A capacity management tool for a portfolio of industrialization projects

Caio Lima[0000-0001-7655-0621], Anabela Tereso[0000-0001-9802-0074], Madalena Araújo[0000-0002-3515-0135]

Production and Systems Department/Centre ALGORITMI, University of Minho, Campus of Azurém, 4804-533, Guimarães, Portugal
caiofurtado17@gmail.com, anabelat@dps.uminho.pt, mmaraujo@dps.uminho.pt

Abstract. The management of a project portfolio is a complex decision process because it encompasses the achievement of multiple objectives. A critical point that increases the complexity in the decision-making process of a portfolio manager is the allocation of human resources to manage the projects of the portfolio, project managers, which is crucial to the organization's performance. In this case, the project manager can manage more than one project simultaneously and it is necessary to assign project managers to the projects, considering that project activities have an amount of work to be accomplished. The main objective of this work was to provide support for this capacity management problem, which aims to provide an easier decision-making process for the capacity management of an industrialization project portfolio. Therefore, it was developed: a hybrid model that creates a schedule respecting the resource constraints and the established due dates; a recommendation system that considers project managers' allocation and projects requirements; and, an automatic status report that allows identifying the project portfolio capacity usage.

Keywords: Industrialization Projects, Project Management, Portfolio Management, RCPSP.

1 Introduction

Project Portfolio Management (PPM) is a complex decision process, once it seeks to achieve multiple objectives, as better profitability and better use of organizational resources. Abrantes and Figueiredo [1] describe that the change in a project that belongs to a portfolio implies consequently a cascading effect in the portfolio, which results in a scenario of uncertainty and instability. This unsteady scenario may result in resource conflicts, leading to the challenge of gathering useful information about the capacity status, strategic objectives, and resources for the decision-making process. This is similar to the case under study.

Oh, Yang and Lee [2] argue that strategies could be implemented in project portfolio management through a decision-making process that focuses on expected objectives. The authors further add that building a strategic portfolio that considers the business objectives and constraints is so important as it is challenging. Due to the complexity and the dynamic environment in project portfolio management, the application of traditional tools and techniques in the most complex contexts may be inappropriate, so it emerges the need to develop new tools and techniques to better manage the project portfolio providing clear results and to identify critical information, laying down an easier path in the decision-making process [3].

The present work was carried out at a company that belongs to the automotive industry and is responsible for industrialization projects. The main work purpose was to develop a tool that aims to help in the capacity´s management of an industrialization project portfolio. Therefore, to develop the tool it was necessary to develop three main work packages: implement an exact mathematical model and a hybrid model to create the project schedule; develop a recommendation system for assigning projects to a Project Manager (PjM); and, create an automatic status report about the portfolio.

This paper is organized as follows. After the introduction, Section 2 presents the literature review relevant to the context of the study. Section 3 brings forward the methodology adopted to develop the tool. Section 4 describes the problem statement and Section 5 presents the developed tool. Finally, the main conclusions and suggestions for further work are presented in Section 6.

2 Literature Review

Industrialization projects are understood as projects that are related to the design of the manufacturing line to produce a certain product, which aims to reduce costs and increase the production capacity of the manufacturing line [4]. This kind of environment has become more complex and developed challenges in management; thus, many organizations have implemented the quality-gate model as a way to manage the new product development and to ensure that the objectives are met to advance to the next phase [5].

Project Management (PM) is commonly related to processes and tools used to accomplish a temporary and unique work within a specific time, budget and scope, being them the elements of the golden triangle, also known as success criteria for project management. Radujković and Sjekavica [6] claim that the golden triangle overlooks other aspects that the PjM is responsible for managing, which is beyond these elements. Ponsteen and Kusters [7] dissert about a crucial element for PM success, the resource allocation for project execution and management. A class of problems that focus on generating a suitable schedule of a set of activities with scarce resources is well-known as Resource-Constraints Project Schedule Problem (RCPSP). In this class of problems, preemption is not allowed. Tian and Yuan [8] argue that RCPSP arises in the context of approximating the project schedule methods with real problems and describe that RCPSP problems have been classified as NP-Hard. NP-Hard problems have been solved recurring to a considerable number of exact and heuristic solutions, purposely developed in recent years as we can see in Chakrabortty et al. [9] and Kolisch and Hartmann [10]. Thus, RCPSP solutions have been following the trend, and many approaches have been developed for RCPSP as Mixed-Integer Linear Programming

