

DEVELOPMENT OF A MATHEMATICAL MODEL FOR RISK ASSESSMENT FOR DESIGN PROCESSES

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Abstract: *Modelling and analyzing the risk of various processes holds a vast amount of uncertainty factors. This statement is especially true in the field of design and mechanical design within, since human factors have huge impact on these areas considering the risk of processes. The purpose of recent paper was to develop such a method and adjoining mathematical model that has the ability of modelling and monitoring possible risks during design procedure and to collect data in order to evaluate those well in advance. Although the presented mathematical model contains many simplifications it gives the opportunity to expand the number of the treated risk factors and according to this to refine the forward method of risk assessment. The mathematical model based on the well-known management methods and tools (for ex. PERT network, Gantt diagram, etc.) works with fuzzy logic to deal with uncertainties in the process and also points out human subjectivity.*

Key words: Fuzzy logic, project management, risk assessment, design process

1. INTRODUCTION

Nowadays the application of the project management techniques is very common. It helps the work by using a structured, transparent system for any kind of processes. Its role in technology planning processes is also significant, but in this area is not widely used yet. However Fazar hereby introduced mathematical model uses project management tools in many points, such as the PERT method [3], and the critical path calculation. [5] In addition, building our model fuzzy logic was also used, which is a great tool for uncertain cases of the decision making [12]. There is a fuzzy theory developed for managing risks, which was implemented in our work. We performed defuzzification with CFM method [8] which utilizes a more simple calculation process as for the conventional fuzzy techniques.

2. THE PROJECT DEFINATION

The very first step of building the model was defining the project. In our case we mean a design process by saying project. In the first phase of this step the general characteristics of the project should have been clarified. In most cases projects cover a time-limited process and produce a unique product. The second step of defining the project was identifying the project's requirements and objectives. The design of the fully electrical sport car was selected to test our mathematical model (Figure 1). A

student team working on the project in the BME Department of Machine and Product Design. Nowadays the pure electric drive comes to the front thanks to the increasing weights of the environmental aspects. It is common sense, local pollution is not emitted by solely electric driven vehicles. Furthermore – in comparison –, the drive-train of the electric sports car is much simpler than the drive-train of an internal combustion car, for e.g. it requires less moving parts and auxiliary components. A uniquely electric powered vehicle has weak points as well. Most of the difficulties are caused by the batteries because due to their size and weight, although this is the most intensive area of research.

Independently of these disadvantages electric vehicles have great perspective, so leading car manufacturers cannot afford to ignore this type of cars. This area is interesting and – what is more important – really a rewarding area for higher education and research institutions. These reasons led us to choose this subject for the project.



Fig. 1: The design of electric-driven sports car

The car got a modern design and is also a high quality product. Planning the interior design the latest technologies were used. As already mentioned students worked on the car. One student developed one component. This means that the human resources were constant from phase to phase. In the examined project period 6 students were selected to work on the car during their summer internship. In order for students to be able to start work the main parameters of the car were provided. After the development of the design the main characteristics of the drive system must be determined by an MSc student in the context of his/her thesis.

3. PROJECT RISK MANAGEMENT

Risk management projects are complex processes that consists of several steps, continuous iteration [10]. An average project execution is loaded with different risks which is particularly typical in the design processes [2]. Developing the initial model simplifications have been applied. Since the model deals with the planning of the project, which is characterized by a period of time required to complete, it was hard to plan. This is why we decided to calculate the risk of the time needed. The risk of a delay (meaning that the project can not be completed within the scheduled time frame) was analysed. Our goal was to define the risk by numerical data, taking into account during the human factors. The goal of the model

was to reduce the subjectivity of the risk analysis. Future goals include the effect of multiple risk factors be taken into consideration.

