Development of the Mechanism of Risk-Adjusted Scheduling and Cost Budgeting of R&D Projects in Telecommunications

Sergei Grishunin[1,2](✉), Svetlana Suloeva[1](✉), and Tatiana Nekrasova[1]

[1] St. Petersburg State Polytechnical University, St. Petersburg, Russia
sergei.v.grishunin@gmail.com, emm@spbstu.ru, dean@fem.spbstu.ru
[2] Risk Advisory, Deloitte and Touche, Moscow, Russia

Abstract. We developed the mechanism of risk-adjusted scheduling and cost budgeting of research and development (R&D) projects in telecommunication. The relevance of this topic is explained by growing complexity and uncertainty of innovation activity; high importance of cost and time as key metrics of R&D projects' performance. The paper addresses decreasing efficiency of existing mechanisms which poorly incorporate risks and fills the gaps in the research in this area. Results included development of the concept of the mechanism, its block diagram, the specification of its comprising tools, the step-by-step description of its phases. Unlike the "conventional" peers, the developed mechanism allows timely identification of uncertainties; facilitates robust and transparent evaluation of risks; focuses management efforts on key threats; and ensures remediation of risks earlier in the process thus improving speed and quality of decision making. These advantages let us conclude that the suggested mechanism should have a significant practical use.

Keywords: Telecommunications · Investment controlling · Risk controlling
Project management · Project cost and schedule management
Risk-adjusted budgeting

1 Introduction

Telecommunication sector continues to stay a critical force for growth and innovation across multiple industries. On the other hand, it experiences the growing instability and uncertainties coupled with increasing cost and shortening time of innovations. The complexity of risks is increasing; the speed of their onset is growing while their impact on research and development (R&D) projects becomes more severe [1, 3].

In such conditions, executives of telecommunication companies (telcos) responsible for innovations demand the enhancements to R&D cost and schedule management systems. "Conventional" systems [5, 8, 12] fail to keep R&D costs and time within the limits of business plans with the acceptable precision. The solution is the development

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and implementation of risk-adjusted project cost and schedule management systems. They are based on principles, methods and tools of investment controlling and risk controlling [2, 22] and ensure that critical project risks are timely identified and assessed while efficient risk mitigation decisions are made.

In the paper, we develop one of the critical modules of risk controlling-based complex cost and time management system - the mechanism of risk-adjusted scheduling and cost budgeting. The relevance of this topic is explained by: (1) high importance of cost and time as the key metrics of innovation process efficiency; (2) significant difficulties in prediction of project expenditures and time; and (3) growing role of budgeting module as a feedforward project control. In turn, cited in the literature attempts to integrate risk management into these mechanisms [10, 13, 15, 17, 18] are incomplete, discrete and do not provide the systemic view on risk management.

The novelty of the paper is driven by the advantages of developed mechanism over its "conventional" peers. It allows (1) timely identification of uncertainties (2) facilitating more robust and transparent evaluation of risks; (3) focusing management time and efforts on key risks and cost drivers; and (4) performing remediation of risks earlier in the process thus improving speed and quality of scheduling and budgeting.

In the Sects. 1 and 2 the paper presents the outlook for the global telecommunication industry and the literature review of risk-adjusted scheduling and cost budgeting. Section 3 explains the role of risk controlling in R&D project management and provides the reference model of complex R&D expenditures and time management system based on principles of investment controlling. In the Sects. 4 and 5 we develop the mechanism of risk-adjusted scheduling and cost budgeting of R&D project for telcos and formulate the conclusions. Theoretical and methodological basis was the research of Russian and foreign academics and business practitioners in R&D cost management.

2 Telecommunication Industry Outlook

The rapid development of technologies erases the boundaries between communication and information technologies. Nowadays, these two industries are merging into a single info-communication industry (ICT) [1]. In 2018–2023 telecommunication companies (telcos) will continue experiencing the headwinds and fierce competition from the disruptive technologies such as over the top content providers or artificial intelligence. Penetration of smartphones among adults will surpass 90% by 2023 from 85% currently. This growth will be fueled by the introduction of an array of innovations that are largely invisible for users but whose combined impact will be tangible in form of improved functionality and performance (the hardware and software), better entertainment ability (augmented and virtual reality) and deeper usage in a business context. The progress of smartphones will be also driven by penetration of 5G networks offering greater capacity and connectivity speed. Another new opportunities for telcos will come from (1) artificial neural networks, (2) machine learning and the associated hardware; (3) digital media; (4) in-flight connectivity; (5) biometrics; and (5) internet of things. To survive, telcos will continue to expand into these areas from traditional voice telephony and SMS business [7].

