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Discrete-event Simulation and SIMPROCESS Software Usage in Project Management

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Abstract: Simulation modeling and project management are two areas, classified partly under operational research, that are not usually linked. The inclusion of stochastic variables in project management in the PERT method introduced the use of simulations, especially Monte Carlo simulations, also in project planning and time analysis. Another use of simulations in project management is the application of discrete event simulation in project planning. When creating a simulation model, it is usually not distinguished whether it is a project or a process. From this perspective, the use of simulations in project planning is common. However, the opposite view, i.e. project planning with the inclusion of simulation, is not so common. This paper presents the use of the SIMPROCESS software in project management for time and resource analysis. An example describes benefits and drawbacks of the discrete event simulation in SIMPROCESS. The main advantage lies in the possibility of setting different probability distributions to generate the duration of each activity. But this can also be seen as a limitation. For the project manager it is essential to know how the simulation software works. However, a project simulation model can be useful for deeper "what if" or time/cost/risk analysis.

Keywords: project management; discrete-event simulation; time analysis; resource analysis; SIMPROCESS software

JEL Classification: C63; O22; C44

1. Introduction

The issue of project management is quite broad, and although various projects have been a part of human life since ancient times, it is only since the last century that more project management methods and tools have been widely used and described. One of the tools still used in project management today was proposed by Henry Gantt in 1910 and the Gantt chart is one of the pillars of project planning (Baron & Baron, 2020). Until the mid-20th century, projects were managed ad hoc, mostly using Gantt charts and various informal techniques and tools. Even with several war projects, it became clear that standardized methods and techniques were needed, especially for project planning. Gradually, two key methods for project planning and time analysis emerged - the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) along with a network representation of the project (Kerzner, 2013). Almost at the same time, the Monte Carlo simulation method was proposed by tree researchers John von Neumann, Stanislav Ulam and Nicholas Metropolis (Thomopoulos, 2013). Monte Carlo simulation is one of the simulation techniques applied to iteratively evaluate a deterministic model with random number sets as inputs. It simulates the entire system repeatedly, each time randomly choosing a value for each variable from its probability distribution (Kwak & Ingall, 2009). Variables can be, for example, the duration of different activities in a project – therefore Monte Carlo simulation can be incorporated into project planning and time and risk management.

Project management covers several project phases – basic 3 as pre-project, project and post-project phase can be split into 5 phases defined in PMBOK guide (2017): project initiation, project planning, project execution, project monitoring and control, project closure. The methods and techniques for the project time management are usually used in the planning phase, where all activities to be carried out in the project need to be defined completely. The interdependencies of activities must be defined and they can be described by one of the network diagrams (AOA = activity on arrow or AON = activity on node) or in a Gantt chart (Kerzner, 2013). To be able to create a Gantt chart, a duration for each activity must be set. Time estimates can be made as fixed values – then the CPM method for the project length is used – or on the three-way basis with optimistic, most likely and pessimistic times for each activity for the PERT method calculation of the project time. Another possibility is the use of simulation which involves calculating multiple durations with different sets of assumptions (PMBOK, 2017). Monte Carlo simulation can be applied on any large or complex project as basic techniques for time management analysis such as CPM or PERT might underestimate project duration. In this sense project management and simulation modelling can be incorporated. Although simulation modeling is mainly focused on modeling diverse systems in order to analyze their functionality, find bottlenecks or assess the workload of workers, some simulation models (especially Monte Carlo simulations) are also devoted to project modeling. On the contrary, the use of simulation models for project planning is still not common in project management. As Doloi and Jaafari (2002) mentioned, while the development of computer-aided process simulation techniques had been speeding up recently, their usage for project definition and management is not very common. Likewise, one of the best-known project management software, MS Project, commonly includes CPM, PERT methods, network graph or Gantt chart, but does not allow simulation for time or cost analysis.

Despite the facts mentioned above, there are still many options for linking simulation modeling and project management using appropriate software. The aim of this article is to present the possibility of using SIMPROCESS software for project simulation for better management of project time and resources and to show advantages and disadvantages of discrete-event simulation usage in project planning. For the case study the real project analyzed within the bachelor's thesis (Košťálová, 2009) at the College of Polytechnics Jihlava, Czech Republic, is used (the author of this article participated in the thesis as a supervisor).

