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Project Management And The Determination Of Critical Paths Through The Pert/Cpm Method: Case Study In A Civil Construction Company In Brazil

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Abstract: *The present research sought to identify the critical paths existing in the works of a company in the construction industry in Brazil. To this end, an exploratory research of qualitative and quantitative approach was carried out by adopting the PERT/CPM method and a case study. As a result, it was found that the execution of the work of the company under study lasts, on average, 80 weeks. This average duration is subdivided into fifteen activities, which are: excavation of the land (A), foundation of the land (B), masonry (C), roof (D), external plumbing (E), internal plumbing (F), wall construction (G), external painting (H), electrical installation (I), partition (J), laying floors (K), internal painting (L), external finishing (M), internal finishing (N) and finalization (O). The identification of the different paths of the PERT/CPM network allowed to determine the critical path, which was represented by the path associated with the activities "A, B, C, E, F, J, K, L, M, N and O", where any delay in this critical path will have a direct impact on the final deadline of the work. As this path has no slack, managers should give it special attention in order to ensure that the work is carried out within the estimated time.*

Key Word*: Project management; PERT/CPM; Critical paths; Civil construction; work.*

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I. Introduction

Over the past decades, project management has gained recognition and established itself as an essential discipline in many sectors, such as technology, construction, engineering, healthcare, and others. As project complexity increases and stakeholder demands become more stringent, the need for a structured and professional approach to project management also intensifies. As a result, project management becomes increasingly relevant and indispensable, ranging from large companies to governmental organizations and non-profit institutions (VALE et al., 2014).

As reiterated by Pinto, Mello and Spiegel (2019), project management is a strategic approach that allows the efficient planning, execution and control of complex projects. In order to ensure success and meet the established deadlines, many organizations resort to specific methods and techniques to manage the workflow, the resources involved and the activities to be carried out. From this, managers can obtain a clear view of the objectives and goals to be achieved, allowing the identification and effective management of risks, as well as facilitating communication between team members and stakeholders involved.

In the field of construction, project management plays a crucial role in ensuring the success and timely completion of projects. The complex and multidisciplinary nature of construction requires a structured and organized approach to managing all project phases. Because of this, project management plays a key role in ensuring the success of projects by meeting deadlines, controlling costs, coordinating teams, ensuring quality and managing risks. By adopting this structured approach, construction projects are more likely to achieve satisfactory results and exceed the expectations of those involved (RUAS; SILVA; CORRÊA, 2018; HERRERA; RODRIGUES, 2018).

In this scenario, one of the methods widely used in project management in construction is PERT/CPM (Program Evaluation and Review Technique/Critical Path Method). The PERT/CPM method, developed in the 1950s, has become a valuable tool for project managers dealing with large-scale and complex projects. This method is based on networks to visualize the sequence of activities and their interdependencies, allowing a thorough analysis of the schedule and the identification of the critical path (SANTOS; RIBEIRO; OLIVEIRA, 2023; SOUZA et al., 2017).

However, the PERT/CPM method also faces specific challenges in construction. The uncertainty and variability inherent in the sector can affect the accuracy of activity duration estimates, making it more challenging to plan properly. In addition, complex interdependencies between teams, suppliers and contractors can make it difficult to correctly determine the sequence of activities. In this bias, keeping the schedule accurately updated and performing efficient resource management are also challenges faced by the PERT/CPM method in construction (SANTOS, 2018).

Given this context, the present research sought to identify the critical paths existing in the processes of a Brazilian company in the construction industry. The results of this research are expected to contribute to the improvement of project management in the construction industry, providing valuable insights into the specific challenges faced by the PERT/CPM method in this sector. In addition, they will allow the company under study to improve its project management approach, optimizing the use of resources, avoiding delays and achieving better results in its projects.

II. Material And Methods

The present research was characterized as exploratory with a quantitative-qualitative approach, which was carried out under the guidance of the case study technique. The quantitative-qualitative approach was adopted to combine the collection and analysis of quantitative data, such as information on deadlines and duration of activities, as well as to obtain qualitative data, such as perceptions and experiences of the project managers involved. Thus, the case study technique was chosen due to its ability to thoroughly investigate a complex phenomenon in its real context, which allowed the understanding of the specific aspects related to the use of the PERT/CPM method in the construction company under study.

The case study of this research was conducted in a Brazilian company in the construction industry, which has a significant history of large and complex projects. The company is located in the city of Três Rios, in the interior of the state of Rio de Janeiro, in the Southeast region of Brazil. The company has been operating for more than 25 years in the market, and offers services such as: construction of houses and buildings, renovations and revitalizations, project management, civil engineering services and infrastructure and public works. In this research, the case study was based on services related to the construction of houses.