The industry outlook in 2018–2023 depends on geographies. In Europe, the Middle East and Africa (EMEA) telcos will sustain low revenue growth of around 1% annually; Central and Eastern Europe telcos is likely to post around 3% in this period on the back of decent macroeconomic growth. Russia's telcos revenue and EBITDA growth will turn positive; this growth will be in line with the growth of country's GDP of around 1.5%–2% annually. These companies, however, remain subject of geopolitical risks. In Asia-Pacific, year-on-year revenue growth is expected around 2%; the positive impact from GDP growth (of around 3%–4% annually) will be compensated by growing competition. Lastly, in the USA in this period, the revenue will stay flat while profit and cash flow may decline by single percentage digit due to price wars among players [6].

The challenges outlined above require telcos to sustain high level of capital expenditures (we project investments to remain between 15%–20% of revenue in the next 5 years) [3]. The second important target for investments after the core network infrastructure in ICT is the research and development (R&D) of new products and services. In the next chapter we will explain why budgeting of R&D cost has recently become a critical issue for innovation projects without exception of those from ICT industry.

3 Risk-Adjusted Cost and Schedule Management: A Literature Review

The development of efficient mechanisms of R&D cost and schedule management has been in focus of research both domestically and globally [5, 8]. This is underpinned by (1) growing complexity of innovation activity and increasing volatility of project environment; (2) short time-to-the market resulting to "faster-better-cheaper" philosophy; (3) the high costs of R&D projects coupled with low probability of R&D projects' success[1]. The latter is explained by various risks caused by (1) new technologies failures; (2) design errors; (3) non-adoption of products by customers; (4) vendors failures; (5) macroeconomic uncertainties and external shocks; (6) regulatory restrictions; (7) human resource issues; (8) actions of competitors; (9) operational issues; (10) coordination failures [1, 3].

However, in such business environment, "conventional" complex R&D cost and schedule management systems [2, 5, 8, 12, 14] fail to keep project costs/time within the forecasts/schedules with the suitable precision. These systems usually reported variances of actual project expenditures/time vs budgets/schedules of around 15%–40%. This magnitude of variances is above the acceptable levels nowadays [14].

The low efficiency of "conventional" systems is underpinned by that the scheduling and cost budgeting mechanisms in such systems do not serve as true feedforward controls. Their expenditures budgets and projections of duration are largely based on

1 Research performed by Dos Santos [9] revealed that in the United States 80% of R&D projects failed before completion while among the survivors 49% exceeded expected costs; almost 63% of these projects ran late.

historical single-point estimates, standards and metrics. Their sensitivity analysis and stress testing approaches focused on single variance; their assumptions and cost standards are often based on poorly verifiable statistics/expert views as almost every R&D project is unique. Additionally, the feedback and concurrent controls in these systems often provide the late reaction due to rapid onset of the risks. Research shows: the efficiency of complex R&D cost and schedule management systems can be significantly improved if these systems integrate full-cycle risk management processes.

However, literature review shows that existing attempts of integration risk management into cost and schedule management systems are incomplete, discrete and isolated. They do not provide the systemic view on risk management. Researches are concentrated on developing of separate tools and techniques, for example: (1) analysis of internal and external environment and identification of risks [8]; (2) risk assessment techniques with various tools including project risk failure mode and effect analysis (RFMEA) [13, 15] or (3) risk-adjusted cost scheduling and budgeting [10, 17, 18].

We recommend building a complex approach which unites the above-mentioned tools and methods into the integrated risk-adjusted scheduling and cost budgeting mechanism. Such mechanism can be built on the principles and with the methodologies and tools of risk controlling [22].

4 Investment Controlling in Innovation Project Management

Investment controlling (IC) is an application of methods of controlling [2] to project management, a combination of processes, methods, skills and tools which ensuring the achievement of projects' goals in an uncertain and rapidly changing business environment [19]. In telcos, it is applied mainly for projects related to R&D of new technologies, products or services. Our own research and analysis of others' research has demonstrated that implementation of investment controlling, despite the cost of its implementation, allows to decrease the deviation of actual time spent and costs versus initial plans by around 50% [2, 19] and to range of 7%–20%. It helps to achieve earlier innovation project payback as well as gain competitive advantage to the firm.