2. State of the Art

Simulation is a technique for replicating real situations, processes or activities in order to study the system and learn how it works, to find where the problems originate, to compare several variants of the model and select the most appropriate one, to show the possible real impacts of alternative conditions and courses of action, etc. (Banks, 1998). Because simulation models use principles taken from mathematics and statistics, they are usually classified as operational research or management science problems (Turban & Meredith, 1994) where various models are designed to find the optimal solution or the optimal choice. The simulation itself usually does not have as its main objective to find the best alternative but it might help in this process. Likewise, we usually do not encounter a simulation model if we focus on the issue of project management. According to Banks (1998) the typical systems for which simulation models might be used are:

- Business process reengineering and management,
- Construction systems,
- Manufacturing systems,
- Transportation systems,
- Public systems: healthcare, military, natural resources,
- Restaurants and entertainment systems,
- Food processing,
- IT/Computer system performance.

In general, simulation is often used for modelling queuing systems where the entities (people, physical items, information) are moving through the system (Robinson, 2007). Project cannot be described like a queuing system but a queuing system can be a result of a project. Similar topics and applications are mentioned on the web pages of Modeling and Simulation conference (MAS, 2022) which is a part of International Multidisciplinary Modeling & Simulation Multiconference. In 24 applications are, except of those mentioned above, named also applications in:

- Customer Relationship Management,
- Decision Making,
- Enterprise Resource Management,
- Financial Planning,
- Infrastructure Planning & Design,
- Inventory Management,
- Project Management.

Project management techniques, especially the methods for the time, cost and resource management, are also part of operations research. However, in the current concept of operations research, these methods are not linked to simulation modeling. Nevertheless, the mention of simulation modeling is contained in the PMBOK, guide (2017), where it is recommended to use especially Monte Carlo simulations for time analysis or risk analysis. In addition to articles aimed at simulation modeling with the inclusion of projects, where the project is not understood in terms of project management and finding the so-called critical path, the most common connection between project management and simulation is the Monte Carlo method and CPM or PERT method. Those methods should help project managers to find out critical activities (usually forming a critical path) that determine the project duration. While CPM uses deterministic activity durations, PERT and simulations use stochastic (probability) durations. PERT follows Beta distribution only (Premachandra, 2001), simulation can use several other probability distributions for the to estimate the duration of individual activities. Another advantage of Monte Carlo simulation is the ability to provide near-realistic estimation results by equating the probability value of each activity as a critical value (Barraza, 2011).

The combination of CPM/PERT and Monte Carlo simulation was widely used for the purpose of risk analysis in many project management studies. Tysiak and Sereseanu (2010) combined CPM and Monte Carlo simulation for the risk analysis in IT project. Karabulut (2017) applied CPM, PERT and Monte Carlo simulation in planning of construction projects. Hendradewa (2019) performed CPM-PERT and Monte-Carlo simulation analysis to assess and manage schedule risk in three main phases of construction project, such as: feasibility study, design, and construction.

In addition to Monte Carlo simulation, a discrete event simulation model can also be used for project management planning. Discrete event simulation (DES) is suitable for dynamic, stochastic systems that change in a discrete manner (Banks, 1998). DES is conventional for economic and business process models, such as production and manufacturing systems (Fousek et al., 2017), call centers and emergency medical services (Mathew & Nambiar, 2013) or queuing and shops functioning (Kuncová & Skálová, 2018). As it was mentioned above, simulation and discrete event simulation models are used in many areas and usually there is no separation if the simulation is aimed at project or a process. When looking for the papers connected with project management and simulation, more than 54 thousand of results were found in Web of Science (WOS) database – but when PERT/CPM added, WOS offers only 37 papers and the SCOPUS database 64 results. When DES added, only 5 WOS papers and 11 Scopus papers remained. For example Sadeghi et al. (2012) used DES for approximating the project completion time and the critical path in a stochastic resource-constrained project network; Liu et al. (2015) integrated model information with a simulation framework; Pinha and Ahluwalia (2019) presented an approach that aims to reduce project time and costs by allowing project managers to assess different scenarios using a software tool based on flexible discrete event simulation; Jie and Wei (2022) proposed an estimation approach that combines an improved Earned value management, CPM, PERT and Monte Carlo simulation. Lee and Arditi (2006) offered a stochastic simulation-based scheduling system comparing the outcome of CPM, PERT, and DES under different conditions such as different variability or skewness in the activity duration data, the configuration of the network, or the distribution of the activity durations.

