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DEVELOPMENT OF A FRAMEWORK FOR MANAGING CAPACITIES AND SCHEDULES IN INDUSTRIALIZATION PROJECTS: A CASE STUDY IN THE AUTOMOTIVE DOMAIN

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ABSTRACT

The behaviour of the current competitive markets makes project management one of the distinctive factors in companies' success. Its practices have revealed to be crucial in deadlines accomplishment, costs reduction, quality requirements satisfaction, among other benefits. This research was developed as a case study in an automotive company with the aim of developing a framework for visual management of capacities in industrialization projects to tackle overload situations of project managers. The model developed considers industrialization project management a standard process that usually calls for a tipical set of activities, whose duration and effort are defined according to project complexity. The proposed activity scheduling process results from an adaption of Heuristic based Priority Rules, aligned with the problem specifications.

INTRODUCTION

The competitiveness faced nowadays leads companies to invest more and more in robust project management practices. Actually, this field supports project's complexity through standardized processes. As a result, it is possible to perform activities in tight schedules and use resources in an efficient way without compromising quality requirements (Popa & Tanasescu, 2010).
The company under study has developed its own project management practices and tools in the light of what is established by well-known institutions, of which Project Management Institute (PMI) is an example. The study reported in this paper was made in a department of an automative company responsible for industrialization projects. Project management has been considered a core competency at the company due to its huge dimension, the increase in the number of projects and the multinational dependencies. In this context, the present research comes up from the necessity of managing human resources capacities in industrialization projects. This issue is directly related to projects scheduling since it involves the allocation of project resources (Al-jibouri, 2002). The aim is the development of a tool capable of helping the Program Managers to assign a new project to the most suited Project Manager, taking into account his availability. The research work was divided in four main work packages:

- Understanding the relation between Project Managers' qualifications and projects' complexity.
- Defining the industrialization projects' general work packages.
- Collecting data related to the work packages' duration and effort.
- Implementing a Construtive Heuristic, adjusted to the context with a Resource Constraint Project Schedule Problem mindset.

This paper begins with a Literature Review, followed by the Research Methodology. Based on theoretical knowledge acquired and on the pratical envolvement in the company, the Problem Statement and a Conceptual Model are presented. The main contribution of the study is addressed in the Heuristic Approach section. To finish the paper the main Conclusions and suggestions for Further Research are presented.

LITERATURE REVIEW

Many authors and institutions have been defining "project", according to different contexts and research purposes. According to PMI (2017), it is defined as a temporary effort with the aim to create an exclusive product, service or result. To this fundamental definition, concepts related to resources, costs and quality have been added. In the industrialization area, project management processes must also be coordinated with product development processes. To help on this alignment, PMI introduces the concept of "Project Management Process Groups" which integrates the project management life cycle with the product life cycle. The role of a Project Manager (PjM) is to follow and cover the life cycle of the project, from the beginning to its closure. As human resources, project managers are resources limited in their per unit of time availabilty. Multiple projects competing for limited resources make project management a complex procedure. In entrepreneurial environments, it is also common to have programs: a group of related projects, managed in a coordinated manner to obtain benefits. Thus there is the need to have a higher management layer where the Program Manager (PgM) play an important role.While the PjMs manage the project team to meet the project objectives, the Program Manager (PgM) monitor the progress of the program components to ensure that the overall goals, schedules, budget, and benefits of the program will be met.

As the type of projects under scrutinity in the present research are industrialization projects, it is now important to address its uptake.

Industrialization Projects

Industrialization projects encompasses questions related to the development of the product in order to make it ready for mass production and the design of assembly lines able to produce the developed product . During this process it is necessary to identify and understand clients' requirements. In fact, product maturation depends on the requirements fulfillment evaluation. Industrialization projects processes commonly follow a *stage-gate system*. Straightforwardly, an industrialization project is composed of phases (stages) where prototypes are developed and subsequently evaluated at *quality-gates*. During the phases, project managers are called to perform certain tasks regarding the fulfilment of project management standard documents, not to mention the responsibility of following-up the samples developed in each phase (Perrotta, Araújo, Fernandes, Tereso, & Faria, 2017).

