CLOUD COMPUTING ARCHITECTURE

PROPOSAL FOR RESOURCE-CONSTRAINED PROJECT SCHEDULING

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Abstract: The aim of this paper is to develop a computer model based on service-oriented architecture hosted in cloud computing for the process of human resource allocation in multiple projects. We adopted qualitative approach to present computational. The results demonstrate that the proposed computational model can help to reduce the time spent by managers in the process of project elaboration, cost containment, and the scheduling of projects with impact on Resource-Constrained-Project-Scheduling-Problem. The contribution of this study is evidenced in the use of algorithms to achieve the lowest possible cost while respecting the competence of the human resources available in an environment of multiple projects.

Keywords: Space project management, system dynamics, rework

1. INTRODUCTION

The scarcity of resources and schedule problems are increasingly on the agenda of professionals and scholars in project management (Coelho & Vanhoucke, 2020). The process of human resource allocation in projects has gained a prominent position in the face of various restrictions on the traditional techniques of project management. Techniques such as PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method) depict the interconnections of activities using network diagrams, dealing only with the aspect of time without considering the constraints on the use of resources (Burgelman and Vanhoucke, 2019; Cynthia, 2020). The result of these constraints is a problem discussed by the community during the last four decades, known as the Resource-Constrained Project Scheduling Problem (RCPSP).

The RCPSP is considered a severe problem of combinatorial programming to solve because the high number of possible combinations can be considered a challenging and complicated task (Blazewicz et al., 1983; Vanhoucke and Coelho, 2019). Aspects related to this problem category lie in the allocation of human resources in project activities (Agarwal et al., 2011; Sönke, 2013), in which several constraints associated with human resource allocation in multiple projects can occur (Kurtulus and Narula, 1985; Mohanty and Siddiq, 1989). The challenge is to establish a minimum duration schedule, respecting the start date, the precedence of each activity, and the availability of human resources (Lageweg et al., 1977), which characterize the existence of the RCPSP in organizations.

The RCPSP is considered a mathematical problem, classified as NP-Hard resolution (Blazewicz et al., 1983; Ulusoy and Özdamar, 1989; Coelho and Vanhoucke, 2020). We can say that such a problem can be understood when an algorithm seeking to solve a combinatorial problem cannot obtain the solution in a nondeterministic polynomial time because considerable computational means are required (Hochbam, 1997), requiring considerable computational means (Arora et al., 2003; Micu et al., 2011). So, in this type of problem, the use of mathematical models is considered the most effective solution for a computational time (Eugeniusz Nowicki and To, 2003).

This research can be understood as an extension to the study by Coelho and Vanhoucke (2020). In the study, the authors define the number of activities and resources and should be observed in relation to the network structure of the activities in consideration of the resource constraints of the project. In relation to new research, the authors suggest that the new studies develop radically new algorithms to resolve the restrictions imposed by the RCPSP. With this objective in mind, the algorithms proposed in this research extend current studies on the topic, assuming that the available human resources should be allocated to the activities of multiple projects to achieve the lowest possible cost among the set of activities to be allocated.

Therefore, supporting the high processing volume generated by such mathematical models, a cloud computing architecture can mitigate failures associated with redundant processing (Brabra et al., 2019), in addition to allowing the minimization of the overall execution time of a computational process (Kim et al., 2020), contributing for the solution to the problems of the RCPSP to be executed in a timely computational time. In this scenario marked by constraint and the need to optimize the allocation of human resources in projects, the objective of this research is to develop a computer model based on service-oriented architecture hosted in cloud computing for the process of human resource allocation in multiple projects in a software company using computational experiments.

Thus, the contribution of the proposed algorithms is related to the skills of human resources, seeking to allocate the available human resources with the necessary skills to perform them as quickly as possible at the lowest operating cost, contrasting the studies of Herroelen et al. (1998) and Sallam et al. (2020) that characterize the RCPSP with the unique vision of activities without assessing the cost and skills of available human resources. A relevant aspect that must be highlighted is that the software used in the experiments was developed in architecture oriented to microservices, hosted in cloud computing architecture to support the process of allocation of human resources in multiple projects. The results showed less frequent usage of allocations if we consider allocations performed through traditional techniques of project management, which contribute managerially as a support tool to the company.

This article is structured as follows. Besides this section, the introduction, Section 2 presents an overview of the literature on the possible solutions to the RCPSP focused on the adoption of mathematical models. Section 3 describes the methodological procedures and the proposed cloud computing programming model. Section 4 is devoted to computational experiments and results analysis. The paper is finished in Section 5, presenting the conclusions, limitations of this research, and indications for future studies.

