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The core processes of project control: A network analysis

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Abstract

Project control requires many processes which differ from one project management standard to another. In this paper, project control is investigated based on two different standards: PMBOK and PRINCE2. The aim is to identify which processes are central to project control through network analysis. The results open up a new vision of looking at project control by stating that not only the traditional triangle of quality, time, and cost control but also change control and corrective action decision-making are at the core of project control.

Keywords: Project management; project control; PMBOK; PRINCE2; network analysis.

1. Introduction

Project control is of critical importance in project management. For this reason, project managers need to utilize proper project management methodologies to increase project success and to complete projects on time, within

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specified constraints, and with desired features. PMBOK (Project Management Body of Knowledge) and PRINCE2 (PRojects IN Controlled Environments) are among the most popular project management methods [1]. Since these standard methodologies have existed for a significant time, much literature is available [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15]. In short, given the major communalities and differences between the various standards (e.g., PMBOK, PRINCE2, ISO, BS 7000-2:2008, APMBOK and ICB), almost all authors recommended using different standards as complementary to each other. Researchers also tried to find the best combination of project management practices which are generally integrated together based on the three following steps. First, the main components of each project management methodology (e.g., PMBOK and PRINCE2) are determined. These components include principles, themes, processes and knowledge areas. These components are then compared, related and matched together based on a set of comparison criteria, namely by reviewing and examining the structure, strengths and limitations of each of the best practices [2, 9, 11]. Finally, the approach for combining two or more standards usually consists in mapping the processes of one standard (e.g., the 47 PMBOK processes) into the processes of another standard (e.g., the seven activities of PRINCE2). This results in a new methodology proposal that integrates the two standards. This new methodology can be shown in a process model [8].

In this paper, network analysis is used to help explain the two standards of PMBOK and PRINCE2 for the control of projects. Network analysis has been applied to project management in an attempt to improve the performance of projects. For example, Lee et al. [16] showed that degree and betweenness are the most influential centrality measures in the analysis of complex project networks. Zarei et al. [17] argued that network analysis can lead to a more comprehensive understanding of the main causes of delays in large and complex projects, allowing a better identification and mapping of the interrelationships between these key factors. The analysis showed lack of reviews, feedbacks and corrective actions to be the most significant factors. Zhang and Fang [18] used network analysis to show that the owner has absolute central position in construction project organization. In the past two decades, network analysis has emerged as a key approach for analyzing organizational behaviors in construction and other engineering projects and to provide a more relational, contextual, and holistic picture of project organizations in construction [19]. For example, Li and Lu [20] proposed a model of complex project management based on network analysis. Network analysis has been proposed as an analytical tool to explore a construction project as a temporary coalition network [21]. Finally, existing studies have revealed the strong abilities of network analysis in various topics encountered in construction projects, such as: performance and effectiveness; communication and coordination; knowledge management; risk management; governance issue; strategic management; information technology utilization and innovation diffusion; and site and resource management [19, 22].

This paper examines PMBOK and PRINCE2 control processes in order to identify their most central processes. The characterization of central features of project control within each standard will be achieved using network analysis. The reminder of this paper is organized as follows. The following section describes the two standards for project control, PMBOK and PRINCE2, presents the type of network representation that can be used to model these standards and introduces the statistical measures to analyze them. Section 3 then examines the network of PMBOK processes and the network of PRINCE2 activities for project control. A summary and conclusion close the paper.

2. Method

2.1. Project control standards

The PMBOK is a standard developed by the Project Management Institute (PMI) which describes methods, processes, techniques and tools applicable to the management of projects [23]. The PMBOK contains 47 project management processes, including eleven monitoring and controlling processes described in Table 1. These processes ensure that the project objectives are met by enacting change request plans whenever corrective actions are necessary [2]. Each process has inputs and outputs. An output from a process can be used as an input to another process. The inputs and outputs for each PMBOK control process are listed in Table 2.