(MILP) formulations, heuristics and metaheuristics. Borak and Karl [11] add that the use of heuristic and metaheuristic methods, in recent years, has attracted a lot of attention, which has resulted in the development of hybrid models, that is, the integration of these techniques with exact models for solving problems classified as NP-Hard. This kind of techniques are also called *matheuristics*. Again, RCPSP can profit from the application of hybrid models, therefore considering the many approaches to the RCPSP. For the present work it is important to present a classic Integer Linear Programming (ILP) formulation for the RCPSP and the selected *matheuristic* on which the hybrid model was based.

The ILP formulation used in this work can be described as follows. The RCPSP comprises a number of activities (*n*) to be scheduled and a number of resources (*m*) available. Then, the project is defined as a set of *n*+2 activities, where activity 0 and *n+1* are dummy activities, which are the beginning and ending activities of the project, respectively. The set of activities is represented by A = {1,…, n}, which must be scheduled according to the available resources, which belong to R = {1,…, m}. The precedence relations are given by a set P of pairs with index $(m, n) \in P$, that means the activity m is predecessor of n. The processing times or activity durations are represented by the vector d belonging to $\mathbb{N}^{n+2}$, where the *j*th term, d_j, is the duration of the activity. Each activity (*j*) needs an amount $r_{j,k}$ of resource *k* to be processed. Each resource *k* has a capacity of R_k. The decision variable is $x_{j,t}$, indicating that activity *j* starts at period *t*, where $x_{0,0}$ is equal to 1. The variable Z is the project makespan [12]. The set of activities that belong to the critical path of the activity network is represented by CP = $\{cp_1, \ldots, cp_n\}$. Thereby, the RCPSP mathematical formulation adopted in this paper can be represented as follows:

$$Minimize\ Z \tag{1}$$

$$\sum_{t\,=\,e_j}^{l_j} x_{j,t} = 1, \quad j = 0,1,\ldots,n+1 \tag{2}$$

$$\sum_{t\,=\,e_m}^{l_m} t * x_{m,t} + d_m \le \sum_{t\,=\,e_n}^{l_n} t * x_{n,t}\,,\ \forall\,(m,n) \in P \tag{3}$$

$$\sum_{j\,\in\,J_t} \sum_{q\,\in\,Sj_t} r_{j,k} * x_{j,q} \le R_{k,t},\ k = 1,2,\ldots,K; t = 1,2,\ldots,T \tag{4}$$

$$\sum_{t\,=\,e_j}^{l_j} t * x_{j,t} + d_j \le Z,\ \forall\, j\ without\ successor \tag{5}$$

$$\sum_{n\,\in\,CP} d_n \le Z \le \sum_{j=0}^{n+1} d_j\ ,\ j = 0,1,\ldots,n+1; n = cp_1,\ldots,cp_n \tag{6}$$

The objective function (1) represents the shortest time the project can be completed. Constraint (2) ensures that each activity can only be started once. Constraint (3) ensures that the precedence relationships in the activity network are respected. Constraint (4) ensures that at each instant of time (t), the resource consumption of activity (j) of each resource k will not exceed the allowed capacity $R_{k,t}$. Constraint (5) ensures that project completion Z will occur after the completion of the project end activities, i.e., the last project activities. Constraint (6) ensures that the shortest project execution time is longer than the critical project path duration and less than the sum of all project activity durations.

The *matheuristic* that the hybrid model used was based on the *Fix-and-Optimize Variable Neighborhood Search* (VNS). The basic idea is to refine a solution by iteration, with each iteration exploring the neighborhood of the current solution to look for a better one. In Maniezzo e Stutzle [13], the *Fix-and-Optimize* VNS is used, initially with a viable solution that considers the strong constraints of the problem, then changes are made to some variables of the mathematical model of the problem and, finally, the solver is called to optimize the problem.

