tailed: * p<.10, ** p<.05, *** p<.001, **** p<.0001

Hence, the usage of CTs contributes to the product development performance (especially the process and product and manufacturing performance). A point has to be clarified: do respondents assesse the general benefits of cooperation? Or do they assesse the benefits of the CTs in particular?

4.2.6.3. Relationships between the independent variables and the usage of the cooperation tools

This second part of the correlation analysis is dedicated to the link between some independent variables and the usage of the cooperation tools.

a) Relationships between the collaborative behaviour and the usage of the CTs

The collaborative behaviour should have a positive effect on the adoption of the CTs. The correlation between the different variables is presented in the following table:

Table 4.36 – Correlation coefficients: influence of the collaborative behaviour on the CTs usage

	CTs usage score	Proficiency
Cooperation planning	.083	.018
Cooperation improvement	.576****	.370**

Pearson correlation coefficient
Level of significance one-tailed: * p<.10, ** p<.05, *** p<.001, **** p<.0001

<u>P4.1 – Cooperation planning will have a positive influence on the adoption of CTs:</u>

This proposal is not verified. The definition of the information flow and the definition of common processes do not promote the adoption of the CTs. Once again, we can propose the same explanation as for the correlation between cooperation planning and the performance: people doing cooperation planning are those using the least the CTs (i.e. upstream specialists and team members not working in a virtual environment).

<u>P4.2 – Cooperation improvement will have a positive influence on the adoption of CTs:</u>

This proposal is verified. Team members working in a context where measures are taken to improve cooperation are keen to use the CTs. These results reiterate the importance of this variable.

b) Relationships between the quality of the implementation and the usage of the CTs

Several variables were proposed to explain the adoption of the CTs: tools' usefulness, tools' accessibility and training. The correlation between these variables and the CTs usage (as well as proficiency) is presented in the following table:

Table 4.37 – Correlation coefficients: influence of the implementation of the CTs on the CTs usage

	CTs usage score	Proficiency
Tools' usefulness	.188	.213
Tools' accessibility	.344*	.341**
Training	.436**	.356**

Pearson correlation coefficient
Level of significance one-tailed: * p<.10, ** p<.05, *** p<.001, **** p<.0001

P5.1 – The usefulness of the CTs will have a positive influence on the usage of CTs:

This proposal is not verified (the results are positive but not significant). The usefulness of the CTs has no impact on the adoption and the proficiency. The following interpretation can be proposed: the respondents assess the tool useful but it does not explain the usage. Other variables are better explaining the adoption of CTs.

P5.2 – The accessibility of the CTs will have positive influence on the usage of CTs:

This proposal is verified. The accessibility of the CTs has a positive impact on the adoption of the CTs and the proficiency. Hence, it confirms the accessibility (defined as user friendliness and the support provided) as an important element to consider when implementing a new software.

P5.3 – An appropriate training will have a positive influence on the usage of CTs:

This proposal is verified. The training on the CTs has a positive impact on their adoption and the proficiency. These results can be linked to the preceding results: training is the second element to consider when implementing a new system.

c) Miscellaneous relationships

The bivariate analyses suggested a link between the team context and the usage of the CTs. This relationship was further investigated and the correlation results are presented in the following table:

Table 4.38 – Correlation coefficients: influence of the team context on the CTs usage

	CTs usage score	Proficiency
Virtuality	.413**	.479**
Cultural differences	.218*	.248*

Pearson correlation coefficient
Level of significance one-tailed: * p<.10, ** p<.05, *** p<.001, **** p<.0001

The virtuality and the cultural difference have a positive influence on the adoption of the CTs. Hence, team members working in a virtual context are keen to use the CTs. Where cultural differences exists, the usage of CTs is not limited.

4.2.6.4. Summary of the correlation analyses

The following table summarises the main research proposals:

Table 4.39 – Research proposal testing: summary of the results

Propositions		**Results**
P1	P1.1 – virtuality has a negative impact on the performance	Not supported
	P1.2 – cultural differences have a negative impact on the performance	Not supported
P2	P2.1 – sharing of product information has a positive impact on the performance	Not supported
	P2.2 – discussion and agreement has a positive impact on the performance	Not supported
	P2.1 – assessment of product information has a positive impact on the performance	Not supported
P3	P3.1 – cooperation planning has a positive impact on the performance	Not supported
	P3.2 – cooperation improvement has a positive impact on the performance	Partially supported
P4	P4.1 – cooperation planning has a positive impact on the usage of CTs	Not supported
	P4.2 – cooperation improvement has a positive impact on the usage of CTs	Supported
P5	P5.1 – tools' usefulness has a positive impact on the usage of CTs	Not supported
	P5.2 – tools' accessibility has a positive impact on the usage of CTs	Supported
	P5.3 – training has a positive impact on the usage of CTs	Supported

A lot of research propositions made in the third chapter are not supported. Several factors may explain this situation:

(i) <u>Team context:</u> the debate on the advantages and drawbacks of virtual teams is not closed. On the one hand it means the access to new competencies but, on the other hand, could be related to a lower performance (see discussions in the second chapter on this topic). Our results show that the benefits exceed the drawbacks. An additional analysis will be carried out to better understand this situation;

(ii) Collaboration activities: these three activities were defined in the field study (and confirmed by other studies). However, these activities are not related to the performance. Further investigations will be performed to understand if these variables have an impact on other dependent variables (e.g. CTs usage);

(iii) Collaborative behaviour: cooperation planning does not play the expected role. However, cooperation improvement plays an essential role for the performance and the usage of the cooperation tools;

(iv) Implementation of the CTs: the tools' accessibility and the training are two other constituents explaining the adoption of the CTs;

(v) Concluding remarks: the usage of the CTs is highly correlated to performance and the team context influences the usage of the cooperation tools;

The next part will be dedicated to the regression analyses. It helps us to better understand the explaining role of the independent variables on the dependent variables.

4.2.7. Multivariate analyses

Several linear regressions were performed. The first part is dedicated to the investigation of the influence of the research variables on the adoption of the CTs. The second part deals with the elements influencing the product development performance.

A predefined procedure was used to perform the multivariate analyses. The following figure shows how the multivariate analyses were performed on the product development performance:

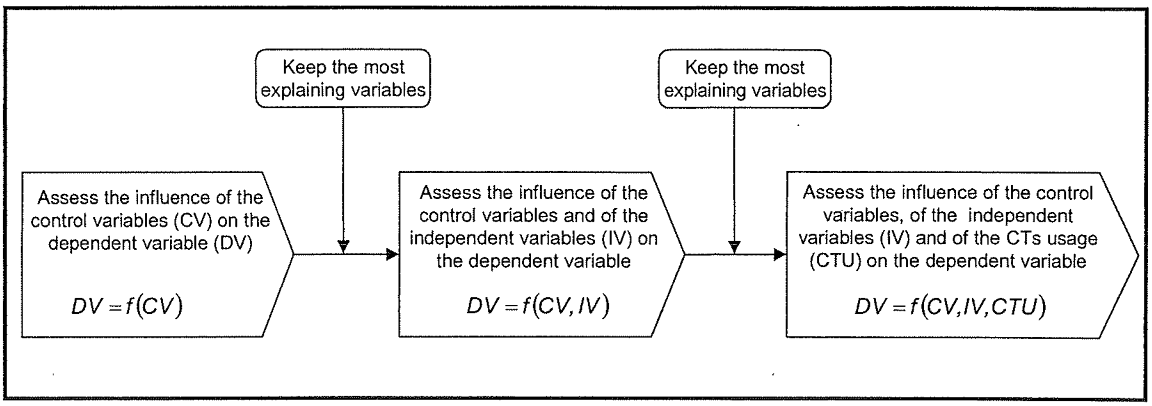


Figure 4.25 – Procedure used to perform the multivariate analyses

First, the impact of the control variables was assessed and the most explaining control variables kept for the subsequent analyses. Then, the impact of the independent variables was assessed. Finally, the CTs' usage was entered in the equation. This process has to be done for each variable of the performance dimension. By this, the researcher can be sure of keeping the most explaining variables.

4.2.7.1. Factors influencing the adoption of the CTs

Any of the control variables was influencing the CTs' usage. An alternative was also explored: the dependent variable being the CTs' usage score multiplied by the proficiency. The following table summarises the factors having the most influence on the CTs' usage:

Table 4.40 – Multivariate analysis: factors influencing the adoption of the CTs (model A)

Variables	**β**[1]	**SIG.**[2]
Virtuality	.248	*
Discussion and agreement	.359	**
Cooperation planning	•.372	**
Training	.309	**
R^2	.276	
Adjusted R^2	.198	
SIG.	**	

[1]standardised value
[2]SIG. *<.10, **<.05

Using this model, 19.8% of the CTs' usage variance can be explained. The greatest factor is "cooperation planning" which has a negative influence on the CTs' usage. Hence, this result confirms our previous analyses. The second factor is the "discussion and agreement": a particular activity in the product development process which indicates a close cooperation. Until now, this item had no relationship with the usage of CTs'. Hence, a team member that cooperates frequently tends to use the CTs'. A third factor explaining the CTs' usage is the training received by the team members. It clearly indicates the need to provide training for users. The cooperation tools look easy to use but a minimum of training is necessary. Finally, as already mentioned earlier the virtuality also promotes the usage of the CTs'.

To summarise, two kinds of factors are influencing the CTs usage: the intrinsic characteristics of the team (virtuality, discussion and agreement) and the actions taken to facilitate the appropriation of the cooperation tools (training).

4.2.7.2. Influence of the control and independent variables on the product development performance

a) Influence of the control variables on the product development performance

Some preliminary bivariate analyses were performed on the control variables to asses their influence on the three variables of the performance dimension. For the process performance, four variables were identified (project manager (+), interactions with suppliers (-), product newness (-) and managers trained and using CTs (+)). Two variables will be kept for the subsequent analyses: product newness and managers trained and using CTs. This choice was guided by the following motivations: the number of variables in the model has to be limited, these two variables were interesting for us. For the innovativeness, no control variables had an influence. This absence of influence of the control variable is also the case for the product and manufacturing performance. For the following analyses, the different dimensions will be split.

b) Influence of the control and independent variables on the process performance

Cooperation improvement was the only independent variable explaining the process performance. By adding this variable with the control variables and the usage of CTs, we obtained a set of six variables explaining 66% of the variance of the process performance (see table on the next page). Factors influencing the process performance in a positive or a negative way were found:

(i) <u>Factors negatively influencing the process performance:</u> two of them have a negative impact on the process performance (interactions with suppliers and product newness). Hence, the more a team member has interactions with suppliers, the lower is the process performance. Therefore, the implication of suppliers in the product development process has clear benefits (access to new resources, cost reduction, etc.) but also a downside: a lower process performance. This situation can be explained by the fact that suppliers are located away (i.e. more frequent travel) and are working differently. The second negative factor is the level of product newness: the higher the product newness, the lower the process performance. Indeed, new products are characterised by a high level of uncertainty which is incompatible with the process performance. A new product requires prototypes, frequent discussions, the exploration of avenues, etc..

