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To cite this version:

Hamdjatou Kane, Alban Tissier. A Resources Allocation Model for Multi-Project Management. 9th International Conference on Modeling, Optimization & SIMulation, Jun 2012, Bordeaux, France. hal-00728599

HAL Id: hal-00728599

https://hal.science/hal-00728599

Submitted on 30 Aug 2012

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9e Conférence Internationale de Modélisation, Optimisation et SIMulation - MOSIM'12
06 au 08 Juin 2012 - Bordeaux - France
« Performance, interopérabilité et sécurité pour le développement durable »

A Resource Allocation Model for Multi-Project Management

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ABSTRACT: *In this paper, we propose a mathematical model which can be used in the phases of planning and organizing of a multi-project program. The model will optimize the costs of completing a group of linked projects while speeding up the realization of the whole program in order to save time. We improve substantially a model that Wiley et al. (1998) had elaborated, and adapt it to the current requirements of the multi-project manager's work, including the extensive use of subcontracting companies. We tested the model through a multi project case to ensure it will be efficient and safe in planning complex multi-project programs. We focused explicitly and practically on the optimization of shared human resources among the various projects in order to save time and lower the costs of the whole project.*

KEYWORDS*:* Multi-project management, Resource allocation, Mathematical programming.

1 INTRODUCTION

The multi-project management, also designated as management by projects, consists in planning, coordinating and controlling a program that comprises several parallel projects (PMI, 2000). Multi-project management is a growing field of research. More and more companies manage several projects in order to carry out their activities (Tissier 2008 ; Frame, 1995). To be efficient, multi-project managers have to optimize time management and resource allocation. Time management is the most important stake in project management. Speeding up the realization of projects saves money, respects time schedule in case of activities that incur delay, and wins contracts by proposing the best time of delivery in a business competition. Speeding up the realization of projects is therefore a key challenge. Few works have been published on this subject (see section 2). Among them, only a small number of papers deal specifically with multi-project management. Resource allocation is the second main task in piloting projects. A literature review shows the allocation of resources issue has been widely dealt in many research reports in the case of managing a unique project. Methods and models have been developed to formalize resource allocation work (Gordon & Tulip, 1997). In multi-project management, this work is more complex. In fact, the allocation of resources is one of the main issues of multi-project management (Payne, 1995). Most of the time, resources are limited and have to be shared among projects led in parallel. This paper deals with the general topic of multi-project management. It investigates more specifically resource allocation works.

Within companies, human, financial and material resources are limited, as is the time allocated to achieve the project. The main objective of this research is to help multi-project managers speed up their projects and allocate the proper amount of resources to make the acceleration of their projects possible. We have focused on the phases of planning and organization of the project within a company that performs multi-project management. The specific aim of our research was to create a mathematical model that allows optimizing the costs of performing a group of projects while speeding up the realization of the whole program in order to save time. Wiley et al. (1998) elaborated a mathematical model to reduce time spent in carrying out a program of several projects and allocate resources at the lowest cost possible. We rewrote it to adapt it to the current requirements of the multi-project manager works. For example, we took into account the use of subcontracting companies achieving tasks in projects led in a multi-project program. Our model has been split in two different parts. The first part deals with the acceleration of the project. In this paper, this first part of the model will not be described (Tissier 2008). Only its results will be showed. The second part deals exclusively with the allocation of the resources. The second part is our main contribution in developing the former model proposed by Wiley et al. (1998). That is why this paper only presents this part in details. All our developments were conducted to simplify the understanding of the model and its use by the multi-project managers. To validate the model, we tested it through a complex case including many conditions. This case deals with the realization of three projects, the characteristics of which (the duration, the budget, the number of operators and the quantities of work) are different from one project to the other. With this approach, we demonstrate that the model can be applied to a large number of real cases. In next section, we review the related literature which allowed us to consider and understand all the points of view about the acceleration of projects and the allocation of resources in multi-project environment. Section 3 outlines the model formulation on multi-project resource allocation. Section 4 presents the case of study. Section 5 concludes this paper with a review of the works and suggests some orientations for further research.