3. Methodology

There are many types of software aimed at DES. Dias et al. (2016) tried to summarized the most used DES software. The list of 19 DES software tools is in Figure 1. SIMPROCESS is one of them (in 2016 it was in the middle of the compared tools – see Figure 1). Although this software is not a new one and is relatively user-friendly, it is still not one of the most used DES products. The name "SIMPROCESS" appears 24 times in WOS papers, 28 times in SCOPUS papers (most are identical to WOS). Most of these papers are aimed at business process simulation or supply chain management. Only one of the ProQuest 50 papers is connected namely with project management – Kienbaum et al. (2013) proposed a systematic approach for model building and analysis of the product lifecycle processes of complex systems development, products and/or services, making use of Project Management, Business Process Management and Simulation techniques in an integrated and unified way.

DES Tools	WSC	DOCS	REVIEWS	SOCIAL	WWW	Growth	tot. (WSC docs social WWW)	Rank 2016
Arena	10	10	10	10	9	10	9,9	1
ProModel	10	9	9	5	9	5	7,6	2
FlexSim	6	7	7	9	8	6	7,2	3
Simul8	6	7	9	7	6	8	7,23	4
WITNESS	8	8	9	7	8	4	7,2	5
ExtendSim	7	8	8	4	5	5	6,2	6
Simio	6	6	4	5	8	9	6,1	7
Plant Simulation	1	6	7	6	7	8	6,1	8
AnyLogic	8	8	8	2	5	7	5,92	9
SIMPROCESS	9	10	4	1	6	4	5,0	10
AutoMod	9	6	7	1	4	4	4,83	11
Micro Saint	4	5	5	0	10	4	4,8	12
QUEST (Delmia)	3	6	4	3	8	4	4,8	13
Enterprise Dynamics	5	4	7	4	4	6	4,8	14
ProcessModel	4	5	1	4	10	3	4,7	15
SimCAD Pro	3	2	5	3	3	5	3,7	16
GPSS World	7	6	2	0	3	4	3,18	17
SLX + Proof 3D	7	3	3	1	3	3	2,9	18
ShowFlow	3	2	5	0	5	0	2,4	19

Figure 1. Final score of DES tools (Dias et al., 2016)

3.1. SIMPROCESS Description

The simulation software SIMPROCESS was developed by the American firm CACI Products Company (2001). SIMPROCESS is a hierarchical and integrated tool for business process simulation, especially for the Business Process Reengineering and the Information Technology. SIMPROCESS offers 3 instruments for the simulation models: Process Mapping, Discrete Simulation and Activity-Based Costing. Process Mapping is used for visual description of the business processes. Discrete Simulation studies the dynamic behavior of systems through experiments with computer model. The changes in the system are not observed continuously during the discrete simulation, but only when the significant event occurs (start or end of a process, arrival of an entity). The event can occur in any point in continuous time. This type of simulation is useful for modelling various business processes (especially production or inventory ones). Activity-Based Costing is a technique for accumulating cost for a given cost object, i.e. product, customer or process. SIMPROCESS uses various 2D graphic components and animation for a process representation. SIMPROCESS Main components:

- Processes and activities: a process may consist of several interrelated activities that create a new value as output for subsequent processes.
- Resources: objects that are used to model the limited capacities of personnel, materials or production assets that are used in the activities.
- Entities: dynamic objects (customers, products, documents, project) that move through the processes and use various resources.

- Connectors: connect processes and activities and define the direction of movement of the entities.
- Pads: serve for the connectors' line-up to an activity.

3.1. Case Study - Project Description

The purpose of this article is to expand the range of articles focused on the combination of project management and DES using SIMPROCESS software.