Table 4.41 – Multivariate analysis: influence of the control and independent variables on the process performance (model B)

Dimensions	Variables	β - standardised	SIG.
Control variables	Project manager	.388	**
	Interactions with suppliers	–.252	**
	Product newness	–.440	**
	Manager trained and uses CTs	.221	**
Independent variables	Cooperation improvement	.236	*
Usage of the CTs		.203	*
	R^2	.736	
	Adjusted R^2	.660	
	SIG.	****	

SIG. *<.10, **<.05, ***<.001 and ****<.0001

(ii) Factors positively influencing the process performance: four factors positively explain the variance of the process performance: the most important one is the role of the team member, the second is the cooperation improvement, the third the fact that the manager is trained and uses the CTs and finally the usage of the CTs. The project managers are team members which either have the role of team leader or are involved in upstream and downstream activities. For them, cooperation can improve the process performance. Cooperation allows to reduce the costs and the delays related to the development process. These people are in a better position to rate the effect of cooperation. Cooperation improvement also influences the process performance. Once again, this variable in an essential factor to explain a dependent variable. Finally, the usage of CTs is also affecting the process performance. This result confirms observations performed during the field study: cooperation tools can reduce the number of travels, avoid unnecessary meetings and reduce decision time. Hence, the usage of CTs also contributes to the process performance;

c) Influence of independent variables on the innovativeness

No control variable explained the performance in term of innovativeness. Among the independent variables, only the cultural differences were explaining the variance of the innovativeness. However, the usage of CTs also has a positive effect. The impact of these two variables is shown in the following table:

Table 4.42 – Multivariate analysis: influence of the independent variables on the innovativeness (model C)

Dimensions	**Variables**	**β - standardised**	**SIG.**
Independent variables	Cultural differences	.344	**
Usage of the CTs		.369	**
	R^2	.302	
	Adjusted R^2	.262	
	SIG.	**	

SIG. *<.10, **<.05, ***<.001 and ****<.0001

These two factors explain 26.2% of the variance. This result clearly indicates the positive influence of the CTs' usage on the innovativeness. Hence, it confirms the positive effects of CTs on the ability to explore new issues and propose alternatives to solve problems (or creativity to retain the terms of Leenders et al. (2003)). The second factor, "cultural differences", is more difficult to explain. We can speculate that greater cultural differences (e.g. teams with members having different backgrounds or mother tongue) lead team members to investigate additional avenues with other team members having a different interest. This result enhances the need to adopt multidisciplinary teams.

d) Influence of the control and independent variables on the product and manufacturing performance

The factors explaining the variance of the product and manufacturing performance are listed in the following table:

Table 4.43 – Multivariate analysis: influence of the control and independent variables on the product and manufacturing performance (model D)

Dimensions	**Variables**	**β - standardised**	**SIG.**
Control variables	Interactions with suppliers	.370	**
Independent variables	Cooperation improvement	.530	**
	R^2	.423	
	Adjusted R^2	.385	
	SIG.	****	

SIG. *<.10, **<.05, ***<.001 and ****<.0001

The most influencing factor is the cooperation improvement. The actions or measures leading to an improvement of the cooperation also have an impact on the performance of the product and the manufacturing processes. The second factor is the interaction with suppliers. Hence, interaction with suppliers is ubiquitous: on the one hand, it leads to a lower performing process but, on the other hand to a better product and better manufacturing processes. This result confirms our observations of the field study: suppliers (parts, manufacturing equipment) are responsible for the suggestion of alternatives leading to a better performance;

d) Summary of the direct effects on the product development performance

The previous results allowed us to identify additional factors explaining the adoption of the cooperation tools and the product development performance. Such a network can help Bosch managers and the people in charge of the implementation of the cooperation tools. All these factors are summarised in the following figure:

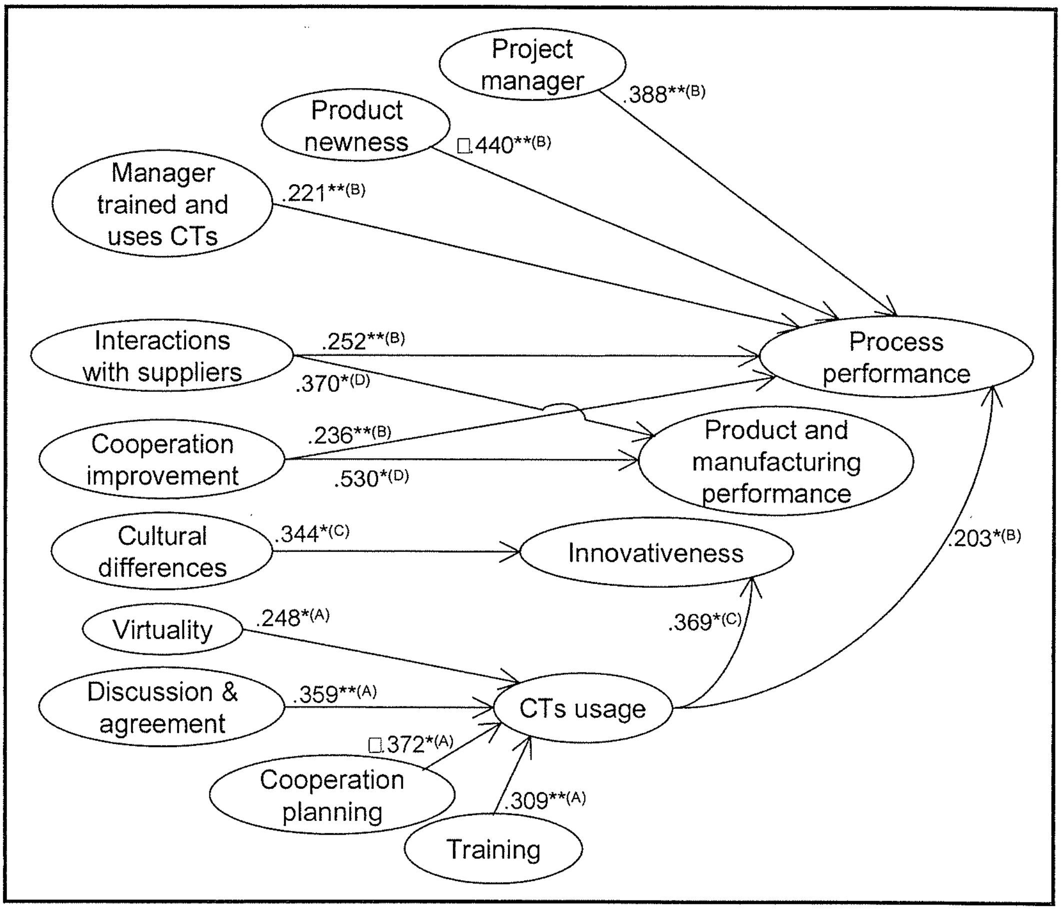


Figure 4.26 – Multivariate analyses: factors influencing the adoption of the CTs and the process performance (model A, B, C and D)

4.2.8. Additional analyses

In this additional analysis, we will try to further investigate the mechanisms responsible for the adoption of the CTs. This will be done by comparing the team members that adopted the CTs with those that did not. The second aspect of the additional analyses is the usage of the CTs. Up to now, the cooperation tools' usage was observed through one variable although this variable was made of four cooperation tools. The role of the different cooperation tools will thus be investigated. First, a new classification was defined for the CTs usage and three groups were defined (this classification overcomes the limits of the first classification in the paragraph 4.2.4.7.):

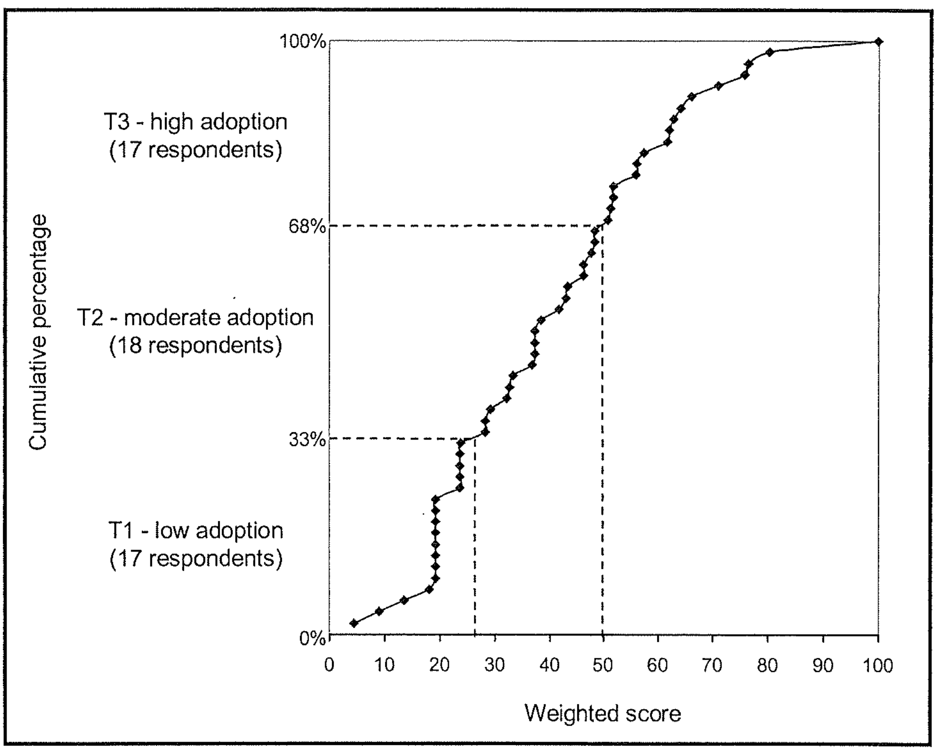


Figure 4.27 – Additional analyses: distribution of the CTs usage score (cumulative percentage)

We decided to divide the sample up into three groups. An alternative, could have been to define quartile. These two avenues were followed but gave the same results. The results with three groups will be presented.

A first group (n_1 = 17) has a score below 28.17. It means they are not fast using the CTs. The second group (n_2 = 18) has a score between 28.17 and 48.35. The third group (n_3 = 17) included the respondents that were most using the CTs. Based on this classification, several bivariate analyses were conducted (T1 vs. T2 vs. T3, T1 vs. T2, and T2 vs. T3). The results are available in APPENDIX 23. The following table summarises the main characteristics of the team members that did not adopt the CTs vs. the characteristics of those who adopted the CTs:

Table 4.44 – Additional analyses: characteristics of the team members having a low CTs adoption rate

Dimensions	Comments
Control variables	They perceived the product newness level higher
	Their managers have a lower training and lower usage of the CTs
Team context	Their work environment is characterised by a lower virtuality and cultural differences
Collaborative behaviour	Actions taken to improve cooperation are lower
Quality of the implementation	The accessibility of the CTs is perceived lower
	They received less training
Product development performance	The benefits of cooperation are lower

Hence, these results confirm the factors identified in the bivariate and multivariate analyses. Team members that did not adopt the CTs are working in a environment which is not forcing the usage of CTs (e.g. virtuality) and where a favourable environment for the adoption does not exist (e.g. cooperation improvement, training, etc.).