Effort vs. Duration

To understand this study, the notions of duration, effort and the relation between them are needed. As the name suggests, effort is defined as the amount of work. In other words, effort is the number of time workers spend focused on a particular activity. On the other hand, duration is defined as the entire time taken to complete an activity. It stretches from when the activity first began to the day it ended (Barry, Mukhopadhyay, & Slaughter, 2002). The relation between effort, resource quantity and time is commonly expressed by:

$$Y_a = \frac{W_a}{x_a} \qquad (1)$$

It can be read by saying that the allocation of x_a units of the resource throughout the execution of activity a, which requires W_a effort, results in duration Y_a (Tereso, Araújo, & Elmaghraby, 2004).

Collecting and grouping the main project manager's activities between *quality-gates* are one of the goals of this study. Likewise, understanding and gathering information about the duration of each work package, as well as the effort required to its execution, are the intermediate steps before considering scheduling issues.

Project Scheduling with Resources Constraints

As the present study was carried out under an industrial context, it was decided not to consider optimization models to deal with the problem due to its expected complexity. Therefore, heuristics strategies were considered, and constructive heuristics strategies were selected from the set of possible approaches, as explained subsequently. Although belonging to the oldests solutions methodology to solve the Resource Constrained Project Scheduling Problem (RCPSP), constructive heuristics are still the most important (heuristic) solution technique. Evidence for this is borne out by Kolisch (1996) research. He defends the method as intuitive and easy to use, fast in terms of computational effort and the one that shows better results when the multi-pass implementation is used. Generically, constructive heuristics hold two crucial components (Kolisch, 1996): *Scheduling generation scheme* and *priority rules*. The first is the nuclear piece of heuristics used in the generation of RCPSP solutions and it is based on a *forward planning* strategy. In other words, each activity is only scheduled after finishing all of its predecessors (*finish-to-start* logical relation between activities is considered). Two different schemes can be distinguished: *serial* and *parallel* method. Despite their own properties, what they have in common is that in each stage of the scheme generation a set of all schedulable activities is formed, the so-called decision set. They can be adapted to the problem of selecting the project manager and scheduling the corresponding project management activities, having into account his/her availability. In order to choose one or more activities from the decision set to be scheduled,

priority rules are employed There are several priority rules that can be used to prioritize an activity, e.g.:

- Shortest Processing Time (SPT): based on activity information;
- Most Total Successors (MTS): based on network information;
- Earliest Finish Time (EFT): based on schedule information;
- Greatest Resource Work Content (GRWC): based on resources information.

For the present study, a single-pass implementation is considered.Moreover, as the serial scheme method generates a set of solutions where the optimal solution can be included, contrarily to the parallel scheme method (Kolisch, 2000), the former method was selected to be used in this research.

Serial Scheduling Scheme

Proposed by Kelley and Walker (1959), the *serial scheduling scheme* is a method that consists of $n = 1, \ldots, N$ stages, in each of which one activity is scheduled considering precedences and resources constraints. The number of stages equals the total number of problem activities represented by set J. Associated with each stage there are two disjoint activity-sets: the set of already scheduled activities S_g and the decision set D_g:

$$D_g = \{ j \in J \setminus S_g \mid P_g \subseteq S_g \} \qquad (2)$$

with j as an activity contained in the set of all activities of the problem J, such that all its predecessors (P_g) are contained in the set of already scheduled activities. The junction of sets S_g and D_g may not represent all the activities of set J. There are activities not able to be scheduled in stage g due to their predecessors being not scheduled yet. In each stage, one activity from D_g is selected with a priority rule (smallest activity number is the most elementary rule) and scheduled at its earliest precedence and resource feasible start time.

Also,

$$RD_k\,(t) = R_k(t) - \textstyle\sum_{j \in A(t)} r_{j,k} \qquad (3)$$

Is the left over capacity of the renewable resource k at instant t. Its value is the result of subtracting the resource k usage of all activities performing in t to the total capacity R_k of resource k.

