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Study of Resources Allocation Entropy in Construction Project Management

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Abstract–

In this paper, we study the relationship between entropy, cost, delay and resources of a Railway project and the development of the mathematical models, which are described by these relations. The aim of this study is to examine the optimization cases of the assignment of the project with limited resources. Also to examine the effect of any delays, resulting from various causes during the project, the project variables, and the connection they have with the resources, the entropy and the cost of the project. A Railway project is simulated in order to study the entropy, the costs, duration and productivity of the project, as well as those affected by the change of project resources. That is to say the disorder, the profit and the delay caused by the increase or decrease of some resources to the project. This project deals with an existing railway project, being an where we examine various cases of events, which can happen, such as during the execution of the project, at some time point, lack of some resources, some activities or some corresponding increase in resources. The method enables the supervisor to take timely, appropriate corrective improvement decisions by using simulation results of various variables of entropy, costs, delays, etc. of the project at any given execution time, in order to obtain the best result. The conclusions indicate that the specific way of correlation of the various variables of the project, face effectively the complexities in large and small projects.

Keywords– entropy, resources management, project management

I. INTRODUCTION

A common problem occurring in construction scheduling, is that required resources are often not available when needed, or in the number/amount needed, or they are more than the required. In this case the engineer has to reschedule the activities, considering the resources fluctuations. The aim is to relate with the best possible way, the various variables of the project, such as entropy, cost, productivity, delay, etc., so in various, favorable or not, for the project conditions, which have a direct impact on available, at each time, resources (increasing or shortening), to provide an optimal solution. In this way, any change to the originally planned project conditions, will give the opportunity to the construction engineer to correct various variables (entropy, cost etc.) of the project in case of diversion, to the best result, which is governed by the principle: " *the project is performed at minimum cost or maximum profit in the minimum possible time, ie with the maximum productivity and entropy close to zero*".

The object of this study is similar to previous researchers (Tezias et al (2010), Christodoulou et al (2009)), but differs in several key aspects. In principle, for the above works, the project entropy is calculated, based on the entropy of resources, using, all possible combinations of them, which will result from an increase or from one of their constraints. Also the above studies are simple, hypothetical projects, using only one resource type. This work deals with a complex real project and all variables are calculated in real conditions. Also, the entropy of this project, is calculated on the basis of the entropy of the duration of resources and activities, and not through the entropy of the resources, as mentioned above. This is because the duration of a resource, or of an activity, may change for various reasons, such as e.g. from how the activity is performed, the weather conditions, labor or social issues, etc., things that should be taken into account for calculating the entropy of the project. So in this study it is considered, that the duration of some resources, of some activities, changes, according to the Poisson distribution, with resolution step d = 1 day, and the Crystal Ball program takes all possible combinations of more possible durations (according to the Poisson distribution of duration of resources), of the fluctuating (increased or constrained) resources.

A new approach has recently been developed based on minimizing the total entropy of the project schedule (Christodoulou et al. (2008a,b); Christodoulou et al. (2009a,b,c)). Entropy (Hx) is a metric generally defined as the product of the probability distribution (px) of a variable, times the natural logarithm of the inverse of that probability distribution (Eq.1).

$$H_{i,j} = p_j \ln (1/p_j) \qquad (1)$$

The progress of an activity and subsequently the project's, is defined by the productivity of the resources and the number of assigned resources (nr) (Griffis and Farr (2006); Christodoulou and Ellinas (2008a)). Therefore, the entropy (H) of an activity (i) produced by a resource (j) is defined by means of the ratio of the required (R) over that of the assigned resources (R') per activity, (Christodoulou and Ellinas (2008a)) (Eq.2). '*Entropy is defined as the disorder brought about by the fluctuation of resources in the project, and a higher entropy value relates to a higher risk in terms of schedule completion'*.

$$H_{ACT} = R/R' \ln(1/ (R/R')) \qquad (2)$$

In order to minimize the total project entropy

$\min H_T = \min\{ \Sigma \Sigma (Ri/ R'i) [\ln (1/(Ri/ R'i))]\}$ (3a)

subject to

$\Sigma(R'i) <= nr$ (3b)

Ri and R´i, integer (3c)

$R'i >= 0$ (3d)

The greater the entropy, the more chaotic the status of activities and therefore that of the project.

In this study the entropy H_T of the project, is the sum of each individual entropy Hij of each activity:

$H_T = \Sigma\Sigma pij * \ln(1/pij)$

where, the entropy of each activity i (Hj) is the sum of the entropy of each independent resource j:

$Hij = \Sigma pj * \ln(1/pj)$

where, pj is the ratio of the durations of the required resources (Ri = required) to the durations of the assigned resources (Ri = assigned) for the activity i and the resource j, namely:

$H_{ACT/R'} = Hij = \Sigma pj * \ln(1/pj) = \Sigma(Ri/Ri') * \ln(1/(Ri/Ri'))$

- if Ri = Ri ', then $H_{ACT / R'} = 0$, in this case the system is stable and in order and
- If Ri '= 0 then $H_{ACTR'} \rightarrow \infty$, in this case the system tends to a chaotic situation and the activity or project cannot be executed.

According to Bushuev and Sochnev (1999), for each activity, the fluctuations of uncertain duration d, is between di <d <du, where di is the best possible duration and du the worst possible duration. In the example, which they use, which is shown below, the activities that point 1 (latest completion date) are after point 2 (worst possible early finish), do not contribute to the set of unfavourable events and, hence, to the project Entropy. In this example the activity D, even in the worst case, has a positive total duration. The unfavourable events occur when activities become critical and with negative durations, ie in this example, when the actual finish of activities falls between points 1 and 2, ie into the following areas of Fig. 1: (A1, A2), (B1, B2), and (C1, C2).