The second aspect of this additional analysis deals with the usage of the different CTs. Using the same classification (T1, T2 and T3), a bivariate analysis was performed on the different tools:

Table 4.45 – Additional analyses: usage of the different cooperation tools

Cooperation tools		T1	T2	T3	K-W test	M-W test (T1 vs. T3)
Visualisation of 3D models	Currently	1.43	3.05	**4.65**	****	****
	In 12 months	3.21	4.00	**4.38**	NS	**
Conferencing with 3D models	Currently	1.09	1.53	**2.71**	****	****
	In 12 months	1.90	2.53	**3.19**	**	**
Application sharing	Currently	1.31	2.21	**4.19**	****	****
	In 12 months	1.67	3.13	**3.94**	**	**
Publication of 3D models	Currently	1.00	1.79	**2.79**	**	****
	In 12 months	1.57	2.64	**3.33**	*	**
Issue manager		4.14	3.47	4.50	NS	NS
Iteration manager		4.92	4.18	5.25	NS	NS
Clearance and assembly tool		5.09	4.36	5.69	NS	NS

The results indicate a clear difference for the usage of the available tools. This is not the case for the tools defined during this study (issue manager, iteration manager and clearance & assembly tool). To better visualise these results, a figure was built:

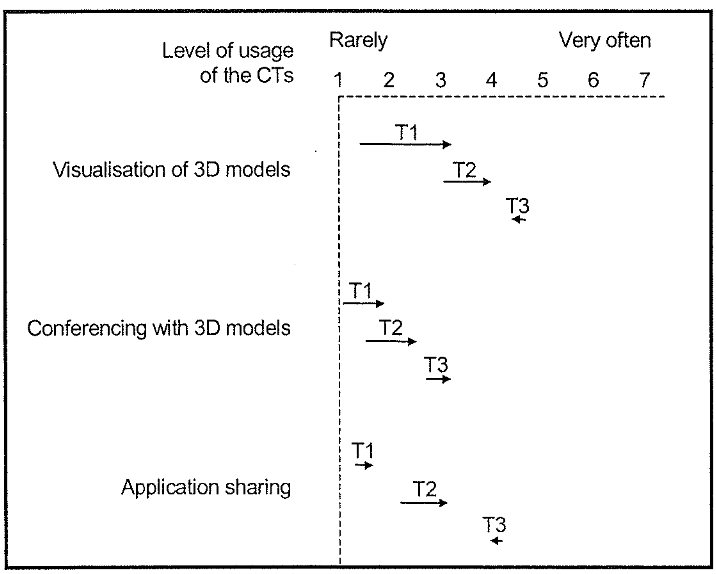


Figure 4.28 – Additional analyses: current and planned usage of CTs

These results must be interpreted with caution: some respondents indicated it was difficult for them to estimate the future usage as some projects were near the product launch (i.e. they thought the tools will be less used once the products are designed). This phenomenon was already encountered when assessing the benefits of cooperation. The tool "publication of 3D models" being a specific tools, it was excluded of the analysis. Several conclusions can be drawn from these results:

(i) An increase of the visualisation of 3D models by T1 and T2: the two groups plan to visualise more frequently the 3D models. Perhaps, they wish to recover their "backwardness";

(ii) A small increase for the usage of 3D conferencing: the groups T1 and T2 wish to increase their usage of 3D conferencing in the near future;

(iii) Application sharing looks less promising: there is only a small increase for the usage of this tool. Its usage looks less promising than the two other tools;

(iv) Emergence of different patterns: the results for T3 are difficult to interpret. As to T2, they wish to increase their usage of the three CTs. The team members belonging to T1 privileged the visualisation of 3D models. The adoption of 3D visualisation is perhaps is it the first step to master the CTs;

To explore this question, several cluster analyses were performed on the three tools. One of these analyses gave an interesting result (see table on the next page) with three groups. The first group (n_1 = 18) is making a low usage of the cooperation tools. A second group (n_2 = 14) is focusing on the visualisation of 3D models. Finally, the third group (n_3 = 14), group team members making a greater usage of the different CTs.

Table 4.46 – Additional analyses: cluster analysis on the CTs

	Group 1 $n_1 = 18$	Group 2 $n_2 = 14$	Group 3 $n_3 = 14$	
	Low usage of the CTs	Focus on 3D visualisation	Equilibrate usage	K-W test
Visualisation of 3D models	1.56	**5.36**	3.21	****
Conferences with 3D models	1.28	2.14	**2.29**	**
Application sharing	1.39	2.21	**4.57**	****

Measure: Chebyshew, Method: Ward
[1]Based on Likert scales where 1 = very low usage and 7 = very high usage

Another interpretation can be made: the group 2 is composed of team members focusing on synchronous cooperation tools whereas the third group uses synchronous CTs. Based on this typology, a bivariate analysis was performed (the results are available in Table 4.47 on the next page). Some control variables have an effect (timing of involvement, time spent in the team and interactions with OEMs). Otherwise, the significant differences were the same as in already mentioned results.

Table 4.47 – Additional analyses: the influence of the CTs configuration on the other research variables (1)

	Low usage of CTs (n1 = 18)	Focus on 3D visualisation (n_2 = 14)	Equilibrate usage (n_3 = 14)	K-W test	M-W test (Group 2 & 3)
Control variables					
Project managers	.22	.43	.29	NS	NS
Upstream specialists	.22	.07	**.29**	NS	*
Downstream specialists	.56	.50	.43	NS	NS
Timing of involvement in the team	4.53	4.00	**5.93**	*	**
Time spent in the team	5.81	4.58	**6.14**	**	**
Interactions with OEMs	1.76	1.62	**3.71**	****	***
Interactions with suppliers	3.41	3.36	4.36	NS	NS
Interactions with "same tasks"	5.18	**5.57**	4.71	NS	**
Interactions with "different tasks"	4.47	**5.29**	4.64	NS	*
Product newness	5.60	5.14	5.38	NS	NS
Manufacturing newness	4.73	5.07	4.91	NS	NS
Manager trained & uses CTs	2.75	3.10	**4.00**	NS	*
Manager understands CTs capa.	4.15	3.20	**4.33**	NS	**
Team context					
Virtuality	4.03	4.96	5.11	NS	NS
Cultural differences	3.47	3.59	**4.51**	**	**
Collaboration activities					
Sharing of PI	4.78	3.87	**4.93**	NS	*
Discussion and agreement	5.10	4.67	5.04	NS	NS
Assessment of PI	4.51	3.64	**4.97**	NS	*
Collaborative behaviour					
Cooperation planning	4.19	4.15	**4.91**	NS	**
Cooperation improvement	2.37	2.92	**3.36**	*	NS
Implementation of the CTs					
Tools' usefulness	5.28	5.54	5.50	NS	NS
Tools' accessibility	4.17	4.50	4.68	NS	NS
Training	4.00	4.79	4.77	NS	NS
Usage of the CTs					
CTs usage score	25	**50**	33	**	NS
Proficiency	2.56	**4.43**	3.86	**	NS
Product development performance					
Process performance	2.89	**4.22**	**4.10**	**	NS
Innovativeness	3.74	**5.00**	4.14	NS	*
Product & manuf. perfor.	2.75	3.06	3.61	NS	NS

*p<.10, **p<.05, ***p<.001, ****p<.0001, except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or high).

The following table shows the behaviour of these three groups concerning the different cooperation tools (currently and in 12 months):

Table 4.48 – Additional analyses: the influence of the CTs configuration on the other research variables (2)

Cooperation tools		Group 1: Low usage of CTs	Group 2: Focus on 3D visualisation	Group 3: Equilibrate usage	K-W test
Visualisation of 3D models	Currently	1.56	***5.36***	3.21	****
	In 12 months	2.88	4.27	**4.57**	**
Conferencing with 3D models	Currently	1.28	2.14	***2.29***	**
	In 12 months	2.07	2.36	**3.43**	*
Application sharing	Currently	1.39	2.21	***4.57***	****
	In 12 months	1.81	2.36	**5.07**	****
Publication of 3D models	Currently	1.50	2.17	2.13	NS
	In 12 months	2.15	2.89	2.71	NS
Issue manager		4.06	3.31	4.54	NS
Iteration manager		5.00	4.64	4.69	NS
Clearance and assembly tool		5.29	5.08	4.83	NS

The results indicate that the team members having an "equilibrate usage of CTs" will be those that will make the greatest usage of the CTs in 12 months. These additional analyses allowed us to gain a better understanding of the profiles of the product life cycle stakeholders. Two conclusions can be drawn:

(i) Confirmation of best practices: the results of preceding analyses are confirmed. The usage of CTs brings benefits. However, these CTs are used or adopted in particular circumstances: context promoting the usage of CTs (e.g. virtuality) and actions to facilitate the adoption (training, cooperation improvement);

(ii) Several CTs usage patterns: the analyses on the planned usage and on the typology let us define a pattern of adoption. Hence, a group of team members focuses on the visualisation of 3D models which can be understood as the follower of 2D drawings. They are not attempting to use additional CTS in the future. A second group is making a greater usage of the different CTs (the characteristics of these team members are described in Table 4.47) and will continue to do so in the future. Such considerations are important when dealing with the implementation (e.g. specific training programs must be proposed to these two different segments). The following figure summarises these two patterns:

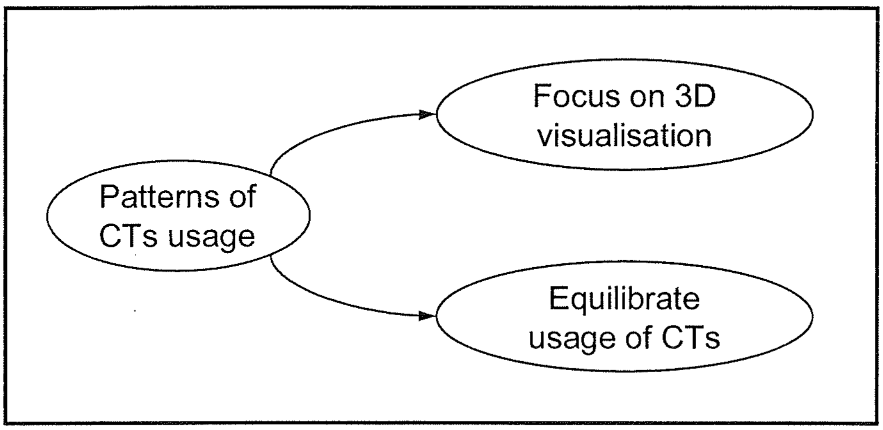


Figure 4.29 – Additional analyses: patterns of adoption of the CTs

CHAPTER 5 : SYNTHESIS AND DISCUSSIONS

The strengths and weaknesses of this study will be presented in the first section of this fifth and last chapter. The main results of the field study and of the survey as well as the implications will be summarised in the second section. Finally, some future research avenues and miscellaneous considerations on product development will be presented in the third section.

5.1. Strengths and weaknesses of the study

The way this study was conducted implied some strengths and weaknesses. The main strength of the study was the "in-depth investigation" of a new technology which took place in an industrial context, the second strength being the methodological path used to conduct this study:

(i) Investigation of new phenomena: the originality of this study was to combine the investigation of new technologies (i.e. DMU and CTs) with emerging business practices in the automotive industry (e.g. dispersed teams or the implication of product life cycle stakeholders in the product development process). In addition, the study being performed in an industrial environment (i.e. with real product development teams), it was not only possible to assess the outcomes of the technologies and of the new business practices but also to identify the predictors for the adoption of these emerging technologies. Hence, this study gives us some important elements helping to understand the ins and outs of computer-based cooperation;

(ii) An appropriate research path: the scope of research methods applied was wide. Different observations were performed (environmental factors in the first chapter and, at a more detailed level, focus groups in the fourth chapter), solutions were proposed (i.e. implementation of the CTs) and a questionnaire was designed (to assess the impacts of the solutions and of other elements).

