Project configuration by means of network theory

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Abstract

In this paper, we propose a novel approach to determine an appropriate sequence to develop the components of a project management plan. Some newcomers to project management become overwhelmed due to the complex relations within these components. Network theory is a widely used tool in fields with complex relations within entities, but it has not yet been applied to configure a project management plan. Although our approach is compatible with any project management standard, the Project Management Body of Knowledge (PMBOK) is an excellent example to illustrate how to apply this methodology due to the complex interdependence among its processes.

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1. Introduction

In recent years, due to enterprise’s environmental changes, many companies have orientated their activity to the execution of projects (PricewaterhouseCoopers, 2012). In this context, several authors have studied the relation between the project management discipline and project management success. For example, Dvir et al. (2003) suggest that even tough project success is not statistically influenced by the level of development of project management processes and procedures, it has a positively correlation with the definition of the project requirements and technical specifications. More recently, Fortune and White (2006) performed a wide literature review over 63 publications on project critical success factors, highlighting—among other factors—the importance of a strong/detailed plan kept up to date. Other recent studies also highlight the impact of project management on project success based on empirical data from project management professionals (Berssaneti and Carvalho, 2013; Golini et al., 2015; Joslin and Müller, 2015; Mir and Pinnington, 2014; Todorović et al., 2015). These studies evidence the importance of project management as a part of project success and thus justify the creation of a well-organized project management plan that ensures that this plan is distributed to all members of the project team and stakeholders of the project (Lester, 2014). Notice, however, that the project plan is only a part of project success. There are many other critical success factors related to goals well defined (Turner and Cochrane, 1993) and organization well defined (Basu, 2014).

Due to the wide diffusion of the Project Management Institute’s (PMI) standard “Project Management Body of Knowledge, PMBOK” (PMI, 2013) as a guide to create a project management plan, many authors have analyzed the relative importance of the PMBOK knowledge areas in project success. For example, Belout and Gauvreau (2004) analyze the impact of human resource management on project success, concluding that personnel factor is only a managerial variable, which is in concordance with the analysis provided by Pinto and Prescott (1988). Raymond and Bergeron (2008) highlight the importance of a project management information system based on an empirical study among 783 project managers and project management consultants; Davis (2014) studies the perception of project success by different stakeholders. In the same line, the empirical study among 783 project managers carried out by Zwikaël (2009) concludes that time, risk, scope and human
resources are the PMBOK knowledge areas that most influence project success. Therefore, there is not a general agreement on what knowledge areas are the most critical. In fact, as the PMBOK states, it is the responsibility of the project team to decide to what extent to develop each knowledge area in every particular project.

Creating a project management plan is one of the first challenges for a project manager. It is not an easy task due to the complex interdependence among its comprising documents: the elaboration of a document requires bearing in mind the information contained in other project documents and it often requires updating other documents already developed. Therefore, it is essential to develop a well-defined procedure that guarantees the coherency among the documents of the project management plan: the configuration management (CM) plan. The PMBOK defines CM as a subsystem of overall project management that deals with the following four aspects: version control, change control, changes notification and changes record (Project Management Institute, 2007). Karlsson and Ågerfalk (2004) propose a meta-method to facilitate configuration work based on pre-made configurations that can be used repetitively. However, configuring a project plan might still be challenging. For example, Ali and Kidd (2014) identify several barriers to effective implementation of CM such as the lack of effective CM tools.

The configuration of a project management plan is a complex system due to the relations among its components. Network theory is a powerful methodology that has been widely applied in complex systems and fields where there exists a strong interdependence within entities, such as biology (food chains, relations among organisms), medicine (disease diffusion), mathematics (graphs), technology (electric networks, transport networks), communication (the World Wide Web, social networks), etc. (Albert and Barabási, 2002; Newman, 2003) and more recently in supply chains (Wen et al., 2013). Moreover, network theory has been used to study other aspects related to project management such as stakeholders influences (Rowley, 1997). However, a review of the literature shows that network theory has not yet been applied to configure a project management plan.