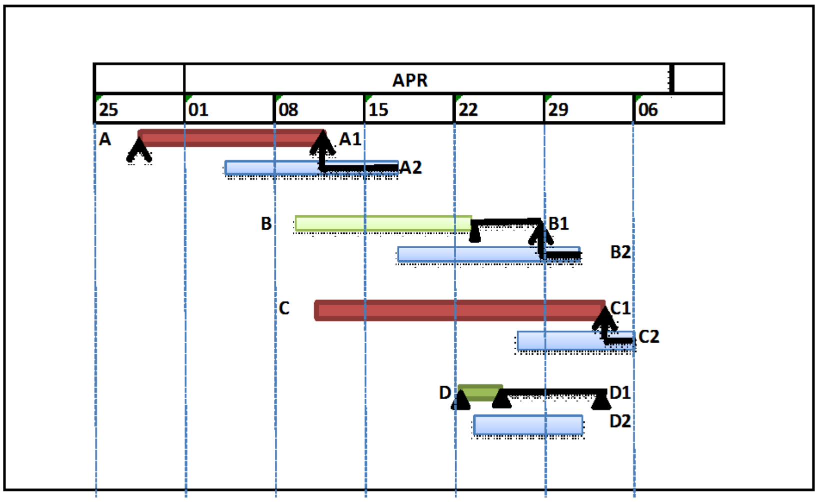

Fig.1. Examination of Activities

Specifically, the set of unfavourable events Eu for activity is a piece from the latest finish to the worst possible finish:

Eu = (LF, EF+(du-d))

where LF: latest finish, EF: earliest finish, d: duration, du: maximum possible duration (Fig. 2).

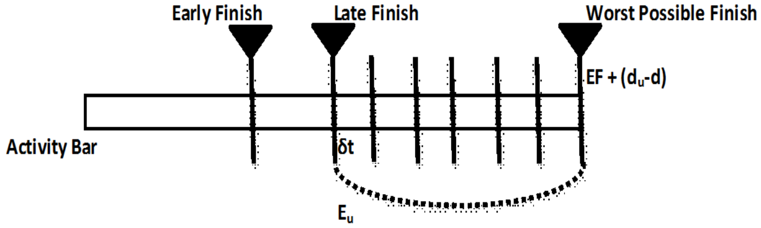

Fig. 2. Maximum Possible Duration

The set of unfavourable events Eu in the case of a negative total duration is determined similarly (di: the minimum possible duration).

(a) Eu = (LF, EF+(du-d)) if LF>EF+(di-d)
(b) Eu = (EF+(di-d), EF+(du-d)) if LF<EF+(di-d)
(c) Eu = 0, if no uncertainty

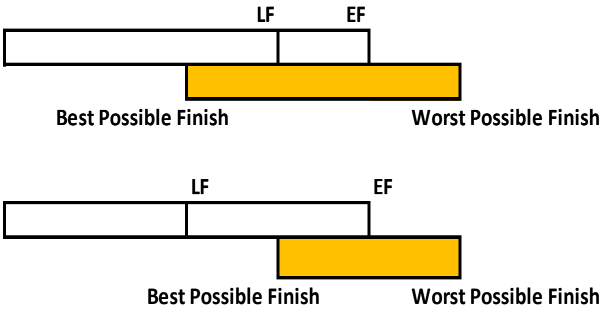

Fig. 3. Best Possible and Worst Possible Finish

Nevertheless, the manager should first compress the schedule to avoid a negative duration before analyzing the risk.

A relevant time interval should be chosen to break the set of unfavourable events Eu, down to elementary states or events. The choice of this interval is very important, because all subsequent calculations will refer to it. If we estimate the schedule Entropy alone, or schedule estimations precede any other risk estimations (budget, quality etc.) it is sensible to designate a relevant time interval **δt** equal to the planning unit of the project.

Usually in practice we can only estimate the possible duration range di< d < du, and very rarely we have information about the probabilities distribution curve. In this paper, we assume that for e.g. with the constraint of a resource, or of an activity, the range of the potential duration "d", of the resource to perform the activity, fluctuates, in a space between (di, du), which follows a Poisson distribution with t = 1 day. I.e. if the resource , Assistant (002) , of the WBS 1.1.1.17 activity, is reduced at the railway project, which is under inspection, this decrease corresponds to an increase of the duration of the resource, which follows the Poisson distribution with the most likely duration of 1,900 days and (di , du) = (1.760 days, 2.040 days).

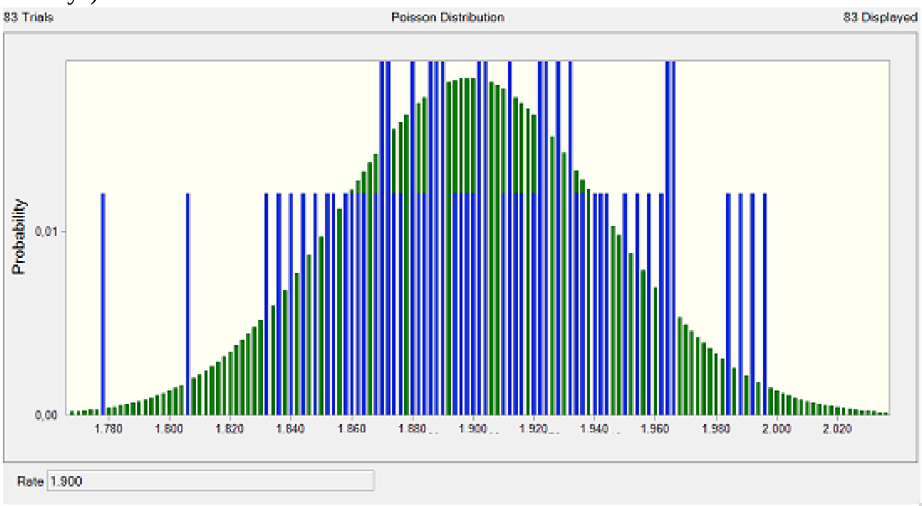

Fig. 4. Poisson Distribution

In our case, the probability pi to have a duration in the range of (di, di + δt), equals pi = δt/(du-di), and we can calculate the Entropy for an individual activity according to the formula:

$$H = -\Sigma Eu*pi*\ln pi = \Sigma Eu*pi*\ln(1/pi) = Eu/(du-di) * \ln\{1/[\delta t/(du-di)]\} = \Sigma Eu*pi*\ln(1/pi) = Eu/(du-di) * \ln((du-di)/\delta t) \quad (3)$$

where Eu = EF+(du-d)-LF = (du-d) - (LF-EF) = ((du-d) - TF), where TF=LF-EF, Total Float.

