Risk Analysis of Defence Acquisition Projects

Methods and Applications

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Prepared for:
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Defence Research and Development Canada
Scientific Report
DRDC-RDDC-2017-R124
October 2017

IMPORTANT INFORMATIVE STATEMENTS

This document was reviewed for Controlled Goods by Defence Research and Development Canada (DRDC) using the Schedule to the Defence Production Act.

Endorsement statement: This publication has been peer-reviewed and published by the Editorial Office of Defence Research and Development Canada, an agency of the Department of National Defence of Canada. Inquiries can be sent to: Publications.DRDC-RDDC@drdc-rddc.gc.ca.

Abstract

Risk analysis is an integral part of the risk management process for defence acquisitions. It provides a means to examine the impact of individual risks on the overall project objectives to determine the probability of concluding the project on a given budget (cost risk analysis) or on a given time (schedule risk analysis). While there is an extensive literature on risk management for defence acquisition programs, there are limited research studies and critical gaps in cost and schedule risk analysis methodologies and techniques. This Scientific Report synthesizes the work conducted by the authors during the past few years on risk analysis research. It provides a literature overview of analytical methods for project risk analysis, and suggests quantitative methods for analyzing cost risk, schedule risk, and integrated cost/schedule risk of defence acquisition projects. The proposed approach would provide defence leadership with useful indicators about the expected cost contingency and schedule buffer.

Significance to defence and security

Large-scale defence acquisition projects are generally complex with long durations and interrelated activities. The ability to accurately handle uncertainty in their costs and schedules is a key factor to their success or failure. However, it has been recognized that the approaches used for conducting risk analyses are generally diffused and inconsistently applied. To address these gaps, the Department of National Defence (DND) has initiated the modernization of defence governance. This governance modernization requires, among other things, the standardization of risk assessment criteria. This work provides analytical methods that can guide cost estimators and project managers in conducting cost risk, schedule risk, and integrated cost/schedule risk of defence acquisition projects. At least three beneficiary communities were identified: ADM(Fin), ADM(Mat) and Allied Nations.

Résumé

L’analyse du risque fait partie intégrante du processus de gestion des risques liés aux acquisitions militaires. Elle permet d'examiner l'impact des risques individuels sur les objectifs globaux d’un projet. Elle détermine la probabilité de réaliser un projet en temps requis (analyse du risque d’échéancier ou de calendrier) et sans dépasser un budget donné (analyse du risque de coût). Malgré la richesse de la littérature sur la gestion des risques, il y a encore des lacunes dans les méthodologies et les techniques d'analyse des risques liés aux acquisitions militaires. Ce rapport scientifique synthétise les travaux menés dernièrement par les auteurs dans ce domaine. Il fournit une vue d'ensemble de la littérature existante et suggère des méthodes quantitatives pour analyser le risque de coût, le risque d’échéancier, et le risque intégré de coût et d’échéancier. L'approche proposée fournirait aux décideurs des indicateurs utiles sur les réserves de coûts et de temps.

Importance pour la défense et la sécurité

Les grands projets militaires d'acquisition sont généralement complexes avec de longues durées et des activités interdépendantes. La capacité de gérer avec précision l'incertitude de leurs coûts et de leurs calendriers est un facteur clé de leur succès ou de leur échec. Cependant, il a été reconnu que les approches utilisées dans l'analyse de leurs risques sont généralement diffuses et appliquées de manière incohérente. Pour remédier à ce genre de lacunes, le Ministère de la défense nationale (MDN) a énoncé la modernisation de la gouvernance de la défense. Cette modernisation implique, entre autres, la standardisation des critères d'évaluation des risques. Ce rapport fournit des techniques pour guider les praticiens d'acquisition de la défense dans la gestion du risque de coût, du risque d’échéancier, et du risque intégré de coût et d’échéancier. Au moins trois communautés bénéficiaires ont été identifiées: SMA (Fin), SMA (Mat) et les alliés du Canada.

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1 Introduction

In times of economic constraints and tightening budgets, with operational requirements driving the need for accelerated acquisition schedules, defence leadership needs an early, independent, and agile approach for assessing the risks of acquisition programs. This assessment is an integral part of the risk management process for defence acquisitions. It will not reduce the risk inherent in a program, but it will help decision makers understand the nature of the risks involved in order to develop effective mitigation strategies.

Risk management is the art and science of planning, identifying, assessing, handling, and monitoring future events [1]. It is essential that acquisition programs define, implement, and document an appropriate risk management approach that is organized, comprehensive, and iterative, by addressing the following questions [2]:

- Risk Planning: what is the program's risk management process?
- Risk Identification: what can go wrong?
- Risk Analysis: what are the likelihoods and consequences of the risks?
- Risk Handling: should the risk be accepted, avoided, transferred, or mitigated?
- Risk Monitoring: how has the risk changed?

Figure 1 depicts the interactions between the different components of a risk management process. The risk identification and the risk analysis are referred to as risk assessment [2].

Risk analysis provides a means to examine the impact of individual risks on the overall project objectives (e.g., cost, schedule) to determine the probability of concluding the project on a given budget (cost risk analysis) or on a given time (schedule risk analysis). Cost risk analysis allows program managers to estimate the requisite contingency reserve needed for a desired level of certainty about achieving the overall project cost. Similarly, schedule risk analysis allows program managers to determine the schedule reserve required for a desired confidence level of the project completion time. These analyses can be conducted in the project's conceptual development phase as soon as there is a notional budget and schedule, and should be continued periodically throughout project execution as the estimate is refined and more risks are identified and quantified.

While there are a considerable number of reports on risk management for defence acquisition programs [2], there are limited research studies and critical gaps in cost and schedule risk analysis methods and techniques [3–4]. These gaps include:

- a lack of common risk taxonomy (e.g., definition of uncertainty);
- inconsistent application of statistical methods for acquisition risk analyses (e.g., the expected monetary value versus the Scenario-Based Method);
- lack of historical acquisition data to support all risk elements and improve robustness and confidence;
- lack of integrated approach for risk analysis (e.g., cost/schedule risk); and
- lack of understanding of interdependencies between risk elements (e.g., foreign exchange and inflation risks).

This paper focuses on developing cost/schedule risk analysis methods for defence acquisition projects.