2 THEORICAL BACKGROUND

This section summarizes the main concepts and possible solutions on RCPSP and the computational model hosted in cloud computing used for human resource allocation across multiple projects.

2. 1 Resource-Constrained Project Scheduling Problem

The RCPSP is known as a problem of combinatorial programming originating in the allocation of human resources in project activities (Akers and Friedman, 1955). The solution to this type of problem is to minimize the total project time without violating the precedence and the restrictions on human resources (Habibi et al., 2018; Van Den Eeckhout et al., 2019).

The scarcity of human resources in activities has occurred in various industries, such as civil engineering, production engineering, software development, among others (Brucker et al., 1999). The organizations are seeking to perform human resources programming more quickly in projects (Eugeniusz Nowicki and To, 2003). The goal of such organizations is to keep as few human resources as possible allocated to various project activities. According to Arkhipov et al. (2019), this is a difficult task to solve. The authors explain that the problem lies in determining the start date of the activities of a given project that meet the human resource precedence and priority relationships, which makes it difficult to minimize the total time or idleness of human resources in a multiple project environment.

In the day-to-day of organizations, the use of adopted tools to support the development of human resource allocation schedules, such as Microsoft Project, Primavera, and Open Project, may have some limitations when there are multiple projects to be completed. In this case, there is evidence of competition in the use of the same human resource since the use of this kind of software can make it difficult to change or reschedule human resources in projects (Sabar et al., 2018).

The resource scaling problems caused by RCPSP can be considered difficult to solve due to the massive quantity of possible simulations to get the best answer promptly (Chand et al., 2019; Noori and Taghizadeh, 2018). Regarding the possible solutions, Condotta et al. (2013) consider nonparametric mathematical models one of the most satisfactory supports for the solution of resource scaling problems caused by RCPSP, to get the best answer promptly (Li et al., 2019).

2.2. Solutions for Resource-Constrained Project Scheduling Problem

The use of mathematical models has satisfactory results to deal with problems associated with resource scheduling (Condotta et al., 2013; Lageweg et al., 1977). Such models aim to allow, through combinatorial actions, tasks to be performed in the shortest possible time and with the lowest idleness among resources (Akers, 1956; Palacios et al., 2015).

To calculate the solution, each mathematical model performs a certain number of hypothesis test. Genetic algorithms have the characteristic of having an adaptive nature. The objective of these algorithms is to solve problems associated with the optimization of complex mathematical operations (Gonçalves et al., 2008; Vanhoucke and Coelho, 2019). Genetic algorithms work with the process of natural selection of possible solutions for a range of problems. These algorithms have high performance and are easily adapted by computational use, being able to provide simple solutions, such as real-world solutions, as well as highly complex mathematical problems, such as those related to the optimization of resources into activities (Pacheco and Santoro, 1999).

2.3. Computational architecture to support the project scheduling problem with resource constraints

The use of mathematical models, through an adequate computational model, can be considered a possible solution for the treatment of problems related to the allocation of resources in activities, among them the RCPSP (Van Den Eeckhout et al., 2019), since the computational architecture allows tasks to be performed in the shortest possible time and with the least idleness among resources, within combinatorial actions (Habibi et al., 2018).

In this context, cloud computing can provide computational resources on-demand, streamlining companies' management processes (Garg et al., 2013). Cloud computing contributes to increasing the performance of highly complex problems (Mauch et al., 2013), such as the NP-Hard problem, existing in the RCPSP. Another architecture's highlight is to allow the dimensioning of the infrastructure automatically in case of high processing volume (Alcaraz Calero and Gutiérrez Aguado, 2015).

3 Proposed Computacional Model

The developed model to perform the computational experiment with the cloud computing architecture for use as a support tool in the process of human resource allocation in multiple projects in a software development company. The proposed computational model is composed of two processes: (i) in the initial allocation process of human resources in various projects and for (ii) resource reallocation(s) Human(s) project(s) running. To conduct this study, the requirements were: 1) a list of available human resources consisting of the competencies and the name of each resource, with hourly value and the tasks each one could perform (e.g., development, analysis, testing, approval, and implementation); 2) a list of tasks to be performed on each project containing the name of each project, its respective tasks, the duration of each task (in hours), and the precedence relationship between the tasks.

The proposed model calculates the time for completion of the projects and the possible deviations relative to the plan. It is worth mentioning that the proposed model presents the terms of the reallocated projects in graph form. The graphs represent different scenarios, which make them a tool to support the decision-making process about which project will have the most significant or least negative financial impact. This assumption is in line with the one proposed by (Ichihara, 2002) because the author states that establishing the best relation between resource-activity allocation can contribute to the reduction of project activity scheduling problems.

