INDEPENDENT JOURNAL OF MANAGEMENT & PRODUCTION (IJM&P)
http://www.ijmp.jor.br v. 7, n. 3, July - September 2016
ISSN: 2236-269X
DOI: 10.14807/ijmp.v7i3.423

OPTIMIZATION OF TIMES AND COSTS OF PROJECT OF HORIZONTAL LAMINATOR PRODUCTION USING PERT/CPM TECHNICAL

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Submission: 13/01/2016
Revision: 30/01/2016
Accept: 02/03/2016

ABSTRACT

The PERT/CPM is a technique widely used in both the scheduling and in the project feasibility in terms of cost control and time. In order to optimize time and costs involved in production, the work presented here aims to apply the PERT/CPM technique in the production project of the Horizontal Laminator, a machine used to cut polyurethane foam blocks in the mattresses industries. For the application of PERT/CPM technique in the project of Horizontal Laminator production were identified the activities that compose the project, the dependence between them, the normal and accelerated durations and the normal and accelerated costs. In this study, deterministic estimates for the duration of the activities were considered.

The results show that the project can be completed in 520 hours at a total cost of R$7,042.50, when all activities are performed in their normal durations. When all the activities that compose the critical path are accelerated, the project can be completed in 333.3 hours at a total cost of R$9,263.01. If the activities slacks have been exploited, it can obtain a final total cost of R$6,157.8, without changing the new duration of the project. It is noteworthy that the final total cost of the project if the slacks are used, will be lower than the initial cost. Regarding the initial cost of the project, after the application of the PERT/CPM technique, it presents a decrease of 12.56% of the total project cost.

Keywords: Network Diagram; Deterministic Estimative; Path Critical; Slack of Activities; Machinery Industry.

1. INTRODUCTION

Projects are unique operations with a finite life span, which present many interrelated activities that must be scheduled and monitored within strict time, cost and performance guidelines (KRAJEWSKI; RITZMAN, 1999). Completing a project on time and within budget is not an easy task (AGYEI, 2015). In the process of planning and control of projects the use of specific techniques to deal with the complexity and temporal nature of projects is required (SLACK, et al., 2009).

The PERT/CPM technique that it is the joining of two techniques developed in the 50s in the United States, is a technique widely used to plan the schedule and control the progress of the project (SLACK, et al., 2009; GRUNWALD NETO; SANCHES, 2013). The PERT/CPM technique aims to simplify the planning and schedules of large and complex projects (KEELLING, 2002), which consist of one of the most challenging jobs that any manager can take, since they require coordination of numerous activities throughout the organization (HILLIER; LIEBERMAN, 2001).

The PERT technique (Program Evaluation and Review Technique) and the CPM technique (Critical Path Method) were developed independently in the end of the 1950s. The PERT was developed by the US Navy Special Projects Office in 1958 as a management tool for programming and control of the Polaris Project, while the CPM was developed in 1957 by J. Kelly and M. R. Walker to assist in scheduling maintenance and shutdowns of chemical processing plants (DAVIS, et al., 2001).

http://www.ijmp.jor.br v. 7, n. 3, July - September 2016
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The PERT and CPM techniques have many similarities, although they have been developed separately, the main difference lies in the fact that the CPM technique is based on deterministic estimates for the duration of activities while the PERT technique is based on probability estimates for the duration of the activities (ARENALES, et al., 2007).

These two techniques, although it had independent development, are so similar that small differences are considered by several authors as PERT/CPM technique, as pointed by Andrade (2009) and according to Gaither and Frazier (2002) these two terms are often used interchangeably.

The PERT/CPM technique can answer the following important questions, as follow: i) How long will the entire project take to be completed?; ii) What are the risks involved?; iii) Which are the critical activities or tasks in the project which could delay the entire project if they were not completed on time?; iv) Which are the noncritical activities or tasks in the project which run later without delayed the entire project? v) Is the project on schedule, behind schedule or ahead of schedule?; and, vi) If the project has to be finished earlier than planned, what is the best way to do this at the least cost? (HEIZER; RENDER, 1996; TAMRAKAR, 2013).

The scheduling information generated by PERT/CPM is vital to the project manager. However, the PERT/CPM technique assists the project manager in other ways. Schedule and budget are key concerns and method of time-cost trade-offs enables investigating ways of reducing the duration of the project at an additional cost (HILLIER; LIEBERMAN, 2001).

In this context, this paper aims to apply the PERT/CPM technique in Horizontal Laminator production project on a machinery industry for foam cutting production in order to optimize the time and cost, considering deterministic estimates for the duration of the activities. This study also will allow to industry management define a planning and control structure of the activities involved in the production process of Horizontal Laminator, since it will provide knowledge of the interdependencies between activities, activities that have slacks, time that each activity can be delayed, and others information’s.