4. PROJECT SCHEDULING MANAGEMENT

Planning and scheduling of the design process is always hard because the output and the run-off paths are affected by numerous factors and therefore the risks are high [13]. So the scheduling of the design process needs careful preparation. The final success of the project is significantly influence by the proper planning of these design steps. Project scheduling always begin with defining the activity and creating the work breakdown structure (WBS) [4]. Here the project managers break the project into separate tasks and activities. In a technical design project the steps of creating the WBS are similar to the other types of projects, but there are some design considerations that have to be taken into account from the beginning of design (for example what kind of design method will be used during the product design). Concurrent engineering (CE) can be used for the product development process [14] CE is the commonly accepted design method in industry for decreasing the time to market of the product. [1]

The project's output is a product, so first it was necessary to determine the main parameters of the product and create the conceptual plan. The applied design method begins with the plan of the conceptual design. All of the required levels of the product and the subassemblies based on the conceptual design. It is called top-down design [7]. In general the subassemblies are designed by an engineer, in this case a student. The subassemblies had to be broken into components and determined what activities should have been done. Each unit had to be broken down until we got those basic activities that are no longer worth breaking down. The result of this phase was a task list that contains the properties of the activities. For better monitoring the tasks were signed with an identification number. The identifier shows the place of the task in the project (which subassembly belongs to the task), and the nature of the task as well.

After the activities were determined the next step was to define the relationship among them, and prepare the network diagram. Pert method was used to plan the network diagram. The activities that do not depend on each other could be done parallel. The activities were organized into branches, which could not contain any iteration, because iteration sections can always be divided to serial sections. In the network diagram rectangles represented the activities, the upper-left corner is the ID in the upper right corner is the time for each task. Arrows indicated the direction of the progress (Figure 2).

The times in the network diagram were counted from the available time for the whole project. Developing the model three times accurate estimate was applied. The accuracy of lead time estimation improved that the risks were taken into account. The lead time, which was available separately for each task, was considered as a realistic time.

After the network diagram was formed and the lead times were defined to each task, then the students got their own

tasks. The development of the subassemblies and the task, which do not depend on each other, were processed parallel.

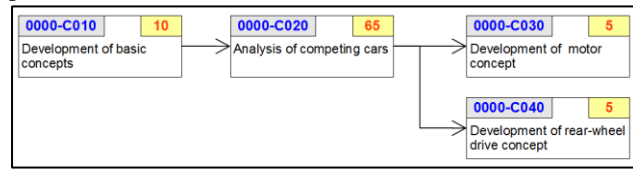


Fig. 2. The network diagram

5. MONITORING

As has already mentioned in our model the main risk was the risk of the completion within a given time frame. So during the monitoring any data should have been collected, whose evaluation made it possible to measure an assumable delay or earlier completion of the project from week to week. While monitoring the participating students had to estimate the probability of their delay or early termination, without dealing the length and severity of these time periods.

The monitoring table had to be filled by the students twice a week, always on the same work day (Figure 3). The table was divided from task to task and the students gave the number of hours spent by working on the given activity. They did not have to use any scientific methods (like PERT method) to estimate the time, they only had to choose from five options, (such as: sure , it is likely, possible , unlikely , impossible) estimating the probability of a delay and a punctual termination. They had to explain the delay by choosing a prepared answer.