To carry out the case study, fieldwork was carried out at the company's administrative headquarters and at the site where a house was being built by the construction company. The fieldwork took place in the second semester of the year 2022 and, as a research instrument, semi-structured interviews were applied with the company's employees, which involved the participation of project managers, civil engineers, architects, masons and painters. The selection of the interviewees to participate in the interviews was done intentionally and considered criteria such as involvement in the housing construction projects and availability to participate in the research. In total, thirteen employees were interviewed, thus encompassing the entire hierarchical structure of the company, from the operational level to the strategic level.

As Fraser and Gondim (2004) point out, semi-structured interviews are a type of data collection technique used in qualitative research. These interviews offer a general structure with a set of predetermined topics and questions, but also allow some flexibility for the interviewer to explore emerging themes and follow the flow of the conversation. Unlike structured interviews, which follow a rigid, standardized script with closed questions, semi-structured interviews are more open-ended and allow for freer interaction between the interviewer and interviewee.

Thus, the semi-structured interviews were guided by a previously prepared questionnaire, which contained open and closed questions. The questionnaire addressed questions inherent to the processes involved in house building, such as the main activities involved, preceding activities, average time taken in weeks, among other factors. The semi-structured interview offered flexibility by allowing interviewers to adapt the order and style of questions according to the context and the respondents' answers. This provided a more dynamic interaction and a greater opportunity to explore emerging topics or obtain further clarification on the interviewees' responses, corroborating with what Boni and Quaresma (2005) suggest.

The research also included the analysis of internal company documents, such as previous project reports, activity control sheets and schedules. These documents were used to complement the information obtained from the interviews and provide a more comprehensive view of the practices and processes used by the company in the construction of houses. In addition to the interviews and document analysis, a direct observation of the activities carried out by the company during the execution of a house building project was also conducted, as recommended by Poupart et al. (2008). This allowed a deeper understanding of the processes and the interactions between the different professionals involved.

The combination of these different data collection approaches - interviews, document analysis and direct observation - enabled a more complete and in-depth investigation into the processes involved in house building of the construction company under study. As a consequence, quantitative and qualitative information was obtained, as well as a detailed understanding of the context and specific aspects related to the use of the method.

After the fieldwork, the data were analyzed. For the qualitative data analysis, the responses from the semi-structured interviews were transcribed and organized to facilitate the analysis. The content of the responses was examined and categorized into themes, and this categorization allowed for the identification of the main aspects related to the house construction processes, such as the main activities involved, preceding activities and average duration time in weeks. This information was grouped and categorized to provide a more comprehensive understanding of the house building processes in the company under study.

As far as quantitative data analysis is concerned, time frames and duration of activities were recorded and tabulated. Measures such as average, first start date (FSTD), first finish date (FSTD) and available slack of the work of the company under study were calculated. In order to facilitate the analysis, tables and figures were used to visually present the results and facilitate the interpretation of the quantitative data.

III. Result

As evidenced in the theoretical axis, the first step for the elaboration of the PERT/CPM network is to create a table with all the data of the activities involved in the project, thus contemplating the description of the activities, the preceding activities and the duration time of each activity. Table 1 presents the data of the activities involved in the construction project of the company under study.

Table 1. Activities involved in the work of the company under study

ACTIVITIES	DESCRIPTION	PREVIOUS ACTIVITIES	DURATION (IN WEEKS)
A	Excavation of the ground	-	2
B	Foundation of the land	A	4
C	Masonry	B	10
D	Roof	C	6
E	External plumbing	C	4
F	Internal plumbing	E	5
G	Construction of walls	D	7
H	External painting	E, G	9
I	Electrical installation	C	7
J	Partitioning	F, I	8
K	Laying the floors	J	4
L	Internal painting	J	5
M	External finish	H	2
N	Internal finish	K, L	6
O	Finalization	M, N	1
TOTAL			80

Source: Survey data (2023).

The data presented in Table 1 show that the company's work has a total of fifteen processes, which are: excavation of the land, foundation of the land, masonry, roof, external plumbing, internal plumbing, wall construction, external painting, electrical installation, partition, floor laying, internal painting, external finishing, internal finishing and completion. The work begins with the excavation of the land and ends with the completion, the most time-consuming process being masonry, which is the phase of construction of the walls and other structural elements of the building, using blocks, bricks, mortar and other materials.

