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A PRODUCT DEVELOPMENT PROCESS AND ITS MANAGEMENT. AN ENGINEERING STUDENT LABORATORY

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ABSTRACT

This paper reveals the project management techniques and methods that the engineering student could develop as an exercise as well as a proof of the complete understanding of a product development steps. The process of vehicle development is used as an example. The Pert diagram, the probabilities and the minimum costs calculation, the human resources management and the risk management analysis are presented.

Keywords: project management, product development, Pert diagram

1. INTRODUCTION

This paper presents the development process of a vehicle using the concurrent engineering principles revealed by the scientific literature [1, 2].

The ″set-base concurrent engineering″ is used as a point of start of this analysis:

- the multidisciplinary team formulates a set of initial solutions for the future vehicle types;
- these solutions are analysed by the departments involved in the process of the new vehicle development;
- the number of solutions is reduced as the multidisciplinary team gathers new information;
- at the end of the development process, only one solution defines the new vehicle type.

The process announced above is divided in a certain number of activities whose management can be realized using project management techniques.

These techniques are presented successfully in the following sections of this paper:

- Section 2 presents the Pert diagram, a visualization of the flow of the project activities. The ″normal″ and the ″urgent″ time and cost of both the activities and the entire project are analyzed, the critical path(s) (with no time reserved) is (are) revealed.
- Section 3 shows probability calculations that a manager can do at the beginning of the project: the probability to finish the project in a certain period; the time when the project can be finished with a certain probability.
- Section 4 calculates the cost of the project for both the ″normal″ and the ″urgent″ regime, the minimum cost of the project in the ″urgent″ regime as well as the minimum cost of the project for a certain project time whose value lies between the ″normal″ and the ″urgent″ regime project time.
- Section 5 exemplifies the techniques used to assure the human resources: the skills roster, the human resources matrix, the person loading chart and the Gantt chart of the person loading.
- Section 6 presents the risk management analysis (FMEA—″Failure Mode and Effects Analysis″), using the RPN (″Risk Priority Number″) method, for the entire project and ″the definition of the product concept″ activity.

2. THE PERT DIAGRAM

Table 1 presents the activities that the multidisciplinary team takes into consideration in the project analysis. These activities (which are named ″a″÷″y″) are described and the optimist (t_0), the pessimist (t_p) and the medium (t_m) time values of each activity are given ([weeks], representing the order of magnitude throughout the paper, if not stated otherwise) for both regime types: ″normal″ and ″urgent″.

Table 1 also gives, the cost of each week of activity in [thousand lei/week] for both regime types: ″normal″ (c_n) and ″urgent″ (c_u). The company department or the external supplier that performs each activity is mentioned in the last column of Table 1.

Using a beta probabilistic approach [3], the effective ″normal″ and ″urgent″ time (t_n, t_u) [week], cost (C_n, C_u) ([thousand lei]) and cost rate (PC) ([thousand lei/week]) of each activity are calculated. The results are presented by Table 2.