2 LITERRATURE REVIEW

Many researchers have worked on topics related to the acceleration of projects and the allocation of resources. Siemens (1971) developed a model on time and cost parameters to accelerate a project. The model accelerates some tasks and not others in function of their cost by units of time. With this method, the duration of project realization is reduced. However, the cost of the project increases after acceleration and the critical path of the project may change. It would be more efficient to reduce duration with keeping the same critical path. It also appeared thought-provoking to save time at the lowest possible cost. Islam et al. (2004) consider it is more difficult to make business decision now than in the past. Currently, more alternatives have to be taken into account, in order to make a business choice. Moreover, the financial impact of a bad decision is more important, and less tolerable in companies nowadays than in the past. That is why the authors considered that the decision process has to be rationalized. Then, they developed a linear mathematical model to reduce time for completing a project. The model accelerates projects solely on the basis of financial considerations, lowering the cost as much as possible. However, supplies of additional resources are needed for acceleration, and the model does not specify these resources and their extra costs. Moreover, the model deals with a unique project management and not with multi-project management. Azondékon (2002) examined the trade-off between task duration increase – or decrease – and the allocation of resources. The author estimated it is more efficient to consider the trade-off between time and resources than the trade-off between time and the costs of the tasks. The trade-off between time and the costs of the tasks is an aggregation of cost of human resources and other costs. It is not detailed. Azondékon's model uses a different trade-off between the time and the resources for each type of resource – human or material - which acts in a However, the model does not determine the amount of resources. Gordon & Tulip (1997) listed different models and methods for the allocation of resources from 1959 to 1997. Those models and methods try to allocate - human, financial or material - resources under restriction of resources and time. However, the authors explained that those models and methods were rarely adapted to the reality of project management. Azaron et al. (2006) presented a non-linear model to allocate resources. Although the model is considered as versatile by its creators, it is based on restrictive hypothesis. Consequently, the results given by the model are relevant just for a restrictive number of case studies. Moreover, the model gives no detail on the type of resources in its outputs. Most of the researchers studied unique projects, whereas companies are currently managing multi-projects. Moreover, many of these authors consider the acceleration of projects as a cost-increasing factor. Accelerating a task – or a project – is obtained by providing more resources in order to achieve the work faster. Consequently, costs increase. However, we can also consider deceleration of tasks. Projects contain critical and non-critical tasks. Critical path includes all the critical tasks of a project. Non-critical tasks can be achieved in a longer duration and be performed with fewer human resources than initially planned. In this way, the decelerations of non-critical tasks can provide additional human resources to the critical tasks. The challenge is to re-allocate human resources from a task to another to speed up the projects. Using the fewest new external human resources speeds up the projects at the lowest possible cost.

In this paper, we propose a model that deals with resource allocation or re-allocation to make the program acceleration possible. Re-allocation of human resources from a project to another in multi-project program is the main way to accelerate at the lowest possible cost.

3 MULTI-PROJECT RESOURCE ALLOCATION MODEL

Our first contribution in developing a model from Wiley et al. (1998) was to respond to the current requirements of multi-project managers. For example, projects in program can be led by different companies. Consequently in our model, overhead project costs appeared as different costs as they are related to different companies. We propose a mathematical model to formalize the allocation of resources in multi-project program.

Variables of the model

c_{ij}^{l}: number of human resources of type l to be added to - or to be taken off from - task *(i,j)* in order to achieve it.