The aim of this work is to develop an algorithm that, according to Kaiafa and Chassiakos (2015), the following be developed at any time:

a) optimal schedules with regard to resource allocation (subject to resource availability),
b) resource leveling and
c) the minimization (i) of project duration or of confinement, within given deadlines, (ii) of cost and (iii) of entropy (nearest to zero) of the project.

In this way, the Resource Scheduling Problem (RSP), which in this work is complex, will be dealt with since:

(i) the analysis includes multiple and rather conflicting objectives (and corresponding set of constraints or increases),
(ii) the size of the problem is very large, since it increases exponentially with the increase (a) in the number of project activities, (b) of types of resources and (c) of alternative methods of execution out activities,
(iii) the number of alternative (a) of resources constraints and (b) of resources increases, in each activity is large and
(iv) the problem requires finding the best execution of the activity and the appropriate activity placement in time so that the resources are optimally allocated and the resource histogram is as smooth as possible.

II. METHODOLOGY

In this paper we selected some resources and while varying them we observed changes of the entropy, cost and project productivity, we found the best solutions. So with the increase of resources, we observe that the project duration decreases and increases the entropy in absolute value, which is perfectly acceptable. That is, when the duration of the project is close to the conventional agreed, then the entropy is near zero. When the duration of the project is reduced, then the entropy gets higher negative values. Also by reducing the duration of the project, we achieve a reduction in cost.

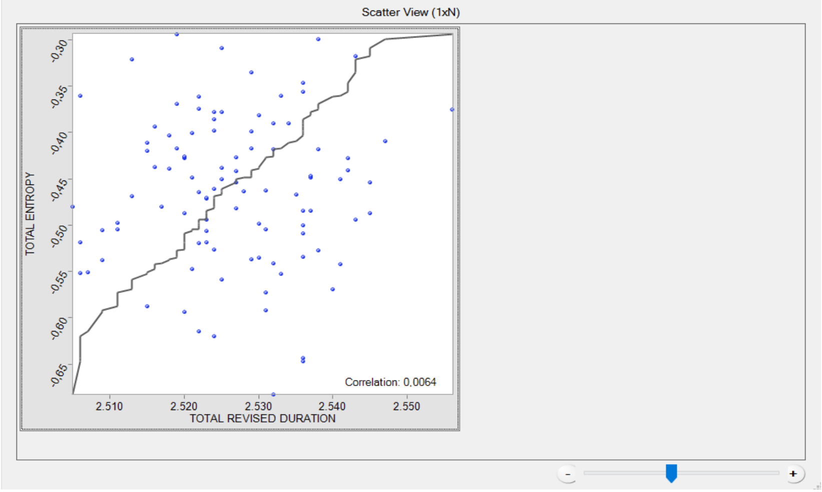

Fig. 5. Total Entropy Vs Total Revised Duration

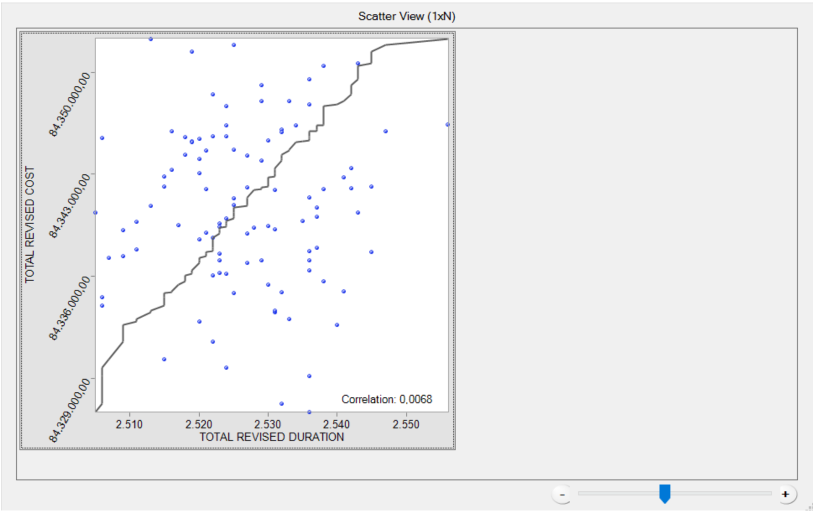

Fig. 6. Total Revised Cost Vs Total Revised Duration

Also by reducing the resources, we observe, that as the duration of the project, increases, the entropy decreases. That is, as the entropy approaches zero, the duration of the project also increases. Also, as the duration of the project increases, the cost decreases.