Consequently, the risk controlling (RC) is an inherent part of all organizational processes of IC. It is a goals-oriented set of methods, processes and tools for organization of risk management in all processes of IC including planning, analysis, control and accounting, organization and regulation. RC solves the problems of development of architecture (infrastructure and processes) of risk management of complex innovation projects. Applying this architecture to particular risks, telcos' managers, as part of self-controlling process, perform risk-adjusted management of innovation project [22]. The functions of risk controlling are listed in Table 1.

Based on these principles, we developed a reference model of complex R&D expenditures and time management system (Fig. 1). Its advantages over "conventional" systems, such as presented in [5, 8, 11, 12], are (1) integration of risk management in all expenditure and time decision making; (2) ensuring integration and coordination of all stages of project cost/time management; (3) application of enhanced planning, control, reporting and decision-making tools with lower tolerance levels than their "conventional" peers. In the next chapter we will build the mechanism of risk-adjusted scheduling and cost budgeting which is the inherent part of this system.

Table 1. Functions of risk controlling in investment controlling system

Functions	Description of functions
Analysis	•Defines characteristics of external and internal environment which expose R&D projects to risks •Identifies and prioritized risks by elements of R&D process •Implements tools and methods of risks analysis •Identify non-compliances of telco's innovation policy with threats
Planning and budgeting	•Develops risk-adjusted planning and budgeting tools •Supplements system of key performance indicators of R&D activity with elements of risk limits and early warning signals
Product development and research	•Consults on management of exposures arising in any R&D project •Helps to integrate risk management practices into R&D process •Recommends remediation measures to reduce risks to acceptable level
Reproduction of project assets	•Develops tools of analysis of specific risks peculiar to R&D tasks •Supplements R&D portfolio management with risk management tools
Control	•Develops models of risk assessment and their impact on project goals •Projects and implement of early warning systems of risk prevention
	•Suggests "barriers" to stop risks from spreading •Consults about and develops control procedures
Monitoring and reporting	•Modifies and consults on creation of risk reporting system
Regulation	•Consults on issues related to decision making on risk management •Suggests options/consultations to manage risks

5 Developing of the Mechanism of Risk-Adjusted Scheduling and Cost Budgeting of R&D Project

5.1 Mechanism's Block Diagram

The developed block diagram of the mechanism is presented at Fig. 2.

It applies: (1) bowtie diagram for risk identification; (2) PERT technique for scheduling; (3) RFMEA method for risk analysis; (4) @Risk software for risk assessment and Monte-Carlo simulation; and (5) Hurwicz criteria for selection of optimal alternative [13, 16, 21, 23]. The prerequisite for applying the mechanism is the developed infrastructure of risk management in the project company. It specifies the roles, the responsibilities, risk communication and risk reporting structure [23].