Figure 1: *Risk management process.*

Examples of the Department of National Defence (DND) acquisition projects that included a risk analysis include the F-35 Joint Strike Fighter (JSF), Canadian Surface Combatant (CSC), Joint Support Ship (JSS), Arctic Offshore Patrol Ships (AOPS), the Fixed Wing Search and Rescue (FWSAR) aircraft replacement, and the Medium Support Vehicle System (MSVS). In Defence Research and Development Canada (DRDC), a number of cost/schedule risk analysis studies were conducted in support for these projects.

- The Chief Review Services (CRS) [5], for example, assessed the DND risk management practices used in projects to ensure strategic and operational risks are identified and managed proactively.
- Sokri and Solomon [3] used a probabilistic risk assessment to portray the major factors of uncertainty and estimate the JSF project cost contingency.
- Ghanmi et al. [5] developed a cost risk framework to standardize the identification, assessment, and reporting of cost risk within DND and CAF. Structured around these three components of cost risk, the framework seamlessly integrates recent academic developments within the constraints of existing public service policies and stakeholder requirements. It has successfully been applied in the cost risk analysis of two major crown projects (i.e., AOPS, MSVS).
- Sokri and Ghanmi [6] provided a comprehensive historical review of the predominant research developments in cost risk analysis. The authors examined the best practice

approaches for conducting cost risk analysis. They discussed their underlying assumptions, their methodologies, and how they can be used in the defence acquisition context.

- Sokri and Ghanmi [7] developed a novel schedule risk analysis approach for defence acquisition projects. The approach integrates Monte Carlo simulation, decision analysis and optimization techniques to determine the expected critical path and completion time of an acquisition project. It was applied to the FWSAR project approval milestones.
- Sokri and Ghanmi [8] proposed a probabilistic risk method to portray the learning curve risk and estimate the corresponding cost contingency and illustrated the method using a military shipbuilding project. The learning curve shows how unit costs can be expected to fall over time. It has been demonstrated that learning is a major cost risk driver in defence acquisition projects. It can be affected by changes in processes, resource availability, and worker interest.
- Sokri and Ghanmi [9] suggested a new integrated cost/schedule risk assessment approach that combines cost risk and schedules risk analyses within a single mathematical model. This risk analysis focuses on resources required to execute the project activities. The project schedule is constructed within the limited amount of resources available [10].

This Scientific Report synthesizes the work conducted by the authors during the past few years on cost/schedule risk analysis research. It describes how cost and schedule risks have been successfully analyzed and suggests quantitative methods for analyzing cost risk, schedule risk, and integrated cost/schedule risk of defence acquisition projects. The report is organized into five sections. Following the introduction, Section 2 presents the best practice methods used in DND for cost risk analysis. Section 3 presents the best practice methods for conducting schedule risk analysis. Section 4 shows how time and cost can be integrated within the same stochastic framework. Concluding remarks as well as future research directions are indicated in Section 5.

2 Cost risk analysis

In this section, common cost risk analysis methods are presented and discussed. The advantages and disadvantages of each method are highlighted. While a summary of cost risk analysis methods has already been published by the authors in a conference paper [6], this section presents further details of these methods for reference and completeness. It also presents a comprehensive cost risk analysis approach for defence acquisition projects.

2.1 Cost risk analysis methods

While cost estimation determines how much a project will cost, cost risk analysis determines the appropriate contingency reserve for the project. Cost risk analysis can also help in considering and planning risk mitigation actions [11]. Various analytical methods for conducting cost risk analysis are presented in the literature. They can be divided into two categories: Qualitative and quantitative.

2.1.1 Qualitative methods

Qualitative cost risk analysis is a quick and cost-effective method of prioritizing risks. This approach uses ordinal scaling techniques to provide a quick and high level subjective judgment of cost risk. It uses subjective judgments to determine how likely each risk is to occur (probability) and how it would affect the project objectives if it does occur (impact). The analysis should be reviewed during the project's life cycle to take into account any significant changes in project risks. The outputs from a qualitative cost risk analysis could be used to update the risk register and the risk urgency assessment [6].

Qualitative cost risk analysis methods allow decision makers to reduce the level of uncertainty about the project and concentrate on high-priority risks. These methods are typically used when there is limited data to conduct a detailed risk analysis [11]–[14]. In these methods, two dimensions of risk are applied to specific risks: risk probability and risk impact. Risk probability is the likelihood that a risk occurs and risk impact is the consequence on project if the risk does occur. Two dimensions of risk are generally described within a probability/impact risk rating matrix in qualitative terms such as insignificant, minor, moderate, major, and severe. Table 1 gives an example of impact assessment scale.

Table 1: *Example of scoring matrix.*

Score	Impact	Cost
1	Insignificant	<5% increase in cost
2	Minor	6%–15% increase in cost
3	Moderate	16%–30% increase in cost
4	Major	31%–50% increase in cost
5	Severe	>50% increase in cost

The risk matrix in Figure 2 provides a standard output for qualitative risk analysis. In this matrix, each risk *i* is represented by a circle, where *i* is the risk identification number and the circle's colour represents its category [5]. Risks with high probability and high impact are likely to require further analysis, including quantification, and aggressive risk management. Lower risks would require less emphasis and it may be enough to include them in a watch list for monitoring [11].