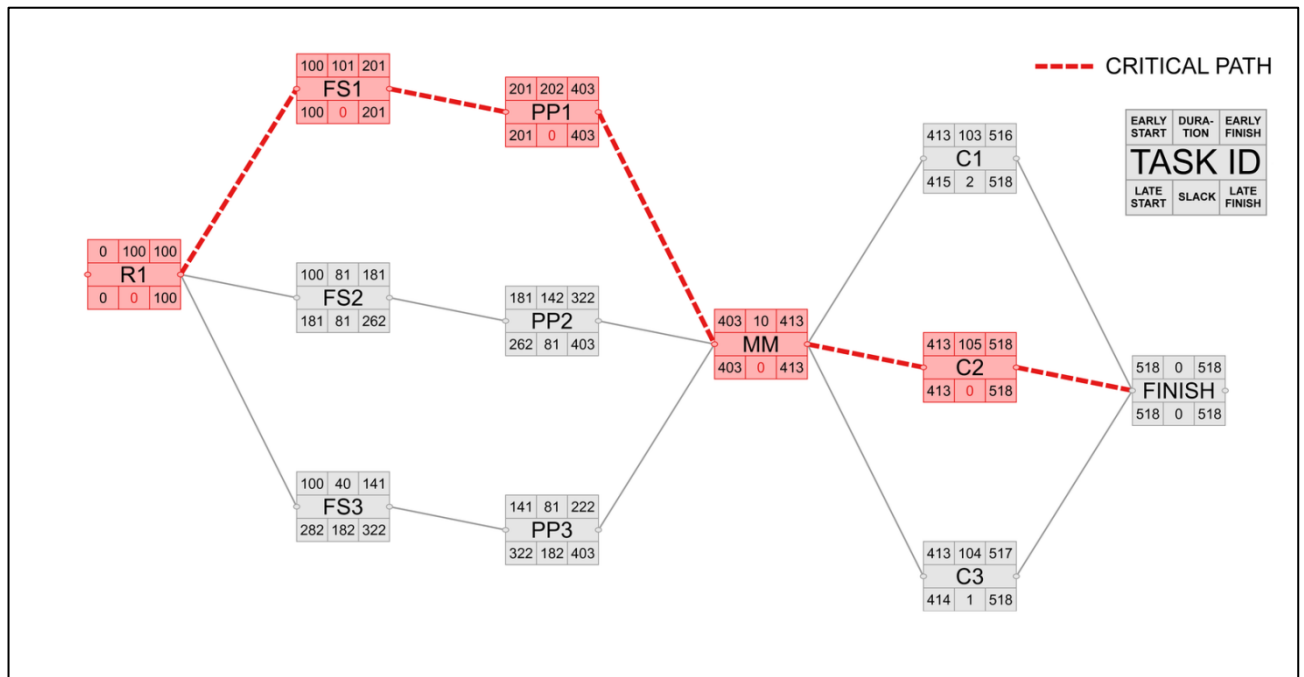
	0000-C010	0000-C020	0000-C030
	10	65	5
1. week Tuesday			
performed hours	6	11	2
probability of early finish	unlikely	possible	sure
probability of delay	it is likely	possible	impossible
reason of delay	bad time estimation	IT problem	software knowledge
1. week Freiday			
performed hours	8	14	3
probability of early finish	impossible	unlikely	sure
probability of delay	it is likely	it is likely	impossible
reason of delay	bad time estimation	IT problem	software knowledge

Fig. 3. The monitoring table

This estimation procedure provided a more accurate view of the delay's probability, as it is better suited to human thinking. Estimating risks the role of human factors is very significant, which could then be treated by a soft computing method of fuzzy logic.

6. CRITICAL PATH METHOD

Design projects usually have complex network diagram as they are required to apply a method, which pays attention to those activities that mean a hazard to the project time. This method is called critical path method [5]. Developing the model realistic times had to be assigned to the tasks, so it was the duration of the tasks. For creating the critical path the earliest start (EST) and earliest finish times (EFT), and the latest start (LST) and latest finish times (LFT) had to be calculated using the duration of the task (D) and the relationship between them. The following formulas could be used to calculate that time:



$$EFT = EST + D$$

$$(1) \quad (8)$$

$$LST = LFT - D$$

$$(2)$$

After that it was necessary to determine the critical path, in which path had no slack time (SLT). The slack time could be calculated the following formulas.

$$SLT = LST - EST$$

$$(3)$$

$$SLT = LFT - EFT$$

$$(4)$$

Calculating these figures would take a long time especially in case of a wide network diagram, therefore this process was automated. A computer program had been used, which was written in MATLAB language [9]. First you should have given the activities, their duration and the dependency relationships in a table for the program. Then, the program calculated with forward analysis the earliest start times. Backward analysis plans the latest completion time, and with the above mentioned formulas it calculated all other required dates. It not only calculated the values, but also drawn out the Pert network and the critical path. The program marked the tasks with different colours, depending on how much slack time it contained (Figure 4). For example red was the colour on the critical path. In the project plan the activities indicated rectangles, which were divided into several smaller cells. The last step of the program wrote back the calculated values into a table, which contained the input data. This table was the base for further analysis containing all the necessary data which were available for the project.

7. FUZZY LOGIC BASED RISK MANAGEMENT

The aim of the mathematical model was to replace subjective risk assessment based on the estimation with fuzzy logic based risk estimation. The risk consists of severity and probability, which were calculated with fuzzy logic [11]. Human factors were also taken into account, based on the obtained data from the monitoring. There was a specific risk for each task. The risk calculation was performed by a program, which was written during the research. The program used fuzzy membership functions to calculate the required values. All of the calculations were done in the program. The first step is the calculation of the risk was based on the the probability and severity.