It is noteworthy that the model will optimize the initial allocation of human resources available in the various project activities with parallel execution. The proposed model assumes that human resources do not have distinct competences for carrying out the set of activities in the projects. Thus, for its execution, the model stipulates the following premises: (1) it should be ensured that a resource has the competence to perform a specific activity; (2) the resource allocation process cannot transcend its availability; (3) a given resource must be allocated from the beginning to the end of the execution of a given activity; and (4) the model does not distinguish or prioritize activities from any project.

3. 1 Data Collection

We selected five projects from the portfolio of the company under study. They have no strategic relationship with each other, and no restrictions associated with the use of human resources. Projects selected were financially approved, and the initial schedule set accordingly to the company's current.

Each project has its activities sequenced, considering the relationship of precedence between them. Each project has a start date of execution, as well as its initial budget calculated concerning the cost of each activity and the hourly value per available resource capable of performing the activity. Regarding the volume of potential projects, respondents have managed an average of 100 annual software projects over the past seven years.

3. 2 Computacional Experiment

The experiment lasted fifteen months, and the team had six human resources available for allocation in project activities. The experiment was divided into two phases. In the first, six human resources were allocated into four projects. In this phase, the allocation was made by the project managers and by the researcher using the computational model.

The second phase included the fifth project to be executed in parallel with the four ongoing projects, considering a new allocation of the six human resources, now for the five projects, also carried out by project managers and managers, and by the researcher using the computational model.

3. 3 Validation of the proposed model

The researcher monitored the activities until the completion of the five projects. The project results were recorded, either by current practices or by the use of the proposed computational model. Information regarding project performance was used to compare both current practices and the use of the proposed computational model.

The performance of the projects was measured utilizing the techniques of Earned Value Management (EVM) proposed by PMI. EVM is a project management technique for measuring project performance and progress with the ability to combine project management scope, time, and cost measures (PMI, 2017).

Regarding managerial contributions, the model was evaluated using the Focus Group (FG) technique. According to (Barbosa, 2008), FG is considered a qualitative research strategy that employs a small discussion group, aiming to obtain in-depth information. The author asserts that the FG is a fast-performing technique that can provide a wealth of qualitative information on the performance of activities delivered, service provision, among other situations.

The composition of the FG is a group of eight project managers of IT (Information Technology) companies. The selected managers have more than nine years of experience in managing and allocating human resources in multiple projects. They all have a Project Management Professional (PMP) certification. PMP is a Project Management Institute (PMI) issued certification and certifies that the professional has the necessary knowledge of good project management practices and techniques.

4 COMPUTACIONAL MODEL IN CLOUD COMPUTING FOR HUMAN RESOURCE ALLOCATION IN MULTIPLE PROJECTS

In the process of conducting this research, a computational model in cloud computing was developed to allocate a set of available human resources, considering the lowest cost and timeframe within a set of simultaneous and concurrent projects. The model assigns the durations of various projects and their activities that will be executed by available human resources. The available human resources should be allocated to the activities of the various projects to achieve the lowest possible cost among the set of activities to be allocated, represented in **Equation 1**.

$$Minimize \sum_{p \in Projects} Value\ E_p Z_p - \sum_{r \in R} \sum_{a \in A} Cost_r, aM_r, a$$

Equation 1: Available human resource.

For the realization of allocations, the model will ensure the integrity of the human resources available for the multiple project activity set. At run time, the model holds that human resource allocation processes cannot transcend their availability. The **Equation 2** represents this relationship.

$$\sum\nolimits_{r,a \in R,A} M_{r,a} \leq Disp_{r'} \forall_r \in R$$

Equation 2: Human resource integrity.

To ensure the allocation of one human resource across multiple projects, the model assumes that the start of a given activity must have a corresponding human resource available between projects for allocation. For this, the premise considers the activity and its associated project, shown in **Equation 3**.

$$\sum_{r,a \in R,A} Y_r, a, i = Z_{p'} \forall (p,a,i) Start$$

Equation 3: Multiple projects.

The model ensures the execution of an activity by a human resource respecting the precedence relationship between all activities of multiple projects. This constraint defines that a given human resource should remain allocated from the beginning to the end of a given activity without interruption. The **Equation 4** represents this restriction.

$$\sum\nolimits_{(p,a,i) \in PAI} Y_{r,a,i} = M_{ra'} \forall (r,a) \in RA$$

Equation 4: Human resource constraint.