Parameters

B_r: budget of the program dedicated to human resource funding

B_{rk}: budget of project k dedicated to human resource funding

I: the set of connected arcs *(i,j)* in the program

I_k: the set of connected arcs *(i,j)* in project k ; $I_k \in I, \forall k$

T_{ij}: normal duration of task *(i,j)*

y_{ij}: maximal quantity of time units on which task *(i,j)* is accelerated

z_{ij}: maximal quantity of time units on which task *(i,j)* is decelerated

E_{ij}^{l}: quantity of human resources of type l, which is allocated to task *(i,j)* before its acceleration or deceleration

h_l: cost of human resources of type l per time unit and per person, in normal conditions

S_{ijl}: cost of human resources of type l per time unit and per person, which are allocated to speed up the task *(i,j)*

V_{ijl}: cost of human resources of type l per time unit and per person, which are allocated to the deceleration of task *(i,j)*

C^{l} maximal quantity of human resources of type l available on the program

C_k^{l} maximal quantity of human resources of type l available on project k.

(1) Objective function:

$$\boxed{Min\ z = \sum_i \sum_j \sum_l (S_{ijl} y_{ij} c_{ij}^l - V_{ijl} z_{ij} c_{ij}^l)}$$

Minimizing the value of the objective function is frameworked by constraints:

(2) Human resources program budget:

$$\sum_i \sum_j \sum_l (h_l T_{ij} E_{ij}^l + S_{ijl} y_{ij} c_{ij}^l - V_{ijl} z_{ij} c_{ij}^l) \leq B_r, \forall l\ and\ (i,j) \in I$$

- In the most restrictive case:

$$B_r = \sum_i \sum_j \sum_l h_l T_{ij} E_{ij}^l\ , \forall l\ and\ (i,j) \in I.$$

- In the less restrictive case:

$$B_r \geq \sum_i \sum_j \sum_l h_l T_{ij} E_{ij}^l\ , \forall l\ and\ (i,j) \in I.$$

(3) Maximal quantity of type *l* human resource available on the program:

$$\sum_i \sum_j (E_{ij}^l \pm c_{ij}^l) \leq C^l\ , \forall l\ and\ (i,j) \in I$$

+ if task *(i, j)* can only be accelerated,
- if task *(i, j)* can only be decelerated.

- In the most restrictive case:

$$C^l = \sum_i \sum_j E_{ij}^l\ , \forall l\ and\ (i,j) \in I.$$

Human resources deducted from decelerated tasks are then re-allocated to speeded-up tasks and $\sum_i \sum_j \sum_l \pm c_{ij}^l = 0$.

- In the less restrictive case:
$C^l \geq \sum_i \sum_j E_{ij}^l\ , \forall l\ and\ (i,j) \in I.$

Human resources deducted from decelerated tasks and human resources allocated to speeded-up tasks are not specifically the same and $\sum_i \sum_j \sum_l \pm c_{ij}^l \geq 0$

(4) Human resources project *k* budget:

$$\sum_i \sum_j \sum_l (h_l T_{ij} E_{ij}^l + S_{ijl} y_{ij} c_{ij}^l - V_{ijl} z_{ij} c_{ij}^l) \leq B_{rk}\ , \forall l\ and\ (i,j) \in I_k$$

- In the most restrictive case:
$B_{rk} = \sum_i \sum_j \sum_l h_l T_{ij} E_{ij}^l\ , \forall l\ and\ (i,j) \in I_k.$

- In the less restrictive case:

$$B_{rk} \geq \sum_i \sum_j \sum_l h_l T_{ij} E_{ij}^l\ , \forall l\ and\ (i,j) \in I_k.$$

(5) maximal quantity of type *l* human resource available on the project *k:*

$$\sum_i \sum_j (E_{ij}^l \pm c_{ij}^l) \leq C_k^l\ , \forall l\ and\ (i,j) \in I_k$$

+ if task *(i, j)* can only be accelerated,

- if task *(i, j)* can only be decelerated.