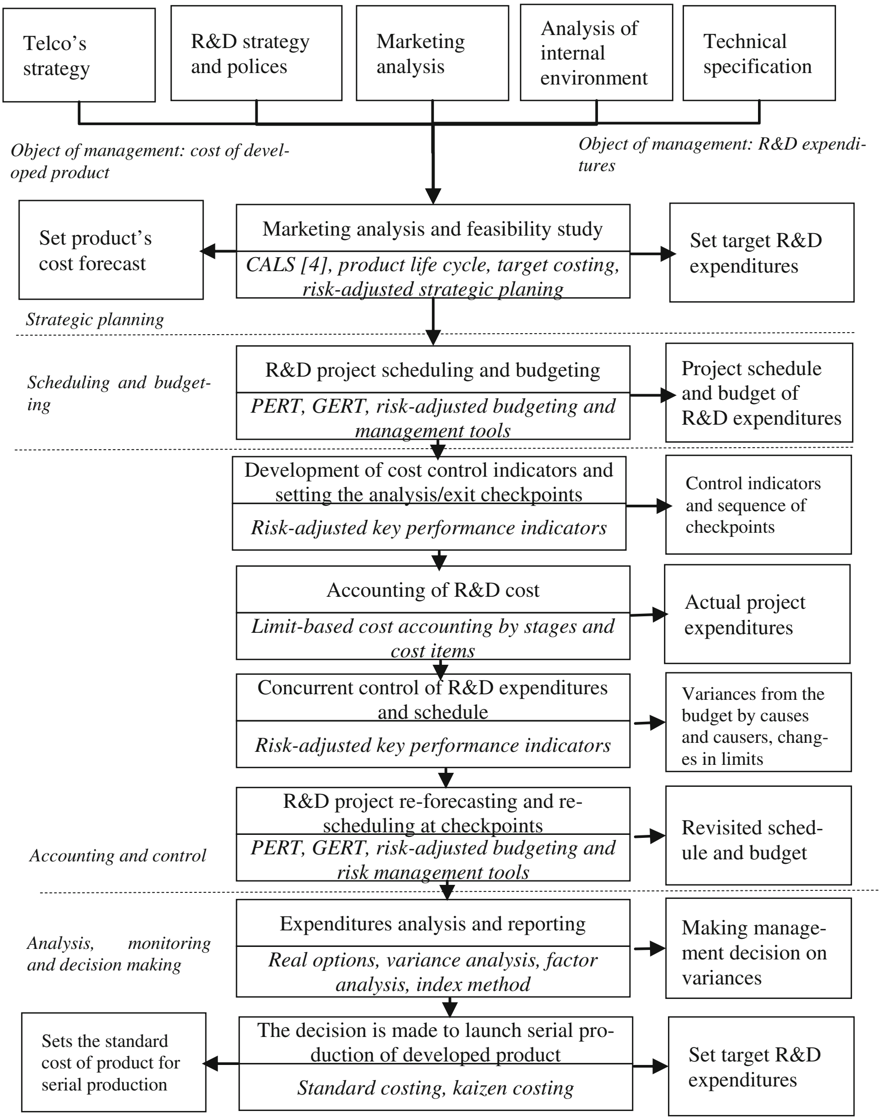

Fig. 1. Reference model of complex R&D expenditures and time management system

5.2 Phase 1: Generate Inputs of the Mechanism

For each option of fulfilling the R&D project (the option) the following key inputs should be formulated at the phase of strategic planning. (Table 2).

At this stage, the project budgeting and scheduling team (comprised from representatives of key diverse functions involved in the project) should be created and trained.