Another set used in the algorithm is CF_g:

$$CF_g = \{F_j \mid j \in S_g\} \qquad (4)$$

which represents the finish times F_j of already scheduled activities j. The implemented algorithm is explained in the following pseudo-code.

```
Initialization: $F_0 = 0, S_0 = \{0\}$
For g = 1 to n
{
    Calculate $D_g, F_g, RD_k(t)$
    Select j $\in D_g$
    $FMC_j = \max_{l \in P_j}\{F_l\} + p_j$
    $F_j = \min\{t \in [FMC_j - p_j, \infty] \cap CF_g \mid r_{j,k} \leq RD_k(\tau), k \in K, \tau \in [t, t + p_j[ \cap CF_g\} + p_j$
    $S_g = S_{g-1} \cup j$
}
End
```

Algorithm initialization assigns 0 to the *dummy activity* ($j = 0$) finish time F_0 and includes the dummy activity in the scheduled set. At the beginning of each stage g, the set of available activities to be scheduled D_g, the set of finish times F_g and $RD_k(t)$ are calculated. The last is calculated for each resource and finish time contained in F_g. Further, it is selected an activity j from the set D_g. Previously, the finish time of j is calculated without considering resources limitations (FMC_j), only the maximum finish time of its predecessors is assumed. By the end, respecting resource availability, it is found instant t that corresponds to the finish time F_j of activity j, being this one added to set of already scheduled activities S_g. This algorithm is the core of the tool proposed to answer to the company requests, being adapted to the problem of selecting the project manager and scheduling the corresponding project managements activities, having into account his/her availability, as explained in the Problem Statement section.

RESEARCH METHODOLOGY

The model developed in this research will be applied to an automotive domain specific company. It means it is necessary to understand the context, to observe and collect information about the purpose of the tool as well as qualitative and quantitative data to the model inputs. Therefore, the research follows a case study strategy. Case studies allow researchers to focus in a particular phenomenon and discover crucial knowledge (Saunders, Lewis, & Thornhill, 2009). In this research, the case study outcomes are a blended learning of documentation analysis and a semi-structured group interview with Program Managers. To understand the project management practices and industrialization projects life-cycle in the company, a documentation analysis was done. In theory, projects are monitored in appropriate platforms. Nevertheless, the analysis of data, contained in these platforms, allows to conclude that there is no rigorous and detailed project progress recording. The scarcity of useful information lies not only in activities duration and effort required but it also fails at the beginning, when PjM activities to be performed between quality-gates, are not well defined. Henceforth, in a group semi-structured interview with the two Program Managers, responsible for industrialization projects department, it was defined the groups of activities which compound a PjM workday. The values of activities duration and effort assumed in the model were established also by Program Managers, according to their knowledge gained from professional experience.

PROBLEM STATEMENT

The purpose of the study is the development of a method capable of supporting decision making processes regarding capacities management. The asked requests led to splitting the problem into two main tasks. The requests were to:

1. Develop a tool which allows visual management of capacities whenever a new project is assigned to a project manager;
2. Generate the best options for project managers to undertake a new project (the PjM is not assigned to any new project in advance).

To explain the approach to the problem, it is important to underline the most important project constraint: respect the *due date* of *quality-gates*. Indeed, industrialization projects are aligned with other types of projects, also concerned with the same product conception. For this reason, it is absolutely important to keep the deadline of *quality-gates*.

In this industrial case study, an entire industrialization project comprises 5 phases: *Request*, *Preparation*, *Conception*, *Implementation* and *Completion* and has 6 *quality-gates* adjusted to 7 project *milestones*, as depicted in Figure 1.