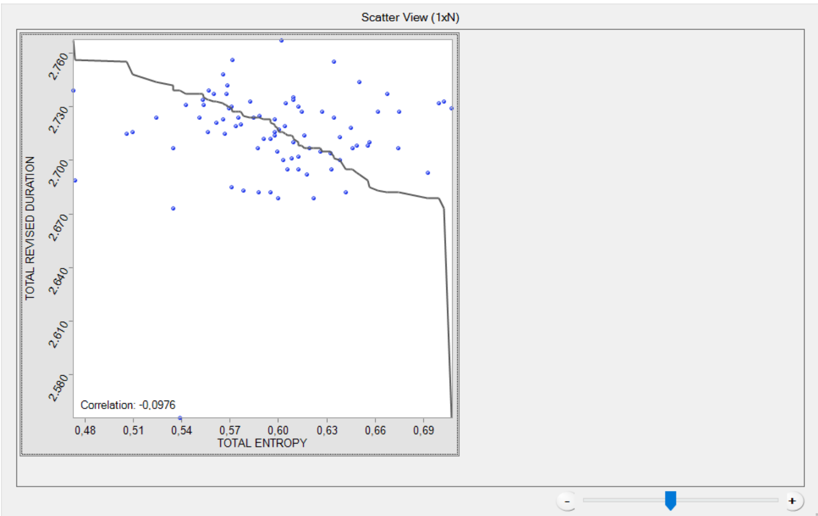

Fig. 7. Total Revised Cost Vs Total Revised Duration

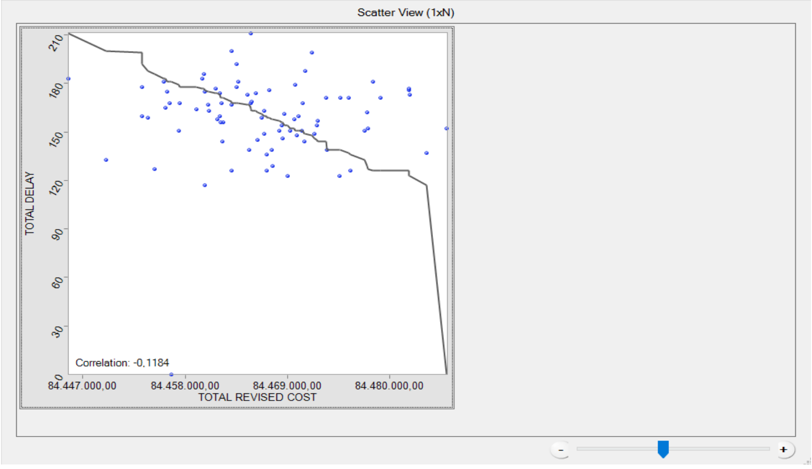

Fig. 8. Total Revised Cost Vs Total Revised Duration

From the study of correlation curves, of time - cost and of time - entropy, of some resources, and of some activities of the project, we can see that these are neither linear nor continuous. This has as a result, the difficulty of shaping algorithm, which ensures the optimum solution. Nevertheless, by the way which we face the problem, we notice that the Engineer of the project has at any time, a clear view, of the status of the project both at the present and the future, in any changes of resources, from various causes (the Crystal Ball, which is used to solve the problem, beyond the capability of storing the test values in the computer's memory, additionally has the ability to predict future values). The continuation of the project depends on the engineer's own choice and experience to achieve the best solution. I.e. the specific way of addressing the problem, corresponds to the algorithm, which ensures (depending on the engineer's decisions) the optimal solution. Also we observe that the entropy of the project increases from negative to positive values as resources decrease, i.e. as the possible duration of resources increase. When resources are unchanged (placed resources equal to resources required), then the entropy is zero.

According to the bibliography, the graphical representation of the relationship of entropy with resources $H_{ACT/R'} = R/R' \ln (1/ (R/R'))$, is the following:

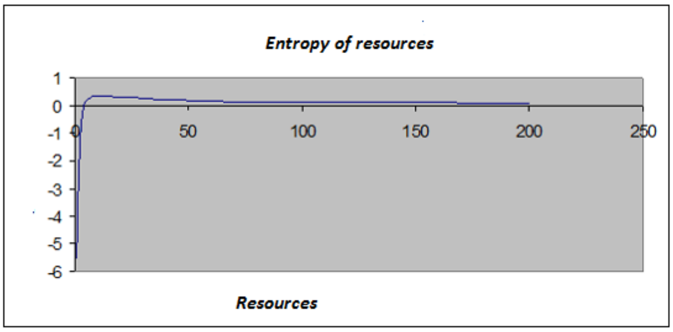

Fig. 9. Entropy of Resources

It is observed that the entropy values are initially negative until the placed resources, are equal to the required, thus zero - rising entropy. Then as the number of resources increases, the entropy acquires positive values until a maximum point and then begins to decrease, tending to zero. Similar is the shape of the curve when the entropy is calculated by the *duration of resources* rather than the number of resources. Applying the above, the relationship of entropy to the duration of the resources (and not on resources), i.e. if to the above formula, R and R ', correspond to *possible durations placed and required resources* (and *not* resources) we get the following curve:

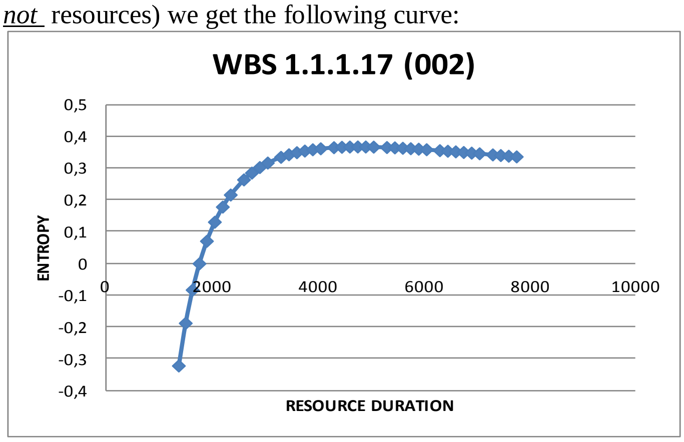

Fig. 10. Entropy Vs Resource Duration

III. CASE STUDY

The project being studied is a rail project in Thriassio Attikis. The project budget approaches 200,000,000 €. This project includes works such as infrastructure railway projects, electromechanical, signaling, telecommunications, electrification and building projects, necessary for implementation - completion of the project. The analysis followed in this work, is based on the relationship that governs the duration, cost and the entropy of the project. Reference is also made to the productivity of the project, relative to the entropy of the project.

Specifically in this work:

- Scheduling, to the MS - Project, the project Schedule.
- Transferred from MS - Project in the MS - Excel file sheet, the dates ES, EF and LS, LF of all activities to be calculated each time, through relationships of Rules Calculation Networker Graph by Method M.P.M.
- On another sheet of MS - Excel file are transferred (from MS - Project) the durations (days), of resource activities, as originally had scheduled in MS - Project.
- In the next sheet of MS - Excel are transferred (from MS - Project), the durations (days) of resources of activities, as originally had scheduled in MS - Project, which (durations) vary in this sheet in accordance with the change, which is caused to the respective resources, during the test.