Similarly, PRINCE2 is a structured but flexible, process-based project management standard developed by the UK Office of Government Commerce to improve the effectiveness of project management. PRINCE2 is composed of several principles, themes, and processes. PRINCE2 has 40 activities that are demonstrated throughout the project in the different processes. This compares to the 47 processes in PMBOK. PRINCE2 contains seven processes, including one control process that is a set of eight activities required to control a project. The purpose of the control process in PRINCE2 is to assign work to be done, monitor such work, deal with issues, report progress to the project board. and take corrective actions to ensure that the stage remains within tolerance. Again, each activity has inputs and outputs. Table 3 lists the project control activities identified in the PRINCE2 training manual [24]. The inputs and outputs for each PRINCE2 control activity are listed in Table 4.

Table 1. PMBOK project monitoring and controlling processes.

Process	Description
Monitor and control project work	Tracks, reviews, and reports the progress to meet the performance objectives defined in the project management plan
Perform integrated change control	Reviews all requests for changes or modifications to project documents, deliverables, baselines or the project management plan, and approves or rejects the changes
Validate scope	Formalizes acceptance of the completed project deliverables.
Control scope	Monitors the status of the project and product scope and manages changes to the scope baseline
Control schedule	Monitors the status of project activities to update project progress and manage changes to the schedule baseline to achieve the plan
Control costs	Monitors the status of the project to update the project costs and manages changes to the cost baseline
Control quality	Monitors and records results of executing the quality activities to assess performance and recommend necessary changes
Control communications	Monitors and controls communications throughout the entire project life cycle to ensure the information needs of the project stakeholders are met
Control risks	Implements risk response plans, tracks identified risks, monitors residual risks, identifies new risks, and evaluates risk process effectiveness throughout the project
Control procurements	Manages procurement relationships, monitors contract performance, and makes changes and corrections to contracts as appropriate
Control stakeholder engagement	Monitors overall project stakeholder relationships and adjusts strategies and plans for engaging stakeholders

Table 2. PMBOK project control processes: inputs (I) and outputs (O).

Processes	(1) Project management plan	(2) Schedule forecasts	(3) Cost forecasts	(4) Validated changes	(5) Work performance information	(6) Enterprise environmental factors	(7) Organizational process assets	(9) Work performance reports	(10) Change requests	(12) Requirements documentation	(13) Requirements traceability matrix	(14) Verified deliverables	(15) Work performance data	(18) Project schedule	(19) Project calendars	(20) Schedule data	(22) Project funding requirements	(24) Quality metrics	(25) Quality checklists	(26) Approved change requests	(27) Deliverables	(28) Project documents	(30) Project communications	(31) Issue log	(33) Risk register	(35) Procurement documents	(36) Agreements	(39) Project management plan updates	(40) Project documents updates	(41) Change log	(42) Accepted deliverables	(43) Organizational process assets updates	(44) Quality control measurements
(8) Monitor and control project work	I	I	I	I	I	I	I	O	O																			O	O				
(11) Perform integrated change control	I					I	I	I	I											O								O	O	O			
(16) Validate scope	I				O				O	I	I	I	I																O		O		
(17) Control scope	I				O		I		O	I	I		I															O	O			O	
(21) Control schedule	I	O			O		I		O				I	I	I	I												O	O			O	
(23) Control costs	I		O		O		I		O				I				I											O	O			O	
(29) Control quality	I			O	O		I		O			O	I					I	I	I	I	I						O	O			O	O
(32) Control communications	I				O		I		O				I										I	I				O	O			O	
(34) Control risks	I				O			I	O				I												I			O	O			O	
(37) Control procurements	I				O			I	O				I							I						I	I	O	O			O	
(38) Control stakeholder engagement	I				O				O				I									I		I				O	O			O	

Table 3. PRINCE2 project control activities: inputs (I) and outputs (O).

Activity	Description
Authorize a work package	Assigns and agrees a work package with the team manager
Review work package status	Checks on work package progress
Receive completed work package	Checks quality and configuration management
Review the stage status	Continually compares status to stage plan
Report highlights	Regulars reports to the project board
Capture and examine issues and risks	Categorizes and assesses impact
Escalate issues and risks	Creates exception report and sends to the project board
Take corrective action	Solves issue or risk while keeping stage within tolerance

Table 4. PRINCE2 project control activities: inputs (I) and outputs (O).

