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A new model to select fasteners in design for disassembly

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Abstract

Product disassembly will only take place if there is enough generated profit. But as the end-of-life is often overlooked during the design process it makes the disassembly hard to perform and therefore the profitability is especially reduced. Design for disassembly is one of proposed solutions and fasteners are one of the points that have most impact on the disassembly of products. The aim of the proposed model is to determine among several alternatives which one allows to meet the requirements in assembly, in-use, services and disassembly. The model takes into account the semi-destructive disassembly (deteriorate a part of a sub-assembly to recover valuable components or materials and while reducing the disassembly time without important value loss). The model developed in this paper is mainly based on the Analytic Network Process (ANP) to define the best alternative and make the fastener selection during the design process easily. An example is presented for a better comprehension.

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1. Introduction

Having to take into account disassembly has become a necessity for manufacturers. Indeed, respect of the environment is a point more and more important and products cannot be developed without taking their environmental impact into account. So manufacturers have had to adapt to these new constraints. One possibility is to facilitate the revival of products at the end of their life to minimize their impact. For this it is necessary to design products taking into account disassembly that will be performed at the end of the life cycle in order to recover the parts or materials as efficiently as possible. Some manufacturers have well understood that end of life products are not only wastes and that they can derive many benefits from the disassembly. We can for example quote Fuji Film Co. Ltd, which produces single-use cameras [1]. A very thoughtful design allows efficient disassembly through an automated factory. By reusing parts and recycling materials, about 95% of the products weight is recycled. Moreover, the recovery of parts that are used in the manufacture of new products, allows reducing the time and the production cost.

Different methods have been developed to facilitate the work of designers, they are a part of the Design for Disassembly, DfD. Different approaches are possible as the optimization of disassembly strategy or techniques [2], the aspect that interests us more specifically is the choice of fasteners. They have a strong influence on disassembly and a poor choice of fasteners can cause a long and difficult disassembly and therefore significantly reduce profitability. The main problem that arises in the selection of fasteners is the consideration of all aspects of the different phases of the life cycle. An attachment must both, ease as much as possible the assembly, withstand stresses during use of the product and enable an efficient disassembly. The designer must therefore succeed in finding the best compromise.

Different methods of choice for fasteners have already been developed; we can first mention the method developed by Güngör [3]. This method relies on the Analytic Network Process (ANP). The different phases of the life cycle are taken into account with parameters representing the difficulties of assembly, number of fasteners, the required space, tools ..., others representing the constraints related to product use such as reliability or appearance and finally parameters representing the problems encountered during disassembly. The evaluation of alternatives is based on comparisons

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between parameters and cannot be enough accurate, moreover the method is long to set up and may lengthen the duration of the product development phase. Another method that we can quote was developed by Ghazilla et al. [4]. It uses the decision making method PROMETHEE with different qualitative and quantitative parameters which primarily represent problems related to the disassembly. Parameters related to the costs and physical properties of attachments are also taken into account.

The results obtained through these methods are interesting, but some aspects are not taken into account consequently the use of these methods is limited to certain cases. A very important aspect of the disassembly which is not considered is the possibility of a semi-destructive disassembly of the product. This involves destroying a fastener or a part to recover easily a more valuable part. The time saving is often important without losing many values compared to a non-destructive disassembly. The presented method addresses this disassembly aspect in order to offer a more complete method.

2. The ANP method

To assess the possible fastener alternatives to assemble a product we decided to use the ANP method developed by Saaty [5] which is a decision making method. This method has proven itself in various fields and allows evaluating different possibilities taking into account a large number of parameters. This method uses a system of pairwise comparison between the parameters related. We must determine which parameter is the most important and how many more important. A comparison scale was developed, ranging between equal importance of parameters until absolute importance of a parameter on another. Before performing these comparisons it is necessary to create the network that represents the problem studied by defining all the parameters taken into account and the links between them.

We tried to represent the majority of the problems encountered when selecting fasteners that are related to assembly problems, to the product use and to the disassembly process. The network that we used includes 4 groups, a group that includes the proposed fastener alternatives and a group for each of the product life cycle phases. The parameters included in these groups are detailed in the following sections.