The model uses another constraint to establish the best human resource x activity x project ratio and ensure the shortest allocation downtime. The model establishes that the resource x activity relationship comprises the duration of the activity of the multiple projects, thus minimizing possible problems of time deviations. The **Equation 5** demonstrates this.

$$Estimate_{r,a} \leq Duration_a X_{r,a'} \forall (r,a) \in RA$$

Equation 5: Minimizing allocation´s problems.

Finally, the model assumes that resources have the same competencies to perform a specific set of activities of various projects. At this moment, the model's purpose is to ensure that a resource, with appropriate competence, performs a particular activity in the set of projects available for allocation, shown in **Equation 6**.

$$Z_p \in \{0,1\}, \forall_p \in Projects$$

Equation 6: Human resource allocation.

It is essential to say that the model does not distinguish or prioritize activities between projects. Another determining factor is that the model does not reconsider the critical path of projects since tasks have predefined durations from the beginning. Importantly, the mathematical equations have as a primary objective minimizing the total cost through the allocation of available human resources in activities of multiple projects. Thus, this model provides scenarios to assist decision making in case of constraints imposed by the RCPSP. The relationship between competing activities by the RCPSP and the proposed model equations is described in **Figure 1**.

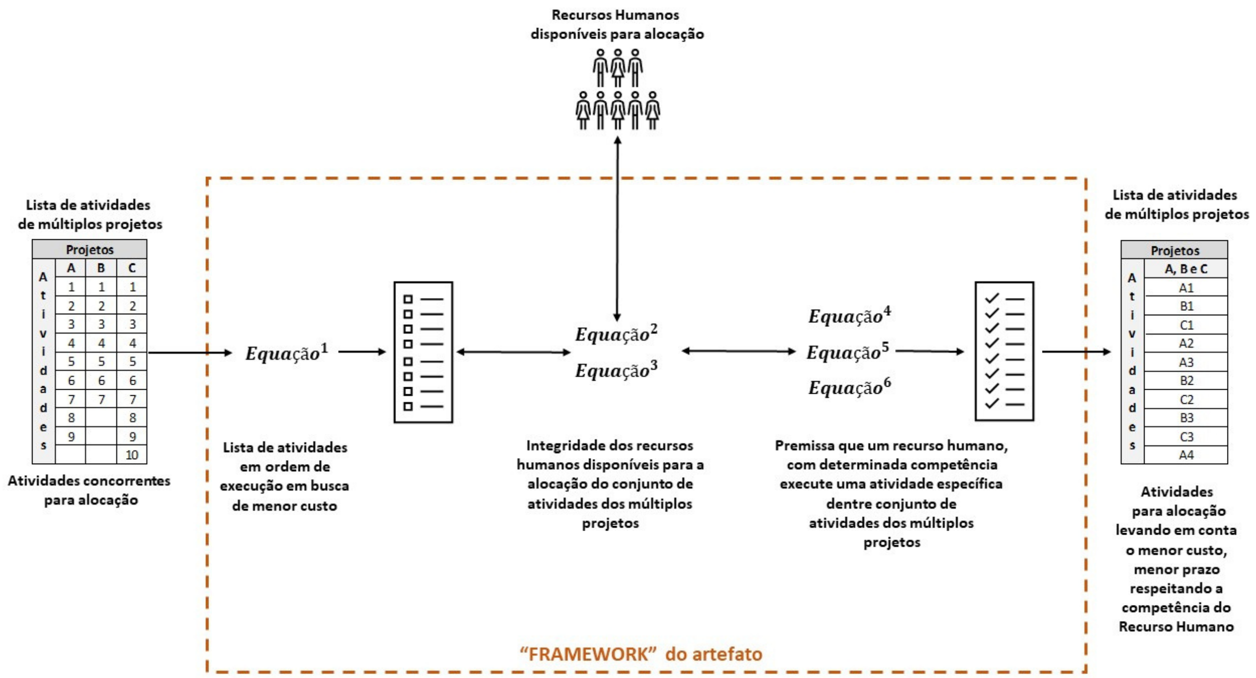

FIGURE 1: CLOUD ARCHITECTURE PROPOSED AND THE RELATIONSHIP WITH THE MODEL EQUATIONS.

In terms of its architecture, the proposed computational model was developed under the standards of service-oriented architecture and coded under Microsoft Visual Studio 2019 platform, using ASP .NET MVC and Microsoft C# programming languages, hosted in cloud computing.

4.1 Description of the cloud architecture of the proposed computational model

The cloud architecture of the proposed computational model is composed of the following components: Application built under the Progressive Web App (PWA) paradigm, where there is no update of the pages to load the data. Written under the current paradigms of web programming, always aiming at data security and already in compliance with European data protection laws. The model was developed based on simulations of activities of multiple projects, with the objective of obtaining yield obtained considering the team size and the work limit to be performed (Lunesu et al., 2018).