- In the most restrictive case:
$C_k^l = \sum_i \sum_j E_{ij}^l\ , \forall l\ and\ (i,j) \in I_k.$

Human resources deducted from decelerated tasks are then re-allocated to speeded-up tasks and $\sum_i \sum_j \sum_l \pm c_{ij}^l = 0$.

- In the less restrictive case:

$$C_k^l \geq \sum_i \sum_j E_{ij}^l\ , \forall l\ and\ (i,j) \in I_k.$$

Human resources deducted from decelerated tasks and human resources allocated to speeded-up tasks are not specifically the same and $\sum_i \sum_j \sum_l \pm c_{ij}^l \geq 0$.

(6) Lower bound of c_{ij}^l for speeding-up task *(i, j)*

$$\frac{y_{ij}}{T_{ij}} E_{ij}^l \leq c_{ij}^l, \forall l$$

(7) Upper bound of c_{ij}^l to decelerate task *(i, j)*

If z_{ij} is lower than T_{ij} then we consider the following constraint: $c_{ij}^l \leq \frac{z_{ij}}{T_{ij}} (E_{ij}^l - 1), \forall l$

If z_{ij} is bigger than T_{ij} then we consider the following constraint: $c_{ij}^l \leq \frac{T_{ij}}{z_{ij}} (E_{ij}^l - 1), \forall l$

(8) Non-negativity

$$c_{ij}^l \geq 0$$

4 NUMERICAL APPLICATION

Multi-project management is really a common type of management in construction companies or in air-space firms. However, this type of management is recommended to every company, which wants to realise big achievements in a very limited duration. The case study presentation will be split in three parts. First, a multi-project program and its characteristics will be presented. Then, model results concerning this context will be presented. Finally, those results will be analysed.

Program presentation

We consider a program made up of three projects (A, B and C). Each project has a set of precedence constraints dictated by the program network in Fig. 1. All the three projects have the same completion date. The assumption is that each task begins at the earliest possible date in the projects. Only the data necessary for the model will be presented. We are using the PERT network illustration method. Arrows (also designated as arcs) represent tasks and nodes represent beginning or completion dates. Critical tasks are double-lined. All the nodes are numbered.