Table 1. *The activities, their description, time and cost*

Acti-vity	Activity description	t_o	t_p	t_m		C_n	C_u	The department
				urgent	normal			
a	The definition of the product concept	10	20	9	15	10	15	Multidisci-plinary team
b	The definition of 5÷10 versions of the model at a scale of 1/5	8	16	9	12	6	8	"Styling" department
c	The analysis of the models realized at a scale of 1/5 by the Manufacturing department	2	4	2,7	3	1	1,5	Manufacturing department
d	The analysis of the models realized at a scale of 1/5 by the Design department	3	5	2,5	4	1	1,5	Design department
e	The analysis of the models realized at a scale of 1/5 by the Marketing department	2	4	3	3	1	1,5	Marketing department
f	The realization of the drawings of the subsystem that do not depend on the chosen model	8	8	8	8	5	7	Design department
g	The multidisciplinary team chooses 1 version of the 5÷10 models realized at a scale of 1/5 based on the ″c″÷″e″ activities, as well as the subsystems 1 and 2	1	1	1	1	1	1,5	Multidisci-plinary team
h	The design of the model at a scale of 1/1	5	7	4,5	6	10	15	Design department
i	The manufacturing of the model at a scale of 1/1	6	7,5	5,625	7,125	12	14	Manufacturing department
j	Prototype testing/certification	3	4	2,75	4,25	8	11	Multidisci-plinary team
k	The extern supplier of the 1st subsystem designs the versions for the 5÷10 models at the 1/5 scale	3	5	2,8	4	1	2	1st extern supplier
l	The performances of the 1st subsystem versions are tested and the parameters dependencies are established.	2	3	2,5	2,8	1,5	3	1st extern supplier
m	The performances of the 1st subsystem versions are prepared to be presented to the managerial committee	0,5	0,5	0,5	0,5	0,5	0,5	1st extern supplier
n	The manufacturing of the 1st subsystem that will be assembled on the prototype	4	6	3,8	5	3,5	5	1st extern supplier
o	The external supplier of the 2nd subsystem designs the versions for the 5÷10 models at the 1/5 scale	4	5	4,5	4,65	1,5	2,5	2nd extern supplier
p	The performances of the 2nd subsystem versions are tested and the parameters dependencies are established.	2,5	3	1,625	2,975	1,5	3,2	2nd extern supplier
r	The performances of the 2nd subsystem versions are prepared to be presented to the managerial committee	0,5	0,5	0,5	0,5	0,5	0,5	2nd extern supplier
s	The manufacturing of the 2nd subsystem that will be assembled on the prototype	6	8	6,4	7	4	6	2nd extern supplier
t	The manufacturing technology definition	8	10	7,5	9	5	7	Manufacturing department
v	The SDV (tools-devices-verification tools) design starting from the parts drawings	7	9	8	8	5	6	Design department
x	Technical drawings yet unrealized	8	10	7,5	9	5	7	Design department
y	The realization of the execution documentation	1	1	1	1	0,5	0,5	Multidisci-plinary team