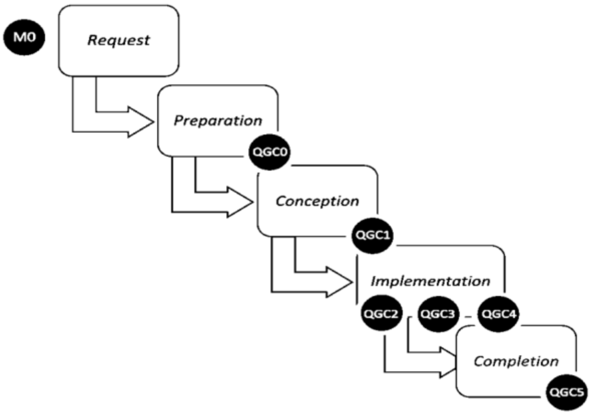

Figure 1: Company industrialization projects: quality-gate system.

It is interesting to mention the fact that the begining of the project coincides with the first milestone (M0) and the industrialization project closes in the last quality-gate (QGC5). Even so, activities scheduling is made considering every quality-gate (QGC0 - QGC5) since all of them have to be reached. Moreover, the number of activities in each phase is known (and which activities they are) as well as precedence relations between them. The activity network is not presented due to its size, as can be expected from a total number of 48 activities (46 plus dummy start and dummy finish activities).

The research is grounded on the assumption that every project calls for the same set of activities, regardless its complexity. However, activities duration and effort vary depending on project complexity. In the studied company context, projects are categorized in 4 levels - A, B, C, D - according to their complexity measured through criteria related to economic impact, innovation, etc.. Category 'A' is the type of project which requires more involvement, and so on. Each project category has its own *duration vs. allocation profile*. Aligned with this, it is assumed that the qualification of the PjMs follow closely the same categorization as the projects they can manage. For simplification matters, 4 types of project managers are considered: A, B, C, D. It is intentional the matching of project category letters with project manager category letters.

DEVELOPED APPROACH

Conceptual Model

To answer to the first request, a classical RCPSP should be considered, stated as follows: a single project which consists of $j = 0, \dots, 48$ activities with a duration of d_j periods, respectively. Lets assume that activity 0 is the *dummy start activity*, *activity* 48 *is the dummy finish activity* and the activities are already organized according to a rule that prioritizes the activity with the smaller value of latest finish time (LF_j). The activities are interrelated by two kinds of constraints. Precedence constraints force an activity not be started before all its predecessors have finished. Additionally, resource constraint arises to define that activity j processing requires k_{jr} units of resource r during every period of its duration. Since resource r is only available with the constant period availability of K, activities might not be scheduled at their earliest time but later. The objective of the present study is to schedule the activities such that precedence and resource constraints are obeyed as well as QGCs dates. This last point is the differentiating one comparing to classical RCPSP. Based on it, a heuristic approach, adjusted to the aim of the problem, was developed and is explained in the next subsection. In order to complete the modulation, the following additional notation was used: Let P_j define the set of immediate predecessors of activity j. For ease of notation, activities are topologically ordered, i.e. each predecessor of activity j has a smaller number than j. A conceptual model of the problem can be formulated as follows:

$$\min totalexceeded \qquad (5)$$

$$\max totalavailability \qquad (6)$$

subject to

$$FT_l \leq QGC_x \qquad (7)$$

$$FT_i \leq FT_j - d_j \quad j = 1, \dots, 48; i \in P_j \qquad (8)$$

$$\sum_{j \in A_t} k_{jr} \leq K \quad r \in R; \; t = 1, \dots, T \qquad (9)$$

The variable FT_l denotes the finish time of the last activity before each quality gate. In the case considered $l = \{23, 31, 35, 39, 43, 48\}$. The set of activities in progress in period t is defined as $A_t := \{j \mid j = 0, \dots, J, FT_j - d_j + 1 \leq t \leq FT_j\}$. Note there is no mechanism to identify A_t in any equation. This deficiency is overcomed with the heuristic used to schedule. The objective function differs for the first solicitation (5) and the second (6), according to the company requests. Variables "totalexceeded" and "totalavailability" are explored next. Constraint (7) imposes that each QGC date is accomplished, being the finish time of the previous activity not greater than the QGC date. Constraint (8) takes into consideration the precedence relations between each pair of activities (i, j) where i immediately precedes j. Finally, constraint (9) limits the total resource usage within each period to the available amount. To answer the second request we followed the same logic but the PjM is not assigned to the project in advance. In the Heuristic Approach section it is explained the approach used to select the possible and best options of PjM for a specific project. This approach is based on a heuristic adjusted to the company context.