The choice of this path insured the usefulness of the study for the practitioners (or for the "substantive area", to keep the term of Glasser, 1998). In other words, we think that some factors or attitudes are essential for the success of the implementation of new software. A kind of bottom-up strategy was adopted: we started small by testing the technology, in order to understand how the CTs will change the work pattern and accumulate experience by implementing the tools in real teams. This approach allowed us to quickly learn and perform iterations (i.e. improvement). Hence, a kind of "experimental design" was followed. We hope this process gives our work a credibility and increases the success of these new technologies;

However, like in any other study, several intrinsic weaknesses or limitations exist:

(i) <u>Focus on one industrial sector:</u> this study focused on the automotive sector and this fact has several consequences. One the one hand, some authors stressed the importance of focusing on one sector for emergent phenomena or exploratory studies (Léger, 2003 and Cassivi, 2003). The rational behind this argument is the fact that respondents work in the same industrial context (e.g. the same competitive pressure exists). On the other hand, the validity and the generalisability of the results for other sectors are limited. However, we think that some of the results could also be used in other sectors by firms which are confronted with similar challenges and wishing to implement CTs;

(ii) <u>Sample size:</u> the sample was relatively small. Of course, this fact limits the generalisability of the results (which are "function of the sample selected" according to Vadapalli and Mone, 2000). As mentioned earlier, two main reasons were proposed to explain the low participation of external firms: the technology is still at the evaluation stage in many firms and such an exercise is unusual in Germany. However, the sample allowed us to distinguish between different groups with interesting characteristics;

(iii) Elements of the conceptual model and variables used: some variables were not drawn from existing literature but from focus groups and others were the object of a consensus (e.g. creativity). The robustness of the alpha Cronbach and of some results showed that the choice was appropriate. In addition, product development is a complex topic and it is difficult to grasp the overall elements belonging to the "product development process". For example, we could have added variables like the level of experience of the respondents, the work climate, etc.. However, the claim to synthesise all the elements is difficult. Indeed, Hauser and Zettelmeyer (1996) identified 80 product development success factors in the literature;

(iv) Contextual factors: the study was performed during a tough economical period in the automotive industry characterised by very slow growth and a heavy discount battle. This situation influenced the context of the study. The resources' tightness (e.g. time capacity) prevents teams from taking the time to "play" with the tools;

5.2. Implications and contributions of this study

Based on a summary of the key results, the main implications of this study will now be presented. In addition, some theoretical contributions to the existing body of knowledge will be suggested.

5.2.1. The main results and their implications

The implications for product development team leaders and people in charge of the implementation of CTs will now be presented. First, the behaviour of two interesting groups will be summarised. Then, the variables influencing the product development performance will be presented as well as some implications. Finally, the prerequisites for the adoption of the CTs and their implications will be described.

5.2.1.1. Definition of groups and of their behaviour

Automotive suppliers are confronted with several challenges and their strategies were presented in the first chapter. Among others, actions like the creation of virtual teams, the development of complex products or the increase of cooperation with business partners were identified as essential. The bivariate analyses allowed us to characterise the behaviour of team members working in this environment:

(i) Virtuality, product and manufacturing newness: one of the interesting results is the fact that innovative (or new) products tend to be developed in a more collocated environment. This confirms the results of previous studies on the development of innovative products (e.g. Leenders et al., 2003). Hence, the role of CTs is perhaps less important for innovative products (as long as collocation exists or is possible). A different pattern is observed for the manufacturing newness where the level of virtuality is higher when the manufacturing is newer. Even if the border between product and manufacturing design is blurred in the automotive industry, the support of the manufacturing process design is perhaps a promising avenue for the CTs. It is important to notice that manufacturing issues are important for suppliers (the three first performance criteria for suppliers identified by von Corswant and Frediksson (2002) being: delivery precision, quality and product costs);

(ii) Interactions with business partners: team members having frequent interactions with business partners naturally rated the virtuality and the cultural differences higher. Team members having higher interactions with suppliers have also more frequent interactions with people coming from different disciplines and are assessing more product information. This result confirms the richness of the relationships between Bosch and its suppliers. Therefore, the usage of CTs should be promoted to support cooperation between Bosch and its supply network;

5.2.1.2. Implications for the improvement of the product development performance

The following table presents the variables influencing the product development performance (based on the correlation and multivariate analyses, the results are not classified by importance):

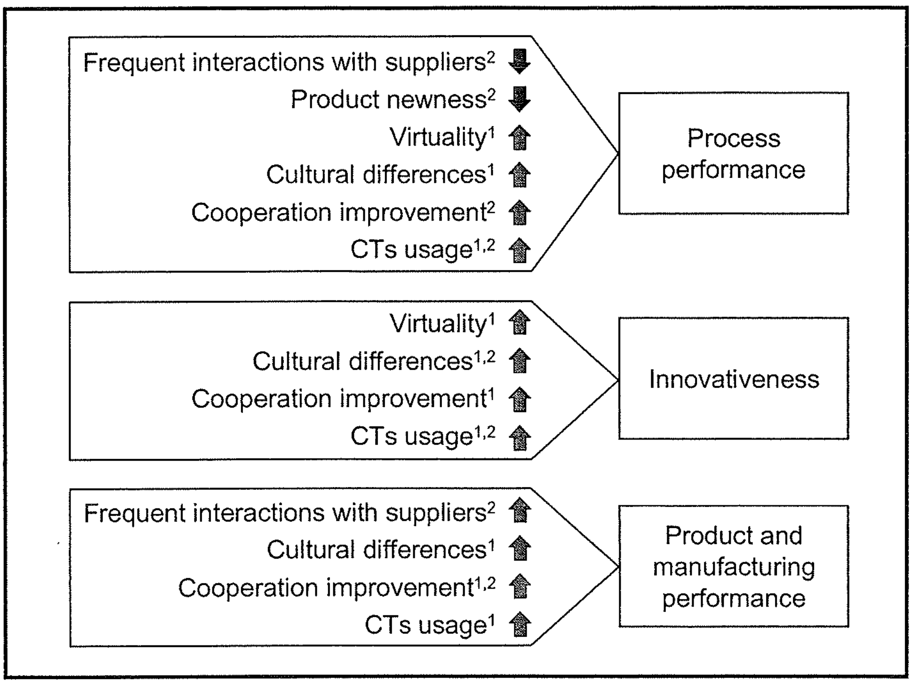


Figure 5.1 – Summary of the research variables influencing the product development performance

[1]correlation analysis
[2]multivariate analysis

Some factors improving the product development performance were identified and their implications will now be discussed:

(i) The ubiquitous impacts of interactions with suppliers: the fact that team members have frequent interactions with suppliers increases the product & manufacturing performance but decreases the process performance. Once again, this shows that tier one suppliers must take actions to improve their relationships with their second tier suppliers. The promotion of the CTs usage in the supply chain could be a solution. A pilot project was conducted with the DRO team where a supplier had access to the CTs. The results were very positive, in particular for the process performance. The members of this team did not participate in the survey (i.e. the respondents of the survey were not able to use the CTs with suppliers). One of the barriers for the diffusion of these new technologies is the concern about security. Issues like single sign-on, access rights, firewalls or encryption. The first implication is:

> **→ Implication 1: the security issue should be tackled to facilitate the adoption of CTs in the supply chain;**

The second barrier is the lack of IT infrastructure to support cooperation between Bosch and its suppliers or business partners (the DRO team pilot project was performed using a temporary infrastructure). Several OEMs implemented engineering portals on the Internet (e.g. DaimlerChrysler). Dedicated marketplaces in the automotive sector (e.g. SupplyOn and Covisint) are not yet offering similar functionalities to support cooperation in the field of product development. The availability of CTs for the different actors of the supply chain would allow an increase of the product development performance:

> **→ Implication 2: an Internet portal should be built up to facilitate cooperation between the actors of the supply chain;**

However, solely focusing on the IT infrastructure will probably not be sufficient. Indeed, other prerequisites are needed to facilitate the adoption. In the field of supply chain management, the SCOR initiative aims at helping firms to define and improve the relationships between the actors of a supply chain by defining an agreement and a joint business plan at the beginning of the relationships. The second aspect of this initiative is to propose best practices in the field of supply chain management. The "spirit" of this initiative could be adopted for the field of product development. In order to promote the diffusion of these new practices, an independent organisation should also be involved (e.g. the VDA in Germany):

> → **Implication 3: best practices or new work patterns should be identified to understand the role of CTs in the supply chain;**

> → **Implication 4: mechanisms should be defined to facilitate the adoption of the CTs in the supply chain (e.g. recommendations, standards);**

(ii) The influence of product newness: the process performance is better when the level of product newness is lower. In the case of new products, the level of uncertainty is higher and more information has to be gained about the product. Such information comes from prototypes or tests. This situation negatively influences the process performance. In addition, new products are usually developed in a collocated manner (where the usage of CTs is limited). Therefore, new products cannot be managed like other products (e.g. not measured with the same performance indicators). For example, Gomes et al. (2003) found out that the definition of a stage gate model was not necessarily appropriate for highly innovative products:

> → **Implication 5: the product development process and its management should fit with the products' characteristics (e.g. level of newness);**

(iii) Team context (virtuality & cultural differences): relying on virtual, multidisciplinary or multicultural teams has a positive influence on the performance. These results support the proponents of virtual teams;

(iv) The positive influence of cooperation improvement: the actions taken to improve cooperation have a positive influence on the outcomes of a better cooperation. This topic will be discussed in the next paragraph;

(v) Usage of CTs: the correlations and regressions analyses show that the usage of cooperation tools contribute to the performance. However, the univariate analyses showed that the CTs were currently not used so much. The situation must change and an effort must be made to improve their adoption (see next paragraph);

5.2.1.3. Implications for the adoption of CTs

The following figure presents the variables influencing the adoption of the CTs (based on the correlation and multivariate analyses):

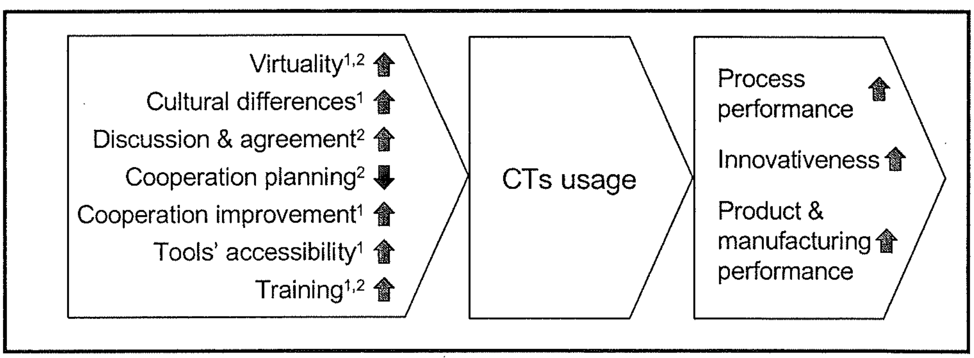


Figure 5.2 – Summary of the research variables influencing the adoption of the CTs

[1]correlation analysis
[2]multivariate analysis

The results of the correlation and regression analyses show that some factors were influencing the adoption of the cooperation tools:

(i) The influence of the team context (virtuality and cultural differences) and of collaboration activities (discussion and agreement): these three variables have a positive impact on the CTs adoption. The profile of the team members making a greater usage of CTs can be proposed. First, team members working in a virtual environment naturally tend to use the CTs. Second, the CTs are appropriate for team members involved in cooperation activities (namely "discussion and agreement"). These elements are important for team leaders wishing to promote the usage of the new CTs and the related business practices.