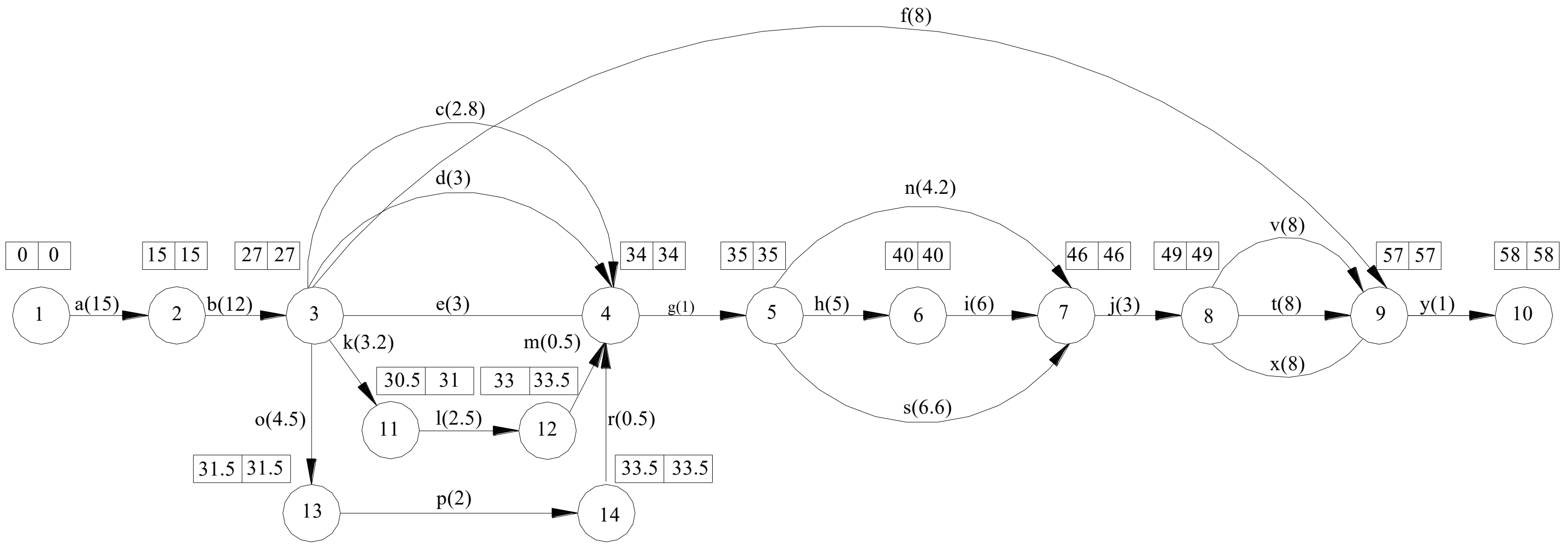


Fig. 1. *The Pert diagram for the ″normal″ regime*

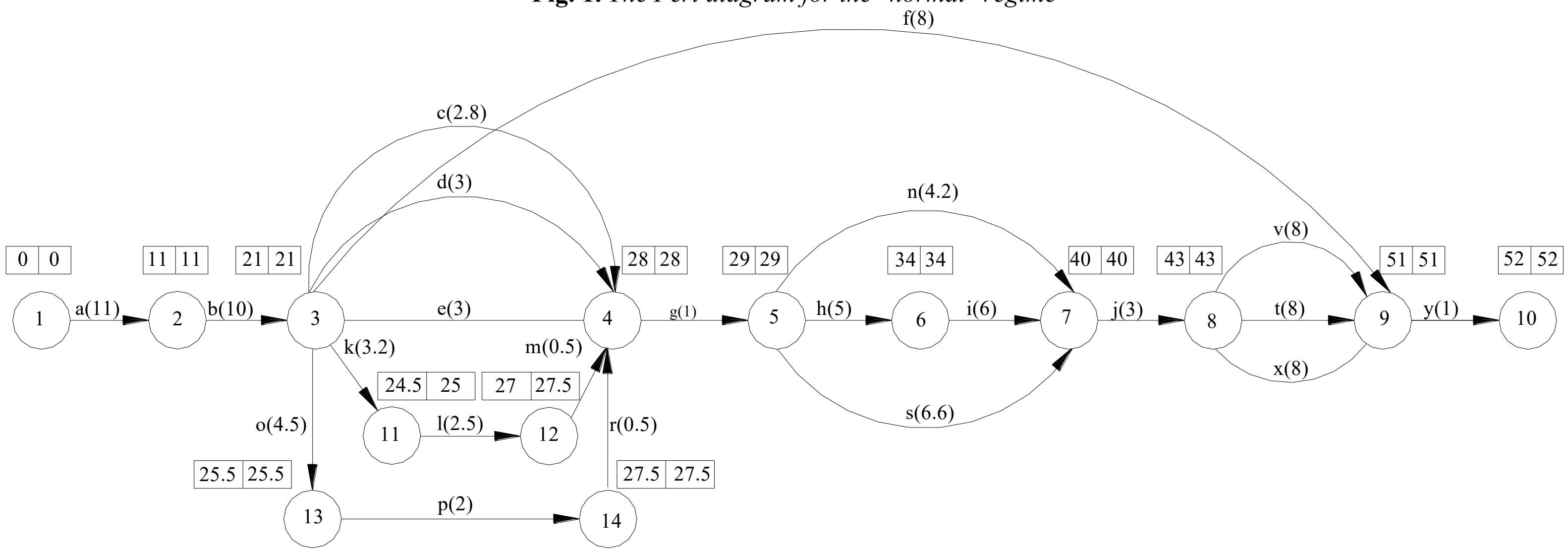


Fig. 2. *The Pert diagram for the ″urgent″ regime*

Table 2. *The effective time, the cost and the cost rate*

Activity	$t_e = (t_o + t_p + 4t_m)/6$		Cost		$PC = \frac{C_u - C_n}{t_n - t_u}$	$\sigma = (t_p - t_o)/6$	σ^2
	Urgent t_u	Normal t_n	Urgent C_u	Normal C_n			
a	11	15	165	150	3,75	1,67	**2,778**
b	10	12	80	72	4	1,33	**1,778**
c	2,8	3	4,2	3	6	0,33	0,111
d	3	4	4,5	4	0,5	0,33	0,111
e	3	3	4,5	3	0	0,33	0,111
f	8	8	56	40	0	0	0
g	1	1	1,5	1	0	0	**0**
h	5	6	75	60	15	0,33	**0,111**
i	6	7	84	84	0	0,25	**0,0625**
j	3	4	33	32	1	0,17	**0,0278**
k	3,2	4	6,4	4	3	0,33	0,111
l	2,5	2,7	7,5	4,05	17,25	0,167	0,0278
m	0,5	0,5	0,25	0,25	0	0	0
n	4,2	5	21	17,5	4,375	0,33	0,111
o	4,5	4,6	11,25	6,9	43,5	0,167	**0,0278**
p	2	2,9	6,4	4,35	2,27	0,0833	**0,0069**
r	0,5	0,5	0,25	0,25	0	0	**0**
s	6,6	7	39,6	28	29	0,333	0,111
t	8	9	56	45	11	0,333	**0,111**
v	8	8	48	40	0	0,333	0,111
x	8	9	56	45	11	0,333	0,111
y	1	1	0,5	0,5	0	0	**0**
Sum			754,85	644,8			

The Pert diagram for the ″normal″ case is presented in Figure 1. We notice the critical path: 0-1-3-13-14-4-5-6-7-8-9-10, or a-b-o-p-r-g-h-i-j-t (or ″v″, or ″x″)-y. We see that we have three critical paths. The time when this project finishes is 58 weeks. The minimum and maximum times of the events are presented above the events circle.

Figure 2 presents the Pert diagram for the ″urgent″ case. The critical paths are the same but the time when the project finishes is 52 weeks. Summing up the σ^2 values of the activities situated on the critical path (bold font on the last column of Table 2), we obtain the variance of the project.