2.1. Alternatives group

Before using this method it is necessary to define several alternative fasteners. These alternatives are included in this first group. The fasteners can be classified into different families according to their characteristics. Sonnenberg [6] proposes in his PhD thesis a separation into 5 main families:

- *Discrete fasteners*. These attachments are independent parts such as screws or rivets.
- *Integral attachments*. The attachments are integrated into parts and generally allow assembly without additional parts such as snap-fits.
- *Adhesive bonding.* The parts are linked with adhesive materials such as glues.
- *Energy bonding.* With an input of energy it is possible to create a link between parts. This is the case for the welding or soldering.
- *Other fasteners.* This family includes various types of fasteners like crimping or zippers.

2.2. Assembly group

This group includes the parameters that reflect the problems encountered during the product assembly. A literature review has allowed us to determine the useful parameters that are:

- *Number of fastener elements*. Depending on the type of fasteners used the number of parts will be more or less important. A small number of parts generally facilitates the assembly.
- *Space required*. Each type of fastener requires a minimum space to be installed which must be as small as possible.
- *Number of assembly steps*. This parameter affects directly the assembly time and therefore the profitability.
- *Probability of damage*. The assembly of the product can cause damage to the parts or the fasteners and thus reduce the quality of the product or force a replacement.
- *Cost of changes*. If a change of fasteners is chosen, the design of the parts must be changed. Depending on the type of attachment selected at the beginning the modifications will be more or less important.
- *Test difficulty*. To validate a design, tests are often necessary. Some types of attachments make these tests difficult.
- *Assembly complexity*. This parameter is actually a global parameter involving several other parameters and is calculated differently. We will detail the calculation in the next section.

2.3. Use of the product group

When using the product, several constraints must be respected. The parameters we chose are the following:

- *Ability to support different environments*. To ensure product reliability, fasteners must be able to withstand different conditions. Some attachments are more effective on this point and more resistant when there are problems with moisture or temperature variations.
- *Fastener reliability*. Ensure a reliable connection is a vital aspect to ensure product quality.
- *Effect on appearance*. The appearance of a product is important and depending on the type of fasteners selected the result will be different. This can lead the user to discard a product because he is no longer satisfied with the appearance of the product. An attractive appearance is a good marketing aspect but it also ensures a longer use of the product before its replacement.

2.4. Disassembly group

Choosing a type of fastener greatly influences the disassembly of the product. To represent the problems related to the disassembly we use the following parameters:

- *Allowance to automated disassembly*. With the automation of the assembly the assembly time of the products has been substantially reduced. This can be also possible for disassembly if the product was well designed.
- *Risk of parts deterioration*. During disassembly, parts can be damaged. This limits the possibilities of reuse. Fasteners ensuring disassembly without damage will therefore preferred.
- *Ease of resale*. A very specific design of parts due to the use of a type of fasteners may reduce the interest of the disassembly and limit the reuse of parts.
- *Disassembly complexity*. As for the assembly complexity this parameter is global that we will detail below.

3. Assembly and disassembly complexities

One problem with the use of the ANP method is the time required to perform all pairwise comparisons. To reduce this time we decided to use a global parameter that includes some parameters. This global parameter is calculated outside the ANP method. The number of parameters used in the ANP method is therefore reduced without loosing information.

3.1. Calculation of the assembly complexity

In a method developed by Das [7] that allows estimating the costs of disassembly and profitability of disassembly, a scale system is used to determine the Disassembly Effort Index (DEI). This score easy to calculate assesses the difficulties related to the disassembly. Tseng et al. [8] use a similar method of scale of value to estimate the liaison intensity among components. We decided to use a similar method to calculate the parameter named assembly complexity. The parameters taken into account in the calculation are:

- *Assembly time*. The assembly time is very important and should be as low as possible. For each alternative the assembly time will be different. To calculate assembly time we used the method proposed by Boothroyd [9] that allows a reliable estimate taking into account the geometry and the different techniques used.
- *Tools*. The tools necessary for the installation of a fastener can be complex and costly.
- *Access*. Some access directions to the work area are preferred to facilitate the assembly work.
- *Operators' qualification.* Some types of attachments require special skills that are additional costs to consider.
- *Required protective equipment.* To ensure the protection of operators some equipment may be necessary.

For each parameter a scale of value and a weighting were defined. With these scales of value a score is determined for each alternative. This score is then converted to be used in the ANP method. The calculation of scores is fast and simple, so it's easy to make changes to refine the calculations.