→ Implication 6: identify teams where the usage of CTs could bring substantial benefits (e.g. virtual environment, active cooperation);

(ii) Influence of the collaborative behaviour and of the quality of the CTs implementation: cooperation planning is not playing its expected role (i.e. a negative instead of a positive impact on the adoption), the main reason being that cooperation planning is performed by teams working locally. Cooperation planning includes actions like the definition of the product information (in terms of frequency, response time, format, content or quality), the definition of method to exchange information (e.g. common data repository) or the definition of systemic procedures to work with colleagues (e.g. to solve problems). Unfortunately this practice is not widespread when the virtuality is high. However, cooperation improvement plays a significant role (which also holds true for the performance). Cooperation improvement includes actions like the allocation of resources for the improvement of cooperation, the evaluation and the benchmarking of cooperation or seminars in the field of cooperation. Tools' accessibility and training are positively influencing the CTs usage. In the survey, the accessibility was defined by the user friendliness and the availability of support. These results have several implications. First, the implementation of CTs should be part of initiatives to improve cooperation:

→ Implication 7: resources should be allocated to the improvement of cooperation when implementing the CTs (e.g. "enactment sessions", support);

For example, some team members made an interesting suggestion during the field study: appoint a cooperation manager in the product development team. This new job should insure that all parties are working together and propose solutions to improve the team cohesion and cooperation. The CTs are an additional tool to master for product development team members. The appropriation of CTs should therefore be facilitated. One avenue suggested by authors (e.g. Mohrman et al., 2003) and confirmed during the field study, is to offer the opportunity for team members to discuss about the CTs' capabilities and how the work could be carried out. Such discussions can be performed between the members of a team. One-to-one training is also an effective mechanism to discuss about the CTs' possibilities and the concern of the team member:

It also appeared that the upstream specialists were not profiting from an increase of cooperation. This result asks the question of incentives. First, team members should be encouraged to cooperate during the product development and to make a greater usage of CTs. For example, objectives could be defined in the yearly member evaluation (e.g. process costs reduction or increase of design alternatives):

→ Implication 8: cooperation should be rewarded;

The creation of a "balanced cooperation scorecard" (like the well known "balanced scorecard") should insure that the different dimensions of performance are taken into account. This would prevent the responsible persons from favouring one dimension (e.g. process performance) against the other (e.g. innovativeness). During the field study, several users complained that the CTs could be more user friendly. For example, the registration process is cumbersome or common pointers exist during a 3D conference:

→ **Implication 9: the user friendliness of the CTs should be improved;**

Training plays a crucial role. I would like to insist on this point. Currently, due to the resources' tightness, firms in the automotive industry are rationalising their activities. In some cases the training time had to be reduced (one day being considered as too long) or was even considered as superfluous. In other words, it is perhaps a symptom that few slacks exist. However, for product development, less slack means less ability to innovate (Richtnér and Åhlström, 2002). This argument is supported by the feedback of team members who found that a half day training was too short:

→ **Implication 10: training plays an essential role for the appropriation of the CTs;**

Moreover, two adoption patterns for CTs were observed (some using 3D visualisation and others making an equilibrate usage of the different CTs). Differentiated training sessions could therefore be offered to focus on the specific user needs:

→ **Implication 12: offer different training concepts around the CTs;**

The aforementioned problems with the training could also be due to the lack of awareness or priority among the managers. On the one hand, the implementation of CTs is welcomed by managers at different levels of the organisation but, on the other hand, specific actions are perhaps missing to improve the diffusion of the CTs. The awareness among managers should increase (e.g. about the capabilities, the benefits and the prerequisites of CTs). In addition, the results of the survey show that managers using the CTs positively influence the usage by the team members. The creation of a seminar in the continuous training programme for managers could be an interesting avenue:

> → **Implication 13: the awareness about the capabilities, the benefits and the prerequisites of CTs should be increased among the managers;**

Other initiatives, especially in the development of software, experience a great success (CMM – Capability Maturity Model). One of the success factors is the proposition of capability levels and measurement tools. Such an initiative could also be proposed to foster cooperation at Bosch (for the mechanical field). Hence, a manager would be able to assess the position or capabilities of his team against a predefined scale. Actions should be suggested to pass from one level to another one. To facilitate the adoption of this system, consulting and audit services should be offered:

> → **Implication 14: a maturity model should be defined;**

5.2.2. Theoretical contributions

Besides the practical contributions offered by this study for organisations wishing to implement cooperation technologies, several theoretical contributions can be derived from this study:

(i) Proposition of a new conceptual model: this model embodied elements explaining the adoption of cooperation tools, the activities performed during the product development process and three measures of the product development performance;

(ii) Evaluation of advanced cooperation tools: this study proposes a description and empirical evaluation of high end cooperation tools. The data were drawn from teams practising a kind of product life cycle strategy;

5.3. Future research initiatives

In this section, new research avenues will be presented. First, avenues to improve the technology will be presented. Then, two initiatives dealing with the improvement of the product development process will be suggested. Finally, a small paragraph will make the link between this study and the current debate on innovation policy in Germany and Europe.

5.3.1. New technological development

The solutions or tools that were presented in this study do not mean the end of the story of cooperation in the product development. First, the "content" of the 3D models needs to be enriched. The product development stakeholders are dealing with different product design representations. The second research avenue should be thus the investigation of new design representation. Finally, security issues have to be resolved.

(i) Completeness and liability of the 3D models: even if the 3D models are now well diffused in the automotive sector, the 2D drawings still play a significant role. First, they contain essential information such as the Product and Manufacturing Information (e.g. tolerances). This information is to be found in the 2D drawings and not in the 3D CAD models. Today, some firms are trying to eliminate the usage of 2D drawings by adding the Product and Manufacturing Information to the 3D models (e.g. DaimlerChrysler). Besides specific initiatives of firms, a working group of the ASME (American Society for Mechanical Engineers) regrouping universities, firms and software provider are trying to harmonise this practice. These standardisation efforts must be promoted so that this Product and Manufacturing Information could be contained in the 3D models. In addition, the 2D drawings are still the basis for contracting between the business partners (e.g. the official document is still the 2D drawing when a supplier makes a contract). Therefore, new solutions have to be investigated to replace the 2D drawings and the 3D models (e.g. archiving, electronic signature);

(ii) Investigate other design representations: as mentioned earlier in this study, 3D models are only one of the design representation. Current products are made of electronics, software and mechanics (mechatronics) that must interplay together. Some software on the market allows to simulate a whole product (geometry, logic). The interplay between these three representations has already been investigated by the telecommunication industry (Sielaff, 2003). However, it would be interesting to investigate the cooperation along two dimensions: (i) between the different design representations (electronics with software and mechanics) and (ii) between "upstream" and "downstream" actors (e.g. cooperation between electronic design – chips and manufacturing and software design and application & marketing);

(iii) Security issues: some barriers still prevent the usage of CTs between business partners. Issues like user-management or network protocols must be solved to facilitate the adoption of the cooperation tools;

5.3.2. Initiatives to improve the development of new products

The three first research avenues focused on new technologies that could facilitate new business practices. The next three research avenues focus more on organisational and business issues:

5.3.2.1. Best practices in cooperation and product development

The results of this study show that the improvement of the product development performance implies the combination of a set of factors (e.g. new technologies like the CTs and initiatives like cooperation improvement). However, the implementation of such technologies and practices requires specific competencies on the side of the firm, especially in the field of "Diffusion of Innovation" (e.g. monitor technological development, assess the appropriateness of the emergent technology for the firm's ecological system, conduct an appropriation process to implement the technology and grasp the benefits, etc.). In other words, I think that the improvement of the product development process through new technologies should not be under the sole responsibility of IT people. More generally, firms wish to improve their ability to develop new products. Indeed, the products developed today are the revenues of tomorrow. Hence, a second argument for the acquisition of best in class product development capabilities is the competitive advantage that could be gained. Some insights from the automotive environment show that sole technological leadership is not sufficient (because innovations are rapidly copied). These new processes or manners of conducting business can bring substantial benefits and are more difficult to copy (e.g. ability to work in virtual teams, ability to better integrate tier 2 suppliers, ability to reduce time and costs). Our contribution is to enable new processes by using emergent technologies. However, other initiatives or ways to improve the product development process exist. Now, we will list some important initiatives. When speaking about improvement and best in class processes, the name "Toyota Production System" (TPS) comes rapidly in mind. This system allowed Toyota to be one of the most powerful car makers world-wide by improving its manufacturing operations and its ability to deliver high quality and reliable products. Besides this system dedicated to the operations, Toyota also developed a "Toyota Development System" (Amasaka, 2002) which is a "systematization of a design management method" based on four pillars: "design process, design technology, design behavior and design philosophy". According to Kennedy (2004), the pillar of this initiative is the "effective management of knowledge". In other words, Toyota wishes "to create technologies through optimum design brought about by information sharing" (Amasaka, 2002). Hence, this initiative aims at fostering learning and cooperation during the product development process. It is to note that Toyota does not heavily rely on "hard technologies". Another initiative in the field of product development is the Product Development &

Management Association (PDMA), an association in the US wishing to "professionalize NPD" by "creating, collecting, and disseminating data about the new product development (NPD) process" (Tomkovick and Miller, 2000). One of their achievement is the creation of a "body of knowledge" which would make "it possible for organizations and individuals to use product development as a tool of policy and strategy in much the same way as has happened for inventory management, quality assurance, and financial systems". In addition, this association proposed a certification for project managers. Finally, I would like to make the link between this study and some innovation policy considerations.

5.3.2.2. "Standort Deutschland" and the importance of IT in Europe

This German expression could be translated by "industrial location Germany". Once at the forefront among the industrial nations, the home of major technological innovation and industrial firms, this country is now crossing a difficult period. Of course, Germany is still the largest exporter in the world, especially for automotive products, but it is confronted with several acute problems (high unemployment rate and low growth among others). These problems are also similar for other western countries, especially in Europe. With the so-called "Lisbon strategy" proposed in the year 2000, the European Union wishes to become the most competitive economic area and promotes reforms to "instituting the transition needed towards a competitive job-creating knowledge-based economy characterised by growth, social cohesion and respect for our environment (Commission of the European Communities, 2004)." According to this report (see citation), one of the main problems

> "The low growth in overall productivity in Europe is due in particular to two main factors: the contribution of information and communication technologies (ICTs) is too low and investment is inadequate. The Union's efforts to increase its productivity must focus on these priorities in order for us to remain competitive with the United States and also more globally with other partners, particularly China and India.... The contribution of information and communication technologies to productivity growth is less than half of that found in the United States. This is largely due to take-up and use of these technologies... this situation is a result of inadequate investment in these technologies and in accompanying measures for training and organisational reform in companies." (Commission of the European Communities, 2004)

in Europe is the low productivity growth. This thesis can modestly contribute to the current debate: ICT can provide substantial benefits for firms but their implementation requires specific methodologies, competencies and the ability to change.

CONCLUSION

This study demonstrated that the adoption of cooperation tools represents an interesting opportunity for manufacturing firms in order to improve their product development process. From my point of view, the challenge was the adoption of the technologies by product development teams. To facilitate it, a pragmatical approach insuring a fit between the CTs and the need of product development stakeholders was taken. We are convinced that these principles contributed to the success of the pilot projects and of the study.

This study also contributes to the body of knowledge in the field of industrial engineering and management of technology. During this study, I had frequent contacts with industrial engineers that were keen to be part of the product development process – which allows them to better apply their know-how (improvement of operations). In addition, this study contributes to the field of technology management. This field of study appeared in North America when academics and agencies concluded that people and organisations where not able to manage changes in the business and technological environment. Hence, our attitude was to leverage the technology, the people and their work process. To conduct this study, sources from different academic fields were reviewed (e.g. from the psychologists up to the IT specialists). Other sources have been reviewed especially for trends and drivers in the automotive industry.