Activities	(1) Stage plan	(2) Project initiation documentation	(3) Team plan	(4) Corrective action	(5) New work package	(6) Stage authorization	(7) Exception plan approved	(9) Work package(s)	(10) Checkpoint report(s)	(11) Quality register	(12) Risk register	(14) Completed work package	(15) Configuration item records	(17) Product status account	(18) Issue register	(19) Project board advice	(21) Lessons log	(22) Daily log	(23) Highlight report (previous period)	(25) New risk	(26) New issue	(28) Tolerance threat	(29) Issue report	(32) Update stage plan	(33) Create work package(s)	(34) Update configurations item records	(35) Update quality register	(36) Update risk register	(37) Update issue register	(38) Authority to deliver a work package	(39) Update work package	(40) Project and approaching	(41) Stage boundary approaching	(42) Request for advice	(43) Update lessons log	(44) Update issue report	(45) Create highlight report (current period)	(46) Update daily log	(47) Create issue report	(48) Create exception report	(49) Exception raised
(8) Authorize a work package	I	I	I	I	I	I	I																	O	O	O	O	O	O	O											
(13) Review work package status	I		I					I	I	I	I													O		O		O	O		O										
(16) Receive complete work packages	I									I		I	I											O		O															
(20) Review the stage status	I	I		I O	O				I	I	I			I	I	I						O		O				O	O			O	O	O	O	O					
(24) Report highlights	I	I							I	I	I			I	I		I	I	I																		O				
(27) Capture and examine issues & risks	I	I														O				I	I							O	O									O	O		
(30) Escalate issues and risks	I	I									I				I							I	I					O	O							O				O	O
(31) Take corrective action	I			I O							I		I		I			I					I	O		O		O	O							O		O			

2.2. Network representation

In this paper, network analysis is used to identify the central control processes of both PMBOK and PRINCE2 standards. The structure of each network can be represented by a directed graph $G = (V, A)$ where $V = \{v_1, v_2,..., v_n\}$ is the vertex set and $A = \{(v_i, v_j) : v_i, v_j \in V \text{ and } i \neq j\}$ is the arc set. Vertices $v_1, v_2,..., v_n$ correspond to processes (PMBOK) or activities (PRINCE2), inputs or outputs. Arcs are used to represent associations between vertices, namely the inputs and outputs of each process. Specifically, if v_j is a process and (v_i, v_j) and (v_j, v_k) are two arcs, then the vertices v_i and v_k are called the input and output of the process v_j, respectively.

2.3. Network centrality measures

The position of a vertex within each network structure is used to determine the relative importance of the vertices in a network. Statistical indices, called *measures of centrality*, are used to identify core vertices of the networks. These indices, which quantify certain features of the networks and vertices, include degree, betweenness and closeness.

The *degree* of a vertex is a measure of the importance of the vertex in the network. Depending on whether a vertex has more incoming or outgoing arcs in a network, the vertex is said to have a high *indegree* or high *outdegree* centrality, respectively. The indegree of a vertex v_i is given by the number of arcs coming into this vertex and its outdegree by the number of arcs going out of this vertex. The indegree centrality can be seen as a measure of support and the out-degree centrality as a measure of influence [25]. Another way to measure the importance of a vertex is to consider the extent to which this vertex lies between other vertices in the network. Vertices with a good value of *betweenness* are critical vertices in the network structure since they usually have a network position (e.g., they lie on the paths between two nonadjacent vertices) that allows them to link different regions of the network [25]. Finally, vertices can be classified by considering the length of their shortest path to each other. Formally, this measure, called *closeness*, can be defined as the inverse of the average length of the shortest paths from all vertices to a given vertex in the network. The length of a shortest path from one vertex to another is defined as the minimal number of arcs linking these two vertices. The closeness centrality measure gives a good estimate of how easily a vertex can be reached in a network. Thus, a high closeness centrality means that the vertex is reachable via relatively few arcs. Usually, the closeness centrality measure is only computed for vertices within the largest component of the network. Table 5 indicates how the four measures can be computed. These metrics may need to be normalized in order to perform comparisons of the two networks.

Table 5. Centrality measures and associated centrality metrics.