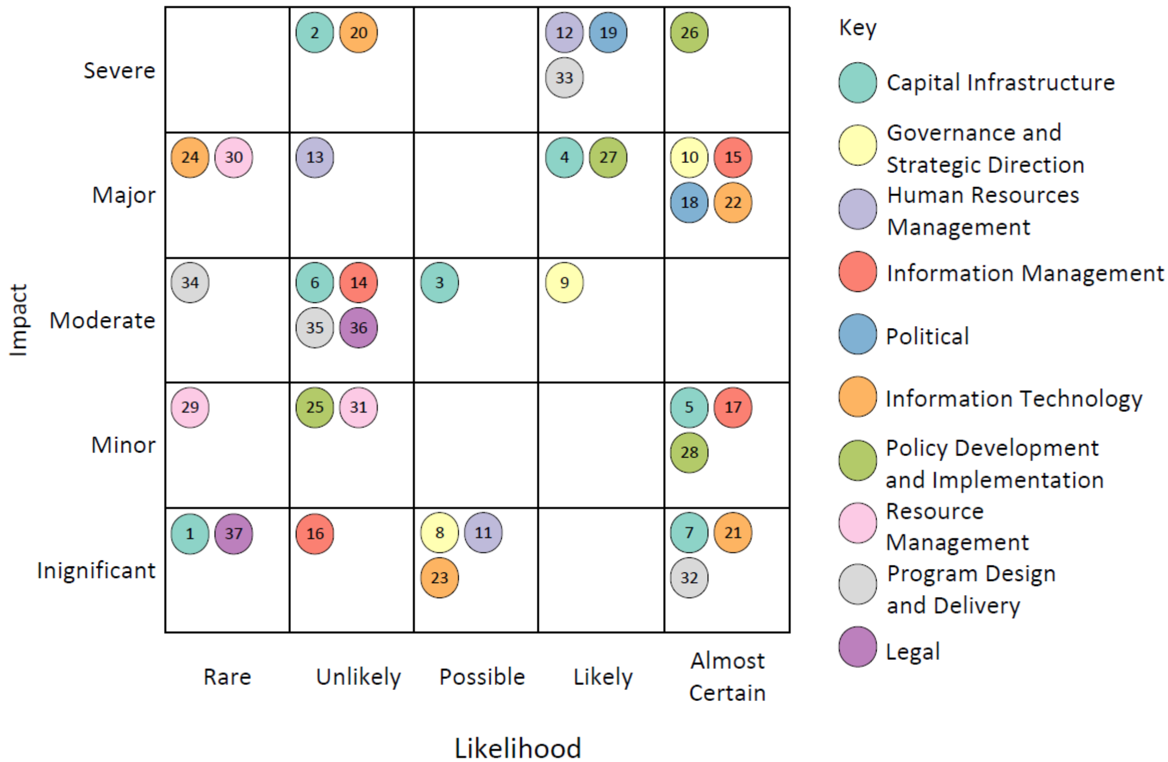

***Figure 2**: Example of risk rating matrix [5].*

2.1.2 Quantitative methods

Many quantitative analytical methods such as analogy and parametric analysis methods could be used to provide a point estimate cost of a project. The determination of such a point estimate without adjustments for data uncertainties and project risks is beyond the scope of this document. The interested reader is referred to the International Cost Estimation and Analysis Association (ICEAA)'s Cost Estimating Body of Knowledge (CEBoK) [15] for further information on point estimation. The focus of the study is on the cost risk analysis which is the continuation and conclusion of cost estimation.

Quantitative methods assign numerical values to both the likelihood and impact of risk factors in order to derive cost contingency for projects. These methods can be grouped into two groups: Statistical techniques and stochastic simulation. Statistical techniques, such as the cost growth technique [8] use trends analysis and multi-attribute regression analysis to estimate the difference between the revised risk-adjusted and the estimated costs. While these high level techniques are well-founded, they do not, however, provide a Cumulative Distribution Function (CDF) (known as the S-curve) of the total cost. The S-curve could be used by decision makers to present the cost risk profile and to define the appropriate contingency reserve. Figure 4 shows an illustrative example of this curve.

The purpose of stochastic simulation, the focus of this section, is to simulate a specific process with uncertain factors many times in order to generate useful distributions of project costs [16]. Stochastic simulation uses probability distributions of the different risk factors to determine a combined probability distribution of the project cost estimate. In contrast with statistical methods, stochastic simulation provides detailed cost estimations and insightful sensitivity analysis to determine major risk factors for risk mitigation. It can be divided into two main approaches: Cost driver and risk driver methods [11].

Cost driver method

The cost driver method divides the total cost into its lower sub-elements (cost elements) using a cost breakdown structure [17]. It places uncertainty on the variation of each element using probability distribution functions. To derive information about the total project cost, this method uses Monte Carlo simulation to combine the probability distributions of the different individual cost elements.

The cost driver method presents many limitations that should be acknowledged [11].

1. The method focuses on the impact of risks rather than the risks themselves. It does not show the underlying forces that cause the uncertainty in cost. The method particularly ignores the possibility that these risks may or may not occur.

2. The method cannot detect if a single risk can impact several cost elements.

3. The method cannot take into account the correlation that can exist between cost elements.

For these reasons, a novel method based on the risk drivers has been proposed for cost risk analysis.

Risk driver method

The method starts by identifying the strategic risks (risk drivers) that would have significant impact on the total project cost estimation. Examples of risk drivers for an acquisition projects include currency and inflationary risks. Each risk factor is characterized by its probability of occurrence and its potential impact. Monte Carlo simulation is used to combine the probability distributions of the individual risk factors to determine the overall impact on total project cost.

The risk driver method presents three main advantages.

1. It can assign a single risk to multiple cost elements

2. It can assign several risks to a single cost element

3. It can capture the implicit correlation between cost elements.

The final output of the cost driver and risk driver analyses is a cost risk profile. The cost risk profile can be presented using the CDF of the project contingency as shown in Figure 4. Further investigation can be undertaken to determine whether a contingency is required as a risk mitigation strategy.

A key decision point in the selection of a cost risk analysis method is the availability of the acquisition data. Data in the context of cost risk analysis refers to the project requirements, technical data, details of the project elements, historical cost data, and risk drivers. A Data Readiness Level (DRL) metric could be used to determine whether a quantitative analysis is an option, or if a qualitative analysis must be undertaken [5]. DRL is a systematic approach that measures the maturity of data (availability and quality) and supports the risk assessment. For example, a low DRL indicates that there is no data available or there is little information about the project to perform a detailed quantitative cost risk analysis.

2.2 A Cost risk analysis approach for the defence project

The suggested cost risk analysis approach is based on the most recent contributions in this area. It will assist defence analysts in conducting cost risk analyses with more transparency and replicability. The approach involves five steps as summarized in the flow diagram in Figure 3.