The finalization activity, in turn, is configured as the process that occurs more quickly, with an average time of one week. As it is a final phase of the work, professionals only check and make adjustments before delivering the project to the client. This stage covers the completion of all stages of construction, finishes, installations and final adjustments, with the aim of ensuring the quality, safety and functionality of the building. In addition, the final touches are made to the finishes, such as corrections in paintings, adjustments in installations and the identification and resolution of possible defects or finishing problems. Comprehensive cleaning is also carried out to ensure that the environment is free of waste and in suitable condition for delivery to the customer.

It is observed that there is a logical order for the execution of the project. The logical sequence of processes is essential to avoid overlapping tasks and ensure that each activity is performed at the appropriate time, which helps to organize the workflow, avoiding overlapping tasks and unnecessary delays. If the activities are carried out individually, the average duration of the work is 80 weeks. However, some activities can be carried out simultaneously with other activities, which can minimize the duration of the work. Among the fifteen activities, only four have preceding activities and therefore depend on the completion of previous activities in order to occur.

By identifying the activities involved in the construction work of the company under study, it became possible to determine the different paths through the PERT/CPM network. Each path represents a specific sequence of activities that lead to the completion of the project. In these paths, the activities are performed in a certain order, taking into account the dependencies between them. To illustrate the possible paths, table 2 shows the identified paths and the total estimated weeks for each path.

Table 2. PERT/CPM network paths

Pathways	**Total weeks**
A, B, C, D, G, H, M, O	2 + 4 + 10 + 6 + 7 + 9 + 2 + 1 = 41
A, B, C, E, H, M, O	2 + 4 + 10 + 4 + 9 + 2 + 1 = 32
A, B, C, E, F, J, K, N, O	2 + 4 + 10 + 4 + 5 + 8 + 4 + 6 + 1 = 44
A, B, C, E, F, J, L, N, O	2 + 4 + 10 + 4 + 5 + 8 + 5 + 6 + 1 = 45
A, B, C, I, J, K, N, O	2 + 4 + 10 + 7 + 8 + 4 + 6 + 1 = 42
A, B, C, I, J, L, N, O	2 + 4 + 10 + 7 + 8 + 5 + 6 + 1 = 43

Source: Survey data (2023).

The table presented provides a comprehensive view of the different sequences of activities and their estimated total times for the completion of the project of the company under study. Each path is clearly shown, indicating the sequence of activities involved and their estimated times. Some paths have lower total times, indicating a more efficient sequence of activities, while other paths have higher total times due to the inclusion of additional activities or changes in the sequence. Each path is composed of a specific sequence of activities that must be performed in a certain order, taking into account their dependencies. These paths are represented by the letters that identify the activities in the framework.

Among the six paths, the sequence "*A, B, C, E, H, M, O*" presents an estimated time of 32 weeks, being the shortest path among all identified. This indicates that by following this sequence of activities, it is possible to complete the project in a shorter time compared to the other paths. The importance of this finding lies in the fact that following this sequence of activities will result in a faster completion of the project compared to the other identified paths, which becomes extremely advantageous for the company, given that it is subject to time constraints and tight deadlines.

On the other hand, the path "*A, B, C, E, F, J, L, N, O*" has the highest estimated time, totaling 45 weeks. This information suggests that this sequence of activities is configured as the critical path of the project, as any delay in these activities can significantly affect the completion of the project. Knowledge of the critical path is essential for effective project management as it allows managers to focus their efforts and resources on the most critical activities. By directing attention to the critical path, managers can identify bottlenecks and take preventive measures to avoid delays and ensure that the project is completed on time.

From this, information related to the nodes of the ongoing civil construction project was identified. Each node represents a stage or activity within the construction project, and the information provided includes the duration of each node, the earliest start date (E-SD), the earliest finish date (E-SD) and the available slack. The duration indicates the estimated time required to complete each stage of the construction, from site preparation to final finishes. The PDI, in turn, represents the earliest time at which each node can be started, taking into account the dependencies between activities and the overall project schedule. The UDI represents the latest time at which each node can be started without affecting the delivery time of the project as a whole. The slack is the difference between the UDI and the PDI, indicating the time available to carry out each activity without delaying the overall schedule. Table 3 shows this information.