Every project management plan can be modeled as a network, were each node represents a component from a project management plan and the relations among components are represented by links among the nodes of the network. This resulting network is complex as the obtained connectivity differs from a regular network (i.e. lattices) or a nearly-regular network (i.e. a random network) (da Fontoura Costa and Rodrigues, 2008). After the construction of the network, valuable conclusions can be drawn from the application of network theory as this article shows.

In this paper, we present novel approach to perform the configuration management plan based on network theory. We propose a method that yields an appropriate order in the elaboration of the components of a project management plan. The application of this approach will mitigate the difficulties involved in the creation of a project management plan by clarifying the relations among its components and thus helping projects managers to determine a sequence to develop the components of a project plan.

To illustrate the benefits of our method, we have applied it to the most spread standard in the project management discipline: the PMBOK. As it proposes the development of several documents that form a network, it is an excellent standard for testing its applicability. Other authors have previously proposed a list of tasks to be performed while creating a project management plan according to the PMBOK guidelines as, for example, Mulcahy (2013). However, the components of the project management plan and their interdependences were not analyzed.

Notice that the method presented in this paper can be applied to any project, regardless of the standard it follows. Furthermore, it can be used with large and complex projects with independence of the number of components comprising the project management plan.

The structure of the article is as follows. In the next section, we will explain how to construct a network based on the project plan documents proposed by the PMBOK 5th edition. Then, we will analyze the obtained network in order to discuss the most appropriate metric from network theory to determine a sequence for the elaboration of the components of a project management plan. Next, we will illustrate how to obtain this sequence by using in-degree, a metric from network theory. Finally, we will present the conclusions of this work and show further applications of our approach.

2. Construction of a network of project plan components based on the PMBOK

The PMBOK 5th edition addresses project management through the execution of 47 processes. The PMBOK describes each of these 47 processes with a number of inputs (i.e. units of information required to conduct the process) and outputs (i.e. units of information that can be developed by means of the execution of that process).

For example, let us focus on 1 of the 47 processes: ‘Define Activities’. The inputs and outputs of this process are depicted in Fig. 1. The aim of this process is to “break down packages into activities that provide a basis for estimating scheduling, executing, monitoring and controlling the project work” (PMI, 2013). So, what information serves as the basis for conducting this process? The PMBOK points out four items to bear in mind (i.e. inputs to this process, Fig. 1): schedule management plan, scope baseline, enterprise environmental factors and organizational process assets. As a result of the execution of the process, the following documents may be generated (i.e. outputs from this process): activity list, activity attributes and milestone list. Then, if we were to create one of these outputs, we should consider all the inputs in Fig. 1.

This means that these four elements should already been developed2 at this point. Now, the question would be: what

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2 According to the PMBOK, there is a strong interdependence among documents. This means a change in one document is likely to provoke a change in other documents. When the PMBOK indicates an input to a process it does not mean that input is necessarily completed. It means that it needs to be taken into account (if it exists). Furthermore, if that input is modified, the outputs from that process should be checked for possible changes.
information do we need to generate these four inputs? For example, if we focus on the scope baseline, the PMBOK states that this element is one of the outputs of the process ‘Create Work Breakdown Structure (WBS)’ (Fig. 2).

According to Fig. 2, in order to develop the scope baseline, we need to take into account several documents (inputs): scope management plan, project scope statement, requirements documentation, enterprise environmental factors and organizational process assets. Again, some of these inputs are outputs from other processes, which in turn require taking into account other inputs, which may be outputs from other processes and so forth. This leads to a complex interdependence among the documents needed for creating a project management plan.

In order to analyze the interdependence among the 47 processes’ inputs and outputs, we have constructed a network in which each node represents a component of a project plan. These components have been taken from the inputs and outputs of these 47 processes. For example, in Fig. 1, the four inputs (schedule management plan, scope baseline, enterprise organizational factors and organizational process assets) and the three outputs (activity list, activity attributes and milestone list) have been considered as nodes of the network. Following this idea, the consideration of the inputs and outputs of the 47 processes of the PMBOK 5th edition generates 75 nodes.

In our network, two nodes (e.g. nodes a and b) are linked by means of an arrow starting from node a and pointing at node b if the information contained in node a should be taken into account to generate the information in node b. In other words, we connect the outputs of each process with the inputs needed for their generation. For example, the relation between the inputs and outputs involved in the process ‘Define Activities’ (Fig. 1) gives rise to the network shown in Fig. 3.