3 Methodology

The present work aimed to develop a tool that gives support to the management of capacities in industrialization projects in an automotive industry, i.e., a tool that creates schedules without over-allocating the PjMs and provides the capacity status of project portfolio capacity according to PjM availability. Therefore it became necessary to understand the context where the research was done. Thus, as the research strategy aims to explore, describe or explain the object of study [14], for this research the strategy adopted was case study, since the present work was developed in a business environment. The methods adopted for data collection were document analysis, observation, interviews and focus group. Using the triangulation of these methods it was possible gathering all organization´s information about previously developed studies, management practices and the lifecycle of the industrialization projects in which this work was based. Thereby, all initial information was gathered and the context in which the tool would be applied was studied.

The Design Science Research (DSR) methodology, commonly used in the development of computational artifacts [15], was adopted in this study for the tool development process. The focus group was the research method used to evaluate the tool developed, in several cycles of the DSR methodology, allowing potential tool users to suggest and test the tool, helping to achieve the main expected tool requirements.

4 Problem Statement

The main objective of this work is the development of a tool that aims to support the capacity management of a portfolio of industrialization projects, that is, provide an easier decision-making process to reach a better Capacity Utilization Rate (CUR) [16]. Hence, three main objectives were established for the tool development. The first objective was to develop project schedules with project allocation profiles without over-allocating PjMs. The second objective was to develop a recommendation system for assigning PjMs to projects, thus allowing an allocation leveling of available PjMs to manage projects. Finally, the third objective was to develop an overview of project portfolio CUR.

To understand the developed tool, it is important to perceive the context of the industrialization projects management where this study was done. Projects in this organization have four categories (A, B, C, and D) and each category has a certain level of complexity and requirements for the PjM that can manage each type of project category.

Although projects have a category distinction, all projects are managed with a quality-gate system, where each Quality-Gate (QG) has a set of activities that need to be performed to be able to go to the next QG. It is important to note that each QG has project milestones (due dates), so it may be necessary to compress or decompress the activities that are between the QG's.

A standard project has a set of 45 activities, that are between five QG's and this is the standard activity network to all project categories. This project activity network, as mentioned, is standard and for projects with less complexity it may not be necessary to perform some activities, so these activities have duration and effort equal to zero. On the other hand, projects with greater complexity require higher effort and/or duration of project activities.

The relationship between effort and duration comprised in this paper follows Tereso et al. [17] description. Given a work content of an activity "a" (W_a) and the amount of resources allocated to that same activity, named as effort work (E_a), the duration of an activity (D_a) is given by expression (7).

$$D_a = {}^{W_a}/_{E_a} \tag{7}$$

Therefore, in scenarios where it is necessary to compress or decompress activities, the calculations accomplished by the tool always preserve the work content of each activity, so the duration and effort values can be changed, however, the amount of work is always preserved.

5 Developed Approach

This section intends to present how the main aspects of the tool, as well as the main objectives of this work, were achieved.

5.1 Project schedule

To achieve the objective of creating project schedules, each project was identified as consisting of five subprojects, in this case, five QG´s. The main constraint for activities scheduling of each QG is that the activities must perform until the due date or in the shortest feasible time and respect the resource availability. In case the activities must be scheduled in the shortest feasible time, the tool creates a schedule according to the ILP formulation for RCPSP previously described. Otherwise, if the QG has a due date, it may be necessary to compress or decompress project activities. The algorithm illustrated in Fig. 1 demonstrates the way that the schedules are developed in case of being necessary to compress or decompress activities. Using the preservation of work content, the activities have the duration, and so the effort, changed to reduce the Critical

Path Method duration (CPMd) of the project in order to reach the due date. Due to restrictions of the organization in which this study was developed the activities have an effort with a lower bound of 5% (0.05) and upper bound of 80% (0.80).