IV. RESULTS

The implementation of Crystal Ball in MS - Excel, is done step by step to any change in resources or their durations, because to every change, the project schedule is rescheduled in MS - Project, and the duration changes of the project activities are automatically transferred to MS - Excel, from where the new project variables are calculated (entropy, cost, delay, etc.). As mentioned above, the change of each resource (e.g., constraint), corresponds to a change of its duration, with a possible duration d, which fluctuates in the range of (di, du), which follows a Poisson distribution with δt = 1 day. When applying Crystal Ball in Excel, the most possible interval durations (di, du) of each variable resource are taken to which (via hyperlink) runs every time the project schedule in MS-Project, and the new times of activities that arise are transferred via a hyperlink in Excel, where calculated, project variables (critical paths, project duration, entropy, productivity performance, etc.).

- Finally correlations of the various variables of the project (entropy, productivity, cost, delay, duration, etc.) are calculated. In this case study, resources refer only to labor resources, and the original resource demands are as shown in Table 1. The initial scheduling of project, with the activities, resources, the durations of each activity, etc., in its final form, is illustrated in Fig. 11:

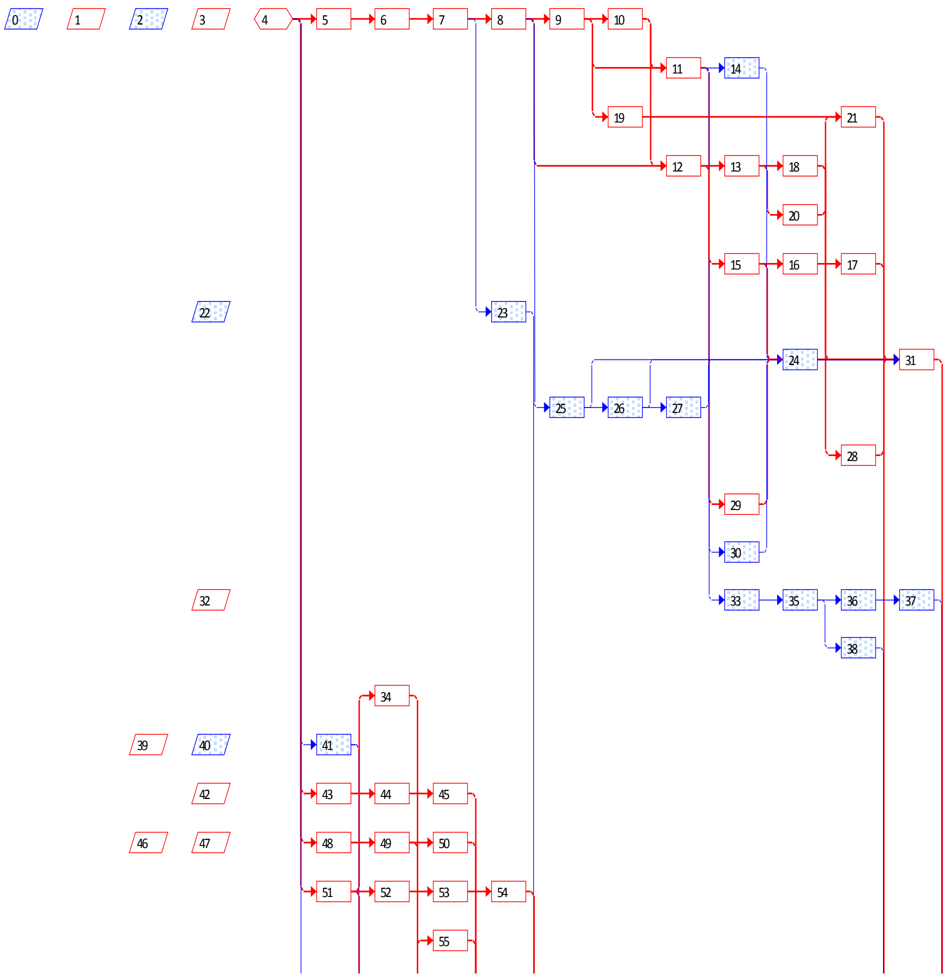

Fig. 11. Pert Diagram of the Project

TABLE I. WBS OF ACTIVITIES

WBS	Duration	Predecessors	Successors	Free Slack	Total Slack	Early Start	Early Finish	Late Start	Late Finish
0	2192 days			0 days	0 days	21/6/2013	21/6/2019	21/6/2013	21/6/2019
1	2192 days			0 days	0 days	21/6/2013	21/6/2019	21/6/2013	21/6/2019
1.1	1096 days			1096 days	1096 days	21/6/2013	20/6/2016	21/6/2013	21/6/2019
1.1.1	733 days			0 days	0 days	21/6/2013	12/4/2016	21/6/2013	12/4/2016
1.1.1.1	0 days		5;41SS;43;48SS;51;68SS	0 days	0 days	21/6/2013	21/6/2013	21/6/2013	21/6/2013
1.1.1.2	930 days	4	6SS+30 days	0 days	0 days	22/7/2013	6/2/2016	22/7/2013	6/2/2016
1.1.1.3	394 days	5SS+30 days	7SS+38 days	0 days	0 days	21/8/2013	18/9/2014	21/8/2013	18/9/2014
1.1.1.4	336 days	6SS+38 days	8SS+33 days;23SS	0 days	0 days	28/9/2013	29/8/2014	28/9/2013	29/8/2014
1.1.1.5	369 days	7SS+33 days	9SS+91 days;12FS-1 day;25FS-112 days	0 days	0 days	31/10/2013	3/11/2014	31/10/2013	3/11/2014
1.1.1.6	575 days	8SS+91 days	10FS-271 days;11FS-258 days;19FS-91 days	0 days	0 days	30/1/2014	27/8/2015	30/1/2014	27/8/2015
1.1.1.7	243 days	9FS-271 days	11;12	0 days	0 days	30/11/2014	30/7/2015	30/11/2014	30/7/2015
1.1.1.8	340 days	9FS-258 days;10	14SS+168 days;29FS-90 days;30FS-60 days;33FS-170 days	0 days	-230 days	13/12/2014	17/11/2015	13/12/2014	17/11/2015
1.1.1.9	149 days	8FS-1 day;10	13FS-95 days;15SS+20 days	0 days	-270 days	3/11/2014	31/3/2015	3/11/2014	31/3/2015
1.1.1.10	105 days	12FS-95 days	18;20SS+28 days	0 days	0 days	1/1/2015	15/4/2015	1/1/2015	15/4/2015
1.1.2	997 days			1 day	1 day	28/9/2013	20/6/2016	17/10/2014	21/6/2016
1.1.2.1	342 days	7SS	91	656 days	656 days	28/9/2013	4/9/2014	16/7/2015	21/6/2016
1.1.2.2	405 days	15SS	31FS-94 days	169 days	169 days	23/11/2014	1/1/2016	11/5/2015	18/6/2016
1.1.2.3	611 days	8FS-112 days	26SS+30 days;31FS-94 days	0 days	94 days	15/7/2014	16/3/2016	17/10/2014	18/6/2016
1.1.2.4	581 days	25SS+30 days	27SS+62 days;31FS-94 days	0 days	94 days	14/8/2014	16/3/2016	16/11/2014	18/6/2016
1.1.2.5	513 days	26SS+62 days	31FS-94 days	100 days	100 days	15/10/2014	10/3/2016	23/1/2015	18/6/2016
1.1.2.6	280 days	18SS	31FS-14 days	0 days	0 days	16/4/2015	20/1/2016	16/4/2015	20/1/2016
1.1.2.7	150 days	11FS-90 days	31	0 days	0 days	20/8/2015	16/1/2016	20/8/2015	16/1/2016
1.1.2.8	90 days	11FS-60 days	31FS-10 days	100 days	100 days	19/9/2015	17/12/2015	28/12/2015	26/3/2016