Heuristic Approach

The development of capacities management method consists of the creation of a tool whose functionality results from the integration of inputs, parameters and outputs. The only inputs needed to the system are regarding the project features, namely: project category, M0 date and QGCs dates. Considering the first request, also the selected PjM should be given as an input. Knowing the project category, a category-specific *duration vs. allocation profile* is considered. In this way, values can be assign to the duration d_j of all $j = 0, \dots, 48$ activities as well as to the effort $r_{j,k}$ required to the selected k PjM to perform activity j throughout its duration.The input given about M0 date has the purpose of calculating the earliest start of the first activity of the project ES_0. With this, recalling for the *serial scheduling scheme* algorithm, we have:

$$FMC_1 - d_1 = ES_1 = M0 \qquad (7)$$

Furthermore, QGC dates define the latest finish LF_l of each last activity before the respective *quality-gate*. Following the *Critical Path Method*, the *forward pass* starts with M0 date and the *backward pass* starts with QGC date.

After these calculations, the list of activities organized according to the priority rule is created. Moreover, this is the moment when modifications are made in the classical *serial scheduling scheme algorithm* since it is mandatory to respect QGCs date. They occur in activity finish time calculation and the algorithm to do this becomes as follows:

$$F_j = \min\{t \in [ES_j + d_j,\ LT_j] \cap CF_g \,|\, r_{j,k} \le RD_k(\tau), k \in K, \tau \in [t, t + d_j[\cap CF_g\} + d_j \qquad (8)$$

The following graphic (figure 2) is used to clarify the ideas presented now. To illustrate, assume a project that begins in $t = 0$, having only one phase, one *quality-gate* and two activities (activity 1 precedes activity 2). Let the duration of activity 1 and 2 be, respectively, $d_1 = 2$ and $d_2 = 1$.

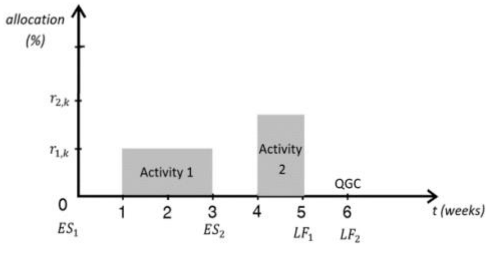

Figure 2: Activities scheduling between its ES and LF.

In resources matters, it is also important to underline a different point in comparison with the classical construtive heuristic. This is a critical issue because the essence of a RCPSP kind of problem can be questioned. Taking into account the first request, it does not matter if the resource availability is breached. What really matters is the choice of the PjM made by the Program Manager. To deal with this, for each activity every t is tested from the start time of the activity, being $ES_j \le t \le LF_j - d_j$. Considering a resource limit $K = 100\%$ and knowing the *allocation profile* of each PjM up to now, for each scenario, it is possible to obtain if and how much is the limit exceeded in each t, for the activity duration. The sum of these values gives the variable “totalexceeded”. The selected scenario is the one with the smallest value of “totalexceeded” unless it is not exceeded at all. In this last situation, the activity is scheduled in its ES as the classical heuristic suggests. Again to illustrate, consider the following graphic (figure 3).

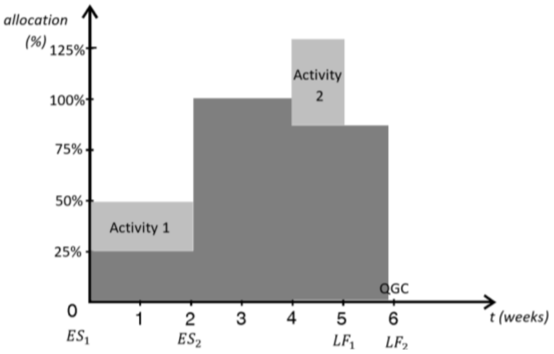

Figure 3: Ilustrative example of how “totalexceeded” variable operates.