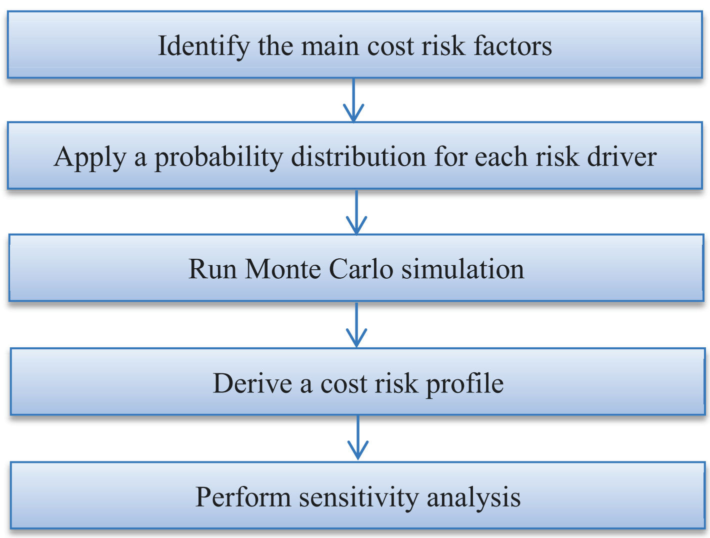

Figure 3: *Schematic presentation of the methodology steps.*

2.2.1 Identify the main cost risk factors

Unlike the cost driver method that uses the cost breakdown structure of a project, the risk driver method uses the risk breakdown structure to perform cost risk analysis [6]. In this step, risk drivers (from the risk register) that would have serious impact on the project cost are listed. Each individual risk is characterized by its probability of occurring and its impact range if it occurs. The impact can be expressed in the form of a multiplicative factor. In this approach, the elements' cost risks are directly derived from the risk themselves. A risk assignment matrix can also be constructed to assign risks to project cost elements. This assignment matrix will implicitly correlate the project cost elements when the simulation proceeds.

2.2.2 Apply a probability distribution for each risk driver

In this step, a probability distribution function is assigned to each risk impact to describe the range of its possible values. Two common probability distributions are particularly suitable to assess the likely fluctuation of each impact: Triangular and Program Evaluation and Review Technique (PERT) distributions. Using a three-point estimates (optimistic, most likely, and pessimistic) approach, the two distributions are comprehensible and very practical. PERT is, however, more adequate than the Triangular distribution in case of skewness or asymmetry in the distribution [2].

2.2.3 Run Monte Carlo simulation

Simulation is a tool used to virtually mimic a real-world or hypothetical system [2]. It is a well-established method for evaluation of risk [18]. In this step, Monte Carlo simulation is used to combine all the input distributions to determine a possible distribution of the outcome. Four techniques are typically used to combine the different probability distributions: manipulation of integrals, moment generating functions, characteristic functions, and Monte Carlo simulation. The approach that has more flexibility and power for combining probability distributions in most circumstances is Monte Carlo simulation.

2.2.4 Derive a cost risk profile

Aversion to risk (or willingness to take risk) affects decision-making strategies and risk mitigation actions. Risk profiling is a process for finding the acceptable level of risk DND and CAF are willing to accept. In DND acquisition projects, a risk profile is generally dependent on three elements: cost of equipment, funding, and risk tolerance. To determine the level of risk the organization may be comfortable with, let the random variable *C* be the project incremental cost and *F* its CDF. In mathematical terms, this function is commonly expressed as the integral of its probability density function *f* as follows:

$$F(c) = P(C \le c) = \int_{-\infty}^{c} f(t)dt. \tag{1}$$

As indicated in Figure 4, for each value c, *F(c)* represents the probability of achieving an incremental cost less than or equal to *c* (assuming that *F* is continuous and strictly increasing). It is bounded between 0 and 1. This incremental cost, more commonly known as contingency, is a financial reserve set aside to offset potential cost increases due to future known or unknown events ([2], [19]–[21]). This provision of money is necessary for providing a risk-adjusted cost estimate and reducing the risk of any cost overrun.

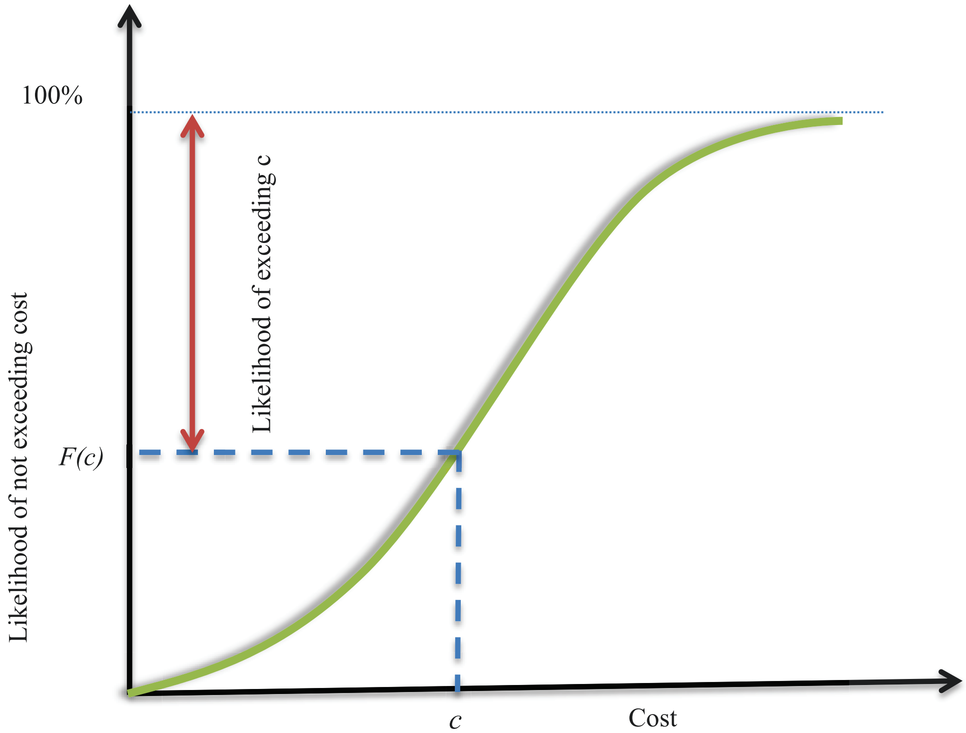

Figure 4: *Project incremental cost cumulative distribution.*

This S-curve shows the likelihood of not exceeding a given cost and provides a non-subjective understanding of risk to determine project cost contingency. While no specific confidence level has been identified ([22], [23]), it is common to fund projects between 50% and 80% bounds. As F is continuous the median is the same as the 50$^{\text{th}}$ percentile $F^{-1}(0.5)$. It is the value separating the higher half of the probability distribution from the lower half. The selected value should correspond to the level of risk the DND is comfortable with. As F is strictly increasing, when the cost contingency (percentile) value is low, the probability of exceeding the cost is high ([2], [13]).