Compress	Decompress
Calculate schedule baseline and keep DDp EDc values	Calculate schedule baseline and keep DDp EDc values
Do	Do
If CPMd > DDp then	If CPMd << DDp then
For each i ∈ CPM activities Do	For each i ∈ CPM activities Do
Reduce CPM Activities Duration	Increase CPM Activities Duration
Calculate new effort (E2)	Calculate new effort (E2)
If E2 < 0.8 then	If E2 > 0.05 then
Keep E2 e D2	Keep E2 e D2
Else	Else
Keep previous duration and effort	Keep previous duration and effort
Else	Else
For each i ∈ CPM activities Do	For each i ∈ CPM activities Do
Reduce CPM Activities Duration	Increase CPM Activities Duration
Calculate new effort (E2)	Calculate new effort (E2)
If E2 < 0.8 then	If E2 > 0.05 then
Keep E2 e D2	Keep E2 e D2
Else	Else
Keep previous duration and effort	Keep previous duration and effort
Calculate new time schedule (DDp)	Calculate new time schedule (DDp)
While DDp > EDc	While DDp < EDc

Fig. 1. Algorithm to compress and decompress

In this way, the tool changes to the duration (D1/D2) of activities, and hence the efforts (E1/E2), that belongs to the critical path of the project in order to approximate the Ending Date of the project (EDp) of the schedule baseline to the Due Date of the project (DDp). Once the dates are closer, i.e., there is a scenario where it is possible to schedule activities within the expected due date, an interactive application of the presented ILP formulation, verification and adjustment process is accomplished with the intent to build a feasible scenario and find the best schedule of activities. Thus, Fig. 2 illustrates the entire project schedule construction process performed by the tool. The algorithm (the exact formulation or the hybrid model) is selected in each QG to create the project schedule.

The time it takes the tool to find the solution may vary, due to the level of activities' to compress/decompress to respect the due dates. The average run time for the project with 45 activities without due dates is 35.56 seconds, and with due dates it is 168.70 seconds. As literature refers, the use of metaheuristics helps to reduce time to find solutions, with less complexity that can be easier to implement in the organizational environment. Therefore, being the algorithm easier to model and program, any further improvements of the algorithm can be easily accommodated in order to make it more competitive concerning computational time.

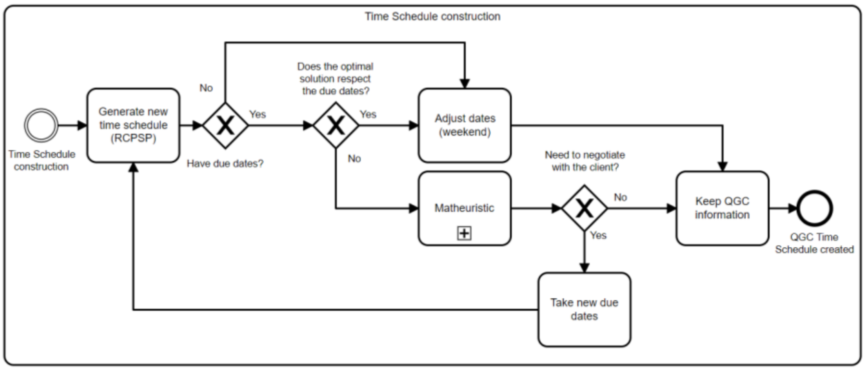

Fig. 2. Construction process of project schedule

5.2 Recommendation system

In order to achieve the objective of creating a recommendation system, it was necessary to develop a formula that reflected the real PjM allocation during the considered period. Usually, as dispersion measures are sensitive to outliers [18], the developed formula seeks to mitigate the variation in the amount of PjM's work over the considered period.

$$CV = {}^{S}/_{\bar{X}} \quad (8)$$

To understand the PjM allocation calculation, it is necessary to explain the concept of Coefficient of Variability (CV). This measure expresses the data variation regarding the average [19], as expressed in (8). After this value is calculated, it is identified whether the PjM allocation is representative or whether adjustments to the average PjM allocation are required. The average adjustment is made according to the coefficient of variability, i.e., the higher the CV, the higher the average adjustment will be required. This adjustment assumes the standard deviation as weight (9).