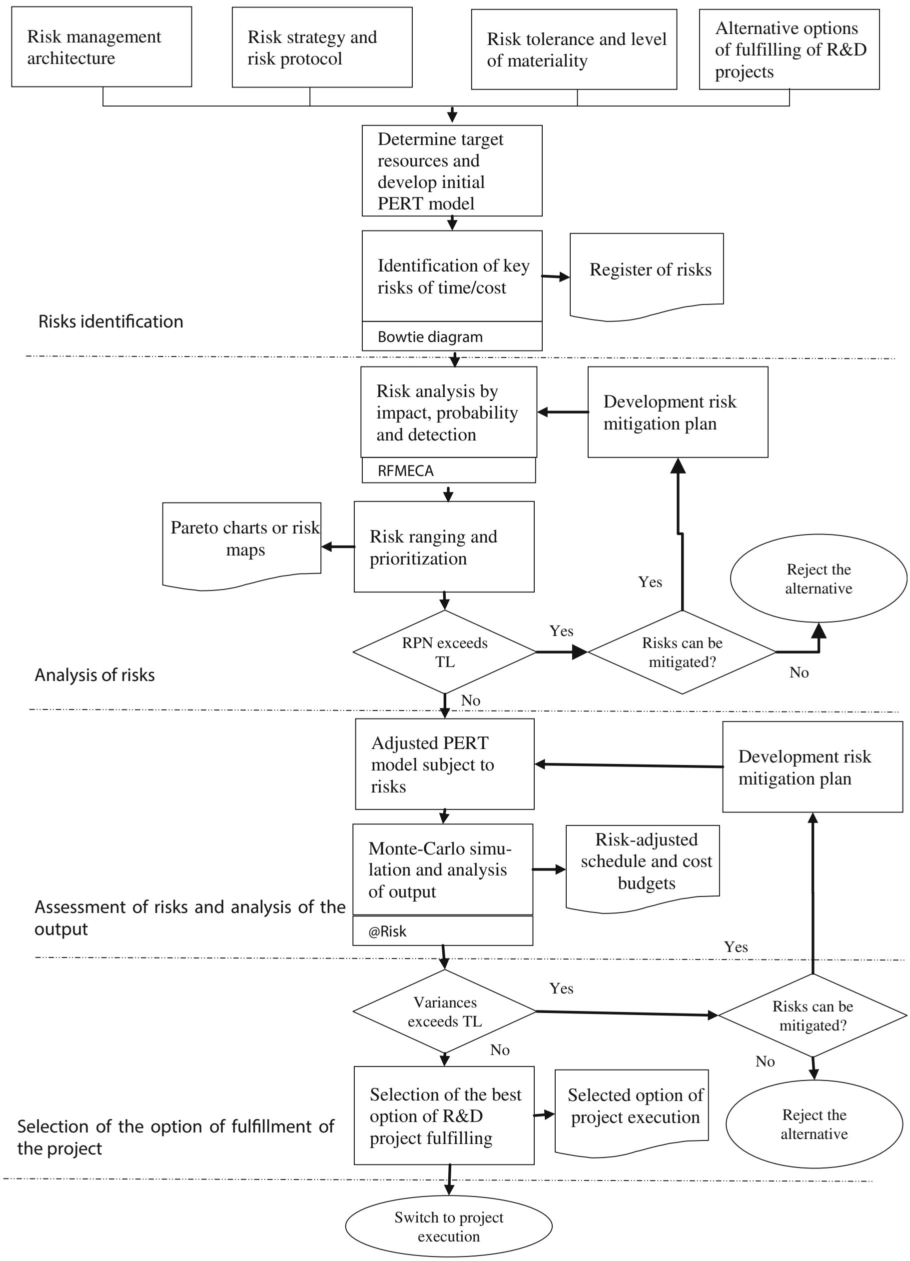

Fig. 2. The block diagram of risk-adjusted scheduling and budgeting mechanism of R&D project

Table 2. Key inputs to risk-adjusted scheduling and budgeting mechanism

Input name	Input definition	Notations/examples
Ultimate goals	Goals that defines total duration and total cost of the project	T – total duration C – total cost
Variances from ultimate goals	Duration (dT) and cost (dC) variances of actual duration (T_a) and costs (C_a) from the ultimate goals	$dV = T - T_a$ $dC = C - C_a$
Intermediate goals	Goals that are defined by splitting the ultimate goals by project stages and/or types of resources	T_i – duration of i-th stage; C_i – cost of i-th stage; c_{ij} – cost of j-th resource at i-th stage; q_{ij}, p_{ij} – consumption/price of j-th resource at i-th stage
Risk tolerance levels	The degree of variability in ultimate goals that project stakeholders willing to withstand	VT – tolerance level for duration VC – tolerance level for total cost
Risk appetite levels	The maximum level of variability in ultimate goals which is acceptable	RT – risk appetite for duration RC – risk appetite for cost
Risk materiality levels	The degree of variability in ultimate goals that project stakeholders consider as immaterial	MT – materiality level for duration MC – materiality level for total cost

5.3 Phase 2: Identification of Risks of Each Option

At the first step, the project team with application PERT techniques [24] and using inputs from phase one (1) identifies and calculates the critical path, critical jobs and time reserves of jobs; (2) models the relationship between the critical path and duration of jobs; (3) identifies the weak links and bottleneck as key risk areas; (4) models the total cost of the project depending on duration, quantity and prices of resources. The team can also perform the optimization of the network project to minimize the project cost at the minimal possible duration of the project [24]. Then, the team identifies key risks affecting the interim and ultimate goals with the application of bowtie diagram (Fig. 3) [23]. It provides structural analysis of risks and the visualization of the relationship between the risk, its causes, consequences; and helping to identify spots for the risk barriers, controls and contingency measures. Identified risks with attributes are recorded in the risk register.

5.4 Phase 3: Analysis of Risks with RFMEA

Each risk is analyzed by three dimensions: its impact on ultimate goals (I); the likelihood of risk event (P); and detection value (S), the ability to spot risk event before it occurs. The ratings are measured by the scale from 1 to 10 and are bundled into the risk priority number (RPN) which is the multiplication of the likelihood, impact, and detection values. The team shall use developed bowtie diagrams for the analysis. Tables 3 and 4 provide guidelines for the rating scores [13, 16].