$$V = \sum_{\text{criticalpath}} \sigma^2 = 4.902778 \ . \qquad (1)$$

3. PROBABILITIES CALCULATION

The students can analyze the information they have at this step by using the probabilistic theory. This analysis takes two directions.

3.1. The probability of finishing the project in a certain period.

At this step, the students receive a certain period in which the project should be finished (″D″). For example, if $D = 56$ weeks, using the formula:

$$Z = \frac{D - T^{\text{proiect}}}{\sqrt{V}}, \qquad (2)$$

where $T^{\text{proiect}} = 58$ weeks, we find that $Z = 0{,}903$ and, according to known scientific results [3], the probability of finishing the project in 56 weeks is 17.62%.

3.2. The period in which the project can be finished with a certain probability

The second step of a probabilistic exercise that the engineering student should solve is the determination of the period which assures a certain probability of success.

For example, if we want a probability of 80% to successfully finish the project [3], then $Z = 0.85$ and, consequently, the project time we should consider is $D = 59.88 \approx 60$ weeks.

4. MINIMUM COST

Table 2 shows the cost of the activities in the ″normal″ and ″urgent″ regimes. These values are obtained by multiplying the effective time by the cost of each week of activity (given in Table 1). We have a total cost of the project of 644.8 thousand lei in the ″normal″ regime and a cost of 754.85 thousand lei in the ″urgent″ regime. Using the working hypothesis that a linear cost rate is valid for each activity of this project, no matter the working regime, the cost rates of the project activities are calculated and presented in Table 2.