The four nodes that represent the inputs of this process may receive links from other project documents if they are outputs from other processes. And in turn, the three nodes that form the output of this process will be linked to other project plan components documents if they are inputs to other processes.

The routine described above for one process is repeated throughout the 47 processes proposed by the PMBOK 5th edition taking into account the PMBOK’s diagrams but also the information that accompanies the diagrams. This results in a network with 75 nodes and 517 links (Fig. 4).

This procedure is independent from the particular project management standard that we use. Nevertheless, each standard might require some clarifications in the construction of the network. In the case of the PMBOK, the clarifications and hypothesis made during the construction of the network have been included in an appendix to this article.

3. Analysis of the resulting network with network theory

In the previous section, we obtained a network composed of 75 nodes (i.e. project plan components) and 517 links (i.e. relations within those project components). In this section, we will analyze the network in terms of network theory. We will calculate different metrics such as network density, network diameter, degree distribution, clustering and modularity. This analysis will show some characteristics of the network that might not be easy to see at first sight. Furthermore, it will let us find a metric that helps us determine a sequence to develop the components of a project plan. This sequence of documents will be presented in the following section. All the metrics analyzed in this section have been calculated using Gephi software.

3.1. Network density

Network density is the ratio between the maximum number of potential links a network can have and the number of links it actually has. In our network, the links have a direction associated

Fig. 1. Define activities. Inputs and outputs. Source PMBOK 5th edition.

Fig. 2. Create WBS. Inputs and outputs. Source PMBOK 5th edition.

Fig. 3. Network diagram of the process ‘Define Activities’.

Fig. 4. Network with 75 nodes and 517 links.
with them: a link starting from node $a$ and pointing at node $b$ implies that the information contained in the component represented by the node $a$ has to be considered when creating the component represented by the node $b$. However, two nodes, $a$ and $b$, can be linked in two directions. This means that after the completion of $b$, the component $a$ should be reviewed for possible changes. In terms of network theory, we say that our network is directed. When a network is directed (i.e., the links have a direction associated with them), the maximum number of potential links is $n \cdot (n-1)$ where $n$ is the number of nodes in the network. In our network, the maximum number of links would be: $75 \cdot 74 = 5,550$. The actual number of links in our network is 517. This means that it presents a density of $517/5550 = 0.093$. Networks with such a low level of density are called sparse networks (Black, 2008). Recall that the nodes in our network represent project plan components and the links represent relations within components. The fact of having a sparse network means that, when creating a new project plan component, the relative number of other components that directly affect it remains low.

3.2. Network diameter

The network diameter is the length of the shortest path (measured in links) between the furthest pair of nodes in the network. This concept could give us some idea of the maximum number of project plan components that we need to develop prior to creating another. However, the diameter of our network is infinite. This means that once you reach these nodes, you cannot move to any other node in the network, which makes sense as these components will only appear when the project is ending. Notice that having a fully connected network would hinder the development of the project plan as one could be indefinitely revisiting nodes (project plan components) even after the closure of the project.

3.3. Degree distribution

The degree of a node represents its number of direct connections with other nodes. A distinction has to be made between in-degree (i.e., the number of links that a node receives) and out-degree (i.e., number of links that depart from a node). Since our nodes represent project plan components, the in-degree of a node shows the number of documents that directly influences
the node, whereas the out-degree indicates the number of documents that this node influences directly.

The in-degree distribution of a network (Fig. 5) is a histogram that represents the number of nodes that have a certain level of in-degree. In this case, we see that most nodes (project plan documents) have in-degree about 4–5 (number of other documents that affect that document).

There are, however, two nodes with a strikingly higher in-degree: work performance information (26) and change requests (46). On the one hand, the document work performance information needs to collect information from many other documents to monitor and control the project progress. On the other hand, when the performance of the project requires a change request, most of the project documents need to be taken into consideration to assess whether they remain valid or need to be updated. It is also noticeable that there are six documents with in-degree 0, which means they are not influenced by any other project document. This is because they are external inputs to the project: project statement of work, business case, agreements, seller proposals, enterprise environmental factors and organizational process assets.