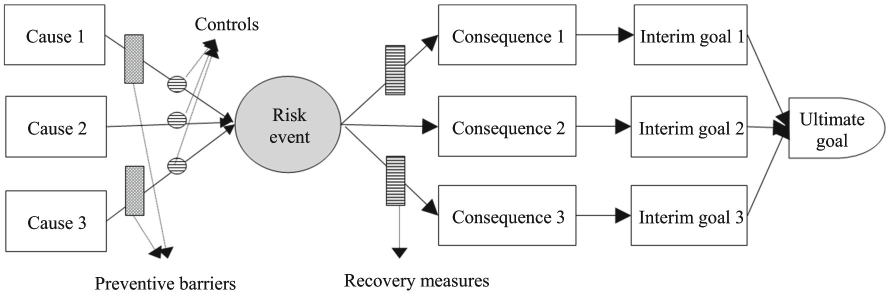

Fig. 3. Example of bowtie diagram

Table 3. Impact rating value guidelines

Impact value scale	Schedule (I_d)	Cost (I_c)
1. Insignificant 2. Very minor 3. Minor 4. Very low 5. Low 6. Moderate 7. High 8. Very high 9. Extremely high 10. Dangerously high	$if\ dT < 0\ then\ I_d = \begin{cases} 1, if\ \lvert dT\rvert \le MT \\ \left\lceil \left(\frac{\lvert dT\rvert - MT}{VT - MT}\right) \times 7 \right\rceil \\ 8\ or\ 9 \\ if\ VT < \lvert dT\rvert < RT \\ 10, if\ \lvert dT\rvert \ge RT \end{cases}\ if\ dT \ge 0\ then\ I_d = 1$ (1)	$if\ dC < 0\ then\ I_c = \begin{cases} 1, if\ \lvert dC\rvert \le MT \\ \left\lceil \left(\frac{\lvert dC\rvert - MT}{VT - MT}\right) \times 7 \right\rceil \\ 8\ or\ 9 \\ if\ VC < \lvert dC\rvert < RC \\ 10, if\ \lvert dC\rvert \ge RC \end{cases}\ if\ dC \ge 0\ then\ I_c = 1$ (2)

The project team may change these guidelines to ensure their fit the particular project (e.g. existence of key milestones which cannot be broken). The probabilities p_k c_{k1} and c_{k2} ($k \in$ (D – duration, C – cost)) can be inferred statistically from the database of past R&Ds projects. For new and/or emerging risks (for which the data do not exist or unreliable), the expert methods can be used. Example of such methods include: additive - multiplication model or modifications of Elmery method [16].

Once the values for the individual ratings are entered, both the risk scores and the RPN values for individual risks are calculated and depicted at the Pareto chart (Fig. 4) [13]. If the team follows the guidelines from Tables 3 and 4 than RPNs for risk tolerance level, risk appetite and materiality levels equal 700, 1000 and 100 respectively [16], however, the team can establish the other boundaries. The team can also establish different decision levels for each cost or duration components. Additionally, the consolidated RPNs for the whole strategy should be calculated using the expert-based correlation coefficients (ρ) [16].

Table 4. The likelihood and detection value guidelines

Likelihood (P_d, P_c)		Detection (S_d, S_c)	
1. Remote	$P_k = \left\{ \begin{array}{c} 1, if\ p_k \in [0, 0.1) \\ \lceil 10p_k \rceil, p_k \in [0.1; 0.9] \\ 10, p_k \in (0.9, 1] \end{array} \right\}$ (3)-probability of risk occurrence, the ratio of frequency of failures to the total number of jobs	1. Almost certain	$S_k = \left\{ \begin{array}{c} 1, if\ f_k \in [0, 0.05) \\ \lceil 10f_k \rceil, p_k \in [0.05; 0.9] \\ 10, f_k \in (0.9, 1] \end{array} \right\}$ (4) $f_k = (1 - s_{1k} \times s_{2k})$ s_{1k} – the probability of detection of risk, the frequency of prevented risks to total number of occurred risks s_{2k} – the probability of early detection of risk with controls
2. Very low		2. Very high	
3. Low		3. High	
4. Mod. low		4. Moder. high	
5. Moderate		5. Moderate	
6. Moderately high		6. Low	
7. High		7. Very low	
8. Very high		8. Remote	
9. Extremely high		9. Very remote	
10. Certain		10. Uncertain	