1.1.3	501 days			0 days	0 days	4/11/2014	18/3/2016	4/11/2014	21/6/2019
1.1.3.1	150 days	11FS-170 days	35SS+42 days	0 days	1332 days	1/6/2015	28/10/2015	23/1/2019	21/6/2019
1.1.3.2	210 days	51FS-24 days	77FS-45 days	0 days	0 days	4/11/2014	1/6/2015	4/11/2014	1/6/2015
1.2	1049 days			0 days	0 days	21/6/2013	4/5/2016	19/4/2015	4/5/2016
1.2.1	20 days			751 days	751 days	21/6/2013	10/7/2013	12/7/2015	31/7/2015
1.2.1.1	20 days	4SS	69;82;71	751 days	751 days	21/6/2013	10/7/2013	12/7/2015	31/7/2015
1.2.2	382 days			0 days	0 days	19/4/2015	4/5/2016	19/4/2015	4/5/2016
1.2.2.1	140 days	4	44SS+70 days	0 days	0 days	19/4/2015	5/9/2015	19/4/2015	5/9/2015
1.2.2.2	80 days	43SS+70 days	45FS-30 days	0 days	0 days	28/6/2015	15/9/2015	28/6/2015	15/9/2015
1.2.2.3	160 days	44FS-30 days	71	0 days	0 days	17/8/2015	23/1/2016	17/8/2015	23/1/2016
1.3	1109 days			0 days	0 days	21/6/2013	3/7/2016	21/6/2013	28/4/2017
1.3.1	1076 days			0 days	0 days	21/6/2013	31/5/2016	21/6/2013	31/5/2016
1.3.1.1	102 days	4SS	49	0 days	0 days	21/6/2013	30/9/2013	21/6/2013	30/9/2013
1.3.1.2	91 days	48	50SS;58FS-29 days	0 days	0 days	1/10/2013	30/12/2013	1/10/2013	30/12/2013
1.3.1.3	242 days	49SS	58	0 days	0 days	1/10/2013	30/5/2014	1/10/2013	30/5/2014
1.3.1.4	102 days	4	52;75SS+2 days;34FS-24 days	0 days	0 days	18/8/2014	27/11/2014	18/8/2014	27/11/2014
1.3.1.5	98 days	51	53SS	0 days	0 days	28/11/2014	5/3/2015	28/11/2014	5/3/2015
1.3.2	1109 days			164 days	164 days	21/6/2013	3/7/2016	2/12/2013	28/4/2017
1.3.2.1	789 days			0 days	0 days	2/12/2013	29/1/2016	2/12/2013	28/4/2017
1.3.2.1.1	211 days	49FS-29 days;50	59;61FS-61 days;63FS-90 days	0 days	-180 days	2/12/2013	30/6/2014	2/12/2013	30/6/2014
1.3.2.1.2	214 days	58	60FS-89 days	0 days	413 days	1/7/2014	30/1/2015	18/8/2015	18/3/2016
1.3.2.1.3	117 days	59FS-89 days	65SS+91 days	0 days	413 days	3/11/2014	27/2/2015	21/12/2015	15/4/2016
1.3.2.1.4	639 days	58FS-61 days	66SS+30 days	322 days	455 days	1/5/2014	29/1/2016	30/7/2015	28/4/2017
1.3.2.2	631 days			133 days	133 days	2/4/2014	23/12/2015	17/3/2015	4/5/2016
1.3.2.2.1	315 days	58FS-90 days	64FS-65 days;65FS-45 days	0 days	349 days	2/4/2014	10/2/2015	17/3/2015	25/1/2016
1.3.2.2.2	165 days	63FS-65 days	71	349 days	349 days	8/12/2014	21/5/2015	22/11/2015	4/5/2016
1.3.2.2.3	45 days	60SS+91 days;63FS-45 days	71	413 days	413 days	2/2/2015	18/3/2015	21/3/2016	4/5/2016
1.3.2.2.4	250 days	61SS+30 days;77SS	71	133 days	133 days	18/4/2015	23/12/2015	29/8/2015	4/5/2016
1.3.2.3	965 days			0 days	0 days	21/6/2013	10/2/2016	19/10/2015	10/2/2016
1.3.2.3.1	55 days	4SS	69	850 days	850 days	21/6/2013	14/8/2013	19/10/2015	12/12/2015
1.3.3	567 days			0 days	0 days	20/8/2014	8/3/2016	20/8/2014	8/3/2016
1.3.3.1	133 days			0 days	0 days	20/8/2014	30/12/2014	20/8/2014	30/12/2014
1.3.3.1.1	133 days	51SS+2 days	77;79	0 days	0 days	20/8/2014	30/12/2014	20/8/2014	30/12/2014
1.3.3.2	309 days			0 days	0 days	10/11/2014	14/9/2015	10/11/2014	29/9/2015
1.3.3.2.1	264 days	34FS-45 days;75	78;66SS;82	0 days	-159 days	10/11/2014	31/7/2015	10/11/2014	31/7/2015
1.3.3.2.2	45 days	77	82FS-60 days	15 days	15 days	1/8/2015	14/9/2015	16/8/2015	29/9/2015
1.3.3.2.3	250 days	75	80;82	0 days	-51 days	10/11/2014	17/7/2015	10/11/2014	17/7/2015
1.3.3.2.4	59 days	79	82FS-60 days	15 days	15 days	18/7/2015	14/9/2015	2/8/2015	29/9/2015
1.3.3.3	221 days		88FS-90 days	0 days	0 days	1/8/2015	8/3/2016	1/8/2015	8/3/2016
1.4	90 days			0 days	0 days	24/3/2016	21/6/2016	24/3/2016	21/6/2016
1.4.1	90 days	84;72;38;31	88;91	0 days	-102 days	24/3/2016	21/6/2016	24/3/2016	21/6/2016
1.5	20 days			0 days	0 days	2/6/2016	21/6/2016	2/6/2016	21/6/2016
1.5.1	20 days	81FS-90 days;70;86	89SS+10 days	0 days	-32 days	2/6/2016	21/6/2016	2/6/2016	21/6/2016
1.6	1095 days			0 days	0 days	22/6/2016	21/6/2019	22/6/2016	21/6/2019
1.6.1	1095 days	89;21;86;37;23		0 days	0 days	22/6/2016	21/6/2019	22/6/2016	21/6/2019