The out-degree distribution of the network (Fig. 6) shows that most documents directly influence few other documents. As an exception, there are two documents that directly influence many other documents: enterprise environmental factors (48) and organizational process assets (64). These values are so high because the elaboration of most documents requires the consideration of the context of the project. It is noteworthy that there are four nodes with out-degree 0: project calendars, selected sellers, final product, service or result transition and closed procurements. It is not surprising that the two latter documents have out-degree 0, as they are the results of the project. However, we cannot say the same about project calendars and selected sellers because they should be taken into account by the project manager while managing and controlling the project.

3.4. Clustering

Given two connected nodes (or neighbor nodes), clustering is the average probability of these two nodes having common neighbors. In this network, a high clustering coefficient would mean that the closely-connected documents have a higher number of connections among them than with other documents located further in the network. The average clustering coefficient of our network is 0.238. Considering that the value of this coefficient ranges between 0 and 1, we deduce that we are not in a strongly group connected network. We can reach the same conclusion by studying the clustering coefficient distribution: all nodes have a low clustering coefficient (Fig. 7).

3.5. Modularity

Modularity indicates how good the network can be divided into communities. A community is a group of nodes with a high density of connections within them and few connections to other nodes not belonging to that group (Newman, 2003). Modularity can take values from 0 to 1. A value of modularity close to 1 means that the network is appropriated for making this division. The modularity of our network is 0.284 and it is associated to four communities. The communities are shown in Fig. 4 in grayscale. Therefore, we conclude that the division is related neither to the PMBOK process groups nor to the PMBOK knowledge areas.

4. Obtaining a sequence to develop the project plan components based on the PMBOK

After the analysis conducted in the previous section, we consider that in-degree is the most suitable metric to obtain a sequence in the elaboration of the documents of a project plan because it easily allows identifying the documents whose inputs have already been developed. Let us recall that the in-degree of a node (i.e. a project plan component) indicates the number of documents needed to elaborate that component. Therefore, the presence of node (document) with in-degree 0 means that we already have all the required information (inputs) for its elaboration.

The procedure that we have followed to obtain the sequence for the elaboration of the documents is the following: first, we use Gephi software to seek for nodes with in-degree 0. As these documents have all the information they need to be developed, they are added to the sequence for the elaboration of documents. Then, we delete the documents with in-degree 0 (as they have already been developed). Afterwards, we use Gephi to recalculate the in-degree of the remaining nodes in the network (i.e.
documents that are pending to be developed). Then, we seek for the nodes that currently have in-degree 0 and so forth. In the event of not finding a node with in-degree 0, this criterion will be replaced for the project manager’s experience. Fig. 8 shows a flow diagram for this process.

4.1. Step 0: Initial network

The initial network has six nodes with in-degree 0: project statement of work, business case, agreements, enterprise environmental factors, organizational process assets and seller proposals. None of these elements are components of the project plan but external inputs that we need to take into account when starting to develop the project plan.

4.2. Step 1

The first project document we can elaborate is the project charter, as it is the only node with in-degree 0 at this point.

4.3. Step 2

Once the project charter has been developed (i.e. its corresponding node is removed from the network) there is only one node with in-degree 0, the configuration management plan, which will be the next document to be developed.

4.4. Step 3

After eliminating the node related to the configuration management plan, we get several documents with in-degree 0. This means we can elaborate all of them at the same time. These documents are: scope management plan, requirements management plan, schedule management plan and cost management plan.

4.5. Step 4

At this step there are no nodes with in-degree 0. This means that we cannot continue using the criterion applied in the previous steps to determine the next document to be developed. In order to find it, we will use the project manager’s experience instead.

If we check the processes that belong to the initiating process group (Develop Project Charter & Identify Stakeholders), we realize that there is a process that we have not carried out yet: Identify the stakeholders. Its corresponding node in the network (stakeholder register) has, however, in-degree 1. The reason for this is that suppliers are key stakeholders but the procurement documents have not yet been developed. Nevertheless, we can identify many other stakeholders at this point and update this document at a later point in time, once the suppliers have been assigned with the procurements. In conclusion, the next document that should be developed is the stakeholder register.