This paper is structured in six sections. After the presentation of the context and objectives of this research, the theoretical framework on the PERT/CPM

ISSN: 2236-269X
DOI: 10.14807/ijmp.v7i3.423

technique is explained in Section 2. In Section 3, the research methodology is presented. Then, the theoretical framework is presented. The application of the PERT/CPM technique on the project of the Horizontal Laminator production and optimization of times and costs associated with the project is presented in Section 4; In Section 5, discussions of the results are present; And, conclusions and final considerations, are explained in the 6 Section.

2. 2. THEORETICAL FRAMEWORK

2.1. PERT/CPM Technique

PERT/CPM technique is based on a network diagram and network planning can help manager monitor and control projects. To managing a project with network planning involves four steps: I) Describing the project; ii) Diagramming the network; iii) Estimative time of completion; and, iv) Monitoring project progress. (MCCLAIN; THOMAS, 1985; KRAJEWSKI; RITZMAN, 1999).

The final outcome of PERT/CPM technique is the construction of the time schedule for the project, and to achieve this goal is convenient, run special calculations to produce the following information in accordance with TAHA (2008): i) Total time needed to complete the project; and ii) Classification of project activities as critical and non-critical.

In order to apply PERT/CPM technique in a project is needed: i) Define the activities involved for each project; ii) Define the precedence relationship of activities; iii) Establish the estimative of time and cost for each activity; iv) Create a network showing the precedence relationship; and v) Develop a schedule for the project through specific calculations of PERT/CPM technique (ACUÑA, 2009).

2.1.1. Critical Path

A critical activity is an activity that has no leeway in determining its start and finish times. According to Gaither and Frazier (2002) the critical path is the longest path network and is a chain of critical activities for the project. If a critical activity runs late, then the entire project will run late (TAHA, 2008; ACUÑA, 2009).

A noncritical activity is an activity that allows some scheduling slack, meaning it can be advanced or delayed (within limits) without affecting the completion time of the project (TAHA, 2008; ACUÑA, 2009).

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Slack of activity is the maximum length of time that an activity can be delayed without delaying the entire project. Activities on the critical path have zero slack. Slack of activity is calculated from four time for each activity: i) earliest start time; ii) earliest finish time; iii) latest start time; and iv) latest finish time (KRAJEWSKI; RITZMAN, 1999).

According to McClain and Thomas (1985), Heizer and Render (1996), Krajewski and Ritzman (1999), Taha (2008), Andrade (2009) and Fernandes and Godinho Filho (2010) the earliest start time and earliest finish time are obtained as follow:

- Earliest Activity Start Time (ES): Time zero is defined to be the earliest start time of the project. Each activity also has an earliest start (ES) time, which supposes that all activities start as early as possible, given the precedence relationships. Since an activity *i* cannot start until all its predecessors are completed, ES can calculate by equation 1.

$$ES_i = \max\{EF\ of\ the\ predecessors\ of\ activity\ i\} \quad (1)$$

- Earliest Activity Finish Time (EF): Is the earliest finish time for an activity *i* is equal its earliest start time plus its expected duration or time (t), according to equation 2.

$$EF_i = ES_i + t_i \quad (2)$$

The ES and EF times for each activity are computed as soon as all predecessors have EF times, and are written on the node of the diagram (MCCLAIN; THOMAS, 1985).

To McClain and Thomas (1985), Heizer and Render (1996), Krajewski and Ritzman (1999), Taha (2008), Andrade (2009) and Fernandes and Godinho Filho (2010) the latest start time and latest finish time are obtained as follow:

- Latest Activity Finish Time (LF): For an activity is the latest finish time of an activity is the latest start time of the immediately following activity. For activities with more than one immediately following, LF is the earliest of the latest start times of those activities. Then LF for an activity *i* can calculate by equation 3.

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$$LF_i = \min\{LS\ of\ the\ sucessors\ of\ \ activity\ \ i\} \quad (3)$$

- Latest Activity Start Time (LS): This is, the latest time an activity can be started without delaying the entire project. All following activities must be completed without delaying the entire project. The LS for an activity is equal its latest finish times minus it's expect duration (t), according to equation 4.

$$LS_i = LF_i - t_i \quad (4)$$

The occurrences times calculations is done directly in the network diagram (ANDRADE, 2009) and involve two passes: i) the forward pass determines the earliest occurrence times of the events (earliest start time and earliest finish time; and ii) the backward pass calculates their latest occurrence times (latest start time and iv) latest finish time) (TAHA, 2008; ACUÑA, 2009).

As previously mentioned activities on the critical path have zero slack. Information on slack are useful to project managers because its help them make decisions regarding reallocation of resources (KRAJEWSKI; RITZMAN, 1999). Slack times give you the amount of time an activity can run late without delaying your project (ACUÑA, 2009).

Slack times can be checked in activities that are outside the critical path and are determined from the earliest and latest occurrence times of the events. Slacks should be known by the project manager so that it can properly allocate the resources to carry out the project activities (ANDRADE, 2009).