Table 1. List of project activities (Košťálová, 2009; own translation)

	Activity	Prev.	Time (days)	Resource
1	project launch and contract signings	-	0.5	Supplier, Customer
2	purchase of materials	1	0.5	Supplier
3	preparation of project documentation	1;2	9	Project Manager
4	initial analysis, preparation of wireframes	1	4	Analyst
5	handover of documents by the customer	1	4	Customer
6	customer's comments on wireframes	4	2	Customer
7	processing of comments	6	2	Analyst
8	written confirmation from the customer	7	0.5	Customer
9	creation of the first graphic design	1	5	Web designer
10	creation of other graphic designs	3;5;8;9	5	Web designer
11	customer's comments on the graphic design	10	2	Customer
12	incorporation of comments	11	2	Web designer
13	confirmation of agreement with graphic designs	12	0.5	Customer
14	creation of the remaining graphic designs	13	10	Web designer
15	customer's comments on the graphic design	14	2	Customer
16	incorporation of comments	15	2	Customer
17	confirmation of agreement with graphic designs	16	0.5	Web designer
18	preparing HTML for flash	12	5	Web develop.
19	convert graphics to flash	14	5	Web designer
20	flash programming	8	25	Flash develop.
21	functionality, quality and completeness testing	17;18;19	3	Project Manager
22	customer's comments on the created part	20;21	1	Customer
23	incorporation of comments	22	2	Flash develop.
24	confirmation of agreement with graphic designs	23	1	Customer
25	trial operation	24	3	Programmer
26	delivery of a list of defects found during the test run	25	1	Customer
27	elimination of defects found during test operation	26	3	Programmer
28	job billing	27	0.5	Supplier
29	handover and acceptance of the work	28	0.5	Supplier, Customer

Project planning, time analysis and simulation model are demonstrated on a real project focused on creating a website for a selected company. The project has 29 activities. List of all activities with their duration (as fixed time), previous activities and resources (people needed for each activity) are in Table 1. The project plan (CPM calculation results) can be made in MS Excel and the Gantt chart can be created based on early start and early finish times of activities (see Figure 2). The length of the project is 49.5 days.

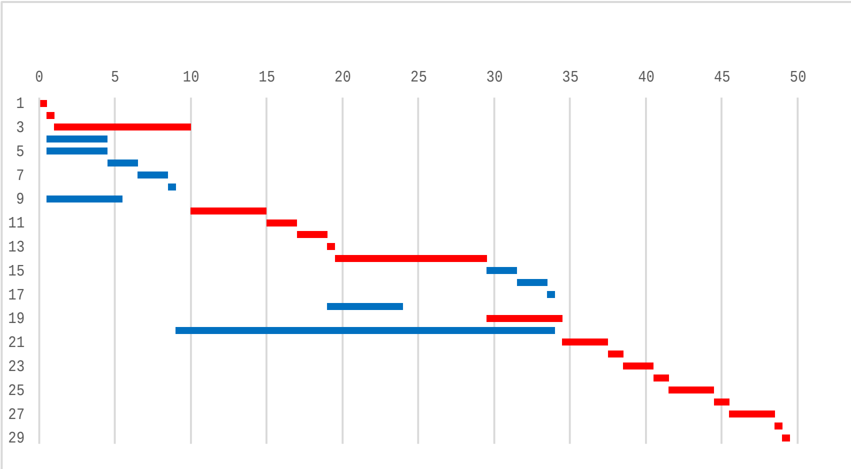

Figure 2. Project Gantt chart in days (Košťálová, 2009)

For the simulation model the times must be stochastic. It is possible to have 3 parameters as in PERT method (optimistic, most expected, pessimistic times) and calculate the results in MS Excel or use Beta distribution and simulate the times and the whole project in SIMPROCESS. The optimistic times were set as 80% of the pre-set times taken now as most expected, and the pessimistic times are equal to 125% of the most expected times. The advantages of the SIMPROCESS usage are also the possibility to incorporate the resources (people) which cannot be analyzed in MS Excel (or Crystal Ball with Monte Carlo simulation).

4. Results

When the project is specified by the list of activities and previous activities, it is possible to create Activity-on-Node (AON) network diagram (see Figure 3) which is useful for the CPM/PERT calculation but it might be also the scheme for the simulation model construction.