From a personal point of view, I appreciated participating in this very interesting project that allowed me to implement a new technology in a social system – or what could be more exactly called "the diffusion of innovation". In addition, this work was conducted in the German automotive industry which combines some exciting characteristics and develops fascinating products: high technical requirements must be met to develop products that combine emotion (or driving pleasure) and emission reduction in an international environment. Moreover, this study was conducted in Stuttgart – which is a sort of "German Motortown" – where the automotive industry was born more than a century ago. This environment is encouraging for the exploration of new possibilities, I hope it will continue to be so!

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APPENDIX 1 – Dependent variables: theoretical justification

Independent variables: Product development performance		
Research variables	Operational measures	Theoretical justification
Time and expenditures	1. Less travel	Field study
	2. Reduction of the number of changes	Souder et al., 1998
	3. Reduction of the time to perform development tasks	May et al., 2000
	4. Begin development task earlier	Field study
Teamwork performance	5. Teamwork satisfaction	Hauptman and Hirji, 1996
	6. Quality of decisions	Huang et al., 2002
	7. Information asymmetry reduction	Field study
Creativity	8. More issues explored	Montoya-Weiss et al., 2001
	9. More alternatives generated	Huang et al., 2002
	10. Alternatives were more creative	Leenders et al., 2003
Manufacturing process performance	11. Investment reduction	Field study
	12. Production time reduction	Beamon, 1999
	13. Improved manufacturability	Takieshi, 2002
Product performance	14. Improved technical performance	Takieshi, 2002
	15. Improved life cycle performance	Takieshi, 2002
	16. Cost reduction	Takieshi, 2002

APPENDIX 2 – Independent variables: theoretical justification

Independent variables: Team context, Collaboration activities, Collaborative behaviour, Quality of the collaboration tools implementation		
Research variables	Operational measures	Theoretical justification
Virtuality	1. Geographical dispersion	Field study
	2. Difficulty to reach colleagues	Field study
Culture	3. Mother tongue	Yoshioka et al, 2002
	4. Technical terms	Griffin and Hauser, 1996
	5. Professional background	Griffin and Hauser, 1996
	6. Time orientation	Yoshioka et al, 2002
	7. Tolerance to ambiguity and uncertainty	Bangert and Doktor, 2003
	8. Decision process	Field study
Product information sharing	9. Prepare and publish product information (external)	Field study
	10. Prepare and publish product information (internal)	Field study
	11. Preliminary information	Field study
Discussion and agreement	12. Requirements collection	Field study
	13. Find agreement	Field study
	14. Prepare alternatives	Field study
	15. Implement changes	Field study
Further usage of PI	16. Plan downstream activities	Field study
	17. Simulation	Field study
Assessment of product information	18. Downstream activities	Field study
	19. Engineering activities	Field study
	20. Impact of changes	Field study

Research variables	Operational measures	Theoretical justification
Cooperation planning	21. Frequency and response time	VDA 4691 (1998)
	22. Format and content	VDA 4691 (1998)
	23. Accuracy and quality	VDA 4691 (1998)
	24. Methods and media to exchange information	VDA 4691 (1998)
	25. Definition of systematic procedures	Mohrman et al., 2003
Cooperation improvement	26. Attend a seminar on cooperation and tools	VDA 4691 (1998)
	27. Document experience	VDA 4691 (1998)
	28. Assign resource to cooperation improvement	VICS-CPFR (1998)
	29. Evaluate and benchmark cooperation	VICS-CPFR (1998)
Quality of the collaboration tool implementation	30. Usefulness of the tools	Robertson and Allen, 1992
	31. Usefulness of the information	Robertson and Allen, 1992
	32. Tools are working well	Robertson and Allen, 1992
	33. User friendliness	Robertson and Allen, 1992
	34. Support	Robertson and Allen, 1992
	35. Training – basic features	Robertson and Allen, 1992
	36. Training – job-related features	Robertson and Allen, 1992
	37. Managers – trained or use tools	Robertson and Allen, 1992
	38. Managers – understand capabilities and limitations of tools	Robertson and Allen, 1992

APPENDIX 3 – Moderating variables: theoretical justification

Moderating variables : Usage of cooperation tools		
Research variables	Operational measures	Theoretical justification
Usage of asynchronous cooperation tools	1. Visualisation of 3D models	Field study
	2. Conversion of 3D CAD models to JT	Field study
Usage of synchronous cooperation tools	3. 3D conferencing	Field study
	4. Application sharing	Field study
Future tools	5. Issue manager	Field study
	6. Iteration manager	Field study
Proficiency	7. Proficiency for the usage of the CTs	Field study

APPENDIX 4 – Control variables: theoretical justification

Dependent variables : Control variables		
Research variables	Operational measures	Theoretical justification
Position in the product development chain	1. Position of the firm in the automotive supply chain	Holland and Plischke (2001)
	2. Position of the team member	Field study
Involvement in the team	3. Early involvement	Von Corswant and Tunalv (2002)
	4. Time spend in the project	Field study
Interactions	5. With colleagues	Field study
	6. With suppliers	Field study
	7. With customers	Field study
	8. With people having the same task	Field study
	9. With people having a different task	Field study
Newness	10. Degree of newness of the product	Swink, 2000
	11. Degree of newness of the process	Swink, 2000

APPENDIX 5 – Constructs validity: dependent variables

Constructs	Items	α Cronbach	Mean	Median	Std. Dev.
Process performance	Less travel was required The number of changes was reduced The time required to perform your task(s) was reduced You were able to begin your task(s) earlier and resolve issues earlier	0.8581	3.94	4.00	1.42
Innovativeness	You were able to explore more issues You were able to generate more alternatives The alternative were more creative	0.8676	4.36	4.67	1.59
Product and manufacturing performance	The investments in manufacturing and assembly equipment were reduced The production time was reduced The manufacturability was improved The technical performance of the part/component was better The life cycle performance of the part/component was better The product and production costs were lower	0.9376	3.66	3.92	1.42

APPENDIX 6 – Constructs validity: independent variables

Constructs	Items	α Cronbach	Mean	Median	Std. Dev.
Virtuality	The people in the development team are geographically dispersed	0.8378	4.63	5.00	1.80
	The people in the development team are difficult to reach				
Culture	Differences exist relative to mother tongue?	0.7122	4.00	4.00	0.98
	Differences exist relative to technical terms used?				
	Differences exist relative to professional background?				
	Differences exist relative to time orientation?				
	Differences exist relative to tolerance to ambiguity and uncertainty?				
	Differences exist relative to the manner decisions are taken?				
Product information sharing	I prepare and publish information for suppliers or customers	0.6310	4.59	4.67	1.33
	I prepare and publish information for internal purposes				
	I prepare and publish "preliminary" product information				
Discussion and agreement	I collect requirements, suggestions and wishes	0.8335	4.97	5.13	1.45
	I explain, discuss and find agreements on product or process issues				
	I prepare different product or process alternatives that are discussed during meetings or submitted for comments				
	I define changes to be made				
Assessment of product information	I assess the product information according to criteria like: manufacturability, assembly and inspections	0.8828	4.31	4.67	1.90
	I assess the product information according to the following criteria: form, fit, function				
	I assess the impact of changes on the product, the process and costs				
Cooperation planning	Define the information to be shared in terms of frequency and response time?	0.7674	4.50	4.60	1.22
	Define the information to be shared in terms of format and content?				
	Define the accuracy, maturity and the data quality?				
	Define methods and media to exchange information?				
	Define and practice systemic procedures or approaches to work with your colleagues?				

Constructs	Items	α Cronbach	Mean	Median	Std. Dev.
Cooperation improvement	Attend a seminar on cooperation and tools?	0.7540	2.97	3.00	1.27
	Document your experience in the current project?				
	Assign resources for the improvement of cooperation				
	Evaluate and benchmark the success of cooperation?				
Tools' usefulness	The functionalities provided by the CTs are useful	0.8125	5.54	6.00	1.27
	The information provided in the 3D models is useful				
Tools' accessibility	The software is easy to use	0.7873	4.65	5.00	1.18
	It is easy to get help when I need to learn a new feature of the cooperation tools				
Training	The training you received showed the basic features of the CTs	0.9138	4.51	5.00	1.73
	The training you received showed what job-related tasks cooperation tools were good for solving				

APPENDIX 7 – Cluster analysis: product newness and manufacturing newness

	Group 1 $n_1 = 17$	Group 2 $n_2 = 12$	Group 3 $n_3 = 20$	
	Moderate product & manufacturing newness	High product & manufacturing newness	High product & moderate manufacturing newness	
	mean[1]	mean[1]	mean[1]	K-W test
Product newness	4.12	6.33	**6.40**	.000
Manufacturing newness	4.82	**6.33**	4.35	.000

Chebyshew measure, Ward method
[1]Based on Likert scales where 1 = very low newness and 7 = very high newness

APPENDIX 8 – Bivariate analysis: the influence of the product and manufacturing newness on the other research variables

Based on the cluster analysis (APPENDIX 7)

	Moderate product & manufacturing newness (n = 17)	High product & manufacturing newness (n = 12)	High product & moderate manufacturing newness (n = 20)	K-W test
Control variables				
Timing of involvement in the team	4.71	**6.40**	4.68	**
Time spent in the team	5.18	6.20	5.37	NS
Interactions with OEMs	2.38	2.18	2.75	NS
Interactions with suppliers	4.00	3.36	3.50	NS
Interactions with "same tasks"	5.06	**5.91**	4.95	*
Interactions with "different tasks"	5.12	5.09	4.70	NS
Product newness	4.12	6.33	**6.40**	****
Manufacturing newness	4.82	**6.33**	4.35	****
Manager trained & uses CTs	3.47	4.00	3.15	NS
Manager understand CTs capa.	3.38	4.80	4.15	NS
Team context				
Virtuality	5.29	4.83	4.17	NS
Cultural differences	4.09	3.69	3.87	NS
Collaboration activities				
Sharing of PI	4.46	4.88	4.90	NS
Discussion and agreement	4.94	4.93	5.27	NS
Assessment of PI	4.62	3.85	4.78	NS
Collaborative behaviour				
Cooperation planning	4.61	4.60	4.44	NS
Cooperation improvement	3.22	2.42	3.11	NS
Implementation of the CTs				
Tools' usefulness	5.47	6.10	5.21	NS
Tools' accessibility	4.68	4.30	4.59	NS
Training	4.94	4.45	4.32	NS
Usage of the CTs				
CTs usage score	42	34	29	NS
Proficiency	3.75	3.90	3.37	NS
Product development performance				
Process performance	**4.45**	3.21	3.57	*
Innovativeness	4.67	4.05	4.09	NS
Product and manufacturing perfor.	3.54	3.06	3.40	NS

*p<.10, **p<.05, ***p<.001, ****p<.0001, Except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or high).