The activity slack (S) for an activity i, according to Heizer and Render (1996), Krajewski and Ritzman (1999), Taha (2008) and Fernandes and Godinho Filho (2010) can be calculated in one of two ways for any activity, as follow:

$$S_i = LS_i - ES_i \quad (5)$$

$$S_i = LF_i - EF_i \quad (6)$$

According to Krajewski and Ritzman (1999) to calculate the duration of the entire project, should determine the EF for the last activity on the critical path. The same authors highlight that the "constantly monitoring of the progress of activities with little or no slack enables managers to identify activities that need to be expedited to keep the project on schedule" (KRAJEWSKI; RITZMAN, 1999, p. 805).

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2.1.2. Deadlines for the Performing Activities

The deadlines for performing the activity are those that enable the allocation resources needed to perform the activity, thus show the most important points for planning the execution, the deadlines for the start and end of the activities are calculated after being obtained the occurrences times of each event of project (ANDRADE, 2009), that are: i) earliest start time; ii) earliest finish time; iii) latest start time; and iv) latest finish time.

The deadlines for performing activities, according to Monks (1987) and Andrade (2009) are:

- First Start Date (FSD): It is the earliest possible date for starting the activity, considering that the previous activities are being performed without delay, according to its planned duration. The FSD for an activity *i* is calculated by equation (7).

$$FSD_i = ES_i + 1 \tag{7}$$

- First Finish Date (FFD): It is the first date to complete an activity, considering that the previous activity has been initiated in the early initial event and its duration has been obeyed. The FFD for an activity *i* is calculated by equation (8).

$$FFD_i = FSD_i + t_i - 1 \tag{8}$$

- Latest Finish Date (LFD): It is the last date to end an activity so as not to cause delays in the following activities. The LFD for an activity *i* is calculated by equation (9).

$$LFD_i = LF_i \tag{9}$$

- Latest Start Date (LSD): Is the maximum date for initiating an activity so as not delay following activities, and consequently, delay the entire project. The LSD for an activity *i* is calculated by equation (10).

$$LSD_i = LFD_i - t_i + 1 \tag{10}$$

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2.1.3. Cost Analysis

Keeping costs at acceptable levels almost always is as important as meeting schedule dates. The reality of project management is that there are time-cost trade-offs (KRAJEWSKI; RITZMAN, 1999).

The cost analysis is used to determine the lowest cost way to reduce the duration of the project. Heizer and Render (1996) emphasize that the objective of cost analysis is to reduce the entire project completion time by a certain amount at the least cost. For this it is necessary to reduce the duration of any critical activity, if only because there are no slacks in these activities (TAHA, 2008).

In the initial phase of the project when one of the activities is to estimate the time spent performing each activity, the budgeting of the activities of costs should also be a concern as it is necessary to create elements for the relationship of three major analysis of the project, as follows: i) identifying the total cost of the project, which is the sum of direct costs, indirect costs and penalty costs; ii) identifying individual cost for each activity, creating the possibility to optimize the project; and, iii) identifying resource requirements per unit of time and analysis of resource leveling (ANDRADE, 2009).

According to Krajewski and Ritzman (1999) and Andrade (2009) to assess whether the activities may provide benefits – from either a cost or a schedule perspective – the manager needs to know the following times and costs:

- Normal Time/Duration: is the time to complete the activity under normal considerations and this time is equal the expected time (t).
- Normal Cost: is the activity cost associated with the normal time.
- Accelerated Time/Duration: is the shortest possible time to complete the activity.
- Accelerated Cost: is the cost associated with the accelerated time.

In this study, based on Krajewski and Ritzman (1999), the assumption that direct costs increase linearly as activity time is reduced from its normal time is considered. This assumption implies that for every time unit the activity is reduced, direct costs increase by a proportional amount.

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To conduct any analysis of the costs of a project initially should know the Marginal Cost (CMg) of an activity *i*, which is obtained by equation (11).

$$CMg_i = \frac{Accelerated\ Cost_i - Normal\ Cost_i}{Normal\ Duration_i - Accelerated\ Duration_i} \quad (11)$$

In the planning phase, it should be noted that the activities that contain slacks, have optimal duration higher than the normal duration. In this scenario, you can reduce the total cost of the project increases the runtime of these activities to its duration or to consume all his slack (ANDRADE, 2009). In this case the assumption that direct costs decrease linearly as activity time is increased in all its slack is considered. This assumption implies that for every time unit the activity is increase, direct costs decrease by a proportional amount.

In practical situations it may be necessary accelerate a project, that is, ends it in a shorter period than anticipated. For this to occur it is necessary to analyze the activities in order to accelerate that contribute most to the project deadline, which are the critical path activities (PRADO, 2004; ANDRADE, 2009).

Once managers have several activities that can be enhanced or accelerated in the project, according to Gaither and Frazier (2002) the general rules for deciding which activities accelerate, which do not accelerate and in what order accelerate are: i) Accelerate only critical activities; ii) First accelerating activity with lower cost of acceleration per unit of time or lower marginal cost; and iii) When there are parallel critical paths, each must be accelerated because the acceleration of just one of the paths will not reduce the total duration of the project.