$$NC = \bar{X} \pm (CV * S) \quad (9)$$

Finally, although the tool considers the requirements necessary to manage the project and, thus, filters which managers may be eligible (have the necessary requirements and are not over-allocated) to manage the project, the decision-making process of assigning a project to a PjM is considered a non-linear process, because there are variables that are beyond those considered in the tool, as organization´s objectives, for instance. In this way, it is necessary a holistic view of the organization itself, which increases the complexity of the decision-making process. Therefore, at the end of the recommendation process, a PjM ranking list is displayed, so that the portfolio manager can choose from among the possible managers who is the best to manage the project and takes the decision in line with other objectives that are not considered by the tool.

5.3 Portfolio report

To achieve the third objective, the tool creates an automatic report and it is always updated when a new project is inserted. This report aims to provide the user with an overview of the portfolio capacity utilization. Fig. 3 illustrates some graphs used in this report.

Briefly, this report contains graphs that identify the number of projects by category and how these projects are distributed within the sectors of the organization. It also provides a project portfolio resource allocation status and this information can be segmented by sector. Then, it is also possible to find out which is the most contributing sector to the identified scenario.

It is also important to mention other two aspects of the report. The first aspect is the recommendation of the minimum appropriate number of PjMs required, given the number of projects considered in the tool. The second aspect is that the report aims to be iterative, enabling scenario simulations regarding project portfolio capacity to facilitate the project portfolio manager in the decision-making process.

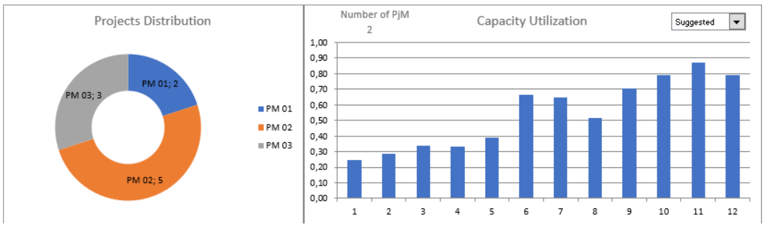

Fig. 3. Some graphs of the portfolio report

6 Conclusions and Future Work

The present work aimed to develop a tool that would help in the portfolio management of industrialization projects. The work has been developed in a case study context and had three main objectives.

The first objective was to develop schedules in line with the required due dates. This objective was achieved by using an ILP formulation for RCPSP and a developed hybrid model that adjusts the critical path activities to compress or decompress and thus interoperate with the ILP formulation to create a schedule that respects project due dates and the resource (PjMs) availability. The second objective has been achieved with a project recommendation system to PjMs so that it did not result in an over-allocation of PjMs. This objective was achieved using some statistical concepts that can quantitatively identify the PjM's allocation and through a ranking list shows which PjMs can better manage that project. The last objective was to create a report that provided a sector status and give support to the project portfolio managers in the decision-making process. This objective has been achieved in the elaboration of a report that enables the identification of capacity status as well as the identification of which sector has contributed the most to the identified scenario. Also, this report makes possible to accomplish the simulation of different scenarios for capacity utilization and the suggestion of a minimum number of PjMs for the portfolio.

As suggestions for future work, a critical point would be to implement improvements to the algorithm, such as adding other heuristic or metaheuristic techniques that adjust more efficiently and faster to develop the schedule. In addition, for future work, we suggest making improvements to the recommendation system, which considers only two variables at the moment – PjM allocation and project requirements. Other relevant variables can be included, namely taking into account the previous experience of PjMs with different customers or project owners, matching the industrialization project with the most experienced manager with the specific project owner, if available. The extension of the proposed solutions to other kind of specific human resources, as the key stakeholders, i.e., the core team, is also under consideration.

Acknowledgements. This work is supported by: European Structural and Investment Funds in the FEDER component, through the Operational Competitiveness and Internationalization Programme (COMPETE 2020) [Project nº 39479; Funding Reference: POCI-01-0247-FEDER-39479].