4.6. Steps 5 to 12

The following list shows the documents to be elaborated in the subsequent steps according to the criterion we established: developing the documents with in-degree 0.

- Step 5: Communications management plan, risk management plan and stakeholder register.
- Step 6: Requirements documentation and requirements traceability matrix.
- Step 7: Project scope statement.
• Step 8: WBS (work breakdown structure).
• Step 9: WBS dictionary.
• Step 10: Scope baseline.
• Step 11: Activity list, activity attributes and milestone list.
• Step 12: Project network diagrams.

4.7. Step 13

At this step there are no nodes with in-degree 0. This means that we will need to use the project manager’s experience again.

Because the document project network diagrams has already been performed, a project manager would probably now want to estimate costs, resources and activity durations. Moreover, these three estimations should be made simultaneously due to their interdependence (notice that, in general terms, the more resources assigned to an activity, the higher the cost and the shorter the duration). In the following paragraphs we will argue why the following five documents should be developed at this step: activity resource requirements, resource breakdown structure, activity cost estimates, basis of estimates and activity duration estimates.

If we observe our network, it might seem that we do not have all the required information to perform these five documents. The apparently needed documents (and not yet performed) are listed below:

• To develop the activity resource requirements&resource breakdown structure we need the human resource calendar, the procurement resource calendar, the risk register and the activity cost estimate.
• To develop the activity cost estimates&basis of estimates we need the project schedule, the risk register and the human resource management plan.
• To develop the activity duration estimates we need the risk register, the resource breakdown structure, the activity resource requirements, the human resource calendar and the procurement resource calendar.

A project manager would probably wonder if she needs all this information to produce the five documents. The following is an explanation of the reasons why this information is not in fact indispensable:

• Human resource calendar: If it refers to the periods of time in which the resources are idle/occupied, this information will only be available once we have assigned the resources to the activities. However, if it means when the resources in the organization are available for assignation, this information is in fact an organizational process asset.
• Procurement resource calendar: We do not need this information at this point, as we have not assigned resources to the activities yet.
• Risk register: This document has not been developed at this point. However, the project manager may now want to create a preliminary risk register that helps her to estimate resources, costs and durations. Therefore, the risk register (at least in a preliminary version) is the next document that should be developed at this step.
• Human resource management plan: This management plan has not yet been performed. However, at this point, the only piece of information needed to complete this plan is precisely the “activity resource requirements”. Consequently, we propose to develop the human resource management plan while estimating the activity resource requirements.
• Project schedule: In order to estimate the cost of the activities, we need to take into account the project schedule (e.g. some activities might be more or less costly depending on the dates they are executed). However, in order to develop the first version of the project schedule will obviously need the activity duration estimates. Therefore, the complete project schedule is not necessary at this point.

In conclusion, in step 13 the following documents can be generated: risk register (a preliminary version), activity resource requirements, resource breakdown structure, activity cost estimates, activity duration estimates, human resource management plan and basis of estimates.

In step 14, the nodes corresponding to the documents developed in step 13 will be deleted from the network, except for the “risk register”, as we only have a preliminary version of this document.

4.8. Step 14

At this point, we have two documents with in-degree 0: human resource calendars and project staff assignments. If we follow the in-degree criterion, these are the two documents that we should perform. However, if we stop and think as a project manager, we realize that the creation of the human resource calendars requires the project schedule to be able to assign staff to the activities; otherwise we may provoke resource over allocation. However, the project schedule has not yet been performed. Although the PMBOK does not take this connection into account, we will add this missing link for the sake of coherence in the elaboration of the documents. Fig. 9 shows the connections among these nodes.

Therefore, now we wonder what documents we need to develop the project schedule. Apart from the documents that we have already performed, we need the human resource calendars, the project staff assignments and the procurement resource...
calendar. These three documents, in turn, require the completion of other documents that have not yet been performed:

- To develop the human resource calendar we need the project schedule.
- To develop the project staff assignments we need the project schedule.
- To develop the procurement resource calendar we need the procurement management plan, the source selection criteria, make or buy decisions, procurement documents and the procurement statement of work.