Regarding the computer services developed to support the equations: (i) manages calendars, including holidays. The objective is guaranteeing the integrity of task allocations apart from schedules (working hours, working days, local, state, national and international holidays); (ii) manages the human resources that will be allocated to the projects. This service manages the availability of the project resources, as well as the skills that each resource can perform; (iii) service that makes persistence and reading the resource allocation history by project. Two layers support the visual pattern and presentation. The first is a standard portal for access, programmed in angular languages 4, CSS 3, and HTML 5. This portal is made available through a website and allocated on the Microsoft Azure as Platform As a Service, represented in **Figure 2**.

The result is the integration of services with the developed equations, to guarantee the necessary calculations to carry out the simulations of possible allocations of human resources in activities of multiple projects, characterized by the RCPSP.

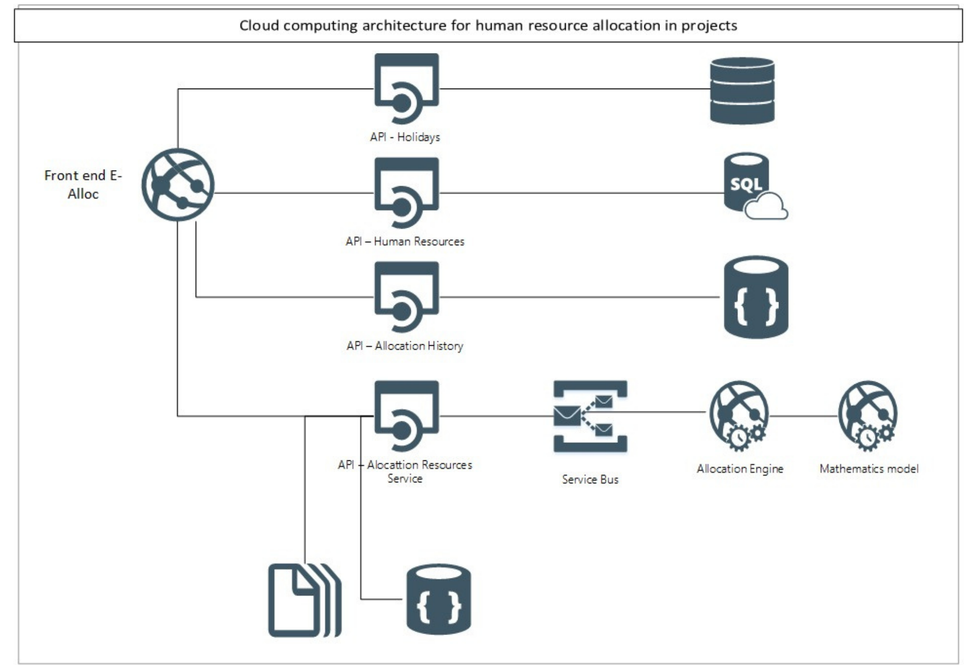

FIGURE 2: CLOUD ARCHITECTURE OF THE PROPOSED COMPUTATIONAL MODEL.

4.2 Results of the first phase of the computational experiment

The first phase allocated the six human resources available in the four projects. The allocation was done manually by project managers responsible for projects at weekly meetings. The approximate time spent by each actor in these processes of allocation was recorded along with the time simulated by the researcher using the computational model proposed for the same allocation. **Table 1** shows the results.

The table 1 shows the time taken by the computer model to allocate the same projects that were also allocated manually. We can say that the time spent was considerably less than the allocation time made by the organization's current process. When it comes to human resource allocation, traditional PM (Project Management) techniques suggest that resource allocation should be performed according to the order of execution of the activities, in which the allocation of resources takes place through the possible constraints of availability - resource scaling (Ichihara, 2002; Laslo, 2010).

