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Determining the Duration of R&D Processes through Monte Carlo Simulation

MOGA Monika[1,a], CALEFARIU Gavrilă[1,b], SMARANDACHE Florentin[2,c], SÂRBU Flavius Aurelian[1,d] and BOGDAN Laura[3,e]

[1] Transilvania University, Faculty of Technological Engineering and Industrial Management, Colina Universitatii nr. 1 corp A, Brașov 500036, Romania.

[2] University of New Mexico, 705 Gurley Ave., Gallup, New Mexico 87301, USA.

[3] Babes-Bolyai University, Faculty of Economics and Business Administration, Str. Teodor Mihali, Nr.58-60, Cluj-Napoca 400591, Romania.

[a]moga_monika@yahoo.com, [b]gcalefariu@unitbv.ro, [c] fsmarandache@gmail.com, [d]sflavius@unitbv.ro, [e]by_laura99@yahoo.com

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Abstract. The research and development (R&D) processes influence the economic development of a company, because in an industry that is changing fast, firms must continually revise their projects and range of products. Therefore in order to determine the specific costs of research and development activity we have to highlight the efforts and effects of these activities and to calculate some indicators of economic efficiency. In the cost calculation process in R & D we have emphasized the identification of the components of cost and the duration of the R & D processes, as a component of the R&D cost, that is why as a new method we used Monte Carlo simulation. The novelty of the paper is that it focuses on determining components of cost and the duration of the R & D processes in its cost calculation procedure. The originality of this work is the use of Monte Carlo simulation to determine the average length of producing a new product.

Introduction

After [1] the R & D function of a firm can be defined as a whole of activities of the industrial organization by which it is conceived and implemented its technical and scientific progress, considering the minimization of deviations between targets and results on the market. Determining the specific costs of R&D activity consist of highlighting the efforts and effects of these activities and the calculating some indicators of economic efficiency. Discrete event simulation is used to simulate situations in which there are identified different events that change the status of the studied system. Events are discrete because it is believed that between two events, the system state does not change. Monte Carlo method is an important component of discrete event simulation to generate random intervals between two successive events, duration of service, etc. [2]. Time points of the events are random. Due to the dynamic nature of the discrete event simulation models, the simulation time is necessary to know the value of the simulated time and it is also a need for a simulated progress of time from one value to another. The purpose and applicability of the simulation is not limited only to assist managerial decision-making processes. Simulation has important uses in: computer aided design, virtual reality systems, for computer game industry, training of professionals (pilots, surgeons) or military applications [3]. Among the objectives of the

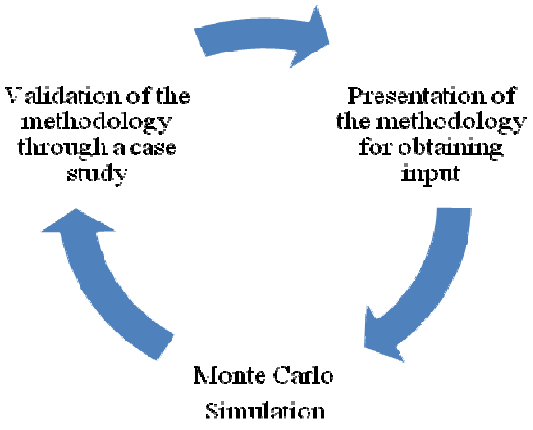

Fig. 1. Stages of the research

paper we list the better sizing of the research team and needs, presentation of the methodology for obtaining the input data, which will be introduced in the Monte-Carlo model, and also validating the methodology through a study case.

Research Stages

Our research referring to the determination of the cost components and duration of a research consists of the stages presented in Fig. 1.

Presentation of the Methodology for Obtaining Input Data. Because of the importance of creativity in the process of R&D appeared the issue of its stimulation. The number practical methods existing in the world today, used to stimulate creativity is of the hundreds. The general classification divides two important methods of stimulating creativity: intuitive methods and analytical methods. Intuitive methods are called so because it is based on the use of intuitive thinking, particular focus on the imagination, freed from the constraints of reality.