Table 3. Site clearances

Knot	Duration	PDI	UDI	Clearance
A	2	0	0	0
B	4	2	2	0
C	10	6	6	0
D	6	16	20	4
E	4	16	16	0
F	5	20	20	0
G	7	22	26	4
H	9	29	33	4
I	7	16	18	2
J	8	25	25	0
K	4	33	34	1
L	5	33	33	0
M	2	38	42	4
N	6	38	38	0
O	1	44	44	0

Source: Survey data (2023).

As far as the PDI is concerned, it provides an overview of the project schedule, showing the duration and elapsed time of each process involved. By analyzing the information present, one can observe some patterns and trends that may be useful in understanding the project as a whole. Firstly, it is evident that the processes have varying durations, which indicates that different activities have different levels of complexity. For example, processes such as C, with a duration of 10 weeks, may involve more elaborate steps compared to other processes that have shorter durations, such as O, which has a duration of only 1 week.

Moreover, the IDP is calculated progressively by adding the duration of the previous process to the corresponding IDP. This sequential dependency between processes suggests that each step is conditional on the completion of the previous step. This structure indicates the need to follow a specific sequence to avoid project interruptions or delays. A general trend observed is the gradual increase of the PDI as the processes progress. This suggests that the time elapsed until the completion of each process tends to increase throughout the project. However, it is important to note some variations in this trend, such as the significant increase in PDI between processes H and I, where the PDI goes from 9 to 16 time units. These variations may indicate specific factors that influence the time required for the completion of certain steps.

Overall, the IDP framework provides an overview of the time needed to complete each process and the total time elapsed until project completion. This information is crucial for project planning, allowing to identify potential bottlenecks, predict the total duration and monitor progress over time. Based on these insights, the project managers of the company under study can make informed decisions and adjust the available resources to ensure successful project completion within the set deadlines.

As for the UDI, the analysis of the results obtained allows a more detailed understanding of the progress of the company's work and the total time elapsed until the completion of each specific process. The UDI demonstrates a linear progression, in which each process contributes with its own time (PDI) and with the accumulated time of the previous processes. The linear progression indicates the sequential execution of the project, following the pre-established order. Additionally, the UDI provides relevant information on the total time elapsed from the start of the project to the completion of each individual process. When considering process O, it is possible to observe that the UDI is equal to 44, indicating that 44 weeks have passed since the beginning of the project until its completion.

In process A, for example, the UDI is 0, indicating that no unit of time has elapsed from the start of the project to the completion of this initial process. In processes B and C, both have a UDI equal to their respective PDI, which means that the time elapsed until the completion of these processes is equal to their estimated duration. In process D, the UDI is 20, indicating that 20 units of time have elapsed from the start of the project to the completion of this process. Processes E, F and J have a UDI equal to their respective PDI, suggesting that they were completed within the estimated time and did not affect the final project deadline. For process G, the UDI is 26, indicating that 26 weeks elapsed from the start of the project to the completion of this process. Finally, processes H, M and O have a UDI that is greater than their PDI, indicating that there was a delay in their completion in relation to the planned schedule.

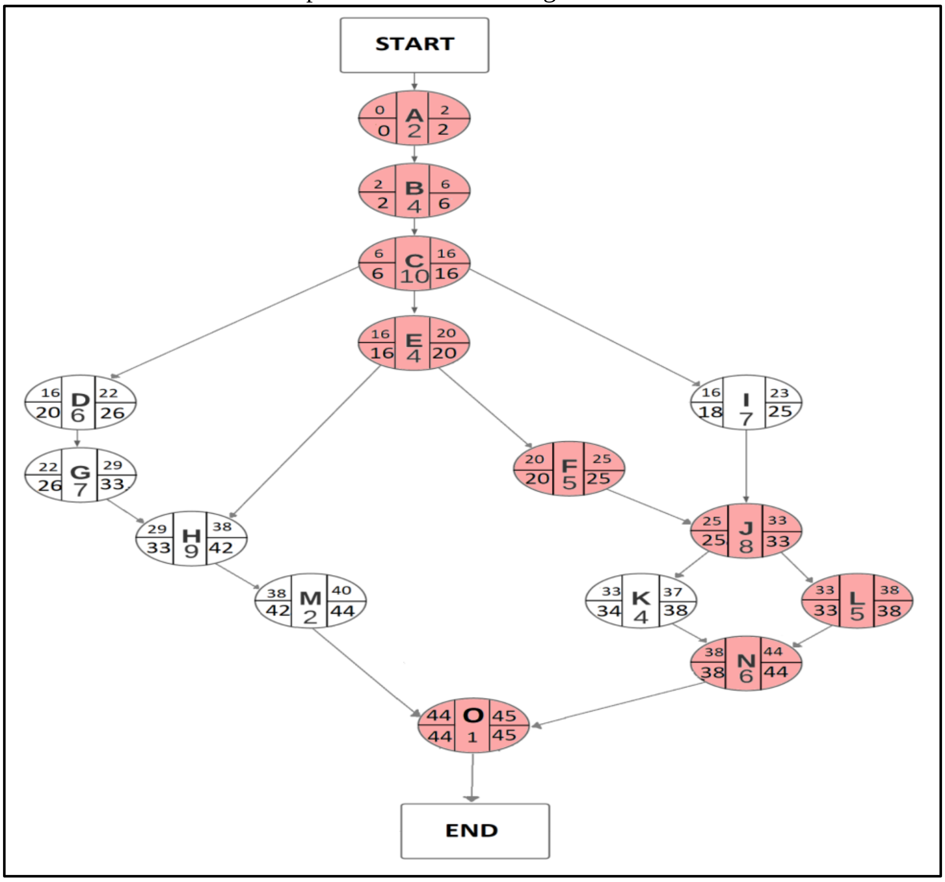
These results allow estimating the total time required for the completion of the project as a whole. By doing so, detailed UDI analysis allows identifying which processes are the most time-sensitive and require special attention to avoid significant delays. In addition, it helps to identify opportunities for improvement and optimization of the schedule, allowing project managers to take corrective actions to ensure successful completion of the project within the established deadlines.