7.1. The severity calculation

In the model the severity was the influence of the time course of the project. If the severity of the tasks was low, the potential slip did not have a significant effect on the time completion of the project. If the task had high severity value, it meant that if the task delays it has a serious impact on the completion of the project. For the calculation of severity a fuzzy membership function was used, which was characterized for the given project, and was determined by the project managers. The

NAME	ID	Predecessors	TO	TML	TP	TRO	PO	SO	TRP	PP	SP	SLT	SUMT	LSTART	LEND
START	1	"	0	0	0	10	0,005	5	3	0,0005	0	0	70	0	0
E041	2	'1'	10	10	10	10	0,005	5	3	0,0005	0	0	70	0	10
E042	3	'2'	5	5	5	10	0,005	5	3	0,0005	0	0	70	10	15
E050	4	'2'	5	5	5	10	0,005	5	3	0,0005	0	0	70	10	15
D011	5	'1'	5	5	5	10	0,005	5	3	0,05	0	5	70	5	10
D012	6	'2 5'	5	5	5	10	0,005	5	3	0,05	0	0	70	10	15
D021	7	'2 5'	5	5	5	10	0,005	5	3	0,05	0	0	70	10	15
D022	8	'3 4 6 7'	20	20	20	10	0,0005	5	3	0,05	0	0	70	15	35
D023	9	'8'	20	20	20	5	0,05	5	5	0,05	0	0	70	35	55
D030	10	'9'	15	15	15	5	0,05	5	5	0,05	0	0	70	55	70
D040	11	'1'	10	10	10	5	0,05	5	5	0,05	0	60	70	60	70

vertical axis represented the severity, and the horizontal axis shown the relative slack time.

The relative slack time (T_{RS}) depended on the task duration (T) and the task's slack time (T_S).

$$T_{RS} = \frac{T_S}{T} \quad (5)$$

In our model the severity function was linear (Figure 6). The membership function's vertical axis was scaled between 0 and 1 values, where 1 represented the lowest severity, as in the defuzzification the CFM method was used. In this method the low values represents the dangerous cases. If the severity was near to 0, that task was serious in the model. The severity of fuzzy membership function equation:

$$U(S) = x(1 - k) + k \quad (6)$$

In our case, x = relative slack time. The k parameter as shown in this project was chosen to be 0.25. Determination of this parameter can be different for each project.

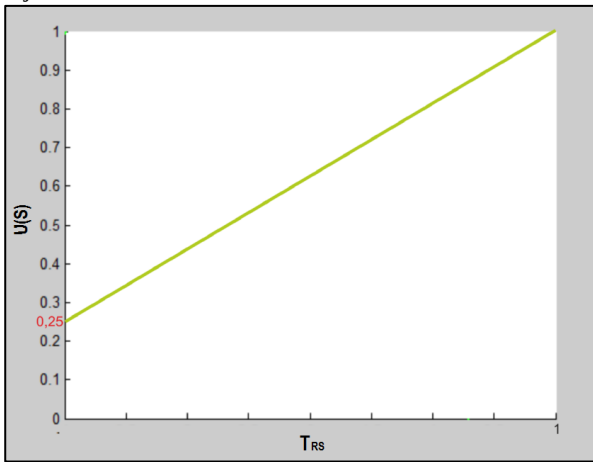


Fig. 6. The severity fuzzy membership function

7.2. Calculation the probability

The probability consisted two parts: the objective and the subjective probability. From the two probability values the fuzzy logic (here is the CFM method) was used to calculate the entire probability.

7.2.1. The objective probability

In the model, the objective probability also had a fuzzy membership function. The vertical axis of the objective probability was scaled from 0 to 1. Values of the horizontal axis were based on the methodology used for general risk management. The manager should have determined these values with estimation before the project begins.