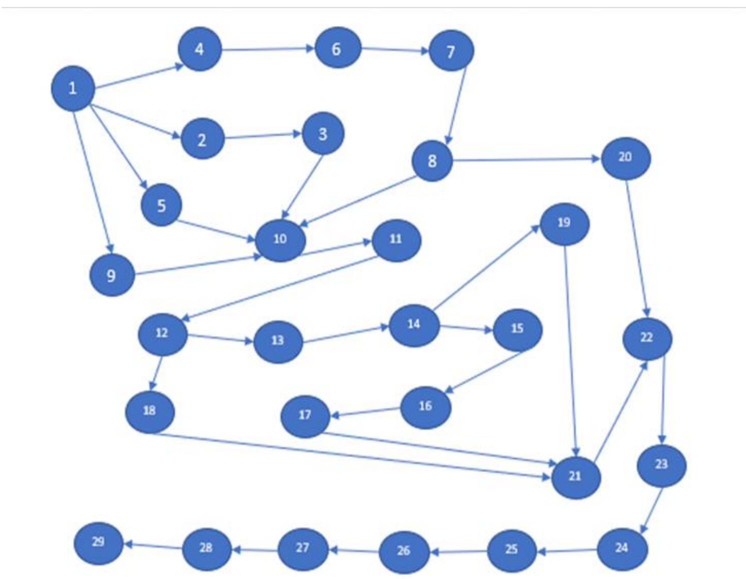

Figure 3. AON diagram (own processing based on Košťálová (2009))

Based on the AON network and 3 times estimations for each activity, which are the parameters of the PertBeta distribution used in SIMPROCESS, the model can be created. The project itself is an entity moving through the model. Since there are several paths and branches in the AON network diagram, it is necessary to define in advance other auxiliary entities as copies of the project, which will pass through parallel paths. A total of 5 entities had to be used (see Figure 4).