In this context, the search for optimized resource allocation in project scheduling can influence the increase in allocation time by traditional PM techniques, thus characterizing the

Project	Current process	Computational Model	Difference	% Reduction
1	1 Hour and 30 minutes	30 seconds	1 Hour, 29 minutes and 30 seconds	99.44%
2	1 Hour and 10 minutes	25 seconds	1 Hour, 9 minutes and 35 seconds	99.40%
3	1 Hour and 20 minutes	22 seconds	1 Hour, 19 minutes and 38 seconds	99.99%
4	40 minutes	18 seconds	39 minutes and 42 seconds	99.25%
Total	**4 Hours and 40 minutes**	**1-minute and 35 seconds**	**3 Hours and 38 minutes and 25 seconds**	

TABLE 1: ALLOCATION TIME BY THE CURRENT ORGANIZATION PROCESS X ALLOCATION TIME THROUGH THE COMPUTATIONAL MODEL.

presence of RCPSP (Blazewicz et al., 1983; Brucker et al., 1999; Kolisch et al., 1995). This scenario is aggravated since that traditional software to support the schedule of development has limitations regarding the optimal management of resources (Schwaber, 2002; Chang et al., 2008) as this software treats the resources, including human resources, as temporary, unique, and part of a team appointed to carry out each project (Kerzner, 2019). This research identified the resource exclusivity scenario by project, at the time of initial allocation. The execution of several projects is a negative impact factor on the company, in which most managers spend hours allocating a project due to competition and lack of insight into the resources allocated to the various competing projects.

Another highlight in addressing resource optimization is associated with project cost. The project cost calculation task requires managers to know the competencies and the unit cost of each of the resources divided by a known metric unit. If there is no information for the unit value of the resource, traditional PM techniques suggest the use of an estimated measure in which the allocation of each resource is done manually by each manager project to project (Tuli et al., 2020).

For the company under study, in which the multiple project scenario is real and constant, the projects, from their initial resource allocation moment, may compete for the allocation of available resources (Kujala et al., 2011). Thus, establishing the best use of resources is an essential factor for the performance increase of the projects (Cooper and Kleinschmidt, 2001), which occurs from the process of the initial allocation of resources (Laslo, 2010).

Based on the results of this phase, it was possible to point out the cost of the projects that were part of this study through the current resource allocation process and the use of the computational model. **Table 2** shows the results.

Given the information presented in Table 2, the allocation made through the computational model was more efficient than the company's current resource allocation process, except for project four, in which the project established the same cost, justified by the model's premise, in which the resource-activity relationship prevails with the lowest cost and lowest possible downtime for each available resource (Plekhanova, 1999). In contrast, the organization has a negative impact or does not achieve better performance because of the challenges associated with the resource allocation process, such as the type of resource and the number of team members that may change during the project life cycle, assignment of resources with lower skills than those required for execution of the activity, and the use of intuition for resource allocation. The result can cause an impact on activities with deviations or delays, or it may cause an unnecessary increase in the total cost of the project (Padovani et al., 2010).

4.3 Results of the second phase of the computational experiment

The second phase of the experiment included a new project to the set of projects proposed in Phase 1 of this research, all still under execution. This new scenario relocates the six human resources across the five projects. For each relocation, the approximate time spent by each actor and the approximate time spent by the proposed computational model were stored.

The organization's current process took approximately 3.5 hours to reallocate resources across the five projects, while the same allocation made through the computational model took approximately 1 minute and 40 seconds, resulting in a 99.20% of the time spent by the proposed computational model compared with time spent by project managers.

TABLE 2: ALLOCATION COST BY CURRENT ORGANIZATION PROCESS X ALLOCATION COST THROUGH A COMPUTATIONAL MODEL.

Project	Current process	Computational model	Difference	% Reduction
1	R $ 46,472.00	R $ 45,944.00	R $ 528.00	**1.14%**
2	R $ 23,848.00	R $ 23,416.00	R $ 432.00	**1.81**
3	R $ 27,284.00	R $ 27,156.00	R $ 128.00	**0.47%**
4	$ 0.00	$ 0.00	$ 0.00	-
Total	**R $ 97,604.00**	**R $ 96,516.00**	**R $ 1,088.00**	

NOTE: CONVERSION FROM R$ TO US$ WITH THE CONVERSION RATE OF R$ 5.21 ON NOVEMBER 11, 2020.

Based on the results shown, when a resource reallocation scenario occurs, or by the event of allocation for a new project occurs, the organization also suffers from the impacts caused by resource escalation (Ichihara, 2002; Laslo, 2010).

Due to the set of projects of the studied company being in progress and thus sharing the same resources (Park & Lee, 2014; Reeves et al., 2013), the task of establishing resource allocation to minimize total project time without violating resource precedence (Mingozzi et al., 1998) cannot be considered a trivial task. The biggest challenges of this activity are associated with allocating and balancing resources in pursuit of project set performance, establishing the allocation respecting the organization's strategy, and maintaining the appropriate number of resources per project (Cooper and Kleinschmidt, 2001).

Based on the results of this phase, it was possible to point out the part of the project's cost incurred through the current process of resource reallocations and the use of the computational model. The result also includes the entry of the fifth project. **Table 3** shows these costs.