Following this reasoning, we see that all the documents above are related in a loop. Consequently, our interpretation is that they should be developed simultaneously. In conclusion, at this point we should develop the following documents: procurement management plan, source selection criteria, procurement documents, make-or-buy decisions, procurement statement of work, project schedule, human resource calendar, project staff assignment and procurement resource calendar.

4.9. Step 15

At this step, we have three documents with in-degree 0: team performance assessments, selected sellers and procurement agreements.

Although it might seem contradictory to do the team performance assessments before the execution of the project starts, it still makes sense: if the project team capabilities and competences are evaluated before the project starts, only then we will be able to take actions to develop the appropriate skills.

4.10. Step 16

At this step, we find that there are no nodes with in-degree 0. However, among the nodes with in-degree 1, there are seven documents that only need the risk register to be developed: quality management plan, process improvement plan, schedule baseline, schedule data, project calendars, cost baseline and project founding requirements. Therefore, if we again resort to the project manager’s experience, we would update the risk register—which we had already started to develop in step 13—and then perform the documents mentioned above.

Notice that at this point, the nodes corresponding to the documents developed in step 16 will be deleted, except for the “risk register”, as we only have a second version of this document.

4.11. Step 17

At this step, the only node with in-degree 0 is the project management plan, so this is the time to develop it. Moreover, among the documents with in-degree 1, we verify that quality metrics and quality checklist only need the risk register to be elaborated. Therefore, we will also be able to develop these three documents at this point, taking into consideration the second version of the risk register that we created in step 16.

4.12. Step 18

The single node with in-degree 0 is close procurements. However, this is not a document we can elaborate at this point as we are still planning the project. In fact, in order to close the procurements, we should consider the work performance information (a document we have not developed yet) despite the fact that the PMBOK does not show this relationship.

If we pay attention to the documents that belong to the planning process group and have not yet been developed, we will find that those from the Risk knowledge area are pending to be elaborated. In order to develop the risk register, however, we need the issue log, and this document has not yet been performed. This document will be developed while executing the project and managing the stakeholders engagements. Following this argumentation, the issue log should be an input to the documents elaborated while controlling the risks and not while planning them. Therefore, what we should do at this point is to complete the risk register.

4.13. Step 19

After developing the full version of the risk register in the previous step, we will be able to perform the qualitative risk analysis and the quantitative risk analysis.


Once the qualitative and quantitative risk analysis have been developed, we will be able to plan the risk responses. This is the last document we need to complete the project plan. Notwithstanding, at this point, a project manager might want to revise the entire plan taking into account the risk analysis, following good practices proposed by the PMBOK.

4.15. Step 21

At this point, the project has already started. A project manager will have to control and track the progress of the project. Change requests related to any aspect of the project might be appearing over time. If that should happen, we would have to register changes in the change log and decide whether to approve or deny them. Moreover, we would have to register all the approved changes (which would be included in a document called approved change requests) and validate them (which would appear in a document called validate changes).

While monitoring the execution of the project, the project manager has to control scope, schedule, cost, quality, stakeholder engagements, procurements, communications, risk and the overall performance of the project. These tasks involve creating the following documents: work performance data, quality control measurements, issue log, cost forecast and schedule forecast. Considering all these data, we will be able to develop the work performance report and subsequently the work performance information. All this relevant information will be registered in the document project communications.
Once the deliverables are completed, we will be able to verify them (yielding verified deliverables) and get them accepted (accepted deliverables). After the deliverables have been accepted, we will be able to close the project with the final product, service or result transition and closing all the procurements (yielding closed procurements).

Through these 21 steps, we have proposed a sequence for the elaboration of the project plan components. A summary of this process is shown in Fig. 10. Nevertheless, it is important to mention that the project plan has to be a coherent document. This means that when we develop a project document, it is often necessary to review other documents elaborated in previous steps in order to make changes or update information. For example, if we find that the project finish date is beyond the deadline, we should reconsider reducing the project scope, providing the project activities with more resources, subcontracting a part of the project, etc. Therefore, the sequence of documents proposed in this paper should be viewed as a clarifying guide of the complex relations among processes presented in the PMBOK.