APPENDIX 9 – Bivariate analysis: the influence of the product newness on the other research variables

	Low product newness (< mean) ($n_1 = 23$)	High product newness (>mean) ($n_2 = 33$)	M-W test
Control variables			
Timing of involvement in the team	5.13	5.33	NS
Time spent in the team	4.91	**5.70**	**
Interactions with OEMs	2.82	2.53	NS
Interactions with suppliers	4.00	3.47	NS
Interactions with "same tasks"	4.91	5.25	NS
Interactions with "different tasks"	4.78	4.91	NS
Product newness	4.26	**6.39**	****
Manufacturing newness	4.82	5.09	NS
Manager trained & uses CTs	3.42	3.39	NS
Manager understand CTs capa.	3.57	**4.33**	*
Team context			
Virtuality	5.07	4.35	NS
Cultural differences	4.05	3.76	NS
Collaboration activities			
Sharing of PI	4.37	4.85	NS
Discussion and agreement	4.65	**5.14**	**
Assessment of PI	4.47	4.33	NS
Collaborative behaviour			
Cooperation planning	4.72	4.56	NS
Cooperation improvement	3.29	2.81	NS
Implementation of the CTs			
Tools' usefulness	5.63	5.52	NS
Tools' accessibility	4.72	4.50	NS
Training	4.52	4.41	NS
Usage of the CTs			
CTs usage score	37	30	NS
Proficiency	3.73	3.50	NS
Product development performance			
Process performance	**4.42**	3.46	**
Innovativeness	**4.72**	4.08	*
Product and manufacturing perfor.	3.64	3.24	NS

*p<.10, **p<.05, ***p<.001, ****p<.0001, Except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or high).

APPENDIX 10 – Bivariate analysis: the influence of the manufacturing newness on the other research variables

	Low manufacturing newness (< mean) ($n_1 = 33$)	High manufacturing newness (>mean) ($n_2 = 18$)	M-W test
Control variables			
Timing of involvement in the team	4.81	5.38	NS
Time spent in the team	5.31	5.87	NS
Interactions with OEMs	2.56	2.35	NS
Interactions with suppliers	3.61	3.82	NS
Interactions with "same tasks"	4.97	**5.65**	**
Interactions with "different tasks"	4.79	**5.29**	*
Product newness	5.61	5.56	NS
Manufacturing newness	4.36	**6.33**	****
Manager trained & uses CTs	3.25	**4.09**	*
Manager understand CTs capa.	3.76	4.36	NS
Team context			
Virtuality	4.61	**5.11**	*
Cultural differences	3.88	4.09	NS
Collaboration activities			
Sharing of PI	4.66	4.73	NS
Discussion and agreement	5.06	5.25	NS
Assessment of PI	4.80	4.04	NS
Collaborative behaviour			
Cooperation planning	4.53	4.46	NS
Cooperation improvement	**3.22**	2.52	**
Implementation of the CTs			
Tools' usefulness	5.25	**6.00**	**
Tools' accessibility	4.62	4.50	NS
Training	4.57	4.69	NS
Usage of the CTs			
CTs usage score	33	35	NS
Proficiency	3.65	3.63	NS
Product development performance			
Process performance	3.84	3.93	NS
Innovativeness	4.27	4.46	NS
Product and manufacturing perfor.	3.58	3.04	NS

*p<.10, **p<.05, ***p<.001, ****p<.0001, Except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or high).

APPENDIX 11 – Bivariate analysis: the influence of the interactions with business partners on the other research variables

	Few interactions with business partners ($n_1 = 28$)	Frequent interactions with suppliers ($n_2 = 20$)	Frequent interactions with OEMs ($n_3 + n_4 = 11$)	K-W test
Team context				
Virtuality	4.06	5.16	5.25	NS
Cultural differences	3.76	4.10	4.14	NS
Collaboration activities				
Sharing of PI	4.17	4.62	**5.47**	**
Discussion and agreement	4.73	5.35	4.85	NS
Assessment of PI	3.83	4.87	4.26	NS
Collaborative behaviour				
Cooperation planning	4.87	4.53	4.48	NS
Cooperation improvement	3.06	2.53	3.48	NS
Implementation of the CTs				
Tools' usefulness	5.54	5.24	6.22	NS
Tools' accessibility	4.63	4.50	5.17	NS
Training	4.30	4.78	4.50	NS
Usage of the CTs				
CTs usage score	43	44	64	NS
Proficiency	3.44	3.63	4.00	NS
Product development performance				
Process performance	4.02	3.83	3.97	NS
Innovativeness	4.51	3.92	5.05	NS
Product & manuf. perfor.	4.24	3.41	3.58	NS

*p<.10, **p<.05, ***p<.001, ****p<.0001, Except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or low).

APPENDIX 12 – Bivariate analysis: the influence of the interactions with suppliers on the other research variables

	Low interactions with suppliers (< mean) ($n_1 = 27$)	High interactions with suppliers (>mean) ($n_2 = 32$)	M-W test
Control variables			
Timing of involvement in the team	5.00	5.28	NS
Time spent in the team	5.43	5.39	NS
Interactions with OEMs	2.46	2.75	NS
Interactions with suppliers	2.04	**5.09**	****
Interactions with "same tasks"	5.11	5.13	NS
Interactions with "different tasks"	4.33	**5.19**	**
Product newness	**5.84**	5.23	*
Manufacturing newness	5.00	5.07	NS
Manager trained & uses CTs	3.50	3.48	NS
Manager understand CTs capa.	4.17	3.96	NS
Team context			
Virtuality	4.06	**5.21**	*
Cultural differences	3.56	**4.07**	**
Collaboration activities			
Sharing of PI	4.44	4.75	NS
Discussion and agreement	4.64	5.23	NS
Assessment of PI	3.78	**4.83**	**
Collaborative behaviour			
Cooperation planning	4.40	4.52	NS
Cooperation improvement	3.00	3.04	NS
Implementation of the CTs			
Tools' usefulness	5.65	5.55	NS
Tools' accessibility	4.58	4.60	NS
Training	4.09	**4.80**	*
Usage of the CTs			
CTs usage score	28	35	NS
Proficiency	3.23	**3.93**	*
Product development performance			
Process performance	3.62	**4.16**	*
Innovativeness	4.38	4.38	NS
Product and manufacturing perfor.	3.00	**3.70**	**

*$p<.10$, **$p<.05$, ***$p<.001$, ****$p<.0001$, Except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or low).

APPENDIX 13 – Bivariate analysis: the influence of the interactions with OEMs on the other research variables

	Low interactions with OEMs (<mean) ($n_1 = 34$)	High interactions with OEMs (>mean) ($n_2 = 24$)	M-W test
Control variables			
Timing of involvement in the team	4.61	**5.91**	**
Time spent in the team	5.32	5.64	NS
Interactions with OEMs	1.38	**4.38**	****
Interactions with suppliers	3.65	3.88	NS
Interactions with "same tasks"	5.24	5.04	NS
Interactions with "different tasks"	4.94	4.58	NS
Product newness	5.59	5.45	NS
Manufacturing newness	5.16	4.94	NS
Manager trained & uses CTs	3.18	3.67	NS
Manager understand CTs capa.	3.71	**4.39**	*
Team context			
Virtuality	4.45	4.96	NS
Cultural differences	3.59	**4.21**	**
Collaboration activities			
Sharing of PI	4.32	**5.06**	**
Discussion and agreement	5.09	4.87	NS
Assessment of PI	4.10	4.68	NS
Collaborative behaviour			
Cooperation planning	4.36	4.58	NS
Cooperation improvement	2.38	**3.77**	****
Implementation of the CTs			
Tools' usefulness	5.25	**6.09**	**
Tools' accessibility	4.32	4.89	NS
Training	4.34	4.52	NS
Usage of the CTs			
CTs usage score	32	31	NS
Proficiency	3.18	**4.24**	**
Product development performance			
Process performance	3.50	**4.43**	**
Innovativeness	4.15	4.62	NS
Product and manufacturing perfor.	2.92	**4.23**	**

*p<.10, **p<.05, ***p<.001, ****p<.0001, Except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or low).

APPENDIX 14 – Bivariate analysis: the influence of the training and the usage of CTs by the managers on the other research variables

The following classification was used: "high level of training and usage" (n_1 = 21, for an answer comprised between 4 and 7), "low level of training and usage" (n_2 = 20, for an answer comprised between 1 and 3) and "N/A" (n_3 = 17, for the respondents who answered N/A):

	High level of training and usage (n_1 = 21)	Low level of training and usage (n_2 = 20)	N/A (n_3 = 17)	K-W test
Control variables				
Timing of involvement in the team	5.20	5.16	5.00	NS
Time spent in the team	5.63	5.00	5.40	NS
Interactions with OEMs	2.55	2.70	2.50	NS
Interactions with suppliers	3.90	**4.10**	2.88	*
Product newness	5.22	5.32	5.88	NS
Manufacturing newness	5.33	4.59	5.07	NS
Manager understand CTs capa.	4.24	3.75	5.00	NS
Team context				
Virtuality	5.43	4.13	4.28	NS
Cultural differences	**4.55**	3.65	3.73	**
Collaboration activities				
Sharing of PI	4.47	**5.13**	3.95	**
Discussion and agreement	5.19	5.20	4.35	NS
Assessment of PI	4.96	3.94	3.833	NS
Collaborative behaviour				
Cooperation planning	4.58	4.16	4.64	NS
Cooperation improvement	3.37	2.80	2.58	NS
Implementation of the CTs				
Tools' usefulness	5.50	5.65	5.43	NS
Tools' accessibility	4.97	4.55	4.29	NS
Training	**5.30**	4.37	3.27	**
Usage of the CTs				
CTs usage score	**59**	38	45	**
Proficiency	**4.10**	3.79	2.73	**
Product development performance				
Process performance	**4.75**	3.49	3.40	**
Innovativeness	**4.94**	4.00	3.95	*
Product and manufacturing perfor.	3.99	3.27	3,56	NS

*p<.10, **p<.05, ***p<.001, ****p<.0001, Except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or low).

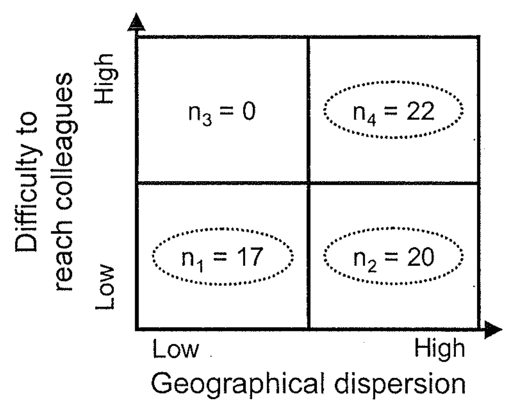
APPENDIX 15 – Bivariate analysis: the influence of the proficiency on the other research variables

	Low proficiency (< mean) $n_1 = 27$	High proficiency (> mean) $n_2 = 29$	M-W test
Control variables			
Timing of the involv. in the team	4.96	5.21	NS
Time spent in the team	**5.79**	4.89	**
Interactions with OEMs	2.11	**2.93**	**
Interactions with suppliers	3.26	4.04	NS
Interactions with "same tasks"	4.96	5.21	NS
Interactions with "different tasks"	4.81	4.71	NS
Product newness	**5.76**	5.26	*
Manufacturing newness	5.05	5.08	NS
Manager trained & uses CTs	3.20	3.76	NS
Manager understands CTs capa.	4.24	4.04	NS
Team context			
Virtuality	4.50	4.81	NS
Cultural differences	3.52	**4.29**	**
Collaboration activities			
Sharing of PI	4.44	4.68	NS
Discussion and agreement	4.80	5.10	NS
Assessment of PI	4.11	4.61	NS
Collaborative behaviour			
Cooperation planning	4.30	4.63	NS
Cooperation improvement	2.28	**3.63**	****
Implementation of the CTs			
Tools' usefulness	5.54	5.73	NS
Tools' accessibility	3.98	**5.02**	**
Training	3.74	**5.15**	**
Usage of the CTs			
CTs usage score	21	**46**	**
Proficiency	2.15	**5.00**	****
Product development performance			
Process performance	3.21	**4.47**	***
Innovativeness	3.95	**4.93**	**
Product & manuf. perfor.	2.38	**4.18**	****

*p<.10, **p<.05, ***p<.001, ****p<.0001, except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or low).