3. METHODOLOGY

In this research were used the methods qualitative and quantitative. For the purpose, this research was classified as to the purposes as descriptive, exploratory, and methodological, and was classified as to the means as bibliographical and case study.

The theoretical framework about the PERT/CPM technique to support the application in the project of Horizontal Laminator production was initially defined. The choice of the production process of Horizontal Laminator for analysis is due the fact

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of this equipment is one of the main products marketed by the Industry X and be a customized or tailored product.

Data collection was accomplished by means of direct observations, documentary analysis and interviews. Direct observations were necessary for the understanding of production process and their respective activities. The analysis of documents, such as the production route, was needed to identify the sequence of production as well as dependencies between activities that compose the project. Interviews were conducted with staff from the Engineering Department of Industry X to identify the time and costs associated with project activities.

The normal durations and the normal costs used the application of PERT/CPM technique is coming from of the Engineering Department of Industry X. It is noteworthy that in the calculation of activities costs were considered the direct and indirect costs associated with the execution of activities.

According to Engineering Department of Industry, the times of activities can be accelerated by up to 37.5% over their normal durations, with the exception of the painting activity. In this study was used for the calculation of the durations accelerated all the percentage allowed by Industry X. The same percentage of 37.5% is added to the cost of activities when they are performed in their accelerated durations, according to Engineering Department of Industry X.

4. APPLICATION OF PERT/CPM TECHNICAL FOR OPTIMIZATION OF TIMES AND COSTS OF PROJECT OF HORIZONTAL LAMINATOR PRODUCTION

4.1. Production Process of Horizontal Laminator

The horizontal laminator is produced by the Industry X, founded in 1986 and located in Araruna City, northwest of Parana State, Brazil. The Industry x is specializes in the development of industrial products customized or tailored.

The horizontal laminator is a machine used for cutting blocks of polyurethane foam with a precision of 1 mm and minimum cut 10mm thick, The structure is made of carbon steel and its operation is made in Programmable Logic Controller (PLC) and Human Machine Interface (HMI), in which the cutting plans and information pertinent to operation of the machine are entered.

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The Horizontal Laminator structure is divided into cutting table and headstock. The table is responsible for transporting the pack in cutting while the headstock ensures the alignment of the blade and precision. In addition to these components the machine has a safety system as can be seen in Figure 1.

Figure 1: Horizontal Laminator

The manufacturing process of Horizontal Laminator begins with cutting of carbon steel bars and carbon steel flat sheets in sizes established by the Department of Product Engineering.

The cut sheets are divided into two groups, as follows: i) group of thin plates (up to 4.75 mm) that are brought into the fold and then sent to the sector responsible for production the machine; and ii) group of plates (larger than 4.75 mm) are taken together with the carbon steel bars cut the company's sector responsible for production machine. The bars and the plates are then subjected to the welding process the components and assembly of the machine.

After the Horizontal laminator is ready, it is disassembled and its components are brought to the paint sector, which are separated into three groups, as follows: i) fixed parts for painting in gray; ii) moving parts to paint in orange; iii) security protections for painting in yellow.

After painted the Horizontal laminator is mounted again and begins the implementation process of the electrical, pneumatic and automation components. After assembled all electrical, pneumatic and automation components, the machine is subjected to quality test, and then released for final disassembly, packing and shipping.

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4.2. Application of PERT/CPM Technique

To optimize the times and costs associated of the project of Horizontal Laminator production through the application of PERT/CPM technique, the sequence of activities and their dependency relationships have been initially identified, based on the production route (Table 1).

Table 1: Sequence and Activities Dependency Relations of Project of Horizontal Laminator Production

Activity	Description	Dependence
A	Cut for Machining	-
B	Cut to Curve	-
C	Cut to Production	-
D	Plasm Cutting	-
E	Machining	A
F	To Curve	B
G	Production Parts	C
H	Assembly 1	E, D, F, G
I	Panel Mounting	A
J	Disassembly 1	H
K	Painting	J
L	Assembly 2	K
M	Automation	L
N	Quality Test	I, M
O	Disassembly 2	N
P	Packing	O
Q	Shipment	P

We emphasize that the indirect dependence is not shown in the project network and the dependencies relationships adopted in this study were provided by the Department of Engineering. However, it is implicit in this study that the activity I depend on all previous activities.

In sequence, it was obtained from the Product Engineering Departament, normal and accelerated times or durations, as well as the normal and accelerated costs, for all the activities that compose the project associated with the production of Horizontal laminator. It is noteworthy that the project activities with the exception of the activity K (painting) can be accelerated by up to 37.5% of their normal times and that the use of financial resources for such accelerations are proportional to the decrease in the time for execution of activities. The marginal cost was calculated using the equation (11) presented in the theoretical framework.

The times or durations and costs of activities that compose the project are presented in Table 2.