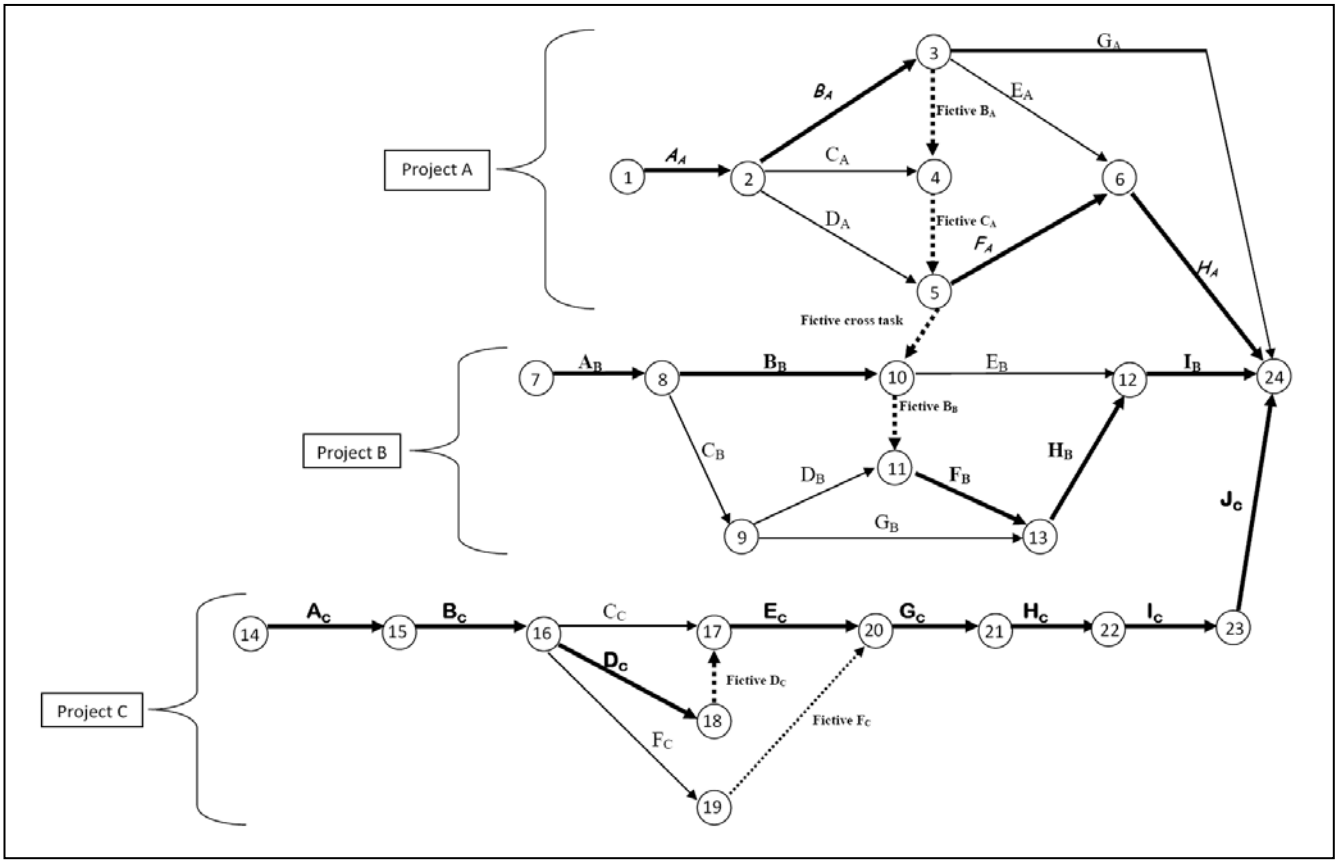

Fig. 1. Program PERT network

The characteristics of the project A, B and C are presented in the following tables.

Table 1. Works breakdown structure of the project A

1	2	3	4	5	6	7	8	9
Name	Task (i, j)	Predecesors	Normal duration T_{ij} [days]	Final durations T_{ij}-y_{ij}+z_{ij} [days]	Normal cost D_{ij} [$]	Hum. Res. of type 1, E_{ij}^{1} [persons]	Hum. Res. of type 2, E_{ij}^{2} [persons]	Hum. Res. of type 3, E_{ij}^{3} [persons]
A_A	**12**	--	**2**	**1**	**3000**	**1**	**2**	**4**
B_A	**23**	A_A	**7**	**7**	**10800**	**2**	**3**	**6**
C_A	24	A_A	4	6	4800	3	1	2
D_A	25	A_A	2	6	2400	1	2	6
E_A	36	B_A	4	4	6000	3	2	4
F_A	**56**	B_A, C_A, D_A	**6**	**5**	**16000**	**2**	**2**	**4**
G_A	324	B_A	3	5	2400	1	1	2
H_A	**624**	E_A, F_A	**2**	**2**	**12000**	**4**	**6**	**12**
			critical duration: 17 days	new critical duration: 15 days	57400$			

Table 2. Works breakdown structure of the project B

1	2	3	4	5	6	7	8	9
Name	Task (i, j)	Predecesors	Normal duration T_{ij} [days]	Final durations T_{ij}-y_{ij}+z_{ij} [days]	Normal cost D_{ij} [$]	Hum. Res. of type 1, E_{ij}^{1} [persons]	Hum. Res. of type 2, E_{ij}^{2} [persons]	Hum. Res. of type 3, E_{ij}^{3} [persons]
A_B	**78**	**--**	**3**	**3**	**16000**	**2**	**4**	**8**
B_B	**810**	**A_B**	**8**	**7**	**20000**	**2**	**4**	**8**
C_B	89	A_B	3	3	4000	1	2	4
D_B	911	C_B	1	2	1000	1	1	2
E_B	1012	B_B	3	4	12000	2	4	8
F_B	**1113**	**B_B, D_B**	**5**	**5**	**20000**	**2**	**5**	**12**
G_B	913	C_B	2	3	1000	0	1	2
H_B	**1312**	**G_B, F_B**	**3**	**1**	**1200**	**1**	**0**	**1**
I_B	**1224**	**E_B, H_B**	**2**	**1**	**1000**	**1**	**1**	**1**
			critical duration: 21 days	new critical duration: 17 days	76200$			