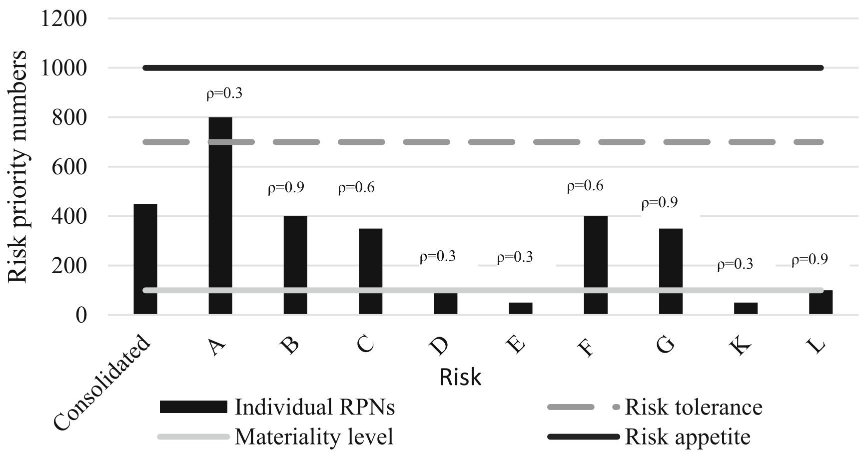

Fig. 4. Example of risk Pareto chart for duration

The Pareto chart allows the understanding, on the level of RPNs, which risk contributed the most to total exposure measured by consolidated RPN. If the individual risk's RPN is below materiality level, then this risk is excluded from further assessment and are not included into the risk management perimeter. For each option the following decision rules are suggested:

1. If consolidated RPNs of at least one component (duration or cost) exceed the risk tolerance, than the option is returned for reworking. The planning team develops and implement risk mitigation measures to return consolidated RPN within the risk tolerance boundaries. If risk mitigation is not possible then the option should be rejected. The team can consider immediate rejection of the alternative without reworking if at least one consolidated RPN materially exceeds risk appetite.
2. In rare cases, when both consolidated and individual RPNs for duration and cost components are below materiality level, such option is considered "risk free" and can be considered as "the optimal" without passing through phases 4 and 5. However, if RPNs from some individual risks exceed materiality level, the option may be sent to phases 4 and 5 for additional analysis.
3. If both consolidated RPNs for duration and cost of option is above materiality level but below risk tolerance level the option is considered acceptable and sent to Phase 4 for further assessment. The individual risks with RPNs above the materiality level are considered as material. However, if RPNs for some individual risks exceed tolerance level, the project team may consider sending the option for reworking if any of these risks are considered critical. The option should be sent for rework if RPN of any individual risk exceeds risk appetite.

Results of analysis of each risk as well as consolidated RPNs for each option must be recorded in the risk register for further quantitative assessment.

5.5 Phase 4: Quantitative Assessment of Risk and Analysis of Output

This assessment is performed for each option considered acceptable at phase 3. At first step, the PERT model of the option is adjusted taking into account the risk mitigation actions performed at phase 3. Then, the PERT model is exported into MS Excel with installed @risk modelling engine. For each job in PERT, the resources budget is modelled and the summary budget for the entire option is worked out.

At the second step, with the help of tools embedded into @risk, the project team determines (1) what variables of duration and cost (including prices or consumption volume or both) exposed to material risks are random variables: and (2) what kind of probability distribution theses variables follow. Given the restrictions of PERT [21], the only distribution option available for duration is the triangle distribution with parameters (a, m, b), where a is the best-case estimate, m is the most likely outcome and b is the worst-case estimate. For parameters of costs, however, @risk provides around 90 alternatives of distributions including normal, binominal, exponential, etc. The outcome of analysis of risk probabilities performed at phase 3 is applied in determining the parameters of these distribution. Once, the modelling of probability distributions has been completed, the team runs Monte Carlo simulation with pseudo-random number generator (the number of simulation varies from 1000 to 10,000 times). The simulation draws of duration/cost parameters values and making calculations according to the model constructed at step 2. The outcome is option's risk-adjusted total duration and cost.

The final step is the analysis of the outcome including: the mean, the median (the quantiles), the dispersion and standard deviation; the mode, the confidence intervals of duration and costs. Additional analysis includes understanding what jobs and/or resource components contributed the most to the deviation of outcome (Fig. 5). During this step the team determines: (1) the expected variance of option's outcome from the budget and the chances that option will be fulfilled in accordance to the budget; (2) the most probable duration/cost of the option; and (3) if the budget is tight and/or not realistic. If the expected variance of duration/cost exceeds the tolerance level (VT and/or VC); the project team will send the option for rework for development and implementation of risk mitigation actions. If variances exceed risk appetitive and/or risk mitigation/adjustments in the budget are not possible, the option is rejected.

Analysis of the output also helps to determine: (1) the risk-adjusted size of financing need to be attracted to fulfill the option; (2) what reserves should be maintained in case of realization of adverse scenarios; (3) what are the key risk areas to concentrate management attention while fulfilling the option; (4) what are the scenarios; and (5) what contingency plans need to be developed in case of realization of worst scenarios.