3.2. Calculation of the disassembly complexity

Operation is the same as before with parameters related to the disassembly. However, it is necessary to distinguish 2 cases. In fact, disassembly can be performed non-destructively or semi-destructively. The problems are different, so it's necessary to define two different scores with parameters adapted to the case studied. For non-destructive disassembly, parameters are :

- *Disassembly time*. The disassembly time is a determining parameter for the profitability of the disassembly. To estimate this time, we based on the results obtained by Kondo [10]. Disassembly of different products allowed obtaining accurate information on disassembly times of the various types of fastener. When the attachment is in good condition the disassembly time is close to the assembly time. But after some time of usage the disassembly time become more important. By estimating the average life span of the product it is consequently possible to apply a factor to the assembly time to get an estimate of the disassembly time. For assemblies using threaded attachments it is also important to take into account the degradation (corrosion, parts deformation) that greatly influence the disassembly time.
- *Tools*. More the tools complexity increase and more disassembly costs will be significant, attachments allowing disassembly with standard tools are therefore preferred.
- *Access*. Some access directions to the work area are preferred to facilitate the disassembly work.
- *Required force for the disassembly*. To unfasten an attachment a force must be applied that can be high and cause problems to machines and make the work of the operators more difficult. To estimate this force we use a method developed by Sonnenberg [6]. The force is determined by the dimensions and forms of fasteners used.
- *Fixture.* Before performing disassembly operations it is often necessary to fix the product. One hand can be enough but sometimes complex and expensive systems are required.
- *Operators' qualification.* Disassembly of a product requires a good knowledge of it. Depending on the complexity, time required for acquiring the right methods will be more or less important.
- *Required protective equipment.* Disassembly is usually done on products that are damaged and may contain hazardous materials.

Table 1 is an example of use of this method. For each parameter several cases are distinguished. A weighting is given to parameters. For the most restrictive case the maximum value of the weighting is given. Intermediate cases are getting more and more low values. Finally the sum of the values given to the parameters is made to obtain the final score. The higher this score, the higher the assembly or disassembly will be complex.

Table 1: Example of use of the scale of value

Parameters	Weighting	1	2	3	4	5	6
Disassembly time	25	10s	20s	30s	40s	50s	60s
Tools	10	None	Air gun	Basic	OEM	Special	Improvised
Access	15	Z axis	X/Y axis	>15cm deep	From below	Multi axis	Not visible
Force	20	0	20	40	60	80	100
Fixture	15	None	One hand	Two Hands	Clamps	System	Automated
Qualification	10	None	10-20 s	>30s	Discussion	Contact OEM	Training
Protective equipment	5	None	Gloves	Mask	Fire protection	Air supply	Body suit

In the case of a semi-destructive disassembly, parameters are somewhat different. It is no longer possible to determine the disassembly time in relying on the assembly time because the semi-destructive disassembly methods are totally different. So we had to find another way to obtain an estimate of the time. We chose to use the method MOST Work Measurement Systems [11] in order to estimate the time required to perform an operation. This method is easy to use and allows the calculation of time for all kinds of operations. Amelia et al. [12] use this method to estimate the disassembly time of a car door and identify the design mistakes that increase the disassembly time. Then we decided to replace the parameter 'Required force for the disassembly' that was difficult to use for a semi-destructive disassembly. To replace it we chose the parameter 'Strength of materials'. Indeed, the semi-destructive disassembly operations often require sawing, drilling or deforming parts. More a material will be resistant and more the effort needed will be high. The other parameters were kept.

We can get a score for each alternative whatever the type of disassembly chosen, however it is still necessary to correct the scores for the semi-destructive disassembly. Indeed, losses are often generated by this type of disassembly and resale of parts and materials is therefore less interesting. We must therefore make a correction to these scores to reflect this problem. For this we have identified 5 different cases in a semi-destructive disassembly and for each case a calculation is performed to estimate losses. Losses are calculated as a percentage of the maximum value that could be recovered if the parts were separated without damages.