Table 3. Works breakdown structure of the project C

1	2	3	4	5	6	7	8	9
Name	Task (i, j)	Predecesors	Normal duration T_{ij} [days]	Final durations T_{ij}-y_{ij}+z_{ij} [days]	Normal cost D_{ij} [$]	Hum. Res. of type 1, E_{ij}^{1} [persons]	Hum. Res. of type 2, E_{ij}^{2} [persons]	Hum. Res. of type 3, E_{ij}^{3} [persons]
A_C	**1415**	--	**1**	**1**	**600**	**1**	**1**	**0**
B_C	**1516**	**A_C**	**14**	**10**	**13300**	**2**	**1**	**1**
C_C	1617	B_C	5	10	5600	2	2	1
D_C	**1618**	**B_C**	**12**	**10**	**14900**	**2**	**2**	**2**
E_C	**1720**	**C_C, D_C**	**5**	**3**	**4800**	**2**	**1**	**1**
F_C	1619	B_C	8	13	4100	1	1	0
G_C	**2021**	**E_C, F_C**	**5**	**5**	**19600**	**2**	**6**	**20**
H_C	**2122**	**G_C**	**7**	**5**	**10700**	**2**	**3**	**3**
I_C	**2223**	**H_C**	**2**	**1**	**1400**	**2**	**0**	**0**
J_C	**2324**	**I_C**	**3**	**2**	**4400**	**0**	**2**	**10**
			critical duration: 49 days	new critical duration: 37 days	79400$			

Table 4. Common parameters across the three projects

Human resources types	Type 1	Type 2	Type 3
Maximal quantity of human resource (type *l*) available on the program [persons]	60	81	166
Costs of type *l* human resource [$/day]	h_1=240	h_2=120	h_3=80
Costs of added type *l* human resource, in case of acceleration [$/day]	S_{ij1}=360	S_{ij2}=180	S_{ij3}=120
Costs of withdrawn type *l* human resource, in case of deceleration [$/day]	V_{ij1}=180	V_{ij2}=90	V_{ij3}=60
program budget dedicated to human resources funding B_{rA}+ B_{rB}+ B_{rC} = B_r	$53 900 + $77 280 + $113 240 = $244 420		

The following table (Table 5) presents results from the model to the program of projects A, B and C. These results allowed proposing human resources to work on the program in addition to the human resources already working on the program. Hiring is then a second factor of allocation, after the re-allocation of human resources from a task to another. Moreover we noticed the acceleration of tasks has a better chance to induce an increase of quantity of human resources than the deceleration of tasks has to induce a decrease of quantity of human resources on a task team. Two reasons can explain this phenomenon. First, we cannot remove resources from a team of only one person; otherwise the task would not be achieved. In our case study, many decelerated tasks are performed by only one person. That is why re-allocation is not really possible. Second, the model does not reduce the quantities of human resources to their minimal values, because it not only chooses the optimal financial values to accelerate the whole program, but also reduces the additional cost on every task. Finally, the model allows detailing for each task how the allocation – or re-allocation – of human resources can induce additional costs and gains.