The main intuitive methods are: *Brainstorming* can be defined as a way to get in a short time, a large number of ideas from a group of people. *Sinectica* is the rival of brainstorming. *Thinking Hats method*, is based on the interpretation of roles depending on the color of the chosen hat. *Delphi method,* the goal is to obtain guidance, forecasts and solutions to complex problems using a group of experts. *Mind-mapping method* involves building a graphical diagram suggesting how ideas arise from each other [4]. Analytical methods are based on the predominant use of logical thinking in order to stimulate the process of combining the real plan using information directly related to the problem. The main analytical methods are: *Osborn's interrogative method* is a list of 60 questions grouped into 9 categories. *Attribute listing technique*: to get new ideas, identify and list as many of the attributes of a problem, then work, in turn, to each of them. *Morphological analysis*, its principle is to describe analytically and systematically, all solutions of the problem, than choose the best. *Multiple criteria analysis* has 5 stages: establish criteria, determination of the weight of each criterion, identifying all variants, granting a grade N, calculate the product of the N notes and the weighting coefficients. *The "ETECTRE" method*, aims to examine a number (m) of possible options in terms of (n) selection criteria through a simple procedure for estimating the "effect". *PINDAR technique*, is a successful combination of morphological analysis with the criteria analysis

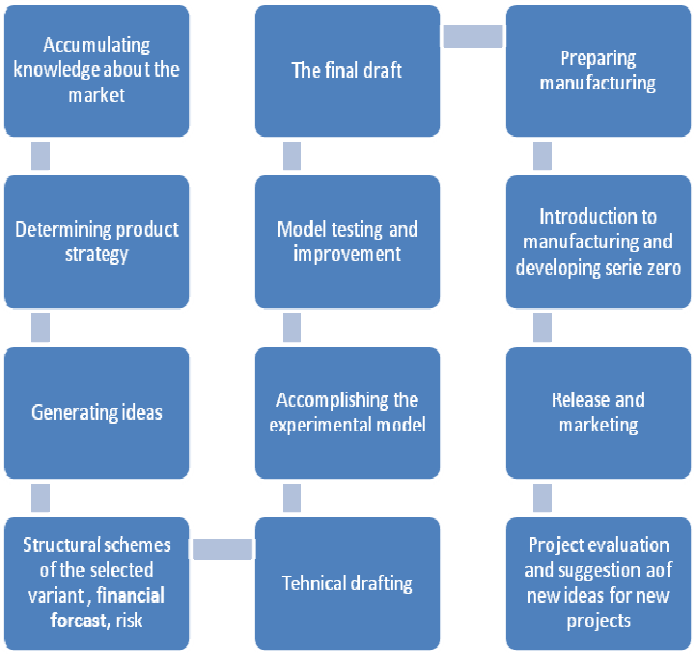

Fig. 2. Stages of product developing

The stages of product development are presented in Fig. 2 after [5].

Cost calculation is made for the first 8 stages of development, including the final draft. Sometimes, for complex projects, after the first eight stages, there is still a prototype development phase. For the input stage in current manufacture, cost issues will be treated in a forthcoming paper. Direct costs are in direct contact with the innovation and development of a new product. Indirect costs are general operating cost of the R & D department. Their highlighting separate from the direct makes sense, especially if the department runs several projects simultaneously.

Table 1. The direct cost of the R&D process

Cost of determining the parameters of innovation	$C_{PI} = E_{MR}+P_P+E_{KH}+E_S$ [unit/project],(1)	E_{MR} is the expenditure with market research; E_P is the expenditure with patents; $E_{KH\ is}$ the expenditure with the Know –how; E_s is the expenditure with the specialized software.
Cost of materials	$C_m = \sum_{k=1}^{N} n_{ck} \times p_{mk}$ [unit/project],(2)	N is the number of components and subassemblies; n_{ck} is the norm of the material consumption for reference k; P_{mk} is the unit price of the material or of the subassemblies.
Cost of technological acquisition – C_{TA}	$C_{TA} = C_E+C_{TE}+C_{DCT}$ [unit/project],(3)	C_{UT} is the expenditure with equipment; C_{TE} is the expenditure with technological equipment; C_{CDT} is the expenditure with the special dispositive checker tools.
Cost of utilities	$C_U = C_E+C_{TF}+C_{IW}$ [unit/project],(4)	C_E is the expenditure with electricity; C_{TF} is the expenditure with technological fuel; C_{IW} is the expenditure with industrial water used in the manufacture, testing and improvement of the experimental model.
Total costs of directly productive staff	$C_{emp/year} = N_s (S_{d/month}+I_{S/month})T$ [unit/project],(5)	Direct productive staff means who is involved in the 8 stages of development. N_S is the average number of employees involved in the 8 stages; S_d is the average gross hourly salary; I_S is the average monthly charges; T is the total project time in months. This duration is determined by the Monte Carlo method.
Total direct costs		Summing the above elements.