Centrality measures	Centrality metrics
In-degree of a vertex v_i	$d_{in}(v_i) = \sum_{j=1}^{n} a_{ji}$, where $a_{ji} = 1$ if an arc exists from vertex v_j to vertex v_i and 0 otherwise
Out-degree of a vertex v_i	$d_{out}(v_i) = \sum_{j=1}^{n} a_{ij}$
Betweenness of a vertex v_i	$b(v_i) = \sum_{v_j, v_k \in V \setminus v_i} \frac{\sigma_{jk}(v_i)}{\sigma_{jk}}$, where σ_{jk} denotes the number of shortest paths between vertices v_j and v_k and $\sigma_{jk}(v_i)$ represents the number of shortest paths containing vertex v_i
Closeness of a vertex v_i	$Cl(v_i) = \frac{n-1}{\sum_{v_j \in V \setminus v_i} d(v_j, v_i)}$, where $d(v_j, v_i)$ denotes the length of the shortest path from vertex v_j to vertex v_i

3. Results

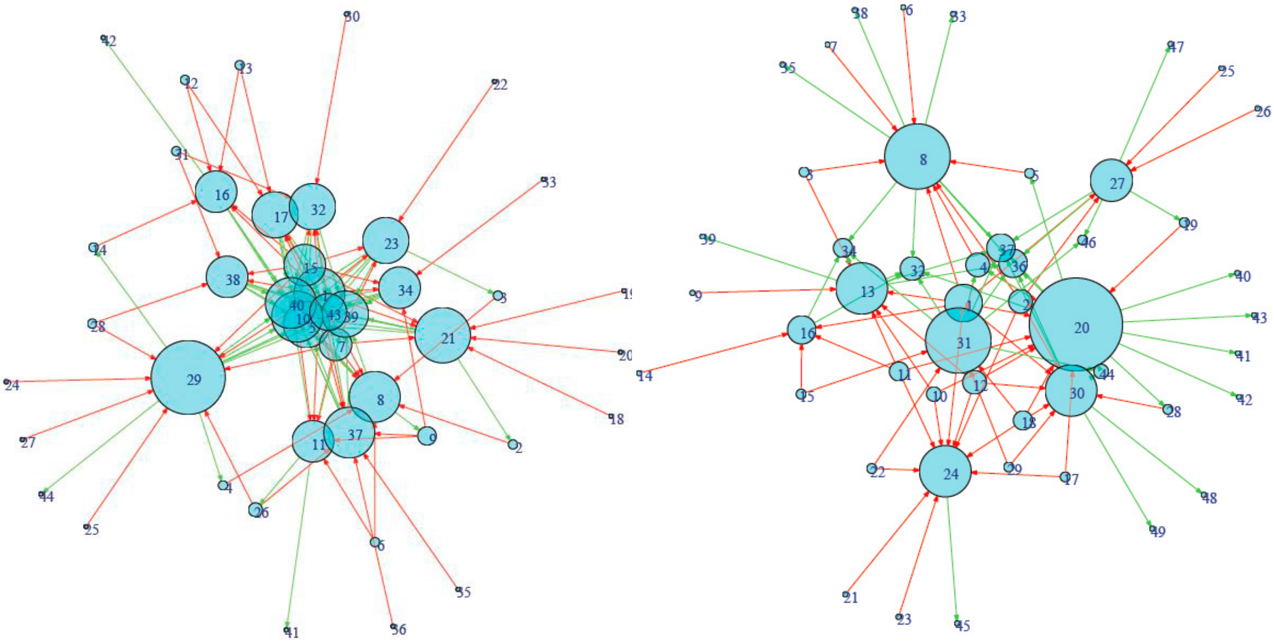
The two network models were constructed and analyzed in *R* (version 3.2.4) using the networkD3 package. The Fruchterman-Reingold force-directed layout algorithm was used for visualizing the networks [26]. In this algorithm, vertex layout is determined by simulating the whole graph as a physical system. Arcs in the graph are seen as springs binding vertices. Vertices are pulled closer together or pushed further apart according to attractive and repulsive forces, respectively. The objective of the algorithm is to minimize the overall energy of the whole system by adjusting the positions of the vertices and changing the physical forces between them so as to achieve an aesthetically pleasing graph layout.