5.6 Phase 5: Selection of the Optimal Option of Fulfillment of R&D Project

The goal of the phase is to find the optimal option of fulfilling R&D projects among the alternatives (lets denote the entire set of options as Z). The inputs of the phase for each z^{th}-option are: (1) consolidated RPNs for duration (RPN_{dz}) and cost (RPN_{cz}); and

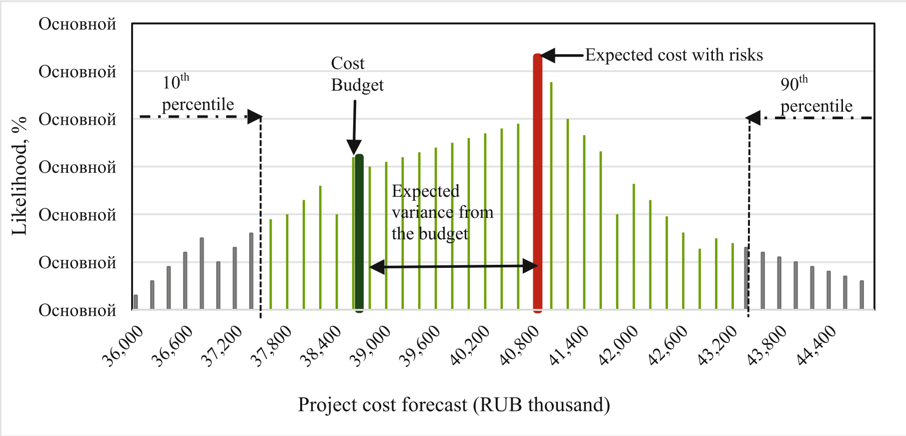

Fig. 5. Example of Monte-Carlo simulation output

(2) the outcome of duration and cost simulation. In the mechanism we apply Hurwicz's optimism – pessimism criterion which assumes that manager, while finding a suitable solution, is searching for a middle ground between the extremes posed by the optimistic and pessimistic cases [16]. At the start, the project team should define the importance of duration and cost in searching for the optimal option (the weights α and β). Then, the criterion (S_z) can be written in the following form:

$$\max\{S_z\}_{z\epsilon[1,Z]} = max\{\alpha GD_z + \beta GC_z\}_{z\epsilon[1,Z]} \tag{5}$$

$$GD_z = \left\{\frac{RPN_{dz}}{1000} \times PD_z + \frac{(1 - RPN_{dz})}{1000} \times OD_z\right\} \tag{6}$$

$$GC_z = \left\{\frac{RPN_{cz}}{1000} \times PC_z + \frac{(1 - RPN_{cz})}{1000} \times OC_z\right\} \tag{7}$$

$$\alpha + \beta = 1; \alpha \in [0, 1], \beta \in [0, 1] \tag{8}$$

GD_z, GD_c - Hurwicz's criteria of z^{th} option for duration and cost respectively; PD_z, PC_z – pessimistic forecasts of duration and cost respectively of z^{th} option; obtained from simulation outcome, given a specified degree of confidence. OD_z, OC_z – optimistic forecasts of duration and cost respectively of z^{th} option; obtained from simulation outcome, given a specified degree of confidence (for example, 10%).

At this phase, project team calculates the value of S_z for each option and determines the option with the maximum value of S_Z. This option is considered by team as the optimal. This option should be presented by the team to the project managers for the discussion and the final approval.

6 Conclusion

We developed the mechanism of risk-adjusted scheduling and cost budgeting of research and development (R&D) project for companies in telecommunication; the inherent part of complex R&D cost and schedule management system. It outperforms the "conventional" approaches of scheduling and cost budgeting. It allows (1) timely identification of risks, (2) facilitating transparent evaluation of risks and uncertainties; (3) focusing management time and efforts on key risks; and (4) performing remediation of risks earlier in the cycle thus improving speed and quality of decision making. Unlike "conventional mechanism" which poorly addressed risks, it integrates risk management process with risk-adjusted budgeting making budgeting and scheduling process dynamic, iterative and responsive to changes in environment; enabling multi-risk scenario modelling thus enhancing confidence in project's schedules and cost budgets. We can, therefore, conclude that the suggested mechanism should have a significant practical use in performing R&D projects in telecommunications.

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