APPENDIX 16 – Bivariate analysis: typologies of virtuality

This dimension deals with the current context in which product development teams are working (rise of the virtuality and of the cultural differences). First, the respondents were asked to qualify the level of virtuality by assessing the level of geographical dispersion and the difficulty to reach other team members. The level of geographical dispersion is relatively high (5.20) whereas the difficulty to reach colleagues is moderate (4.02). The respondents can be classified in three major groups: the largest group (N=22) can be considered as having a high degree of virtuality because they both have problem to reach colleagues and there is a great geographical dispersion; the second group (N= 20) experiences a high geographical dispersion but has no problems reaching colleagues; finally, the last group (N=17) assembles team members having a low degree of dispersion and less difficulty to reach colleagues. The following quadrant shows the typology of the groups:



APPENDIX 17 – Cluster analysis: virtuality

	Group 1 $n_1 = 36$	Group 2 $n_2 = 11$	Group 3 $n_3 = 10$	
	Moderate virtuality	High virtuality	Low virtuality	
	mean[1]	mean[1]	mean[1]	K-W test
Geographical dispersion	4.92	6.59	1.45	****
Difficulty to reach colleagues	4.10	4.27	2.49	****

Chebyshew measure, Ward method
[1]Based on Likert scales where 1 = very low newness and 7 = very high newness

APPENDIX 18 – Bivariate analysis: the influence of the virtuality on the other research variables

Based on the cluster analysis (APPENDIX 17)

	Moderate virtuality (n_1=36)	High virtuality (n_2=11)	Low virtuality (n_3=10)	K-W test
Control variables				
Timing of involvement in the team	5.09	6.00	4.40	NS
Time spent in the team	5.29	6.25	4.90	NS
Interactions with OEMs	**2.97**	2.64	1.50	*
Interactions with suppliers	**4.11**	4.00	2.00	**
Interactions with "same tasks"	5.03	5.18	5.40	NS
Interactions with "different tasks"	4.69	5.00	4.70	NS
Product newness	5.06	6.00	**6.40**	**
Manufacturing newness	4.86	5.64	5.00	NS
Manager trained and uses CTs	**3.83**	3.50	1.50	**
Manager understand CTs capa.	3.97	4.29	4.80	NS
Team context				
Virtuality	4.92	**6.59**	1.45	****
Cultural differences	4.10	**4.27**	2.49	****
Collaboration activities				
Sharing of PI	4.69	4.79	3.89	NS
Discussion and agreement	4.86	4.97	5.17	NS
Assessment of PI	4.48	4.10	3.85	NS
Collaborative behaviour				
Cooperation planning	4.47	3.77	**5.29**	**
Cooperation improvement	3.20	2.26	2.86	NS
Implementation of the CTs				
Tools' usefulness	5.64	5.85	5.10	NS
Tools' accessibility	4.60	4.45	5.25	NS
Training	4.58	4.06	4.35	NS
Usage of the CTs				
CTs usage score	36	37	17	NS
Proficiency	3.86	3.89	2.78	NS
Product development performance				
Process performance	**4.19**	3.95	3.06	*
Innovativeness	4.52	4.86	3.46	NS
Product and manufacturing perfor.	**3.73**	3.15	2.30	*

*p<.10, **p<.05, ***p<.001, ****p<.0001, except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or low).

APPENDIX 19 – Bivariate analysis: the influence of the geographical dispersion on the other research variables

	Low geographical dispersion (< mean)	High geographical dispersion (> mean)	M-W test
Control variables			
Timing of involvement in the team	4.77	5.26	NS
Time spent in the team	5.38	5.39	NS
Interactions with OEMs	2.33	2.77	NS
Interactions with suppliers	2.81	**4.28**	**
Product newness	**6.11**	5.14	**
Manufacturing newness	4.76	5.22	NS
Manager trained & uses CTs	3.36	3.54	NS
Manager understand CTs capa.	4.60	3.74	NS
Team context			
Virtuality	2.80	**5.79**	****
Cultural differences	3.40	**4.32**	**
Collaboration activities			
Sharing of PI	4.30	4.78	NS
Discussion and agreement	4.88	5.02	NS
Assessment of PI	4.20	4.39	NS
Collaborative behaviour			
Cooperation planning	4.49	4.48	NS
Cooperation improvement	2.78	3.01	NS
Implementation of CTs			
Tools' usefulness	5.30	5.70	NS
Tools' accessibility	4.17	**4.89**	*
Training	4.31	4.59	NS
Usage of the CTs			
CTs usage score	36	**55**	**
Proficiency	3.24	3.94	NS
Product development performance			
Process performance	3.22	**4.24**	*
Innovativeness	3.62	**4.78**	*
Product and manuf. perfor.	2.76	3.83	NS

*p<.10, **p<.05, ***p<.001, ****p<.0001, except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or low).

APPENDIX 20 – Bivariate analysis: the influence of the difficulty to reach colleagues on the other research variables

	Low difficulty to reach colleagues (< mean)	High difficulty to reach colleagues (> mean)	M-W test
Control variables			
Timing of involvement in the team	4.82	5.60	NS
Time spent in the team	5.09	**5.84**	*
Interactions with OEMs	2.41	3.00	NS
Interactions with suppliers	3.68	3.77	NS
Interactions with "same tasks"	**5.32**	4.82	*
Interactions with "different taks"	4.79	4.68	NS
Product newness	5.44	5.58	NS
Manufacturing newness	4.78	**5.43**	**
Manager trained & uses CTs	3.00	**4.50**	**
Manager understand CTs capa.	3.96	4.40	NS
Team context			
Virtuality	3.70	**6.11**	****
Cultural differences	3.69	**4.20**	*
Collaboration activities			
Sharing of PI	4.46	4.70	NS
Discussion and agreement	4.92	4.95	NS
Assessment of PI	4.24	4.38	NS
Collaborative behaviour			
Cooperation planning	4.59	4.23	NS
Cooperation improvement	**3.16**	2.68	*
Implementation of CTs			
Tools' usefulness	5.46	5.79	NS
Tools' accessibility	4.76	4.55	NS
Training	4.50	4.35	NS
Usage of the CTs			
CTs usage score	32	34	NS
Proficiency	3.62	3.80	NS
Product development performance			
Process performance	3.68	**4.33**	*
Innovativeness	4.25	4.58	NS
Product and manuf. perfor.	3.43	3.43	NS

*p<.10, **p<.05, ***p<.001, ****p<.0001, except the CTs usage score, all scales are 1 to 7 (1 disagree or low, 7 agree or low).

APPENDIX 21 – Correlation coefficient

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Virtuality (1)														
Cultural differences (2)	.662****													
Sharing of PI (3)	.164	.077												
Discussion and agreement (4)	-.046	-.196	.393**											
Assessment of PI (5)	.062	.107	.197	.301**										
Cooperation planning (6)	-.183	.009	.093	.376**	.551****									
Cooperation improvement (7)	-.070	.354**	.225	.143	.147	.323**								
Tools' usefulness (8)	.162	.000	.156	-.200	.048	-.035	.070							
Tools' accessibility (9)	.203	.244	-.157	-.292*	-.259	-.176	.178	-.014						
Training (10)	.064	.266*	.259*	.135	.356**	.234	.343**	.252*	.313**					
CTs usage score (11)	.413**	.479**	-.11	.032	.056	.083	.576****	.188	.344*	.436**				
Proficiency (12)	.218*	.248*	.058	.052	.029	.018	.370**	.213	.341**	.356**	.746****			
Process performance (13)	.452**	.428**	-.114	-.012	.004	-.007	.254	.249	.456**	.372**	.659****	.565****		
Innovativeness (13)	.329**	.282*	-.055	.101	-.175	.026	.284*	.303*	.493**	.076	.556**	.366**	.559****	
Product and manufacturing perf. (14)	.285	.429**	-.60	-.179	.102	-.199	.631**	.262	.239	.345*	.729****	.701****	.647****	.464**

*p<0.10, **p<0.05, ***p<0.001, ****p<0.0001

APPENDIX 22 – Normality test (Kurtosis & Sknewness)

	Virtuality	Cultural differences	Sharing of PI	Discussion and agreement	Assessment of PI	Coop. Planning	Coop. Improv.	Tools' usefulness	Tools' access.	Training
Kurtosis	-.520	-1.034	-.125	.670	-1.058	-.595	-.359	.827	1.077	-.462
Sknewness	-.787	-.070	-.643	-.829	-.493	-.269	.259	-1.042	-.739	-.749

APPENDIX 23 – Bivariate analysis: influence of the level of adoption

	T1 – low adoption (n_1 = 17)	T2 – moderate adoption (n_2 = 18)	T3 – high adoption (n_1 = 17)	K-W test	M-W test (T1,T2)	M-W test (T1,T3)
Control variables						
Project managers	.29	.32	.41	NS	NS	NS
Upstream specialists	.24	.16	.24	NS	NS	NS
Downstream specialists	.47	.53	.35	NS	NS	NS
Timing of inv. in team	4.88	4.94	5.18	NS	NS	NS
Time spent in the team	5.13	5.71	5.47	NS	NS	NS
Interactions with OEMs	2.38	2.11	**2.94**	NS	*	NS
Inter. with suppliers	3.56	3.21	**4.29**	NS	**	NS
Inter. with "same tasks"	5.38	5.16	5.06	NS	NS	NS
Inter. with "diff. tasks"	5.13	4.63	4.82	NS	NS	NS
Product newness	**5.87**	5.71	4.82	**	**	**
Manufacturing newness	5.17	5.11	4.64	NS	NS	NS
Man. trained & uses CTs	2.25	3.17	**3.88**	*	NS	**
Man. Under. CTs capa.	4.56	3.54	3.88	NS	NS	NS
Team context						
Virtuality	3.41	4.89	**5.24**	**	NS	**
Cultural differences	3.23	3.62	**4.31**	**	**	**
Collaboration activities						
Sharing of PI	4.79	4.35	4.74	NS	NS	NS
Discussion and agree.	5.16	4.53	**5.31**	NS	*	NS
Assessment of PI	3.71	**4.80**	4.27	NS	*	NS
Collaborative behaviour						
Cooperation planning	4.15	4.61	4.63	NS	NS	NS
Cooperation improv.	2.74	2.32	**3.77**	**	***	**
Implementation of the CTs						
Tools' usefulness	5.81	5.45	5.44	NS	NS	NS
Tools' accessibility	4.43	3.97	**5.18**	**	**	**
Training	3.50	4.24	**5.31**	*	*	**
Usage of the CTs						
CTs usage score	12	29	**51**	****	**	***
Proficiency	2.43	3.28	**4.82**	****	**	****
Product development performance						
Process performance	2.92	3.60	**4.57**	**	**	***
Innovativeness	3.64	3.92	**4.78**	NS	*	*
Product & manuf. perfor.	2.73	2.76	**4.01**	**	**	**

*p<.10, **p<.05, ***p<.001, ****p<.0001, all scales are 1 to 7 (1 disagree or low, 7 agree or high), except the CTs usage score and the role in the product development team (0: not, 1: have this role)