![Fig. 10. Proposed sequence for the elaboration of a project plan.](image-url)
5. Conclusions

In this paper, we have proposed a novel method to configure a project management plan. This method is based on network theory, a powerful methodology that has been widely applied in other fields where there exists a strong interdependence within entities. Since a project plan consists of a set of documents that depend on one another, we believe this is the most appropriate approach for its configuration. Notwithstanding, a review of the literature has shown that network theory has not yet been applied to this complex task.

To illustrate how to use the method proposed in this paper, we have applied it to the standard project management discipline: the PMBOK. Through the use of our method, we have constructed a network with the documents of a project plan and their relations according to the PMBOK 5th edition, analyzed its properties and proposed a sequence for their elaboration.

However, in the particular case of the PMBOK, the presence of loops in the network makes it impossible to find an optimal sequence in the elaboration of the project documents. This fact was expected, as a project plan can be seen as a complex system due to the high interrelations within its documents. In fact, creating a new project document often requires checking and reviewing other documents that have already been developed.

We reached the conclusion that the best way to obtain a sequence in the elaboration of the project plan documents is combining a criterion based on network theory (specifically, in-degree) and the project manager's experience. Despite the fact that the project manager’s experience is necessary to configure the project plan, network theory allows us to deal with Complexity more easily; our work proves that software for network analysis such as Gephi is really useful as a tool for project management configuration. For example, once the project plan documents and their relations have been introduced in Gephi, one can easily see what components we need to perform a particular project document.

Following the PMBOK’s philosophy, the order of the processes proposed in this article corresponds to the most complete case: a hypothetical project that requires all of the processes (including all the inputs and outputs) proposed by the PMBOK. Consequently, a real-life project will result in a less complex network (i.e. fewer nodes and links).

Our approach also allows us to identify what documents we have to update when modifying a particular document: we have to check all the documents that are at the same step and onwards. For example, as we see in Fig. 10, if we modify the activity list we have to update all the documents from step 11. With this information, we can easily develop an automatic system that warns the project manager about the documents to be updated.

Furthermore, according to the PMBOK, it is the responsibility of the project team to select the processes and project documents that will be useful for a particular project. Therefore, each project team will determine what documents are necessary to develop their project with independence of the standard used. Our tool, which is appropriate for configuration management regardless of the particular documents defined to manage the project, provides a straightforward way to find out how the information flow changes in the network when we decide not to include a particular document in a project plan or when we decide that some components could be merged in one. We can do this simply by removing the node corresponding to the project document that will not be developed and redefining the relations involving that particular node. Therefore, this tool is especially useful for the management of large and complex projects. Our approach enables the project manager to check if the changes made in the project plan configuration simplify or conversely it complicates the relations among the documents due to the potential emergence of new loops. This was a challenging goal to achieve prior to the introduction of our method. In addition, this approach can be easily extrapolated to other parts of the project: it can be used while defining the relations between activities, work-packages, deliverables, milestones, etc.

Focusing on the analysis of the PMBOK 5th edition, we have reached some specific conclusions:

- The analysis of the clustering coefficient and the modularity class in the network shows that the relations between project documents are not strongly influenced by the process group or knowledge area they belong to. Therefore, the classification of documents and processes in knowledge areas or process groups that we find in the PMBOK is a useful description to understand the aspects we have to manage and when we have to manage them. However, our study concludes that the relations of documents within a particular knowledge area or process group are not more frequent than the relations of documents of different knowledge areas. This means that a project is a complex system that should be managed as a whole and not area by area.
- The analysis shows that the components change requests, work performance information and risk register are key documents while developing and managing a project. In our network, the most important documents correspond to nodes with a high number of links. Particularly, the degree distribution of the network shows that these three components are the most connected. This fact is in accordance with other works such as Dvir and Lechler (2004) who emphasize the negative impacts of goal changes in the project (which shows the importance of change management while executing a project); Raymond and Bergeron (2008), who highlight the importance of a management information system to make decisions during the project execution (notice that work performance information is, in fact, a part of a management information system) and Zwikael (2009) who indicates that Risk Management is among the PMBOK knowledge areas which most influence project success.
- While constructing the PMBOK network, our tool identified some unspecified and ambiguous relations between documents. For example, in our opinion, project calendars should be an input while monitoring and controlling the project. On the other hand, selected sellers and work performance information should be and input to close procurements, etc.
The application of the approach that we have presented in this paper might contribute to improve the robustness of the relations among project documents towards future editions of the PMBOK.