4.1. The minimum cost of the project in the ″urgent″ regime

Having as a starting point the project in the ″urgent″ case, we are trying to reduce the project cost by increasing the length of the non-critical activities. We start with the activities that have the smallest cost rate [3]. From Table 2 we retain the non-critical activities and for a clearer working style, we are writing them in Table 3 by discarding the activities with zero cost rates (e, f, m, r, v). The first activity that we increase is the ″s″ activity with 0.4 weeks. The cost reduction is 11.6 [thousand lei].

In order, we read in Table 3 all the non-critical activities whose lengths are increased.

The total reduction is 22.65 [thousand lei] and the cost of the project becomes $754.85 - 22.65 = 732.2$ [thousand lei].

Table 3. The cost reduction in the ″urgent″ regime.

Activity	t_e [weeks]		PC [thousand lei/week]	The time increase [weeks]	Cost reduction [thousand lei]
	urgent	normal			
s	6.6	7	29	0.4	11.6
l	2.5	2.7	17.25	0.2	3.45
x	8	9	11	-	-
c	2.8	3	6	0.2	1.2
n	4.2	5	4.375	0.8	3.5
k	3.2	4	3	0.8	2.4
d	3	4	0.5	1	0.5

4.2. The minimum cost of the project for a certain project time

Having as a starting point the project in the ″normal″ regime, we can calculate the minimum cost of the project for a project time between the ″urgent″ and the ″normal″ time. For the data used in this paper, we are considering the project time between 52 weeks and 58 weeks.

We are interested in reducing the time of the activities situated on the critical path and we are focusing our attention on the activities with the smallest cost rate. Table 4 presents, in order, the activities whose time is reduced, the cost increase and the time of the project at the considered moment.

Figure 3 presents the Project cost — Project time diagram using the results of Section 4.

Table 4. *The cost of the project for different values of the project time*

Activity	t_e [weeks]		PC [thousand lei/week]	The time reduction of the activity [week]	Cost increase [thousand lei]	The time of the project [weeks]	The cost of the project [thousand lei]
	urgent	normal					
i	6	7	0	1	0	57	644.8
r	0.5	0.5	0	-	0	-	
y	1	1	0	-	0	-	
j	3	4	1	1	1	56	645.8
p	2	2.9	2.27	0.9	2.043	55.1	647.843
a	11	15	3.75	1	3.75	54.1	651.593
				2	7.5	53.1	655.343
				3	11.25	52.1	659.093

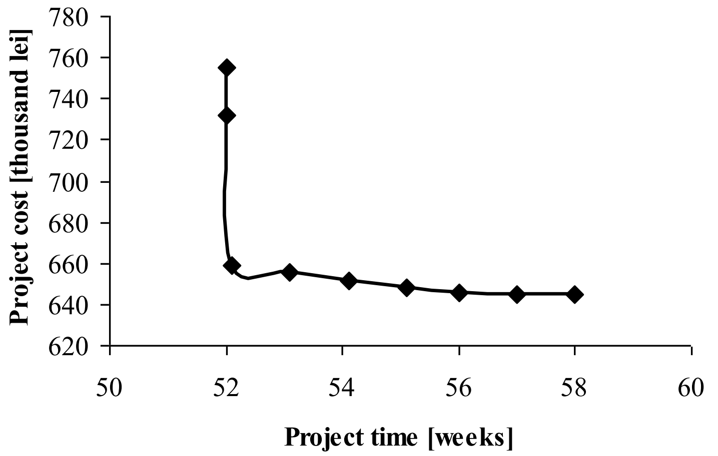


Fig. 3. *The project cost vs. the project time variation*

5. THE HUMAN RESOURCES MANAGEMENT

This section exemplifies the human resources management for the ″A″ activity —″The definition of the product concept″. The activities and their time are given in Table 6, while their Pert diagram is represented graphically in Figure 4.