Assuming that the darker region of the graphic represents a supposed PjM *allocation profile* and considering now the resource limits: since activity 1 never exceeds K during its duration (totalexcedeed=0), it is scheduled in $t = ES_1 = 0$. Activity 2 scheduling exemplifies the purpose of “totalexceeded” variable. The earliest start time of activity 2 is equal to the finish time of activity 1, in $t = 2$. However, activity 2 just starts at the minimum t (between ES_2 and $LF_2 - d_2$) for which “totalexceeded” is the smallest possible value, wich is $t = 4$. In addition, in the sytem, the PjM *allocation profile* is recorded per project per period. When it exceeds the limit of 100%, the program manager has the possibility to choose between keeping the PjM overloaded or remove one or more already assigned projects to the PjM that just received the new project. Already assigned projects can then be re-assigned to other PjM also using the tool. It works as if the project removed from the overloaded PjM was truncated and considered finished, and a new project is started, with the activities yet to be executed, which has to be allocated to another PjM. It is just needed to know the activity in progress and the scheduling is made from this moment on, assuming the start time to be the earliest starting activity if none is already ongoing. In this case, it can happen that some QGC have already been achieved, so there is no value as input for these QGC deadlines. Also, in certain circumstances, a project can start in more advanced phases or, more generically, can have only a subset of QGCs. In both situations, it is necessary to indicate the first activity of the process as an input of the system. The system situates the activity in its respective phase and the scheduling is made from this activity onwards. Otherwise, the dummy start activity (0) is considered the beginning of the project by default. As a final note, for the application of construtive heuristics to this problem, the priority rules are not necessary since there is no imposed resource limit, being only necessary to respect precedence relations. However, it is used in the second requested scenario, explored next. When the PjM is not assigned in advance, the approach follows the classical algorithm in terms of resource-associated decisions. On the other hand, it follows the previous idea regarding ES and LF since the QGC date remains mandatory. Using the list of Project Managers, the new project can be assigned to the ones whose category corresponds to the project category and for which $K \leq 100\%$ is not violated at any time during the temporal horizon of the project (between M0 and QGC5). Among the possible project managers, the one with the greater value of "totalavailability" will be assigned to the project. This variable is then calculated. It represents the sum of the difference between K and the total allocation of the PjM in every period *t*.

When the project is actualy assigned to a PjM, its *allocation profile* is updated and kept in the system as a parameter. To avoid overloading the system and since the tool developed is a way to plan programs, the current date should be given as input. By doing so, old data is deleted and the temporal horizon of the problem starts at the new plan time. The idea is to keep it a living document.

CONCLUSIONS AND FURTHER RESEARCH

During this research, the main aspect retained is the company concern about client satisfaction, measured by, for instance, deadlines and quality requirements accomplishement. This is possible, essentially, due to the integration of the different types of projects which is feasible because of respecting QGCs. The developed method to managing capacities imposes this point and provides to the Program Manager the visual capacity of analyzing their resources allocation so that they make good decisions in the moment of assigning a new project to a project manager. A critical point to note to further work is the necessity of creating a database which, within the project monitoring, is capable of recording the project activities duration and effort. From there, it will be possible to create a model with more realiable parameters. To add features to the the developed tool, it could be suggested a multicriteria PjM selection (for the second request). For instance, additionally to "totalavailability" variable, the client linked to the project should be considered in order to select the PjM who is used to work with that client. Finally, the last suggested improvement is the inclusion of a "fine-tuning" feature to compensate the possible innacuracy associated to the assumptions made for project and PjM category. Two projects could be evaluated with the same category but one of them could be more complex than the other. Using the same logic, two PjM could be included in the same category but one of them could have more experience, for instance. It is a call for competencies modelling and evaluation, allowing for a better matching with each new project specific requisites or stakeholders alignment.

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