2.2.5 Perform sensitivity analysis

Sensitivity analysis provides a useful way of dealing with uncertainty and investigating the robustness of cost estimates. This what-if analysis can determine how sensitive the costs are to the different cost drivers. It also allows for better informed decisions to be made on which risk mitigation strategies would have the most impact [24]. This analysis can be performed by varying a single factor while all other parameters are held constant (one-way sensitivity analysis). It can be conducted by varying more than one factor at the same time (multi-way sensitivity analysis). It can also be done by analyzing the output distributions (probabilistic sensitivity analysis) ([2], [25]).

Critical drivers can be identified and displayed graphically using different techniques. These techniques include bivariate correlation, regression analysis, and Monte Carlo simulation are the most useful methods. These techniques estimate the pairwise association between the final output and one of its predictors. The correlation coefficient, for example, determines the strength and direction of this association. The higher the correlation between the risk factor and the incremental cost, the more significant the factor is in influencing the total cost [5].

Two main assumptions are implicitly made in the suggested approach. It is assumed that the appropriate project horizon (the project planning horizon) is given. It is also expected that a risk-free total cost (a point estimate) of the analyzed project is already calculated over the project horizon.

2.3 Illustrative example

In this subsection, a case study using a military aircraft replacement project is presented to illustrate the cost risk analysis approach. This illustrative example outlines the cost risk analysis for the acquisition portion of this project. The main cost risk factors are identified based on previous studies conducted by the authors [2]–[5].

2.3.1 Identify the main cost risk factors

Four major risk factors were identified for the acquisition portion of the project:

- **Foreign exchange risk**: the risk that the domestic currency (i.e., the Canadian dollar (CAD)) depreciates against the foreign currency (e.g., the United States dollar (USD)) more than the exchange rate already built into the cost estimate. This results in a significant increase in the prices of imported goods and services. This risk was assessed as very high for this large defence acquisition project [2].
- **Inflation risk**: the risk that the foreign inflation increases above the expected amount built into the cost estimate. This generates the erosion of the local purchasing power. This risk is assessed as high particularly when the defence inflation exceeds that in the overall economy.
- **Demand risk**: the risk that the actual demand of allies who are also purchasing the same equipment may be lower than the forecasted demand. This risk is assessed as high. The partners may reduce the quantity of the demanded aircraft or delay the timing of their acquisitions.
- **Learning curve**: the risk that the producer may not realize the projected production efficiency. The actual learning efficiency may be lower than that built into the cost estimate.

  Table 2 presents the optimistic, the most likely, and the pessimistic values (illustrative) of the impact of each risk factor on the project cost. For example, the minimum, the most likely, and the maximum incremental costs associated with the learning curve risk amount to approximately 0, \$1.2M, and \$1,027M respectively.

Table 2: *Key risk factors for the aircraft replacement project.*

Risk factors	**Impact** (in $\$10^6$)		
	Optimistic	Most likely	Pessimistic
Foreign exchange	0	1.3	1,094
Inflation	0	0.3	400
Demand	0	0.3	400
Learning curve	0	1.2	1,027

2.3.2 Apply a probability distribution for each risk driver

Any uncertainty in the four major risk factors will have an impact on the total cost. Each factor is represented by a PERT distribution function indicating the variability of its impact on the total cost estimate. Figure 5 describes the distributions of the main risk factors. These four input distributions should now be aggregated to generate the distribution of their combined effect. As the four distributions have different means and variances, aggregating them analytically would not be straightforward. That is why a Monte Carlo simulation will be used to combine these distributions. Simulation is a lot more flexible than the analytical approach.

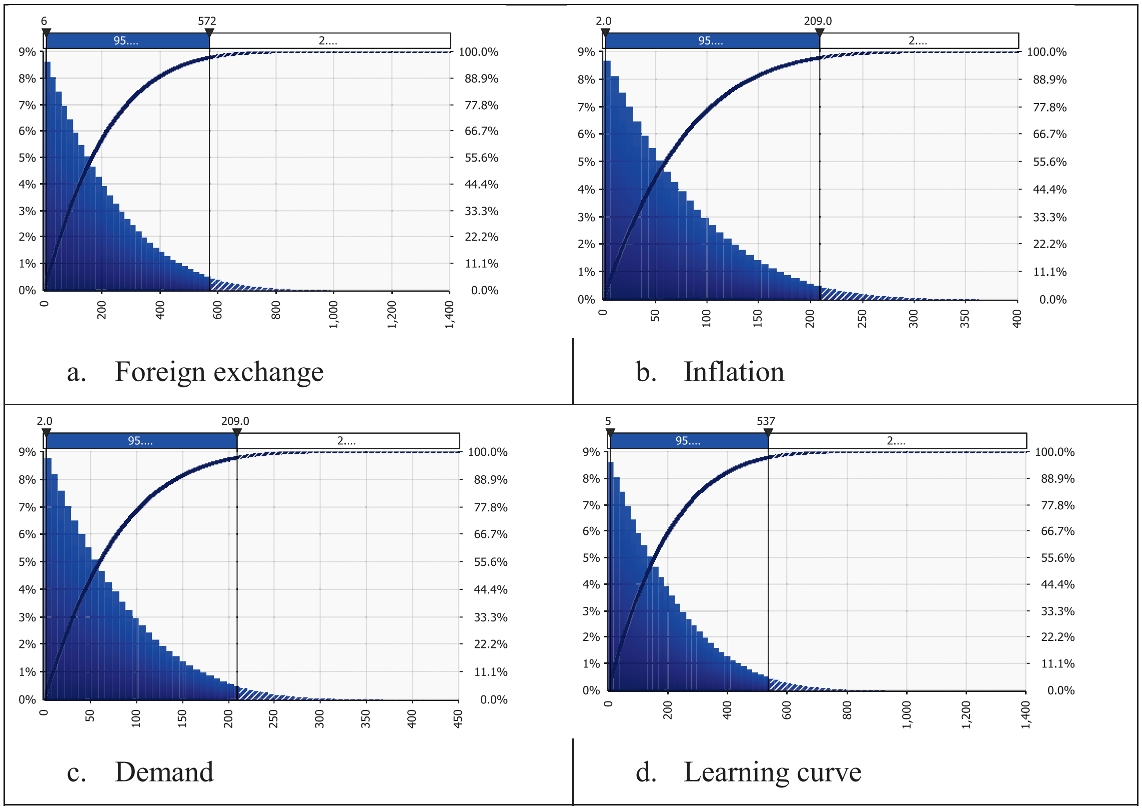

Figure 5: *Distributions of the main risk factors.*

2.3.3 Run Monte Carlo simulation

Simulation is used to combine all the input distributions to derive a possible distribution of the outcome. To understand how Monte Carlo simulation can be used in this context, let $X_1, X_2, \ldots, X_n$ be n continuous random variables with density functions f_X and f_Y. To determine the distribution function of the variable $Z = X_1, X_2, \ldots, X_n$, the Monte Carlo simulation would consider all possible combinations of the input distributions to calculate likely values for Z. At each iteration, different sets of values from the probability distributions of X_i*'s* are randomly selected and a new value of Z is recalculated [26]–[28].