Table 2. The indirect cost of the R&D process

Expenses for maintenance and repair		$C_{MR/year}$ [unit/project]
Material expenses DCT normal and special		$C_{DCT/year}$ [unit/project]
Energy expenditure, other than that used in the process, including lighting departments, offices etc.	$C_{EE2/year} = (N_{TSP} - N_{TMS}) \cdot p_{UE} T$ [unit/project], (6)	N_{TPS} [kW] is the total power used by the entire system of production; N_{TMS} [kW] is the total power used by the manufacturing system; T is the effective time of functioning in one, two or three shifts; p_{UE} [mu / kWh] is the unit price of electricity.
Fuel costs for heating and for preparing domestic hot water	$C_{GM2/year} = (N_{GMH}+ N_{GMW}) \cdot p_{UG} T$ [unit/project], (7)	N_{GMH} [m^3] is the volume of gas used for heating purposes; N_{GMW} [m^3] is the volume of gas consumed for hot water; p_{UG} [unit/m^3] is the unit price of natural gas.
Annual expenses for amortization of fixed assets	$C_{A/year} = \sum_{i=1}^{q} \frac{C_{MF\ i}}{T_{A\ i}}$ [unit/project], (8)	q is the number of fixed assets of the company; C_{MFi} is the expense recorded with the i [unit] asset purchase including transportation charges, installation, commissioning, and so on; T_{Ai} is the normal duration of operation of the i[years] asset, based on that given in the catalog of normal duration of fixed assets.
Expenses with the indirectly productive employees	C_{elP} [unit/project]	Calculated similarly as those with the direct productive personnel, taking into consideration the number of people, average salary, and duration.
Total annual indirect costs		Summing the above elements.

Monte Carlo Simulation. The relative probability and the cumulative probability was calculated according. Than in a two axes coordinate system we presented the durations and the cumulative probabilities. On each interval associated with a duration a vertical bar was built having an equal height to the corresponding cumulative probability of that duration. Next it was generated a set of N random numbers uniformly distributed in the interval [0, 1] using a random number generator. Then these numbers were represented by a point on the horizontal axis, from that point a parallel was led to the vertical axis until it meets the vertical front and the length of the base bar was read. Finally, the average of duration was calculated, its standard deviation, and the confidence interval of the mean.

The Validation of the Methodology through a Case Study. This paper serves on determining the financial projections from step 4 (Fig. 2). It should be also noted that the Monte Carlo method can be used for determining total duration of the development process based on accumulated experiments from firms and other developments that they made.

Table 3. The duration of the operations and the number of experiments

The duration of the operation (xi) months	The number of the experiments(ni)
3.5	1
4	3
4.5	3
5	4
6.5	5
7	2

Table 4. The relative and the cumulated probability

Relative Prob.	Cumulated Prob.
0.06	0.06
0.17	0.22
0.17	0.39
0.22	0.61
0.28	0.89
0.11	1.00

Next it was determined for a company with Monte Carlo simulation the total duration of the development process based on accumulated experiments from the company of middle size from the domain of rubber roller construction with relative low complexity products with a medium size, owning 30% of the local market with the intention of increasing its market share. It should be noted that these values are for incremental innovation. For determining the time required there were carried 18 experiments with the results presented in Table 3.

Because the determination of the average duration with a good accuracy requires a large number of experiments, which are time, energy, materials and not least human resource consuming, we use the Monte Carlo method that can generate simulated observations.

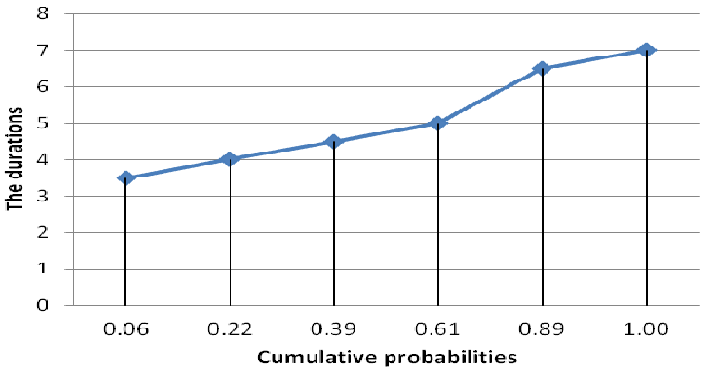

Fig. 3. Representation of the durations and the cumulative probabilities

1. The relative and the cumulative probability was calculated:
2. In a two axes coordinate system we presented vertically the durations and horizontally the cumulative probabilities. On each interval associated with a duration a vertical bar was built having the height of the corresponding cumulative probability of that duration.
3. After that it was generated a set of 50 N random numbers distributed in the interval [0, 1] using a random number generator.
4. Each generated number was represented by a point on the horizontal axis, from that point a parallel was led to the vertical axis until it meets the vertical front and the length of the base bar was read. This resulted a series of N simulated durations as in [6,7].
5. Finally, it was calculated the average of duration m = 5.13 months and its standard deviation = 5.09 and the confidence interval of the mean, which is about 5.2 months.