Data presented in Table 3 points out that upon the entry of a new project, the process of reallocating human resources in multiple projects had better results using the computational model compared to the current practices of the project in the studied company. For this company, this scenario of resource reprogramming is presented as typical and existing in software development projects (Brucker et al., 1999). To minimize negative impacts, it is necessary to take action as soon as possible to establish a reprogram that can bring financial benefits to the organization (Sönke, 2015).

It is worth mentioning that the compliance of the cost and time has a close relationship with project performance. Projects that exceed their costs or time limits cannot reach their goals (Jeffery & Leliveld, 2004), or even taking the risk of not deliver any product (Group, 2019). Thus, to increase the project's performance concerning cost and schedule, to minimize the idleness of resources between more than one project can contribute to the increase of company results.

When it comes to initial resource allocation and the resource reallocation process, the flexibility of the proposed computational model can contribute to matrix structure organizations for both cost optimization and impact on possible lead time deviations. Matrix organizations carry out their work through projects coordinated by managers who have the responsibility to execute their projects within a pre-planned cost, time, and quality (White & Fortune, 2002). The following relationships can establish the contribution of proposed computational model: (1) the lower the allocation cost, the higher the financial performance of project trends to be; (2) regarding the deadline, ensuring the delivery deadline may minimize contractual issues, customer dissatisfaction, and resource reallocation risks of other projects.

When it comes to financial performance, regarding a sample of only five projects, the cost reduction percentage does not appear to be very representative. However, when looking at the costs involved in projects, Gartner's research predicts that spending on information technology projects in Brazil will total US$ 64 Billion in 2020, representing an increase of 2.5% compared to the accumulated amount in 2019 (“Gartner IT SYMPOSIUM|Xpo,” 2019). By observing these

TABLE 3: INITIAL ALLOCATION COST BY CURRENT ORGANIZATION PROCESS X ALLOCATION COST THROUGH COMPUTATIONAL MODEL

Project	Current process	Computational model	Difference	% Reduction
1	R $ 47,272.00	R $ 46,600.00	R $ 672.00	1.42%
2	R $ 25,096.00	R $ 24,344.00	R $ 752.00	3.00%
3	R $ 27,417.00	R $ 26,932.00	R $ 485.00	1.77
4	R $ 16,424.00	R $ 16,424.00	$ 0.00	-
5th	R $ 13,476.00	R $ 12,492.00	R $ 984.00	7.30%
Total	**R $ 129,685.00**	**R $ 126,792.00**	**R $ 2,893.00**	

NOTE: CONVERSION FROM R$ TO US$ WITH THE CONVERSION RATE OF R$ 5.21 ON NOVEMBER 11, 2020.

values and applying the average reduction of the five projects (2.68%), shown in Table 3, the use of the proposed model would represent a reduction of approximately US$ 1,715,200,000.00 (One billion seven hundred and fifteen million two hundred thousand dollars) for companies in this sector in Brazil.

After the end of the second phase, we may conclude that the higher the number of projects involved in the allocation of human resources, thus enhancing the constraints imposed by RCPSP, the proposed computational model has more effective results, as can be seen in Tables 2 and 3. When applied to four projects, the model presented an average cost reduction of 0.85%, but when applied to five concurrent projects, the model presented an average cost reduction of 2.68%. Thus, we concluded that as more significant is the restrictions imposed by RCPSP in business are, the higher the effectiveness of the model in search of cost reduction associated with the allocation of human resources across multiple projects is.

4.4 Focus group validation of the model

The proposed computational model and the results of Phases 1 and 2 were presented to the FG. The FG evaluated the data for 30 days and presented their opinions regarding the proposed computational model concerning the process of initial allocation or reallocation of resources in the projects. Regarding managerial contributions, FG highlighted the speed provided by the use of the model, helping reduce the time spent on allocations tasks and free time for project managers to perform other management activities. Another contribution pointed out by the FG was the end of internal disputes by project managers to allocate one or more human resources. The managerial highlight of the purposed computational model is presenting the multiple critical paths involving the projects in execution, transforming the model into a decision support tool regarding the constraints imposed by the RCPSP.

The model showing the various critical paths in projects running can help companies achieve more exceptional project performance in terms of cost, time, and efficiency of human resources use (Salas-Morera et al., 2018). The FG pointed out two suggestions for model improvements. The first refers to highlighting the activities of a human resource in the various projects of the company. With this view, FG stressed that it would be possible to analyze the impact on projects when a human resource is prioritized or withdrawn from a project. This feature of the model may contribute to the human resource view throughout the project lifecycle in the organization, which may contribute to the time and cost performance of projects (Kerzner, 2019). The second suggested improvement was the storage of project activity estimates, considering the human resources competencies needed to carry out each activity. The purpose of the storage is that the model contributes to create or collect knowledge necessary for the execution of new projects (Pospieszny et al., 2018).