The following project management techniques and methods are used to ensure the human resource necessary for the ″A″ activity:

- the skill roster – given by Table 5, where the activities are presented on the vertical left column (named ″a1″÷″a9″), while the available personnel is presented on the top line (named ″A″÷″J″). The qualification of each person is presented graphically showing their interest, knowledge and expertise:

● excellent skill and knowledge

O good skill and knowledge

△ interest

From this table, we have chosen the right person for the proper activity according to their qualifications. The result takes the shape of the human resources matrix;

- the human resources matrix – given in Table 6. Here, we can read the working effort each person is given for each activity. To avoid overworking situations, two more project management techniques are available;
- the person loading chart (see Table 7);
- the Gantt chart of the person loading (see Table 8).

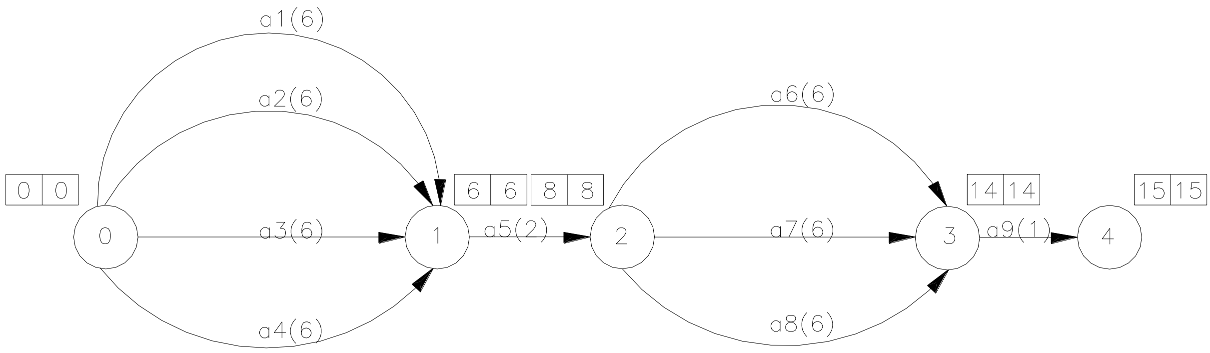


Fig. 4. *The Pert diagram for the ″a″—″The definition of the product concept″— activity*

Table 5. *The skills roster for the ″a″ activity*

Personnel/ Activities	A	B	C	D	E	F	G	H	I	J
Programming/Numerical simulation	●	O	●							△
The analysis of the research and the theoretical studies		●	△	O				●		O
Design	O				△	●	O			

The initiation and development of the laboratory tests	△		O			△		O		●
The analysis of the laws, the standards and the norms	O			△	●		●		O	
The analysis of the drawings, the products, the technological records and the manufacturing plans		△		●		O	O	△		
Statistical and market studies					O		△		●	

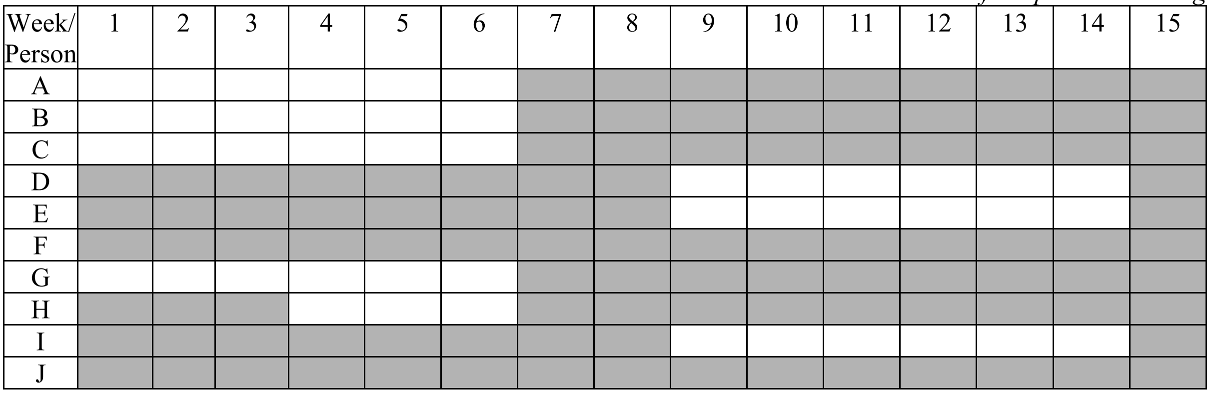
Table 6. *The human resources matrix for the "A" activity*