Table 2: Durations and costs of activities of Project of Horizontal Laminator Production

Activity	Normal Duration (hours)	Accelerated Duration (hours)	Normal Cost (R$)	Accelerated Cost (R$)	Marginal Cost (R$)
A	4	2.5	45	61.87	11.24
B	12	7.5	135	185.62	11.24
C	24	15.1	270	371.25	11.37
D	2	1.2	22.50	30.93	10.53
E	16	10	180	247.5	11.25
F	32	20.2	360	495	11.44
G	32	20.2	360	495	11.44
H	240	151.2	2700	3,712.5	11.40
I	40	25.2	450	618.75	11.40
J	16	10	180	247.5	11.25
K	16	16	180	180	0
L	32	20.2	360	495	11.44
M	48	30.2	540	742.5	11.37
N	16	10	180	247.5	11.25
O	32	20.2	360	495	11.44
P	32	20.2	360	495	11.44
Q	32	20.2	360	495	11.44

Based on the dependency relations (Table 1) and in the normal times of activities (Table 2) was constructed the initial PERT/CPM network for the project (Figure 2) which has a total cost of R$ 7,042.50. It also calculated the total cost of the project and identified the critical path.

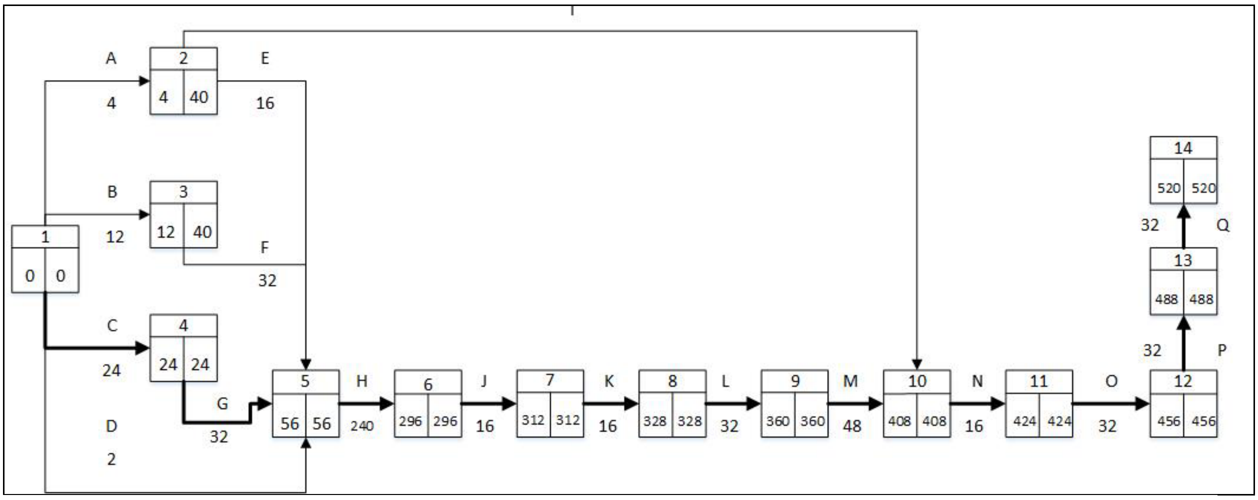

Figure 2: Initial PERT/CPM Network of Project of Horizontal Laminator Production

The project of horizontal laminator production, with all activities performed in normal times, has total duration of 520 hours and, as shown in network (Figure 2) the activities C, G, H, J, K, L, M, N, O, P and Q composing the critical path.

As shown in the theoretical framework, to reduce the total duration of a project, it is necessary to accelerate the activities on the critical path, i.e. to reduce

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their duration to the limits. Thus, with the exception of the activity K (paint), since whom it has the normal period equal to accelerated life, it was possible to accelerate the C, G, H, J, K, L, M, N, O and Q activities, for which the variations of times and costs are presented in Table 3.

Table 3: Variations of Durations and Costs of Accelerating of C, G, H, J, K, L, M, N, O and Q Activities

Activity	Normal Duration (hours)	Accelerated Duration (hours)	Variation in Duration (hours)	Marginal Cost (R$)	Increase in Activity Cost (R$)
C	24	15.1	8.9	11.37	101.19
G	32	20.2	11.8	11.44	134.99
H	240	151.2	88.8	11.40	1,012.32
J	16	10	6	11.25	67.5
L	32	20.2	11.8	11.44	134.99
M	48	30.2	9.8	11.37	111.42
N	16	10	6	11.25	67.5
O	32	20.2	11.8	11.44	134.99
P	32	20.2	11.8	11.44	134.99
Q	32	20.2	11.8	11.44	134.99
Total Increase in Total Cost of Project					**2,034.89**

Based on new activity durations (Table 3) was constructed the PERT/CPM network for the project, calculated the new total duration of the project and identified the new critical path, as can be seen in Figure 3.