Regarding the possible restrictions on the model's use, the FG pointed to the need to apply it in a more significant number of projects and other company's departments to validate the results.

5 CONCLUSION

The result also pointed to the effectiveness of the computational model in reducing resource idleness, benefiting the organization through less time deviation from the start of projects. The results showed that the use of a computational model as a tool to support the process of human resource allocation in multiple projects could contribute to minimizing the impacts caused by the RCPSP.

The first contribution is related to the time spent by managers to prepare the allocation schedule. The proposed model presented considerably reduced allocation times compared to what is currently spent by the organization using traditional project management techniques. By reducing time in setting the schedule, managers can focus their competencies on other management activities, such as intensifying project control and monitoring to increase delivery quality or in advance, to participate in activities associated with new projects that will soon integrate the project portfolio. The computational model, due to its architecture, streamlined the company's management processes concerning the allocation of human resources in multiple projects, as suggested by (Alcaraz Calero and Gutiérrez Aguado, 2015).

Another contribution refers to the resource optimization used in the studied company either in the initial allocation or in reallocation. The model presented satisfactory results for making the allocation by trying to obtain the best cost per activity ratio with the shortest possible idle time of each human resource. This scenario contributed to the reduction of project costs, both in the initial allocation activities and in the entry of new projects.

In terms of managerial contribution, the proposed model, by addressing the available human resources for allocation in the shortest possible time and without internal dispute, offers project managers the possible critical paths in the process of human resource allocation in multiple projects, which can be explained by the cloud architecture of the proposed computational model (Tuli et al., 2020) guaranteeing the solution of the RCPSP in a timely computational time (Alcaraz Calero and Gutiérrez Aguado, 2015).

This view goes in the opposite direction proposed by PMI (2017), in which the critical path is defined as the sequence of activities that represents the longest path of a project, which determines the shortest possible duration for the project. Using the proposed computational model in a multi-project environment, project managers will gain insight into the current critical paths involving the allocation of human resources arising from the need to prioritize resources or projects, as well as new project needs or the cancelation of ongoing projects.

In terms of practical contribution, the proposed software, by treating the human resources available for allocation in the shortest possible time without internal dispute for allocation, presents project managers with the possible critical paths in a process of human resource allocation in multiple projects. This view goes in the opposite direction to that proposed by PMI (2017), where the critical path is defined as the sequence of activities that represents the longest path of a single project, which determines the shortest possible duration for the project. From the use of the proposed software, in an environment of multiple projects, project managers will have a vision of the critical paths that exist involving the allocation of human resources, arising from the need to prioritize resources or projects, as well as the entry or canceling an ongoing project. In this context, the proposed software can be used as a tool to support decision making involving human resource restrictions in an environment of multiple projects, where the objective will be to guarantee the efficient use of human resources in search of increased performance.

Thus, the proposed computational model can be used as a support tool for decision-making involving human resource constraints in a multiple project environment, in which the goal is to ensure the efficient use of human resources supporting project performance increase.

By observing the results of this research, it can be recommended that organizations address the problems caused by the resource scheduling no longer through traditional human resources allocation methods, which are interpreted as temporary and exclusive to a project (PMI, 2017; Kerzner, 2019), but through a view in which the resource is no longer unique to a project but instead is allocated to some project activity within its competencies in search of performance increase (Sandhu et al., 2019; Wikstrom et al., 2009).

Finally, the proposed computational model can be used to support schedule development tools such as Microsoft Project, Primavera, and Open Project to eliminate limitations on optimal resource management (Chang et al., 2008), besides allowing the proposed model to contribute to minimizing the time spent by managers in the manual resource allocation process (Schwaber and Beedle, 2002).

The computational model elaborated in this research was built from the perspective of an architecture hosted in cloud computing, presenting flexibility and agility for implementation in organizations that support a more significant number of projects. However, this work is limited only to the presentation of a computational model and the exclusive use in IT projects. In this sense, such limitations generate a vast opportunity for future studies, such as the construction and application of the proposed computational model in IT projects and the comparison of project results by current project management techniques and the use of the computational model suggested by the FG. Another possibility for future work is to apply the model proposed in companies that are not part of the Information Technology sector and compare the results.

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CLOUD COMPUTING ARCHITECTURE

PROPOSAL FOR RESOURCE-CONSTRAINED PROJECT SCHEDULING