At first we increase by one the Resources: (a) Assistant (002) and (b) Technician (003) until all be done three (3), to the activities with WBS: (a) 1.1.1.6 and 1.1.1.17, (b) 1.1.1.8 and 1.1.1.17, and (c) 1.1.1.16, 1.1.1.17 and 1.1.1.18.

Then, we constrain by one the Resources: (a) Assistant (002) and (b) Technician (003) until a final price (1) in the WBS activities: (a) 1.1.1.6 and 1.1.1.17 (b) 1.1.1.8 and 1.1.1.17, (c) 1.1.1.6, 1.1.1.8 and 1.1.1.17, and (d) 1.1.1.5, 1.1.1.6, 1.1.1.8 and 1.1.1.17.

For the total cost (TOTAL REVISED COST), the delay (TOTAL DELAY) and the entropy (ENTROPY) of the project by the constrain of resources (a) Assistant (002) and (b) Technician (003), the activities with WBS 1.1 .1.5, 1.1.1.6, 1.1.1.8 and 1.1.1.17, have the following graphs:

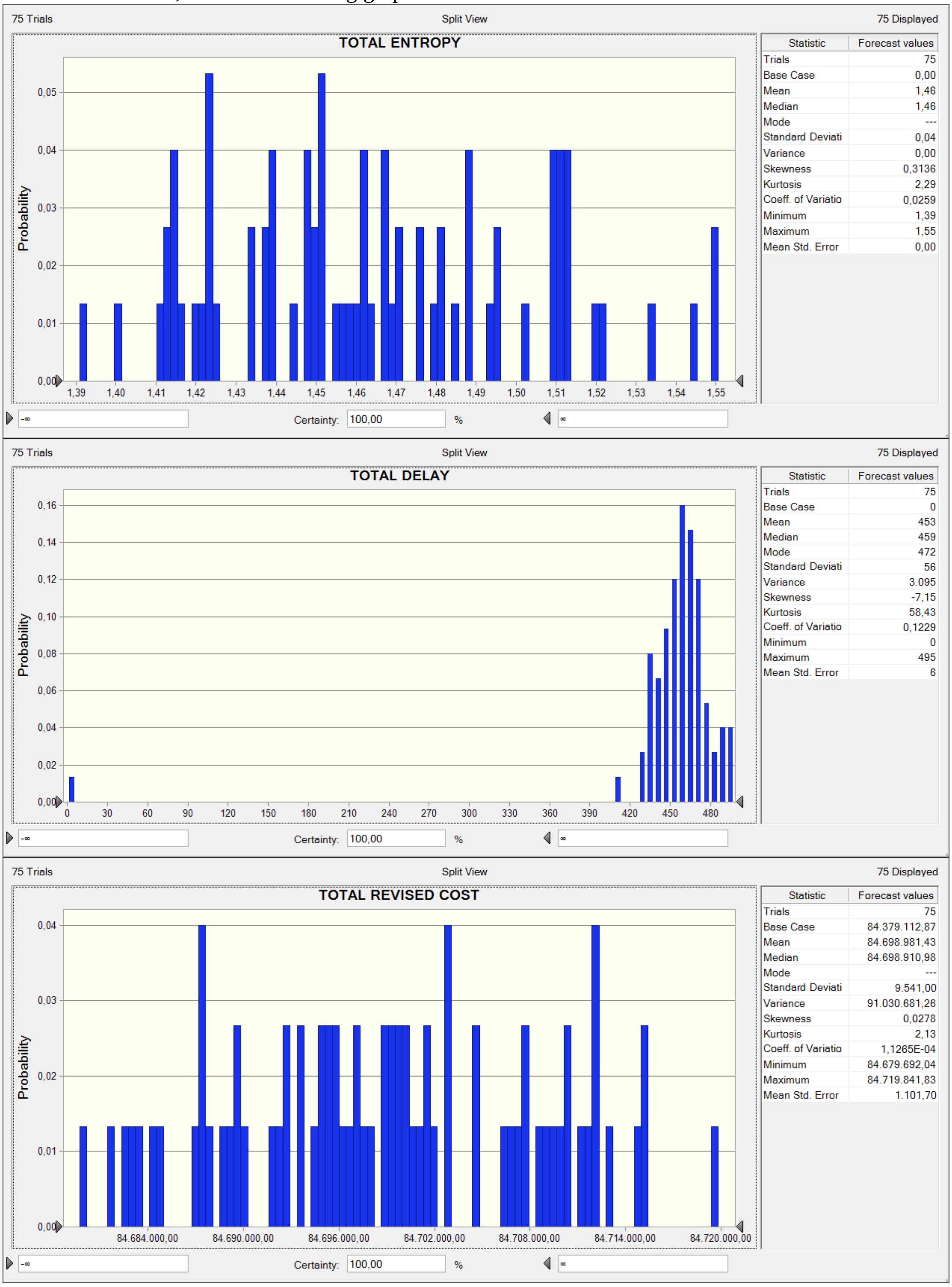

Fig.12. Results

Also, the sensitivity of the total delay of the project (TOTAL DELAY), by the resource constraint (a) Assistant (002) and (b) Technician (003), to the activities with WBS 1.1.1.5, 1.1.1.6, 1.1.1.8 and 1.1 .1.17, shown below:

As the number of installed resources increases, which undertake to perform a particular activity, the shorter the period of completion of the activity and consequently that of the project, if such an activity is critical. There is a point beyond which, any increase in the number of resources that are engaged in this activity, brings no further process improvement. Conversely, the resource productivity is reduced and the cost is increased and so does the entropy (disorder) and productivity efficiency (absorptions) project. In fact, beyond a certain point of resource increase, the productivity of the project, instead of increasing, is decreasing, since the system disorder has exceeded a limit, beyond which condition is impossible to control.

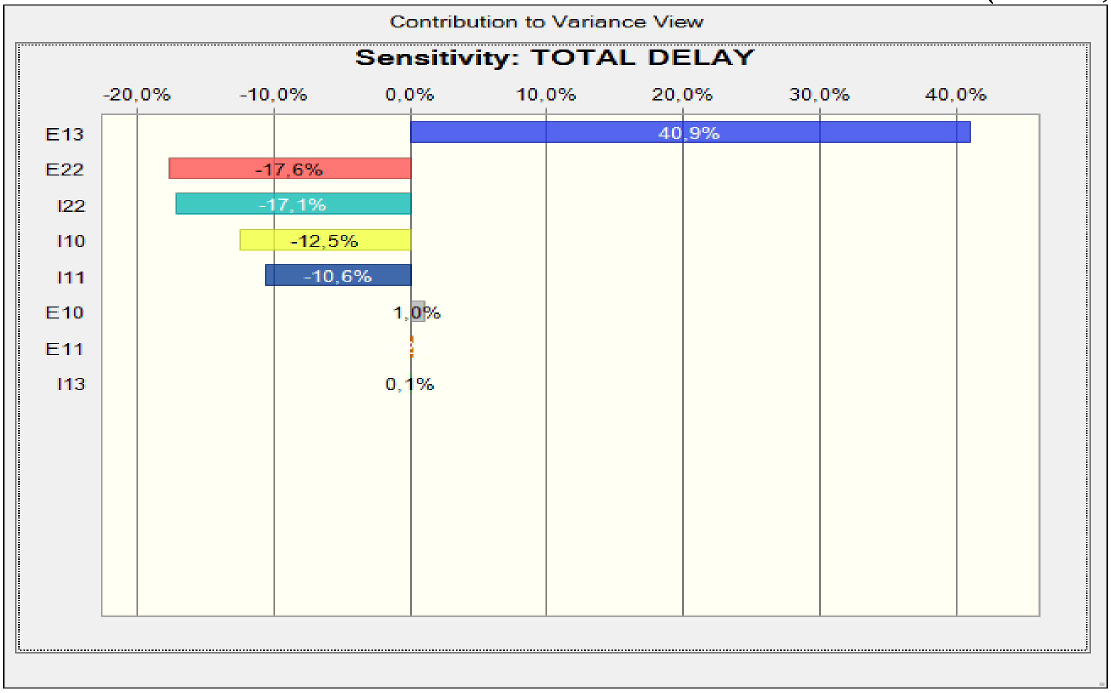

Fig. 13. Total Delay

V. CONCLUSIONS