2.3.4 Derive a cost risk profile

A Monte Carlo simulation model is run to generate the total incremental cost and to estimate the cost contingency of the project. Figure 6 presents the project cost risk profile. This graph depicts the CDF for each percentile. It shows, for example, that if the 90^{th} percentile is used, the amount of the risk contingency will be approximately $800 million. It also indicates that the average cost contingency amounts to approximately $489 million. The 95% confidence interval for this financial reserve is [$140 million, $1,004 million].

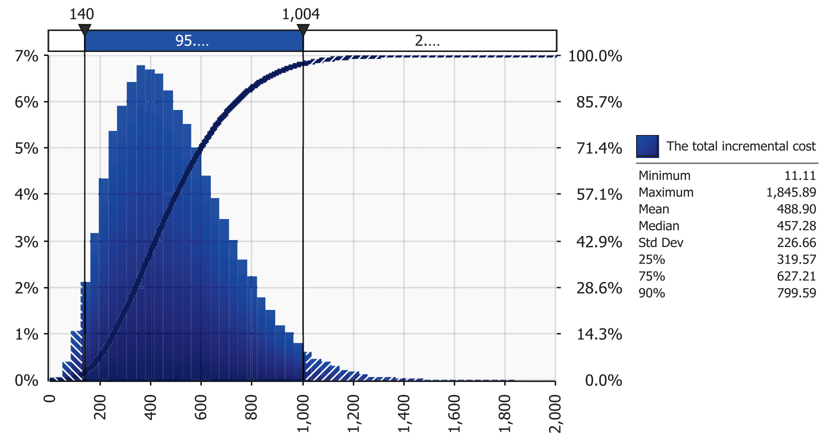

Figure 6: *Distribution of the total incremental cost.*

2.3.5 Perform sensitivity analysis

A sensitivity analysis using stochastic simulation is carried out to evaluate the robustness of the cost risk profile. Figure 7 shows what would happen to the total incremental cost if the impacts of the key cost drivers vary. This graph shows that foreign exchange and learning curve are the most crucial risks for the project cost. These two risk factors have the highest impact on the average incremental cost. The correlation coefficients between the incremental cost and these two predictors are 0.64 and 0.61 respectively. Any increase in these two variables would expectedly push the project cost upward. A strategy to mitigate the impact of their variability should therefore be defined.

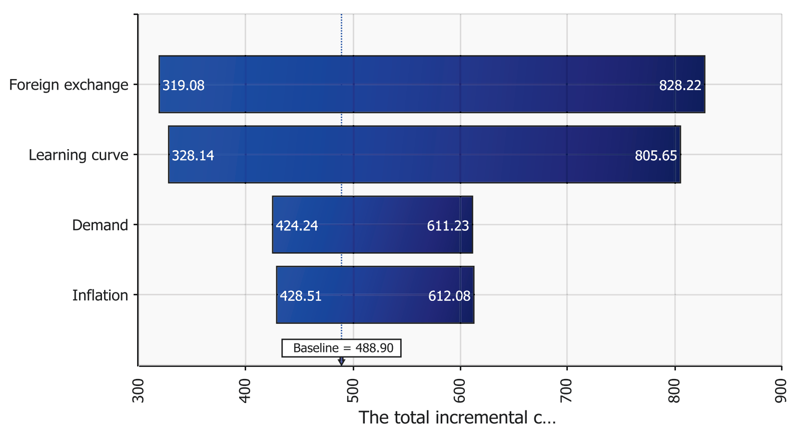

Figure 7: *Effects of the main risk factors on the incremental cost.*

3 Schedule risk analysis methods and applications

In the previous section, we discussed cost risk analysis methods for defence acquisitions. This section focuses on schedule risk analysis methods and applications. Schedule risk analysis is the process of associating a degree of confidence with the schedule duration estimate [7]. As a result, project delivery dates can be represented by a probability distribution rather than a single point estimate [16]. Uncertainty in project scheduling can have three categories of sources [29]–[30]: ambiguity (i.e., lack or incompleteness of data), variability (i.e., trade-off between available and required resources), and occurrence of uncertain causal events.

Following this introduction, an overview of analytical methods for project schedule risk analysis is provided. While a summary of schedule risk analysis methods has already been published by the authors in a conference paper [7], this section presents further details of these methods for reference and completeness. It also presents a novel schedule risk analysis approach for defence acquisition projects. A case study using a military aircraft replacement project for the CAF is presented to illustrate the approach.

3.1 Schedule risk analysis methods

Large-scale defence acquisition projects are generally complex with long durations and interrelated activities. The ability to accurately manage them is challenged by the impact of technological change, resource constraints, and programmatic obstacles. Handling uncertainty in their schedules is a key factor to their success or failure. In general, there are two main approaches for conducting schedule risk analysis, depending on data availability for the project [7]: phase driven approach and event driven approach.

3.1.1 Phase driven approach

The phase driven approach is a high level method for assessing schedule risk. Using this approach, the project schedule is divided into a number of phases with different distributions of completion times. A confidence interval around the mean schedule time is estimated by combining the probability distributions of all the phase completion times. Phase completion times can be derived from historical projects. The beginning and end of each phase are associated with the occurrence of some major project milestones. The approach applies econometric techniques to historical data to identify the major schedule drivers of the phase completion times. The schedule drivers are then used in the schedule estimating relationships of the analyzed project [31]. Once a set of phase duration times is determined, the project schedule distribution can be derived. Examples of schedule drivers would include type of equipment, system capabilities, and acquisition strategy.