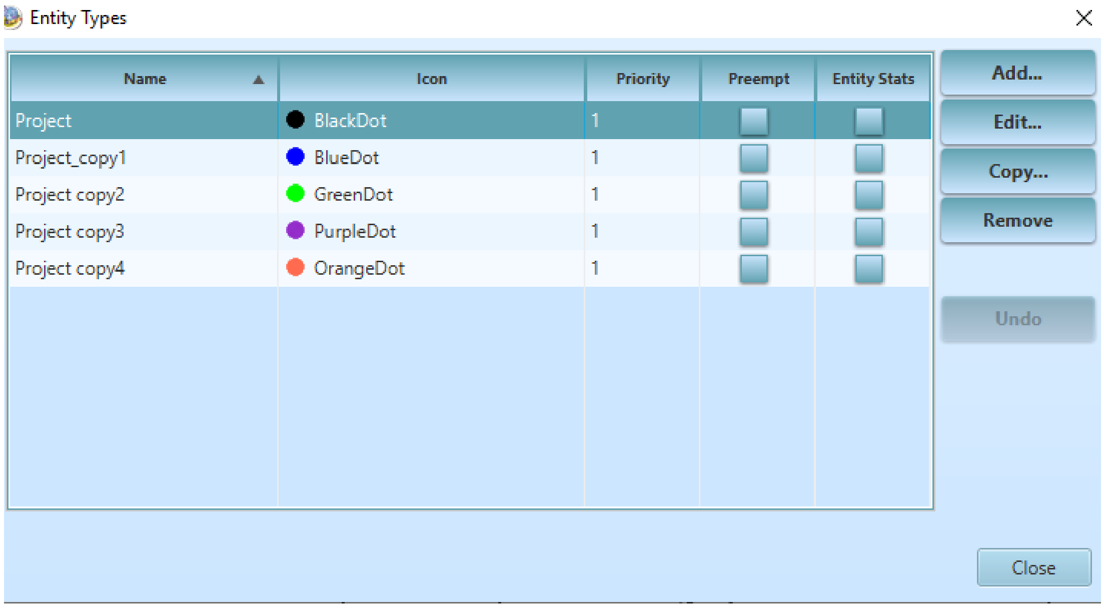

Figure 4. Entity definition in SIMPROCESS

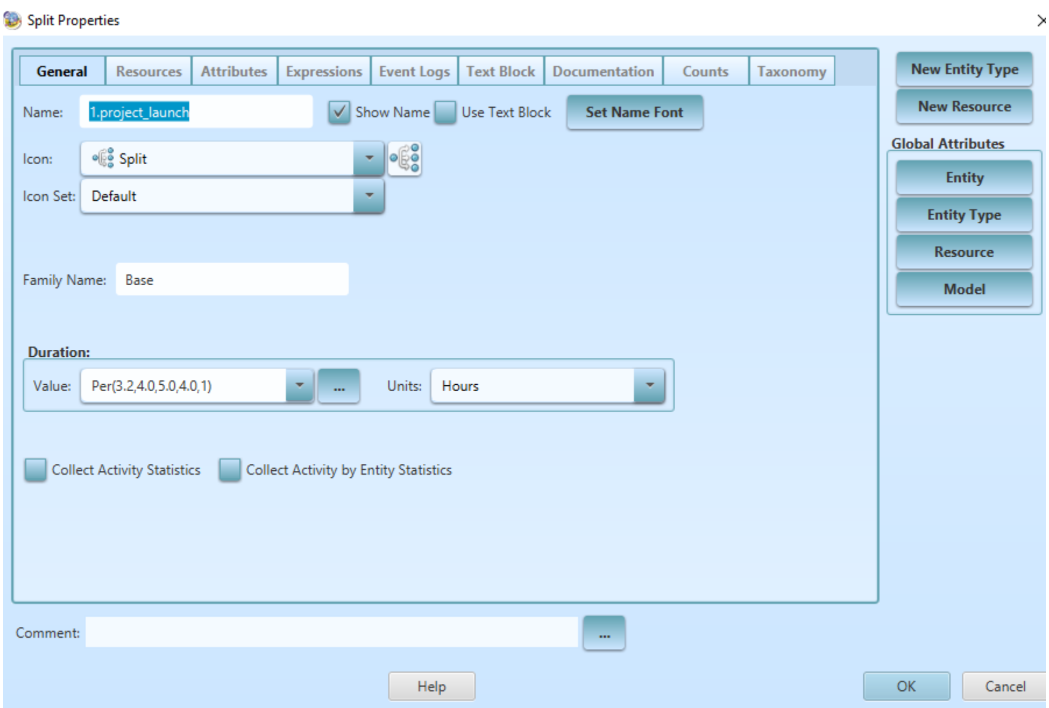

Figure 5. Split properties in SIMPROCESS with PertBeta distribution for activity duration

SIMPROCESS allows to split an entity into multiple clones using the Split activity and later merge everything again using the Join activity and the same Family name (see Figure 5). Finally, all the resources are defined. The whole model is on Figure 6.