3.1. PMBOK and PRINCE2 models

Fig. 1 (a) and (b) present the PMBOK and the PRINCE2 networks, respectively. The vertex numbers follow the numbering of the information presented in Tables 2 and 4. Vertex size represents the number of arcs incident to a vertex (degree centrality value). For each network, the relationship among vertices gradually structuralizes to form a hierarchical network topology from the center to periphery. Processes in the center of a network represent core items to the project control network. As shown in Fig. 1 (a), *Project management plan* (1), *Work performance information* (5), *Organizational process assets* (7), *Change requests* (10), *Work performance data* (15), *Project management plan updates* (39), *Project document updates* (40) and *Organizational process asset updates* (43) fell at the center of the

PMBOK network, suggesting that these inputs and outputs may be core to project control. In fact, all the processes of the PMBOK network (8, 11, 16, 17, 21, 23, 29, 32, 34, 37 and 38) gravitate around these core inputs and outputs. Most other inputs and outputs are positioned somewhat at the periphery of the network. Interestingly, among the eleven gravitational processes, the three processes of *Control schedule* (21), *Control costs* (23) and *Control quality* (29) together form a triangle in the network, suggesting that these key processes always need to be controlled. This result is consistent with findings related to the traditional viewpoint of project control where quality, time and cost are at the core of project control [3]. Key processes are often controlled first, while the other peripheral processes can be discarded or controlled at a later stage.

Similarly, as shown in Fig. 1 (b), the activity *Take corrective action* (31) and the inputs *Stage plan* (1) and *Risk register* (12) are at the center of the PRINCE2 network and can thus be considered as core elements to project control. The other seven project control activities (8, 13, 16, 20, 24, 27 and 30) are positioned not so far from the center of the PRINCE2 network. Nearly half of the inputs and outputs revolve around the center of the network (2, 4, 10, 11, 15, 17, 18, 22, 29, 32, 34, 36, 37, 44 and 46), while the others are located somewhat at the periphery of the network.