A growing body of literature uses phase driven method as an effective schedule risk analysis approach. Younossi et al. [32], for example, explored the parameters that affect the development phase duration of the military jet engine. The authors applied econometric techniques to develop a series of parametric relationships for forecasting the engine development time.

Nierwinski [33], for example, conducted a schedule risk analysis to support the U.S. Army in Analysis of Alternative and other major Army acquisition studies. The author used Monte Carlo simulations and mathematical models to build a confidence interval for the probability of meeting the schedule developed by the Program Manager. The author focused on the phase-level approach because the data is more readily available than event level information.

More recently, Desmier [34] used Copula functions to forecast under uncertainty the milestones for major crown projects. The author used information from 309 projects to develop the joint probability distribution between planned and actual durations from one milestone to another. Copula functions are a general tool to construct multivariate distributions and to investigate dependence structure between random variables [35]. For more mathematical details, interested readers are referred to [36]–[37].

3.1.2 Event driven approach

In contrast with the phase driven approach, the event driven approach provides a detailed assessment of the project schedule risk. In this approach, each activity has a predecessor to its start date and a successor from its finish date. The total project duration is calculated using the Critical Path Method (CPM). The critical path is formed by the activities that must be finished on time to complete the project in the shortest possible duration. The critical path defines the minimum time required for the project to be complete [11]. The activity duration can be determined by historical standards. When there is little or no historical data, subject matter expertise can be useful. Two event driven methods are generally used for schedule risk analysis: risk driver method and activity driver method.

Risk driver method

As indicated in the cost risk analysis section, the risk driver method is a top-down approach for analyzing risk using stochastic simulations [7]. It applies the most prioritized risks to the entire schedule rather than placing uncertainty on each activity. It uses Monte Carlo simulation to generate a probability distribution for the total schedule time. The list of risks is drawn from the risk register. This document records the risk that have historically had a significant impact on projects similar to the analyzed one.

Activity driver method

The activity driver method is comparable to the cost driver method in the cost risk analysis section. It places uncertainty on each activity in the schedule. The activity driver method can be divided into four main categories of techniques: (1) Project Evaluation and Review Technique (PERT), (2) Critical Chain Methods (CCM), (3) Bayesian Networks (BN), and (4) Simulation Models (SMs) [36].

PERT incorporates uncertainty by using three-point estimates (optimistic, most likely, and pessimistic) for each activity [39]. CCM focuses on the resources required to execute project activities. It removes safety time from individual activities and places it in project buffer (at the end of the project) and feeding buffers (at nodes where non-critical activities feed into the critical chain) [40].

BN is a directed graph of nodes and arcs with marginal probabilities for prior nodes and conditional probabilities for nodes with parents. This approach integrates the causal relations between project parameters to inform project scheduling [41]. SMs use computer representations to virtually mimic a real-world project. The project assessment by simulation technique can use different what-if analyses and provide various critical paths [38].

3.2 A proposed schedule risk analysis approach for defence acquisition projects

Two elements are crucial in solving a scheduling problem. The first is the critical path and the second is the shortest time in which the project can be completed [42]. This section suggests a new stochastic approach that combines optimization and Monte Carlo simulation techniques to conduct schedule risk analysis. Optimization is used to objectively identify the most likely critical path. Monte Carlo simulation is used to derive a schedule risk profile. The approach involves seven steps as summarized in the flow diagram in Figure 8.

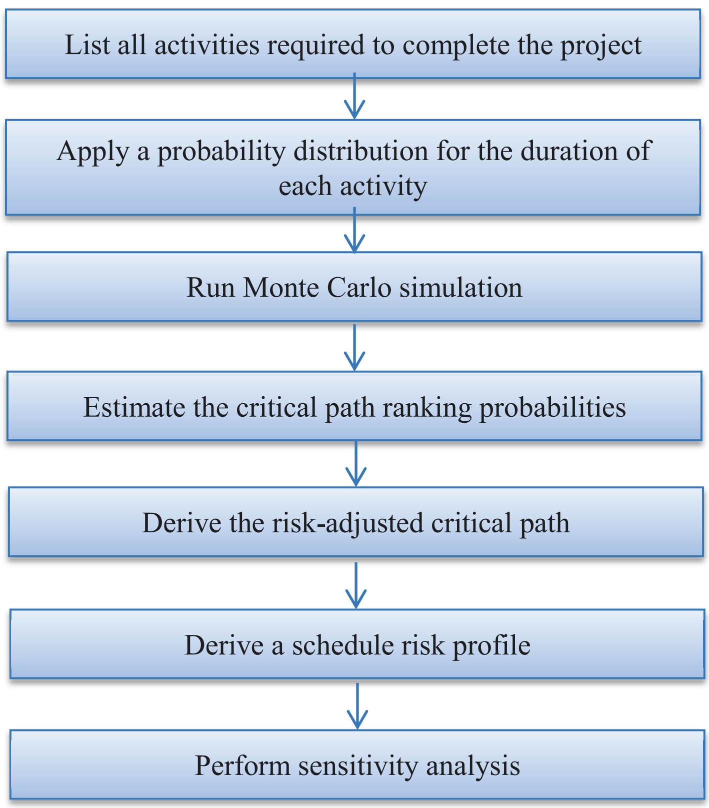

Figure 8: *Schematic presentation of the schedule risk analysis approach steps.*

3.2.1 List all activities required to complete the project

In this step, each project stage is decomposed into individual activity lines [16]. A work breakdown structure is used to correctly identify predecessor and successor activities and summarize the causal dependencies between them.

3.2.2 Apply a probability distribution for the duration of each activity

A three-point estimate approach is particularly suitable to assess the likely fluctuation of activity durations. The estimated time to complete an activity is computed if the optimistic, most likely, and pessimistic estimates of its duration are known. PERT distribution, for example, is a powerful method for estimating the time required to complete a given activity.

3.2.3 Run Monte Carlo simulation

In this step, Monte Carlo simulation is used to generate multiple schedules. At each iteration of the simulation, the potential critical paths are ranked based on their total durations. Results from all iterations are combined at the end of the simulation to determine the number of times a path i is ranked at a position j.

3.2.4 Estimate the critical path ranking probabilities

The probability p_{ij} that path i ranks at position j is generated by dividing the number of times path i is ranked at a position j by the total number of simulation runs. A ranking probability matrix can be used to consolidate the ranking results from Monte Carlo simulation.