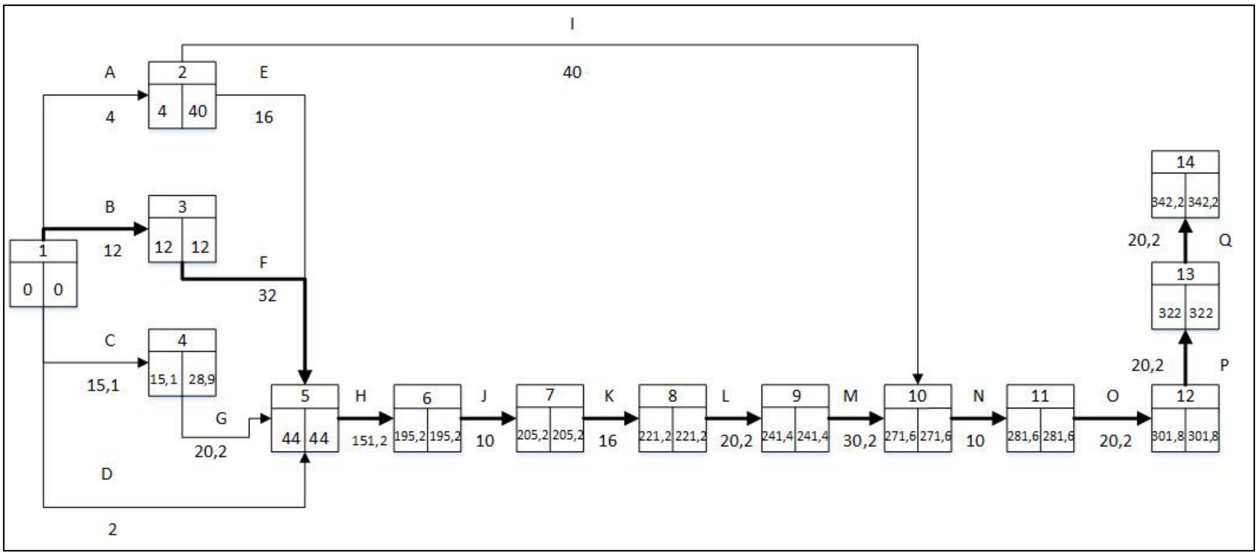

Figure 3: Network PERT/CPM with a decrease in the times of the activities C, G, H, J, L, M, N, O and P

The reduction in the duration of the activities C, G, H, J, L, M, N, O and P resulted in an increase of R $ 2,034.89 in the total project cost and reduction of 177.8 hours in the total duration of the project. Thus, the total cost of the project increased

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from R$7,042.50 to R$9,077.39 and the total duration of the project decreased from 520.0 hours to 342.2 hours.

After the construction of the new PERT/CPM network (Figure 3) it was found that the critical path is now composed by the activities B, F, H, J, K, L, M, N, O, P and Q. As the activities H, J, K, L, M, N, O, P and Q are already in their accelerated durations (minimal duration), only activities B and F should be adjusted, i.e. accelerated. The variations of times and costs resulting from changes in the activities B and F are presented in Table 4.

Table 4: Variations of Durations and Costs of Accelerating of B and F Activities

Activity	Normal Duration (hours)	Accelerated Duration (hours)	Variation in Duration (hours)	Marginal Cost (R$)	Increase in Activity Cost (R$)
B	12	7.5	4.5	11.25	50.62
F	32	20.2	11.8	11.44	134.99
				Total Increase in Total Cost of Project	**185.61**

Based on new activity durations B and F (Table 4) was constructed PERT/CPM network for the project, computed the new total duration of the project and identified the new critical path, as can be seen in Figure 4.

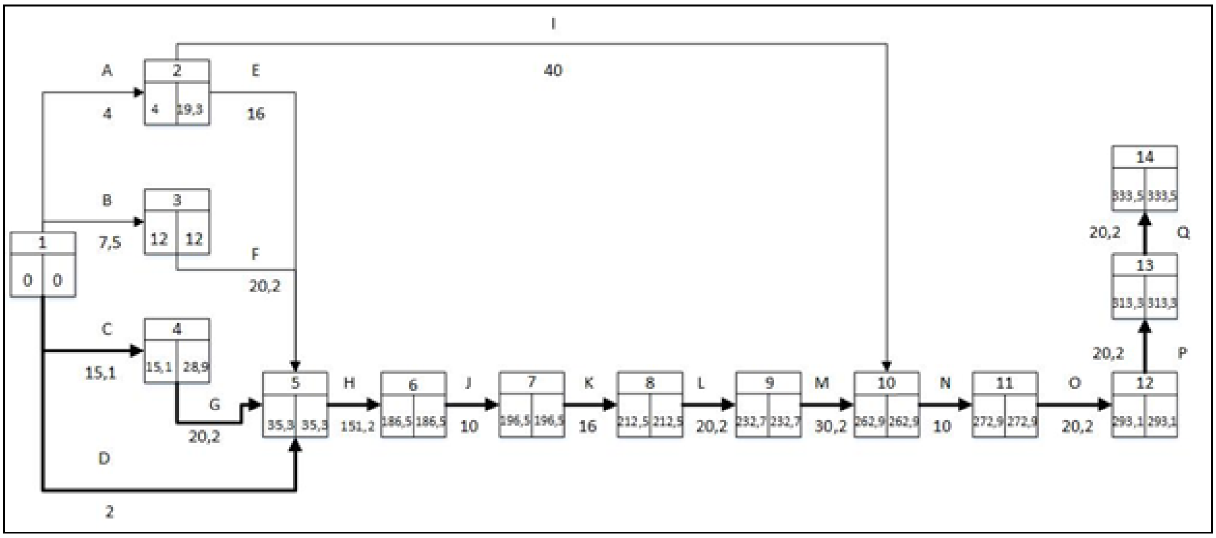

Figure 4: Network PERT/CPM with a decrease in the times of the activities B and F