Activities description		Time [weeks]	Human effort [pers.h]	A	B	C	D	E	F	G	H	I	J
a1	The analysis of the research and the theoretical studies	6	720		**240**	240							240
a2	Statistical and market studies	6	240									**240**	
a3	The analysis of the laws, the standards and the norms	6	240					**240**					
a4	The analysis of the drawings, the products, the technological records and the manufacturing plans	6	60				**240**		240		120		
a5	The definition of the new product characteristics by the multidisciplinary team	2	600	60	60	60	60	60	60	60	60	60	60
a6	Programming/Numerical simulation	6	720	**240**	240	240							
a7	The initiation and the development of the laboratory tests	6	480								240		240
a8	Design	6	480						**240**	240			
a9	The definition of the final product characteristics by the multidisciplinary team	1	400	40	40	40	40	40	40	40	40	40	40

Table 7. *The persons loading chart [person-hours]*

Week/ Person	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A							40	20	40	40	40	40	40	40	40
B							40	20	40	40	40	40	40	40	40
C							40	20	40	40	40	40	40	40	40
D	40	40	40	40	40	40	40	20							40
E	40	40	40	40	40	40	40	20							40
F	40	40	40	40	40	40	40	20	40	40	40	40	40	40	40
G							40	20	40	40	40	40	40	40	40
H	40	40	40				40	20	40	40	40	40	40	40	40
I	40	40	40	40	40	40	40	20							40
J	40	40	40	40	40	40	40	20	40	40	40	40	40	40	40

Table 8. *The Gantt chart of the persons loading*



6. FAILURE MODE AND EFFECTS ANALYSIS

The analysis of the risk factors and the effects of their appearance (FMEA—″Failure Mode and Effects Analysis″) is realized using the RPN (″Risk Priority Number″) method [4÷9]. This factor can be evaluated using the following formula:

$$RPN = S \times O \times D\,, \qquad (3)$$

where:

S — the severity of the effect;

O — the probability of a certain risk to manifest itself;

D — the probability of detecting failure.

Using this method, Table 9 presents the value that these factors take for the ″a″÷″y″ activities. The values are appreciated using the Tables 5.4÷5.6 [9].

Table 9 shows that the ″B″ activity —″The definition of 5÷10 versions of the model at a scale of 1/5″— has the highest RPN number. According to the decisions of the multidisciplinary team, certain activities will be analysed further, risk management analysis will be developed for them and prevention measures will be established and applied.

Further, the ″A″ activity —″The definition of the product concept ″— will be analysed. Its activities, possible failure modes and causes as well as control methods are established. Table 10 presents the results, and the RPN coefficients for the ″A″ activity.

The analysis of the results of Table 10 underlines the importance of the ″a1″÷″a4″ activities that receive the highest RPN coefficient (15,86%).