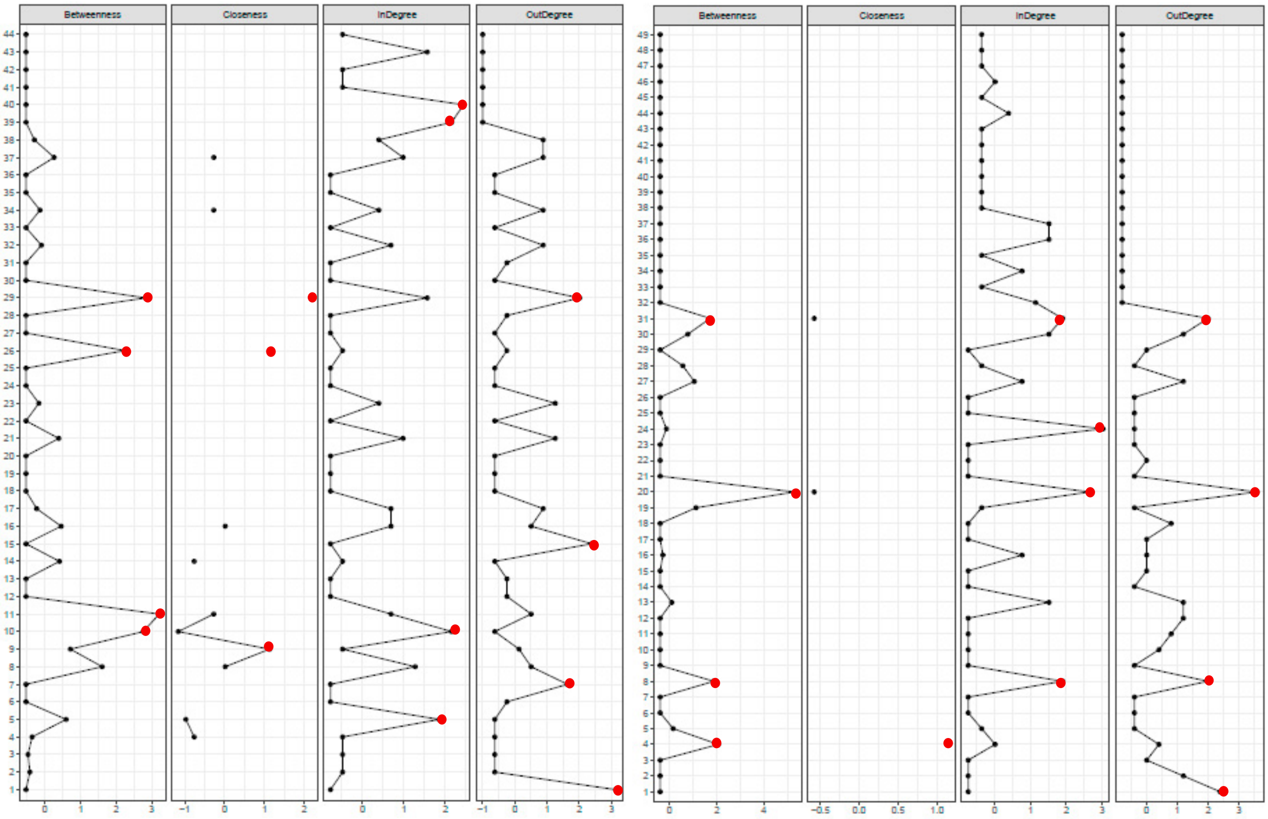


(a) (b)

Fig. 1. (a) PMBOK network; (b) PRINCE2 network.

3.2. Centrality indices

Fig. 2 (a) and (b) show the centrality indices for the PMBOK and the PRINCE2 networks, respectively. Higher numbers indicate that the element is more central to the network. Highest values are indicated within each index by a red dot. Values shown on the x-axis are standardized z-scores. The indices of centrality support the findings that *Project management plan* (1), *Work performance information* (5), *Organizational process assets* (7), *Change requests* (10), *Work performance data* (15), *Project management plan updates* (39) and *Project document updates* (40) are core inputs and outputs to the PMBOK network. Other inputs and outputs with high centrality include *Work performance reports* (9) and *Approved change requests* (26), while the *Performed integrated change control* (11) and *Control quality* (29) processes also have higher centrality. The indices of centrality for the PRINCE2 network also support the results of Section 3.1. *Authorize a work package* (8), *Review the stage status* (20), *Report highlights* (24) and *Take corrective action* (31) were the activities with the highest centrality, whereas *Stage plan* (1) and *Corrective action* (4) were the inputs and outputs with the highest centrality.



(a) (b)

Fig. 2. (a) Centrality indices for PMBOK network; (b) Centrality indices for PRINCE2 network.

4. Conclusions

Overall, one common theme emerged in these two networks: the center of each network is mostly composed of inputs and outputs, while processes gravitate around them. Several processes and activities of project control with high centrality were also identified: *Performed integrated change control*, *Control quality*, *Authorize a work package*, *Review the stage status*, *Report highlights* and *Take corrective action*. The *Take corrective action* (31) activity was identified as highly central to project control in the PRINCE2 network, while its PMBOK counterpart, *Perform integrated change control* (11) also had higher centrality. This finding supports research suggesting that corrective action decision making is central to project control [17]. Also, as highlighted by Khoja et al. [3] and Ghosh et al. [9], the major risks associated with any project are cost, time and quality. Interestingly, the PMBOK network highlights these risks as the three angles of a triangle, suggesting that this three tier structure needs proper control.

This study was limited to the analysis of PMBOK and PRINCE2 project control processes. However, many other global standards on project management are now available [9]. Standards worth mentioning include PMI Foundational Standards, PMI Practice Standards and Frameworks, PMI Standards Extensions, ISO 1006, P3M3, Australian Institute of Project Management, HERMES and Information Technology Infrastructure Library. Future research could thus use network analysis to incorporate information from these project management standards. Since each standard has its own strengths and weaknesses, the combination of the core elements of different standards would be distinct in designing a project management methodology for controlling projects. The ultimate goal being to the development of a fully integrated project management software that incorporates decision-aiding methods, techniques, and tools supporting the planning, scheduling, monitoring, and control functions of project management.

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