The reduction in the duration of the activities B and F resulted in an increase of R$185.61 in the total project cost and reduction of 8.7 hours in the total duration of the project. Thus, the total cost of the project increased from R$9,077.39 to R$9,263.01and the total duration of the project decreased from 342.2 hours to 333.3 hours.

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DOI: 10.14807/ijmp.v7i3.423

After the construction of the new PERT/CPM network (Figure 4) it was found that the critical path is now composed by the activities C, D, G, H, J, K, L, M, N, O, P and Q. As the activities C, G, H, J, K, L, M, N, O, P and Q are already in their accelerated durations (minimal duration), only activities D should be adjusted. However, it was decided to not accelerate D activity because the reduction in its duration will result in cost increase and will not result in reduction of total project time, as this activity must be completed together with G, F and E activities so that H activity starts, as can be seen in Figure 4.

After the acceleration of activities, and reduced total duration in the duration of the project, adjustments were made in the project network through the use of slack free in order to reduce the total cost of the project. As there is a not optimal time for the activities, all slack free of activities were used. The slack free for all activities of project, variations of times and costs resulting from changes in the activities are presented in Table 5.

Table 5: Slack Free, Variations of Durations and Costs Resulting From Changes in the Activities of Project

Activity	Current Duration (hours)	Slack Free (hours)	Variation in Duration (hours)	Marginal Cost (R$)	Decrease in Activity Cost (R$)
A	4	0	0	11.24	0
B	7.5	0	0	11.24	0
C	15.1	0	0	11.37	0
D	2	33.3	33.3	10.53	350.64
E	16	15.3	15.3	11.25	172.12
F	20.2	7.6	7.6	11.44	86.94
G	20.2	0	0	11.44	0
H	151.2	0	0	11.40	0
I	40	218.9	218.9	11.40	2,495.46
J	40	0	0	11.25	0
K	16	0	0	0	0
L	20.2	0	0	11.44	0
M	30.2	0	0	11.37	0
N	10	0	0	11.25	0
O	20.2	0	0	11.44	0
P	20.2	0	0	11.44	0
Q	20.2	0	0	11.44	0
Total Decrease in Total Cost of Project					**3,105.17**

With the use of slack free of activities, that not affecting the total duration of the project as discoursed on the theoretical framework, it was possible to obtain a decrease of R$ 3,105.17 in the total project cost, and therefore, R$ 6,157.83 the final cost of the project. Based on new activity durations (Table 5) was constructed the

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final PERT/CPM network for the project of Horizontal Laminator Production (Figure 5).

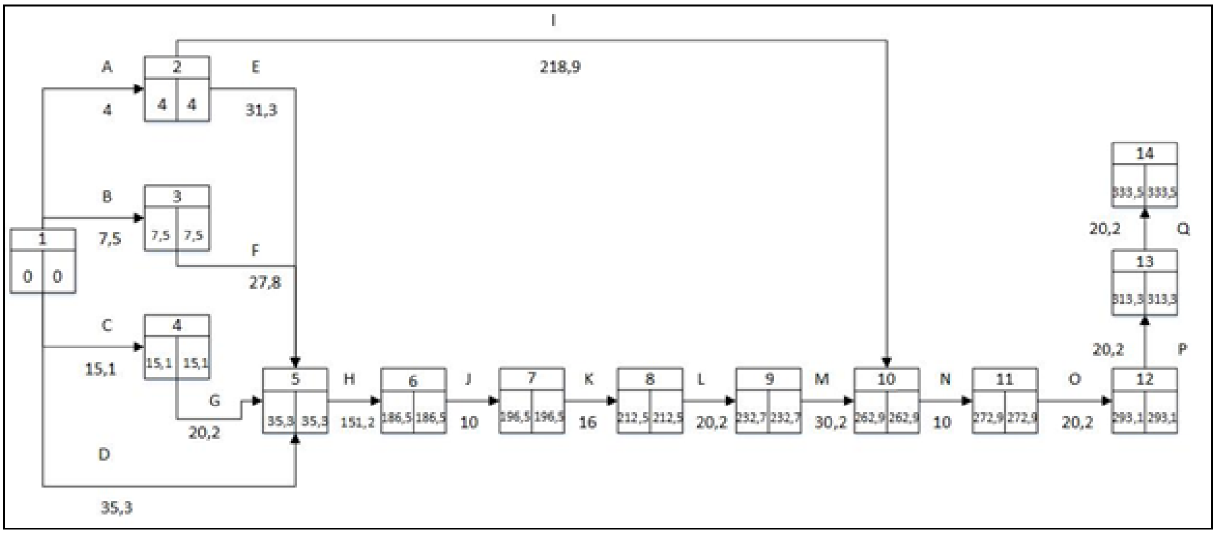

Figure 5: Final PERT/CPM network with utilization of slacks free

5. DISCUSSIONS

With the application of PERT/CPM technique in the project of the horizontal laminator production process the production time was reduced by 35.86%, i.e. from 520.0 hours to 333.5 hours, resulting in an increase of 31.53% in the total cost of the project, i.e., from R$ 7,042.50 to R $ 9,263.01.