Table 5. Human resources comparison between initial statement and model results

		initial states							**Model results**						
	Tasks	***initial duration***	E_{ij}^{1}	E_{ij}^{1}.day	E_{ij}^{2}	E_{ij}^{2}.day	E_{ij}^{3}	E_{ij}^{3}.day	***final duration***	$E_{ij}^{1} \pm c_{ij}^{1}$	$(E_{ij}^{1} \pm c_{ij}^{1})$.day	$E_{ij}^{2} \pm c_{ij}^{2}$	$(E_{ij}^{2} \pm c_{ij}^{2})$.day	$E_{ij}^{3} \pm c_{ij}^{3}$	$(E_{ij}^{3} \pm c_{ij}^{3})$.day
Projet A	**12**	***2***	1	2	2	4	4	8	***1***	2	2	3	3	6	6
	23	***7***	2	14	3	21	6	42	***7***	2	14	3	21	6	42
	24	***4***	3	12	1	4	2	8	***6***	2	12	1	6	2	12
	25	***2***	1	2	2	4	6	12	***6***	1	6	2	12	4	24
	36	***4***	3	12	2	8	4	16	***4***	3	12	2	8	4	16
	56	***6***	2	12	2	12	4	24	***5***	3	15	3	15	5	25
	324	***3***	1	3	1	3	2	6	***5***	1	5	1	5	2	10
	624	***2***	4	8	6	12	12	24	***2***	4	8	6	12	12	24
Projet B	**78**	***3***	2	6	4	12	8	24	***3***	2	6	4	12	8	24
	810	***8***	2	16	4	32	8	64	***7***	3	21	5	35	9	63
	89	***3***	1	3	2	6	4	12	***3***	1	3	2	6	4	12
	911	***1***	1	1	1	1	2	2	***2***	1	2	1	2	1	2
	1012	***3***	2	6	4	12	8	24	***4***	2	8	3	12	6	24
	1113	***5***	2	10	5	25	12	60	***5***	2	10	5	25	12	60
	913	***2***	0	0	1	2	2	4	***3***	0	0	1	3	2	6
	1312	***3***	2	6	0	0	1	3	***1***	2	2	0	0	2	2
	1224	***2***	1	2	1	2	1	2	***1***	2	2	2	2	2	2
Projet C	**1415**	***1***	1	1	1	1	0	0	***1***	1	1	1	1	0	0
	1516	***14***	2	28	1	14	1	14	***10***	3	30	2	20	2	20
	1617	***5***	2	10	2	10	1	5	***10***	1	10	1	10	1	10
	1618	***12***	2	24	2	24	2	24	***10***	3	30	3	30	3	30
	1720	***5***	2	10	1	5	1	5	***3***	3	9	2	6	2	6
	1619	***8***	1	8	1	8	0	0	***13***	1	13	1	13	0	0
	2021	***5***	2	10	6	30	20	100	***5***	2	10	6	30	20	100
	2122	***7***	2	14	3	21	3	21	***5***	3	15	4	20	4	20
	2223	***2***	2	4	0	0	0	0	***1***	3	3	0	0	0	0
	2324	***3***	0	0	2	6	10	30	***2***	0	0	3	6	14	28
Totals				224		279		534			249		315		568
									gaps		25		36		34
									gaps (%)		+11,2		+12,9		+6,4

Note: ± means + in case the task is accelerate and means – in case the task is decelerate.

5 CONCLUSION

The allocation of resources is a difficult challenge in multi-project management. It is mainly due to the interaction of time and resources between the projects included in the same program. However, their benefits can allow companies to increase their capacities to succeed in the current global competition. We also presented how it can propose an allocation of resources to make this acceleration possible. Moreover, the model presents results that minimize additional costs from the initial budget and maximize gains by decelerating tasks. All our work was based on the will to make our model as understandable and user-friendly as possible for managers. However, our model can be improved. We only considered human resources in our work. Further research could investigate other resources in project management. By evaluating material resources - for example - in addition to human resources researchers could be able to present a more detailed model that will be able to propose more detailed results.

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