In our model values of this axis were determined the following way: the activities were arranged to categories based on the nature of the tasks and we assigned a specific value to each category, depending on the probability of the delay due to the nature of activities. If an activity got a high value of the delay probability, the objective probability value became small (similar to the severity range). If the objective probability got the higher value, the delay due to the nature of probability was

lower. The horizontal axis was logarithmically scaled up in -0.7 - to -4, where the values of the probability of base exponent of ten (10^x).

7.2.2. The subjective probability

In the subjective probabilities human factors and the estimation trends based on the literature read and monitored measurement data were also taken into account.

The estimation depends mainly on people being optimistic or pessimistic, and also depends on what is needed to estimate, and whether the outcome of the event is, positive or negative. Therefore, on the monitoring it was asked separately about the delay and earlier completion probability. Generally people have always underestimated the probability of delay. In addition, it is also typical that people assigned small probability events to a greater probability events, and the greater probability events to a small probability events. [6] These characteristics were taken into account the probability calculation. We expect that risk assessment profile will be formed, based on the data collection of the monitoring. The risk assessment profile will be different from person to person. As the real run is available for the entire project it is possible to compare it with the planned time, and by these test the accuracy of the estimation.

Subjective probability also had a fuzzy membership function. It had a value for each specific task was assigned. The function's horizontal axis represented the probability estimated by the students during the monitoring, and the vertical axis represented the subjective probability. It was not considered to be a linear function, because we wanted to illustrate the human factors in the model, so that the shape of a function was changing based on how the people estimated the probability.

The shape of subjective probability membership function is shown in Figure 7. It was used the same scaling like the values of the objective probability membership function, During the monitoring the students only had to estimate the probability of the delay the earlier completion with choosing from the following values: sure, it is likely, possible, unlikely, impossible. These values were entered on the horizontal axis of the fuzzy membership function.

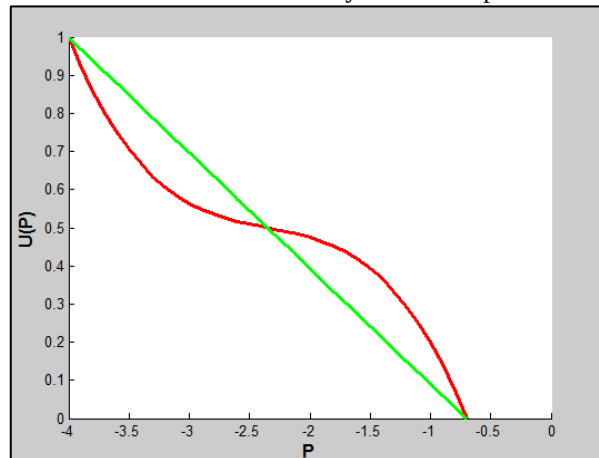


Fig. 7. The objective and the subjective probability membership function

7.3. The aggregate probability calculation

After the subjective (U (Phum)) and objective (U (Pobj)) probabilities were available, the aggregate probability could be calculated (U (P)). This part of the fuzzy logic risk analysis was the defuzzification. In the model CFM method was used. The probability was calculated in this case with the following formula:

$$U(P) = \frac{U(P_{hum}) * U(P_{obj})}{\frac{U(P_{hum}) + U(P_{obj})}{2}} \quad (7)$$

7.4. Risk calculations

If the task's severity (U(S)) and the aggregate probability (U(P)) was determined, risks (U(R)) were calculable. The CFM method had been used for the risk calculation. The formula is:

$$U(R) = \frac{U(P) * U(S)}{\frac{U(P) + U(S)}{2}} \quad (8)$$

This part of the model is suitable for modelling any risk, depending on the monitoring.

8. EVALUATION

After the risks have been calculated, in which the human factor also played a role, the evaluation could begin. The aim of evaluation was to determine how good the human estimation of the probability of the delay during the project. The results of the real-runs were also available, so we could judge the accuracy of the estimates from a given monitoring occasion to the next project phase. If the task had high-risk from the estimation, it is probably going to show delay compared to the planned runs. If the risk was low, then the task is not likely to delay. In these cases, the estimate was rated as good, if the risk, based on estimates, was consistent with the real progress. To qualify the estimation the risk and the relative delays were taken into account. The risk assessment was available to all tasks and monitoring occasion. The relative delay was calculated using the given task's current delay and the task length. The program considered different cases, depending on how the given task should have stood on the given monitoring occasion. In this development phase of the model, only those cases were examined in which contains delay on the task. In this case, the program calculated the relative delay of the task according to the following equation:

$$T_{RD} = \frac{T_P - T_R}{T} \quad (9)$$

T_{RD} : relative delay

T_P : completed hours in the planned case

T_R : completed hours in the real case

T : duration

In the model, to qualification the estimations a matrix (Qualification matrix) was applied. One side of the matrix stood the risk, and the other side was the relative delay located. Both were given in percentage and broken down by categories. The qualification matrix is shown in Table 2. In the interpretation of the matrix, if the task had low risk and the relative delay was also low, the estimation

was good (G). M denoted moderate estimates. B was for bad estimates. In case of bad estimation low risk was estimated, but there was a huge delay on the tasks, or high risk was estimated, but there was no delay in the next monitoring occasion. These cases could be read from the matrix.

Table 2. Qualification matrix

Qualification matrix		Relative delay		
		0%		-100%
Risk	0%	G	M	B
		M	G	M
	100%	B	M	G

Ratings of the matrix could be displayed on a Gantt chart. The program drawn the Gantt chart based on the proposed network diagram. In the Gantt chart the columns represented the individual tasks. On the vertical axis were shown the tasks, and the horizontal axis stood for the time of the project. This program gave different colours for the tasks based on its qualification. The red denoted the bad estimation, the moderate estimation was blue, and green was for the good estimation. The program can displayed the estimation separately by monitoring occasion (Figure 8), but it could give a more comprehensive view about the project by colouring the whole diagram (Figure 9).

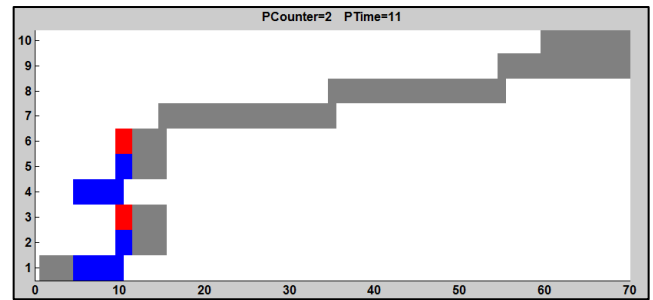


Fig. 8. The Gantt-diagram on the second monitoring occasion

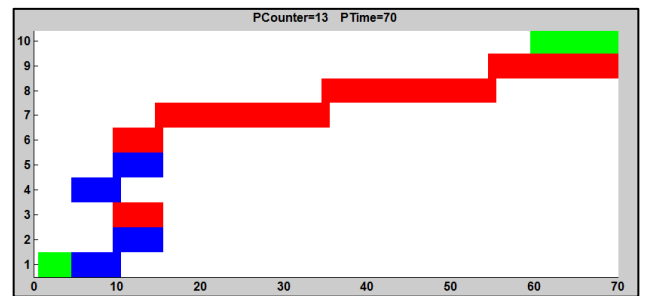


Fig. 9. Colouring the whole project

The finalized Gantt chart is very useful because it shows the changes of the estimation over time in a selected task. In addition, it shows how the estimation was changing during the project run. This can be very useful for every project, because we can infer from it to the further development of the project. A possible direction for further improvement of the model is developing risk assessment profiles for people, who are working on the

project. Risk assessment profiles can be applied in all project estimates in the future.

9. CONCLUSION

The greatest achievement of the research is the creation of a mathematical model that supports modelling of risk-related projects, especially the risks of the period of the project. It reduces the risk of human factors and estimation by using fuzzy logic. Because simplifications have been applied in many places our further objectives also includes the elimination of these simplifications, meaning taking into account multiple risk factors. Besides these several other options are available for further improvement. We are planning to collect more data, to use the model for other projects, and to develop a risk manager profile by qualifying estimates. We also would like to take into account more human factors while estimating the risk.

Our model has been developed primarily for design projects with a lot of high risk and significant role of human factors in the estimates. In spite of this the method can be applied in all aspects with any project. Our model is based on known processes of the professional literature, but is also a new, working system for risk management.

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