With regard to slack, it can be observed that some activities have slack, while others have no margin for delay. Activities that have slack indicate that it is possible to delay them for a certain period without causing delays to the project as a whole. For example, activity D has a slack of 4 days, which means that it can be completed up to 4 days after the estimated date without affecting the overall schedule. Similarly, activities G and H also have slack of 4 days each. On the other hand, activities "*A, B, C, E, F, J, K, L, M, N and O*" have no slack, which indicates that they must be completed exactly on the estimated date to avoid project delays.

Slack analysis is important for project management as it allows identifying activities that have room for delays and those that are critical, i.e. cannot be delayed without impacting the schedule. This assists in the proper allocation of resources and in making decisions to ensure compliance with the established deadlines.

Thus, based on the identification of this information, it became possible to elaborate the PERT/CPM network of the work of the company under study. This is because the slack analysis also allows to identify the critical path of the project. The critical path consists of the sequence of activities that determines the total duration of the project, i.e. any delay in these critical activities will result in a delay in the overall schedule. Figure 1 shows the critical path of the construction work of the company under study.

Table 3. Critical path of the works using the PERT/CPM network



Source: Survey data (2023).

In the case of the given example, activities "*A, B, C, E, F, J, K, L, M, N and O*" have no slack, which means that any delay in these activities will directly impact the project duration. Therefore, they are part of the critical path, and special attention should be paid to them to ensure that they are completed within the estimated time, The critical path of the construction work encompasses a sequencing of activities that follows the following flow: excavation of the land, foundation of the land, masonry, external plumbing (plumbing), internal plumbing (plumbing), partition, internal painting, internal finishing and finalization.

On the other hand, activities "*D, G and H*" have a slack of 4 days each. This indicates that these activities can be delayed by up to 4 days without affecting the overall schedule. These activities are not on the critical path and provide a certain flexibility to the project. However, it is important to monitor these activities to avoid unnecessary delays and to take advantage of this slack, if necessary, to optimize resource allocation or deal with possible unforeseen events.

The elaboration of the PERT/CPM (Program Evaluation and Review Technique/Critical Path Method) network from the slack analysis allows a clearer visualization of the interdependencies between activities, the available slack and the critical path. This network is a powerful project management tool that assists in identifying the most critical activities, planning deadlines and resources, prioritizing tasks and making decisions to keep the project on track.

The critical path analysis shows a sequence of activities required to complete the project. The flow includes everything from site preparation to finalization of the works. In this case, the critical path determines the total duration of the construction work and any delay in this set of activities can result in overall delays in the schedule. Thus, it is important to ensure that each step is completed efficiently and on time to avoid delays and impacts on the project as a whole.

It therefore becomes critical to ensure that each activity is completed efficiently and within the established timeframes in order to avoid subsequent delays in other stages of the project. This is because the critical path is responsible for determining the total duration of the works, highlighting the importance of closely managing these key activities. Site managers must monitor the progress of these activities and adjust the schedule as unforeseen events arise. This involves careful planning, proper allocation of resources, effective communication between the teams involved, and readiness to make adjustments and adaptations when necessary. In addition, the critical path also made it possible to identify the activities that have the least slack, i.e. those that cannot be delayed at all without directly affecting the final deadline.