When take advantage of slack activities it was possible to obtain a decrease of R$ 3,105.17 total cost of the project, i.e. 33.52%, from the total cost of the project from R $ 9,263.01 to R $ 6,157.83.

The final cost of project of horizontal laminator production decreased by approximately 12.56% from the initial total cost of the project, moving from R$ 7,042.50 to R $ 6,157.83, that due to the utilization of slack free activities.

With the application of PERT/CPM technique it was verified that the largest slacks free are in free activities D (Plasm Cuting), E (Machining) e I (Panel Mounting) as show in Table 5. The slacks free in activities D e E are arising from other dependencies of activity H, which can only be started when the activities E, F, G and H are completed. The slack free in activity I are arising from direct dependence of activity A and indirect dependence of activity E.

Important information for properly managing a project is the deadlines for implementation of activities, i.e. the earlier and later dates to start the activities and

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earlier and later dates for completion of activities. Thus, the deadlines for implementation of the project activities were calculated and are presented in Table 6 below. The equations (7), (8), (9) and (10) used for the calculation of deadlines form presented in the theoretical framework.

Table 6: Deadlines for Implementation of Activities

Activity	FSD	LSD	FFD	LFD
A	1	1	4	4
B	1	1	7.5	7.5
C	1	1	15.1	15.1
D	1	1	35,3	35,3
E	5	5	35.3	35.3
F	8.5	8.5	35.3	35.3
G	16.1	16.1	35.3	35.3
H	36.3	36.3	186.5	186.5
I	5	45	222,9	262.9
J	187.5	187.5	196.5	196.5
K	197.5	197.5	212.5	212.5
L	213.5	213.5	232.7	232.7
M	233.7	233.7	262.9	262.9
N	263.9	263.9	272.9	272.9
O	273.9	273.9	293.1	293.1
P	294.1	294.1	313.3	313.3
Q	314.3	314.3	333.5	333.5

Analyzing the data in Table 6 it can be seen that the later date to completion the activity Q, the last activity of the project should be 333.5 hours, which is equivalent to the time obtained for full completion of the project.

Armed with information regarding to critical activities, slacks of activities and deadlines for performing activities, the manager of a project can take various decisions such as: i) reduction of work in process, reduction of use of manpower , among others; ii) allocate the right resources at the right quantity and at the right time; iii) integrate and coordinate efforts of all involved; iv) eliminate problems related to the incidence of losses and low productivity; and v) ensure good communication between the participants of the work, increasing the transparency of procedures.

For managers of industry subject of this study the PERT/CPM technique also gives a pretty good idea about the completing the projects so that they can plan ahead to expedite certain activities if necessary, since the horizontal laminator is not the only equipment produced by industry.

6. CONCLUSIONS

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The PERT/CPM technique as part an information system transforms data on individual activities into information about the project as a whole. Identification of the critical path, slack time of activities and potential trouble spots exist in the system are the most important information for management a project using this technique.

The total time initially estimated by PERT/CPM technique for conclusion the project of the horizontal laminator production process was 520.0 hours. After accelerate all activities that compose the critical path, the total time for conclusion the project moved to 333.5 hours.

This change in the duration of the project represents a reduction of 35.8% in project conclusion time, with an increase of 31.53% in the total cost of the project, which increased from R$7,042.50 to R$9,263.01.

However, after obtaining the shortest possible duration for the project (333.5 hours), an analysis of slacks of activities and consequently the use of these slacks, without changing the total time execution of the project there was obtained a reduction of 33.52% in total cost of the project, which decreased from R$9,263.01 to R $ 6,157.80.

In this study, attention should be paid to the fact that the final cost of project of horizontal laminator production decreased by approximately 12.56% from the initial total cost of the project, moving from R$ 7,042.50 to R $ 6,157.83, that due to the utilization of slack free activities.

The results show that the PERT/CPM technique can bring a great contribution to the optimization of the times and costs of project of the horizontal laminator production process and that applied to other Industry projects, can lead to reduced costs and even increase the amount of projects undertaken, and consequently lead to an increase in its competitiveness.

PERT/CPM is a valuable technique for projects planning and control, but not a substitute for a judgment, with attention to organizational and behavioral implications. PERT/CPM helps manager to focus attention on the most significant decisions, and to identify the implication of a decision.

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