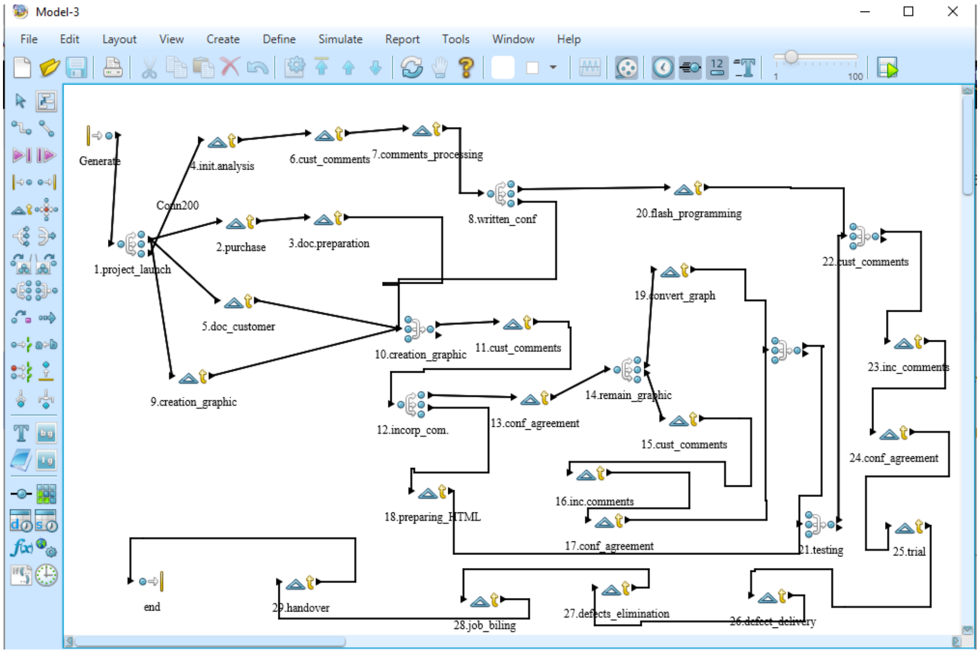

Figure 6. Model of the project in SIMPROCESS

The results of one replication are on Figure 7. They correspond with the results calculated in MS Excel and PERT method where the average time was calculated time as 399 hours, which is nearly 50 working days (when 1 day is equal to 8 working hours). The project time was about 71 days including weekends (see Figure 7, red oval).

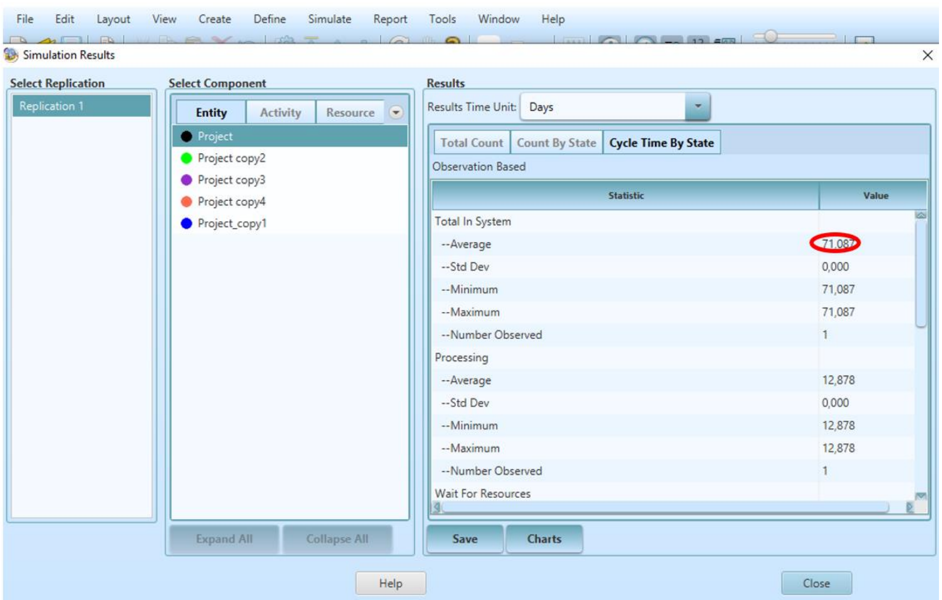

Figure 7. Total project time (red oval), 1 replication

If we include weekends into MS Excel calculations, we have 50 working days + 20 weekend days. Other results showed the workload of individual workers (see Figure 8), the highest utility is about 55% for the flash developer and web designer. SIMPROCESS offers also the Gantt chart visualization – Figure 9 shows first part of the Gantt chart.

Resource : Percent Utilization By State When Available: Replication 1

Resource Names	Idle	Busy	Reserved
Analyst	87,693%	12,307%	0,000%
Customer	65,179%	34,821%	0,000%
Flash developer	44,717%	55,283%	0,000%
Programmer	88,039%	11,961%	0,000%
Proj.Manager	78,144%	21,856%	0,000%
Supplier	95,999%	4,001%	0,000%
Web designer	44,893%	55,107%	0,000%
Web developer	90,225%	9,775%	0,000%