- *Case 1: Materials recycling, same materials*. Disassembly is performed to remove the fasteners that could reduce the quality of materials or cause problems during recycling operations. Losses of value are caused by the degradation caused on the parts during the disassembly that reduce the amounts of recoverable material. Losses are measured as a percentage of the volume or a percentage of the mass of the part.
- *Case 2: Materials recycling, different materials.* The purpose of the disassembly is to separate the different materials present in the product in order to obtain a better quality compared to a recycling of materials by grinding the pieces and sort debris. Losses are always caused by the diminution of recoverable material. However, as the materials are different it is necessary to take into account the difference of the resale price. For this, a ratio of value is used (part 1 material is X times more interesting than part 2 material). With this report and evaluating weight losses or volume losses on parts it is possible to estimate the loss in value caused by the semi-destructive disassembly.
- *Case 3: Reuse of the parts, no damage caused during the disassembly*. This case represents the ideal situation or even by performing a semi-destructive disassembly the parts can be retrieved intact. This is for example the case for disassembly of some rivets, only the rivet is destroyed. No losses of value are generated.
- *Case 4: Reuse of the parts, some repairs is necessary.* The disassembly operations entail damage on parts that must undergo repairs before to be reused. The repair cost is estimated in percentage of the value of the piece. With a ratio of value between the parts (part 1 is X times more interesting than the part 2) it is possible to determine the overall losses.
- *Case 5: Reuse of some parts and materials recycling.* This last case arises when some parts have not enough interest to be recovered to be reuse, so only a recycling of materials is contemplated. The calculation of losses corresponds to a mix of cases 2 and 4. A ratio between the value of the recovered parts and the value of recycled materials is necessary (The part is X times more valuable than the recycled material).

The results for losses of value obtained in the different cases have to be weighted one compared from the other. Indeed, some cases are more interesting than others. Reuse a part is often more profitable than just recycle materials. If for example two alternatives of fasteners are considered, the first one allows reusing the parts and the second only allows recycling materials. It is then necessary to define a relationship between these two alternatives in order to reflect the differences (reuse the parts is X times more profitable than recycling the materials). Finally the results allow us to weight the disassembly complexities. A loss of 20% during a semi-destructive disassembly causes a 20% increase of the disassembly complexity.

4. Example

We will now discuss the application of this method on a simple case. We will consider the assembly of two blocks of plastics. The simplicity of the geometry will allow us to investigate different alternatives using fasteners belonging to the main families. The possible alternatives are a system with 4 bolts and nuts, an assembly with 2 screws through the blocks, 4 rivets, 4 cantilever snap-fits, an assembly by soldering and an adhesive joint. We will also distinguish two different situations, the first in which materials are recycled, and a second in which the parts are considered to be enough interesting to be reused. For each alternative we calculated the time of assembly and disassembly, the losses if a semi-destructive disassembly was performed, and the assembly and disassembly complexities. This information is summarized in Table 2.

4.1. First situation, materials recycling

In this situation, we just want to separate the materials to recycle them. For screws and bolts-nuts alternatives, the disassembly is done by unscrewing the fasteners to release parts. In the other cases a semi-destructive disassembly is required. The rivets are drilled, the cantilever snap-fits have to be deformed, and soldered assembly and adhesive assembly require a cutting of the product in order to separate the 2 parts. The cutting of the product causes a small loss of material unlike other technics.

Table 2 contains the assembly and disassembly complexities for each alternative. They are estimated on a scale from 0 to 100, the higher the score, the higher the assembly or disassembly will be difficult. We can see that the cantilever snap-fits get the lowest score. Integral attachments are indeed very well suited for the assembly because they minimize the number of components, enable a fast assembly and often without tools. For disassembly, the alternative using the screws is the most interesting because disassembly is easy to perform and fast enough. Cutting the product allow reducing the disassembly time, however it requires more resources and precautions. The complexities were then converted in order to be used in the ANP method. In this method it is possible to give more or less importance to groups. Depending on the objectives of the manufacturer it is possible to give more or less importance to the different life cycle phases of a product. We will detail two different cases. The first in which the phases are considered equally important and another in which the disassembly is considered much more important than the assembly and use phase. The results are listed in Table 3.