Based on the project studied we arrive at the following conclusions:

While limiting the number of installed resources participating in the execution of some activities, maximises the duration of completion of activities. Also increasing the duration of a resource of an activity, the entropy of the project is reduced, since the longer the duration of a resource for the performance of an activity, the easier and more flexible is the execution. While the entropy of some activities approaches zero, the greater the duration of the activities. Also, as the duration of completion of some activities increases, the cost of the project decreases.

The various variables that characterize a project such as entropy, delay, cost, etc., have different sensitivity to the change of some resources and some activities. The change of these resources, affect the project variables differently, depending on the activities, involved.

Because productivity is influenced by several incalculable factors (eg, weather, social and labor environment, etc.), it is difficult to include these factors in the productivity calculation during the execution of the project, so the estimate of productivity fluctuation of a project with respect to the variation of some resources, of some activities is made indirectly by the entropy change of the project resources. Thus, where the entropy is close to zero, i.e. there is no disorder in the system, or otherwise, there is stability in the system, then the productivity is not reduced and remains constant. As the entropy moves away from zero (positive or negative), the system disorder increases, resulting in reduced productivity.

In the project we examined, changes to a small number of activities resources were induced, in relation to the overall resources. It was observed that small resource changes caused minor changes in project variables (Cost, entropy etc.).

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