Figure 8. Resource utilization – SIMPROCESS results' list

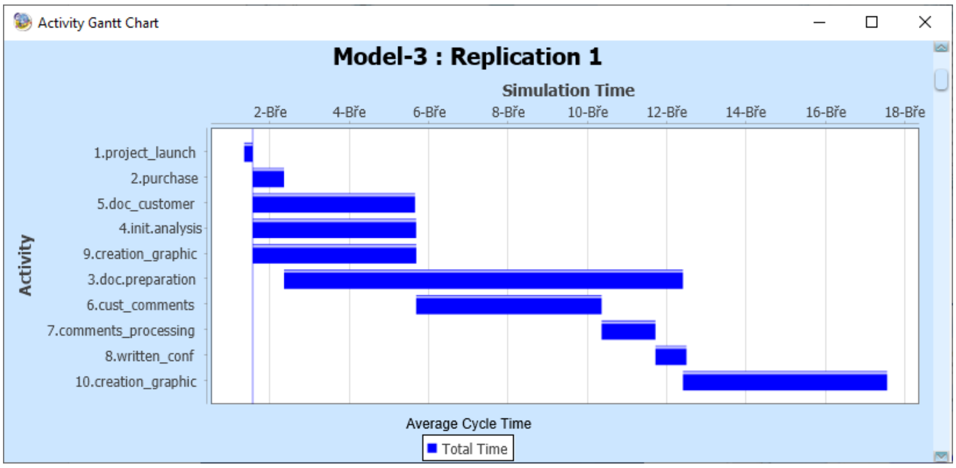

Figure 9. Gant chart taken from SIMPROCESS

Multiple replications can be run to get the average, minimum, and maximum project length – here 100 replications were tested, the results showed that the average project time is around 70 days – 10 weeks, 50 working days, minimum is around 66 days, maximum around 77 days (11 weeks).

4. Discussion

The simulation modeling and project management could be incorporated using a DES simulation software. SIMPROCESS can be one of them. It is easy to operate and it has a tool for the project modeling and Gantt chart specification. The model offers not only the result concerning the project time but also the resources workload and it is possible to incorporate the costs as well. Although the visualization of results is slightly different from the usual in project management software, it is still sufficient for time or cost analysis or project planning. The great advantage of simulations and the use of SIMPROCESS lies primarily in the possibility of setting other probability distributions for generating the durations of individual activities. A suitable extension of the project time analysis is an animation showing the progress of the project supplemented by the display of a specific date and time. Kwak and Ingall (2009) mentioned that simulation is still not a preferred tool in current project management practice due to its statistical nature, which many project managers are reluctant to address. However, knowledge of simulation modeling and the use of probability distributions to generate activity durations can contribute to better project planning or analysis of time, costs and project risks. Based on the above example, we can agree with the Doloi and Jaafari (2002) statement that DES is a valuable tool to improve the projects' base line value, but, as Kienbaum et al. (2013) mentioned, project management and simulation modeling has been designed with different purposes and knowledge bases in mind, without taking into account their complementary nature, and therefore it is still not common to connect them in real projects. This article tries to show that it is possible and useful. For the future research, cost and/or sensitivity and risk analysis could be also mentioned and incorporated into simulation model. An example of other DES software (such as SIMUL8) would be interesting to compare different approaches of the creation of a project simulation model.

The interconnection of DES and project planning has several limitations. First, the project manager must be able to define not only the duration of each activity, but also the probability distribution for the time generation. Second, it is necessary to create the AON network before the simulation model is built. Third, it is necessary to know the environment of the simulation software and how it works. And finally, the Gantt chart (for example in SIMPROCESS) is the result of one simulation experiment, i.e. it can show an optimistic or, conversely, pessimistic scenario only, not more possible scenarios. It can be shared with other members of the project team only in the form of a fixed image. However, the project simulation model can be useful for deeper what if analysis or time/cost/risk analysis.

5. Conclusions

Project management and simulation modeling has been designed with different purposes. Their interconnection can help the researchers or project managers to better plan or analyze projects not only in terms of the time but also in terms of other resources (human, material, financial). The use of Monte Carlo simulation in project management is quite common, but discrete event simulation and the use of corresponding software offers a further extension of project planning capabilities. SIMPROCESS or similarly oriented software can also be used in project management, especially if variable durations of project activities can be expected. This software can help project managers to better allocate human resources within a project and to analyze the variability of project time and costs. These are the biggest benefits of linking DES and project management.

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