The results were standardized to facilitate the reading. The alternative with the lowest result is considered ideal and gets the 100% score. The other alternatives are estimated based on this ideal alternative. First of all, when the lifecycle phases are considered with an equal importance, the cantilever snap-fits appear as the best alternative. They have very good characteristics in assembly and during the phase of use of the product. Although disassembly is more difficult than with discrete fasteners, it remains relatively easy and does not involve loss. When disassembly is preferred cantilever snap-fits are always the ideal alternative but the gap is much lower with the others. Indeed the alternative using screws gets a great score and appears to be a good choice that will help facilitate the disassembly of the product and the materials recycling.

Table 2: Data on the alternatives

Alternative	Nut and bolt	Screw	Rivet	Cantilever	Welded	Glue
Assembly time	48,36 s	22,6 s	40,6 s	9,5 s	17 s	22 s
Assembly complexity	47,83	29,25	43,75	17,67	47,58	38,33
Type of disassembly	Non destructive	Non destructive	Semi destructive	Semi destructive	Semi destructive	Semi destructive
Disassembly time	45 s	20 s	19,44 s	13,68 s	7,56 s	7,56 s
Losses, 1st situation	/	/	0	0	3 %	3 %
Losses, 2nd situation	/	/	0	45 %	90,3 %	90,3 %
Disassembly complexity, 1st situation	43,08	33,5	35,83	35,83	43,78	43,78
Disassembly complexity, 2nd situation	43,08	33,5	35,83	51,96	80,88	80,88

Table 3: Results for the first situation

Example	Equal importance	Disassembly
Nut and bolt	49,41 %	77,49 %
Screw	62,38 %	93,95 %
Rivet	53,19 %	61,23 %
Cantilever	100 %	100 %
Welded	77,55 %	76,50 %
Glue	64,09 %	63,64 %

4.2. Second situation, part reusing

In this second situation, the alternatives are identical; assembly techniques and disassembly are also unchanged. However the end of life desired for parts is different. We will assume that the parts can be reused if they are recovered in good condition. Otherwise, material will be recycled. The value of the part is estimated to be 10 times greater than the value of the material. It is much more interesting to get the parts intact. The results obtained for the losses of values are given in Table 3. For the first three alternatives, the disassembly does not damage the parts and thus allows their reuse. For soldered and adhesive alternative, saw the product prevents to recover the parts. The loss of value is very important because the materials are far less interesting. Finally for the alternative using cantilever snap-fits it is only possible to recover the female part because the snap-fits are integrated on the male part and must be deformed to release the link between the two parts. Disassembly complexities have been modified with these new results of loss. The alternatives which do not allow reuse of the parts are heavily penalized and get a score much higher than previously. We then make a new calculation with the ANP method, the results are shown in Table 4, and two different cases are also presented.

Table 4: Results for the second situation

Example	Equal importance	Disassembly
Nut and bolt	50,78 %	82,16 %
Screw	64,06 %	99,85 %
Rivet	54,71 %	66,05 %
Cantilever	100 %	100 %
Welded	76,93 %	74,32 %
Glue	63,36 %	61,12 %

It is interesting to compare the results obtained in this situation with the previous results. We can see that the results are quite similar when the lifecycle phases are considered with an equal importance. Changes have been made to only one parameter among 14 which is not more important than the others. It is normal that the changes are quite low. The results are much more interesting for the second case. Indeed, the scores for alternatives that allow the reuse of parts have been increased by approximately 5%. Otherwise, the results for welded and adhesive alternatives that are less profitable are reduced by 2%. Furthermore in this situation, the alternative with screws can be considered as interesting as that with cantilever snap-fits.

Taking into account of losses related to different disassembly techniques, it is possible to refine comparisons between different alternatives and therefore provide more accurate results.

5. Conclusion

We have seen that the choice of fasteners is influenced by many parameters that make the choice difficult for designers. This choice is especially difficult because fasteners have a great influence on all phases of the life cycle of a product. This paper presents a new method to facilitate the selection of fasteners which allows comparing different alternatives based on different parameters representing all phases of the life cycle of a product as well as the different possibilities of disassembly. The integration of semi-destructive disassembly in this method provides more accurate results and allows considering an aspect of disassembly still few studied. The results obtained through this method provide a guide for designers in order to analyze possible fasteners alternatives. The method relies on numerous parameters that can be modified to best represent the constraints related to the product. The results are only a help during the decision making. The best result will not necessarily be the wisest choice. Other aspects such as the manufacturer's production means or the available technology should be taken into account.

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