Table 9. *The RPN factors for the project activities [9]*

Activity	Activity description	S	O	D	RPN	RPN [%]
a	The definition of the product concept	7	3	5	105	4,49
b	The definition of 5÷10 versions of the model at a scale of 1/5	7	6	5	210	8,98
c	The analysis of the models realized at a scale of 1/5 by the Manufacturing department	8	5	3	120	5,13
d	The analysis of the models realized at a scale of 1/5 by the Design department	8	4	3	96	4,10
e	The analysis of the models realized at a scale of 1/5 by the Marketing department	4	4	8	128	5,47
f	The realization of the first drawings of the subsystem that do not depend on the chosen model	8	2	6	96	4,10
g	The multidisciplinary team chooses 1 version of the 5÷10 models realized at a scale of 1/5 based on the activities: ″c″÷″e″, as well as the subsystems 1 and 2	7	3	3	63	2,69
h	The design of the model at a scale of 1/1	10	5	2	100	4,27
i	The manufacturing of the model at a scale of 1/1	10	3	1	30	1,28
j	Prototype testing/certification	10	1	2	20	0,85
k	The extern supplier of the 1st subsystem designs the versions for the 5÷10 models at the 1/5 scale	9	4	4	144	6,15
l	The performances of the 1st subsystem versions are tested and the parameters dependencies are established.	9	4	4	144	6,15
m	The performances of the 1st subsystem versions are prepared to be presented to the managerial committee	9	4	4	144	6,15

n	The manufacturing of the 1st subsystem that will be assembled on the prototype	9	4	4	144	6,15
o	The extern supplier of the 2nd subsystem designs the versions for the 5÷10 models at the 1/5 scale	9	4	4	144	6,15
p	The performances of the 2nd subsystem versions are tested and the parameters dependencies are established.	9	4	4	144	6,15
r	The performances of the 2nd subsystem versions are prepared to be presented to the managerial committee	9	4	4	144	6,15
s	The manufacturing of the 2nd subsystem that will be assembled on the prototype	9	4	4	144	6,15
t	The manufacturing technology definition	9	2	3	54	2,31
v	The SDV (tools-devices-verification tools) design starting from the parts drawings	7	2	4	56	2,39
x	Technical drawings un-realized yet	7	3	4	84	3,59
y	The realization of the execution documentation	4	2	3	24	1,02

Table 10. *The RPN factors for the "a" activity — "The definition of the product concept"*

Activity	Failure mode	S	Failure cause	O	Control	D	RPN	RPN [%]
a1	Important information omission; Incomplete analysis	7	Short working time; incomplete documentation	6	Utilisation of external experts	5	210	15,86
a2	Important information omission; Incomplete analysis and report	7	Insufficient understanding of the personnel/results	6	Utilisation of external experts	5	210	15,86
a3	Incomplete analysis	7	Team members' lack of experience	6	Utilisation of external experts	5	210	15,86
a4	Incomplete analysis	7	Team members' lack of experience	6	Utilisation of external experts	5	210	15,86
a5	The new product will have a certain degree of novelty but it will not have a significant success	7	Incomplete discovery of the documentation; lack of understanding; lack of valorisation of the fundamental research	4	Utilisation of external experts	2	56	4,22
a6	Incorrect results	8	Lack of experience	6	Utilisation of external experts	4	192	14,50
a7	The experiments were realised incorrectly; wrong results can compromise the entire product development process	8	Insufficient preparation of experiments; experiments carelessly realised; results carelessly analysed	4	Verification of the results by external experts	5	160	12,08
a8	Incorrect proposed versions that can be corrected	8	Lack of experience; lack of consideration of all the constraints	3	Verification of the results by external experts	2	48	3,62
a9	The new product is not viable; a small novelty degree	7	Lack of consideration of all the previous results	2	Verification of the results by external experts	2	28	2,11

The activities that have a high RPN should have a risk management plan attached to them and they should be monitored throughout the entire project time.

7. CONCLUSIONS

The project management techniques can be used successfully to emphasize to the engineering student the steps of product development.

The aim is exemplified by the case of vehicle development. Techniques and methods of project management are used to construct the Pert diagram, perform probabilistic analysis, calculate the minimum cost for different project periods, to define the team and to manage the human resources, to develop risk management plans and to exemplify to the student the way of proceeding in a product development process.

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