IV. Conclusion

Given the results presented and the analysis of the PERT/CPM network, it can be concluded that the elaboration of this network provides a clear view of the activities involved in the construction project of the company under study, their dependencies and the estimated times for completion. The logical sequence of activities is essential to avoid overlapping tasks and ensure an organized workflow, avoiding unnecessary delays.

In this perspective, the identification of the different paths of the PERT/CPM network allowed us to determine the critical path, which was represented by the path associated with activities "*A, B, C, E, F, J, K, L, M, N and O*". Any delay in this critical path will have a direct impact on the final deadline of the work. On the other hand, activities that have slack offer some flexibility to the project, but must be monitored to avoid unnecessary delays. The analysis of the PDI, UDI and slack information provided a more detailed understanding of the project schedule, allowing to identify the most time-sensitive activities and those that can be delayed without affecting the final deadline.

The information is critical to project planning and management, enabling progress monitoring, appropriate resource allocation and informed decision making to ensure successful completion of the project within the set deadlines. Therefore, the use of PERT/CPM network and the analysis of PDI, UDI and slack information provided a solid foundation for effective planning and management of the construction project of the company under study. The critical path identification highlighted the most important activities that require special attention to avoid delays in the overall schedule. In addition, the slack analysis allowed identifying the activities with the greatest flexibility and those that need to be carried out within the estimated timeframe.

Thus, the application of the PERT/CPM network and the understanding of the information obtained are valuable tools for the success of the project, providing a comprehensive view of the activities, their interdependencies and the deadlines involved. These project management techniques enable more efficient scheduling, progress monitoring and identification of possible delays or bottlenecks, helping managers to make informed decisions to ensure the successful completion of the construction project on time.

References

[1]. Boni, V.; Quaresma, S. J. Aprendendo A Entrevistar: Como Fazer Entrevistas Em Ciências Sociais. Revista Eletrônica Dos Pós-Graduandos Em Sociologia Política Da Ufsc, V. 2, N. 1, P.68-80, Jan./Jul., 2005.
[2]. Fraser, M. T. D.; Gondim, S. M. G. Da Fala Do Outro Ao Texto Negociado: Discussões Sobre A Entrevista Na Pesquisa Qualitativa. Paidéia, 14 (28), P. 139-152, 2004.
[3]. Godoy, A. S. Pesquisa Qualitativa: Tipos Fundamentais. Revista De Administração De Empresas, São Paulo, V. 35, N. 3, P. 20-29, 1995.
[4]. Herrera, F. J.; Rodrigues, D. C. Gestão De Projetos Na Construção Civil. Intertemas, V. 14, N. 14, 2018.
[5]. Pinto, G. O.; Mello, L. C. B. B.; Spiegel, T. Melhores Práticas Na Implantação De Um Escritório De Gerenciamento De Projetos: Uma Revisão Sistemática Da Literatura. Revista Eletrônica Sistemas & Gestão, V. 14, N. 4, P. 448-464, 2019.
[6]. Pouparte, J. Et Al. A Pesquisa Qualitativa: Enfoques Epistemológico E Metodológicos. Editora Vozes, 2008.
[7]. Ruas, A. X. A. R. X. A.; Silva, M. A. O.; Corrêa, L. R. Gerenciamento De Projetos Na Construção Civil: Tempo, Custo E Qualidade. Revista Construindo, Belo Horizonte, V. 10, N. 02, P. 01 – 20, Jul./Dez., 2018.
[8]. Santos, L. H. Aplicação Do Método Pert/Cpm Na Construção Civil. 2018. Trabalho De Conclusão De Curso (Bacharelado Em Engenharia De Produção) – Universidade Tecnológica Federal Do Paraná, Medianeira, 2018.
[9]. Santos, M. S.; Ribeiro, G.; Oliveira, G. O Método Pert/Cpm: Uma Ferramenta Para O Planejamento De Obras. Simpósio, [S.L.], N. 11, P. 1, Maio, 2023.
[10]. Souza, V. B. Et Al. Utilização Do Modelo Pert/Cpm Para Otimizar A Relação Entre Tempo-Custo: Um Estudo De Caso. Revista Interdisciplinar Pensamento Científico, 3(1), 2017.
[11]. Valle, A. B. Et Al. Fundamentos Do Gerenciamento De Projetos. 3° Ed. Editora Ide, 2014.