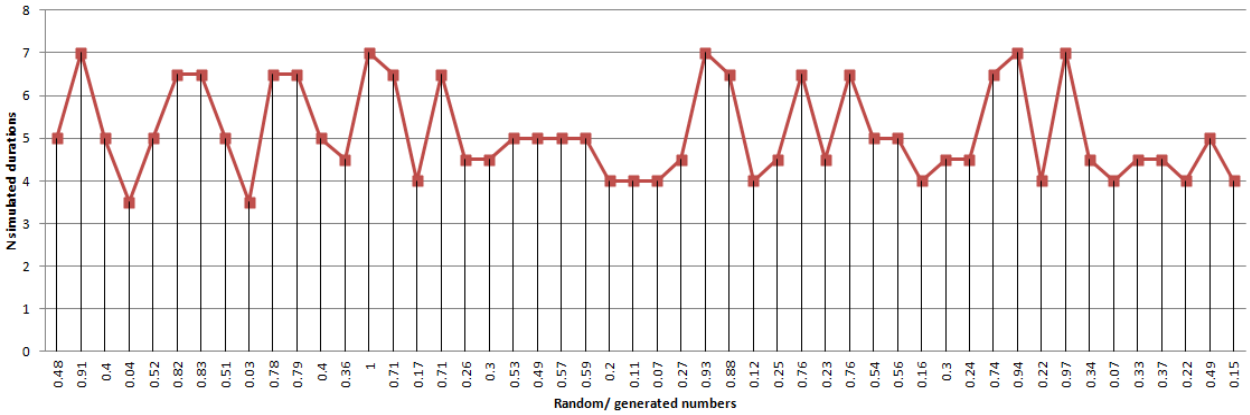

Fig. 4. Representation of the random numbers and N simulated durations

Research Method

In the process of the cost calculation in R & D, the presented study was focused on determining components of cost and the duration of the R & D processes, as an important component of the R&D cost. A new method Monte Carlo simulation was used. Determination of average duration with good accuracy requires a large number of experiments that consumes much time, energy, materials and human resources. Therefore the Monte Carlo method was used for generate simulated observations with the help of cumulative distribution of the duration of realizing a new product and a generator of random numbers uniformly distributed in [0, 1].

Conclusions

The major novelty of the work is that it emphasizes the components of cost and also the duration of R&D processes. The calculation of costs was realized through Monte Carlo simulation. This method can be defined as a random variable modeling method for the calculation of the characteristics of their distributions. Thus by using the Monte Carlo simulation it could be forecast the research cost and the duration of achievement. The validation of the methodology was realized through a case study. In a future work it is possible to discuss a comparative study, applying full method. Then, for different industries or for groups of companies producing similar goods, it is possible to obtain forecast of R&D costs and time. Furthermore, by using the fuzzy matrices it is possible to determine the optimum parameters in R&D.

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References

[1] R.D. Marinescu, M. Iliescu, I. Grecu, The economic analyze in the industrial organizations from the domain of classic and nonconventional technological systems (in Romanian), BREN Publishing House, Bucureşti, 2003.

[2] D.P. Landau, K. Binder, A guide to Monte Carlo simulations in statistical physics, Cambridge University Press, Cambridge, New-York, 2000.

[3] C. Doydum, N. D. Perreira, Use of Monte Carlo Simulation to Select Dimensions, Tolerances, and Precision for Automated Assembly. Journal of Manufacturing Systems. 10 (1991) 209-222.

[4] G. Paicu, Creativity (in Romanian). PIM Publishing House, Iaşi, 2011.

[5] L. Gorchels, Product manager's guide, III. edition (in Romanian), Rosetti Educational Publishing House, Bucuresti, 2006.

[6] H. Barreto, F. Howland**,** Introductory Econometrics: Using Monte Carlo Simulation with Microsoft Excel, Cambridge University Press, Cambridge, New-York, 2005.

[7] S. E. Perez, G. Zachrich, M. Cockburn, Monte Carlo Simulation for Determination of the Stream Function. Computer Applications in Engineering Education. 8 (2000) 38-42.

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DOI References

[3] C. Doydum, N. D. Perreira, Use of Monte Carlo Simulation to Select Dimensions, Tolerances, and Precision for Automated Assembly. Journal of Manufacturing Systems. 10 (1991) 209-222.
10.1016/0278-6125(91)90034-Y
[6] H. Barreto, F. Howland, Introductory Econometrics: Using Monte Carlo Simulation with Microsoft Excel, Cambridge University Press, Cambridge, New-York, (2005).
10.1017/CBO9780511809231
[7] S. E. Perez, G. Zachrich, M. Cockburn, Monte Carlo Simulation for Determination of the Stream Function. Computer Applications in Engineering Education. 8 (2000) 38-42.
10.1002/(SICI)1099-0542(2000)8:1<38::AID-CAE5>3.0.CO;2-0