In spite of the novel findings presented in this article, the limitation of this work is that the conclusions should be validated by a detailed field research and/or a case study. However, this field research and/or case study is beyond the scope of this paper.

**Conflict of interest**

There are no conflicts of interest.

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**Appendix A. Hypothesis and clarifications during the construction of the PMBOK 5th edition network**

Although the mechanism to build the PMBOK network may seem straightforward, there are several important issues to consider:

A.1. The process “Develop the Project Management Plan”

According to the PMBOK guidelines, the project management plan (PMP) includes the project baselines, the subsidiary plans and other important information such as the tools and processes selected by the project team. We will refer to the part of the PMP that contains the selected tools and processes as configuration management plan (CMP).

The PMBOK 5th edition does not use any term to refer to the ensemble of all the documents generated to manage the project. For the sake of clarity, we named that collection of documents project plan. Therefore, in order to manage the project, we need to develop a project plan, which is composed of a PMP and other project documents.

The PMBOK states: “any baselines and subsidiary plans that are an output from other planning processes are inputs to this process”. One of these subsidiary plans is the scope management plan, which is an output from the process Plan Scope Management. Therefore, we need the PMP to create the scope management plan, but, at the same time, the scope management plan is one of the inputs of the process ‘Develop the Project Management Plan’. The same thing occurs to other subsidiary plans.

From our perspective, this loop is a consequence of the two types of information included in the PMP: the baselines and subsidiary management plans (which will only be available after the planning phase) and, the CMP (which will be available from the start of the project). Due to the different information contained, we have split the PMP in two different nodes: the CMP and the PMP itself.

Whenever a process in the PMBOK has the PMP as input, we need to decide to which node it should be connected: the PMP or the CMP. We link the inputs from all the planning processes with the CMP and the inputs from the execution and control processes with the PMP.

The PMP and the CMP will share three inputs: project charter, enterprise environmental factors and the organizational process assets.

A.2. Clarification in the designation of some documents

Some documents (inputs or outputs) of the PMBOK are given the same designation although they refer to different concepts.

The document ‘Resource Calendars’ can refer to human resources calendars or procurement calendars. In the sake of the coherence, we have considered two different documents (nodes): human resource calendars and procurement resource calendars.
The document ‘Agreements’ can refer to procurement agreements or business agreements. To avoid the confusion, we have considered two different documents (nodes): procurement agreements and business agreements.

Something similar happens in the knowledge area Risk Management: the name ‘project document updates’ is somewhat ambiguous. In order to build a coherent network, we have changed the name given to the outputs (which yet does not contradict their philosophy). The output from the process ‘Perform Qualitative Risk Analysis’ will be qualitative risk analysis. The output from the process ‘Perform Quantitative Risk Analysis’ will be quantitative risk analysis. Finally, the output from the process ‘Plan Risk Responses’ will be risk responses. The relation between these elements is shown in Fig. 11.

In addition, some processes have excessively general inputs. For example, the following documents have not been implemented in the network due to their generality: project document updates, project documents, outputs from other processes, organizational process assets updates, enterprise environmental factors updates and project management plan updates.

A.3. Exceptions while defining the connections of the nodes

In the process Direct and Manage Project Work, the input ‘approved change requests’ has not been linked to the output ‘change requests’. When the aim of this process is to generate a change request, it makes no sense to have the approved change requests as inputs. For the same reason, the input ‘validated changes’ has not been linked to the output ‘change requests’ in the process Monitor and Control Project Work.

According to the PMBOK, the outputs from the process Create the WBS are the scope baseline and project documents updates. Scope baseline is the name given by the PMBOK to a set of three documents: the project scope statement, the WBS and the WBS dictionary. Therefore, in the construction of the network we need to split the scope baseline into these three elements. The relations in the process “Create WBS” is shown in Fig. 12.