References

1. Abrantes, R., Figueiredo, J.: Resource management process framework for dynamic NPD portfolios. Int. J. Proj. Manag. 33, 1274–1288 (2015). https://doi.org/10.1016/j.ijproman.2015.03.012
2. Oh, J., Yang, J., Lee, S.: Managing uncertainty to improve decision-making in NPD portfolio management with a fuzzy expert system. Expert Syst. Appl. 39, 9868–9885 (2012). https://doi.org/10.1016/j.eswa.2012.02.164
3. Manole, A.L., Grabara, I.: Methodologies and visualization tools of effective project management. Polish J. Manag. Stud. 14, 137–149 (2016). https://doi.org/10.17512/pjms.2016.14.2.13
4. Perrotta, D., Araújo, M., Fernandes, G., Tereso, A., Faria, J.: Towards the development of a methodology for managing industrialization projects. Procedia Comput. Sci. 121, 874–882 (2017). https://doi.org/10.1016/j.procs.2017.11.113
5. Chirumalla, K.: Managing Product Introduction Projects in Operations: Key challenges in heavy-duty vehicle industry. J. Mod. Proj. Manag. 5, 108–118 (2018). https://doi.org/10.19255/JMPM01512
6. Radujković, M., Sjekavica, M.: Project Management Success Factors. Procedia Eng. 196, 607–615 (2017). https://doi.org/10.1016/j.proeng.2017.08.048
7. Ponsteen, A., Kusters, R.J.: Classification of Human- and Automated Resource Allocation Approaches in Multi-Project Management. Procedia - Soc. Behav. Sci. 194, 165–173 (2015). https://doi.org/10.1016/j.sbspro.2015.06.130
8. Tian, X., Yuan, S.: Genetic algorithm parameters tuning for resource-constrained project scheduling problem. In: AIP Conference Proceedings. p.

040059 (2018)

9. Chakrabortty, R.K., Sarker, R., Essam, D.L.: A Comparative Study of Different Integer Linear Programming Approaches for Resource-Constrained Project Scheduling Problems. Presented at the (2018)
10. Kolisch, R., Hartmann, S.: Experimental investigation of heuristics for resource-constrained project scheduling: An update. Eur. J. Oper. Res. 174, 23–37 (2006). https://doi.org/10.1016/j.ejor.2005.01.065
11. Borak, S., Karl, W.: Matheuristics. Springer US, Boston, MA (2010)
12. Artigues, C., Brucker, P., Knust, S., Koné, O., Lopez, P., Mongeau, M.: A note on "event-based MILP models for resource-constrained project scheduling problems." Comput. Oper. Res. 40, 1060–1063 (2013). https://doi.org/10.1016/j.cor.2012.10.018
13. Maniezzo, V., Stutzle, T.: Matheuristics 2016 - Proceedings of the Sixth International Workshop on Model-based Metaheuristics. IRIDIA, Bruxelles (2016)
14. Saunders, M., Lewis, P., Thornhill, A.: Research Methods for Business Students. (2016)
15. Shrestha, A., Cater-Steel, A., Toleman, M., Rout, T.: Benefits and relevance of International Standards in a design science research project for process assessments. Comput. Stand. Interfaces. 60, 48–56 (2018). https://doi.org/10.1016/j.csi.2018.04.011
16. Wang, D., Wan, K., Song, X., Liu, Y.: Provincial allocation of coal de-capacity targets in China in terms of cost, efficiency, and fairness. Energy Econ. 78, 109–128 (2019). https://doi.org/10.1016/j.eneco.2018.11.004
17. Tereso, A., Araújo, M., Elmaghraby, S.: Adaptive resource allocation in multimodal activity networks. Int. J. Prod. Econ. 92, 1–10 (2004). https://doi.org/10.1016/j.ijpe.2003.09.005
18. Peck, R., Devore, J.L.: Statistics - The exploration & Analysis of data. Brooks / Cole (2010)
19. Keser, İ.K., Kocakoç, İ.D., Şehirlioğlu, A.K.: A New Descriptive Statistic for Functional Data: Functional Coefficient Of Variation. Alphanumeric J. 4, (2016). https://doi.org/10.17093/aj.2016.4.2.5000185408