3.2.5 Derive the risk-adjusted critical path

A schedule may have several potential critical paths with different probabilities of occurrence. To reduce the computation effort, a short list of near-critical paths can be used. Any dominated critical path should be ruled out. A critical path is said to be dominated if its maximal completion time is smaller than the minimal duration of another one ([7], [43]). Let k be the number of the near-critical paths and define the variable x_{ij} $(1 \leq i, j \leq k)$ as:

$$x_{ij} = \begin{cases} 1, \text{if path } i \text{ is ranked at position } j \\ 0, \text{otherwise.} \end{cases} \quad (2)$$

By maximizing the following objective function

$$\max G = \sum_{i=1}^{k} \sum_{j=1}^{k} x_{ij}\, p_{ij} \quad (3)$$

subject to:

$$\sum_{j=1}^{k} x_{ij} \quad = \quad 1 \qquad 1 \leq i \leq k \tag{4}$$

one can determine the most probable paths and its ranking probability. As stated in Equation (4), each potential path is assigned to only one rank position.

3.2.6 Derive a schedule risk profile

The schedule risk profile provides decision makers with a time by which the project will be completed. It can also identify a set amount of buffer time to account for any discrepancies that may arise in the project. The schedule risk profile can be derived by calculating the probability of not exceeding a given duration *t.* This probability is given by

$$F(t) = P(T \leq t) \tag{5}$$

where T represents the project duration seen as a random variable.

3.2.7 Perform sensitivity analysis

Sensitivity analysis shows what would happen to the total completion time if the major sources of uncertainty vary. As stated in the previous section, sensitivity results can be generated and graphically displayed using different analytical techniques. The aim is to compute a pairwise association between the total completion time and one of its predictors or parameters.

3.3 Illustrative example

The approach developed in Section 3.2 is applied to the Fixed Wing Search and Rescue (FWSAR) aircraft replacement project. To analyze the FWSAR approval process, the project management officer developed the project schedule and identified three elements: (1) the set of tasks, (2) their interdependencies, and (3) three point estimates of the task durations. To avoid issues with sensitive information, we used illustrative data for this schedule risk analysis.

3.3.1 Data

The dataset contains 26 tasks of the project schedule. Two categories of tasks are considered: (1) Standard tasks that require resources and execution time (T1 – T22), and (2) Delays or waiting times associated with some tasks (D1 – D4). Typical tasks include the preparation of the procurement documents, requirement foundation documents, release of the request for proposal, in-service support contract documents etc. Delay tasks involve, for example, waiting time for a senior leadership approval. Table 3 provides the successor tasks as well as the minimum, most likely, and maximum durations for each task.

Table 3: *Task, durations, and dependencies.*

Task	Description	Duration (months)			Successors
		Minimum	Most Likely	Maximum	
T1	Start	0	0.5	1	T2
T2		1	1.5	2	T3,T5
T3		2.5	3	3.5	T4
T4		0.5	1	1.5	T6
T5		18	20	22	T10
T6		6	7	8	T7
T7		6	7	8	D1,D2,T10
T8		0.5	1	1.5	T10
T9		1	2	3	T10
T10		0	0.5	1	T11
T11		0.5	1	2	T12,T13
T12		1	3	5	T14
T13		33	35	37	T22
T14		2	4	6	T15,T20
T15		3	4	5	D3,T18
T16		1	3	5	D4,T18
T17		2	3.5	5	T18
T18		1	2	3	T19
T19		1	2	3	T22
T20		4	6	10	T21
T21		0.5	2	3.5	T22
T22	Finish	1	2	2.5	T23
D1	Delay 1	0.5	1	1.5	T8
D2	Delay 2	0.5	0.5	0.5	T9
D3	Delay 3	1	1	1	T16
D4	Delay 4	1	1	1	T17

We applied the proposed schedule risk analysis approach and identified three potential critical paths (CP1, CP2, and CP3) in the schedule. We ruled out all dominated critical paths. Table 4 presents the critical path ranking probability matrix. The probability matrix is obtained after 10,000 simulation runs. It indicates that critical path CP1 has a high ranking probability. It is ranked first for more than 60% of the simulation runs, second for 32.49%, and third for 7.52%. As such, the project manager should primarily focus on path CP1 for schedule risk mitigation but need to pay close attention to critical tasks in paths CP2 and CP3.

Table 4: Critical path ranking probability matrix.

Path	Tasks	Rank Position		
		1	2	3
CP1	T1, T2, T3, T4, T6, T7, D2, T9, T10, T11, T13, T22	60.12%	32.49%	7.52%
CP2	T1, T2, T3, T4, T6, T7, D1, T8, T10, T11, T13, T22	8.86%	47.23%	44.68%
CP3	T1, T2, T5, T10, T11, T13, T22	31.02%	20.28%	47.80%

3.3.2 Schedule risk profile

The project schedule risk profile is shown in Figure 9. It shows the probability for the project to be completed in less than a given time. For example, the median of the project duration distribution is approximately 61 months. This means that the probability that the project will be completed in less than 61 months would be 50%. The 95% confidence interval for this duration would be [58.70, 63.19].

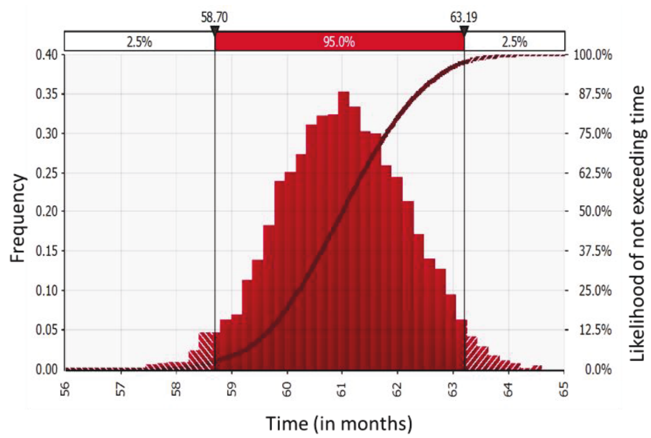

Figure 9: CDF of the total project duration.

3.3.3 Perform sensitivity analysis

A sensitivity analysis was conducted to assess the impact of some key activities on the results. As shown in Figure 10, the most critical activity in terms of schedule risk is T13. This activity has the highest impact on the project duration mean. The correlation coefficient between the project duration and this activity is approximately 0.67. The decision makers should define a strategy to mitigate variability in this activity.

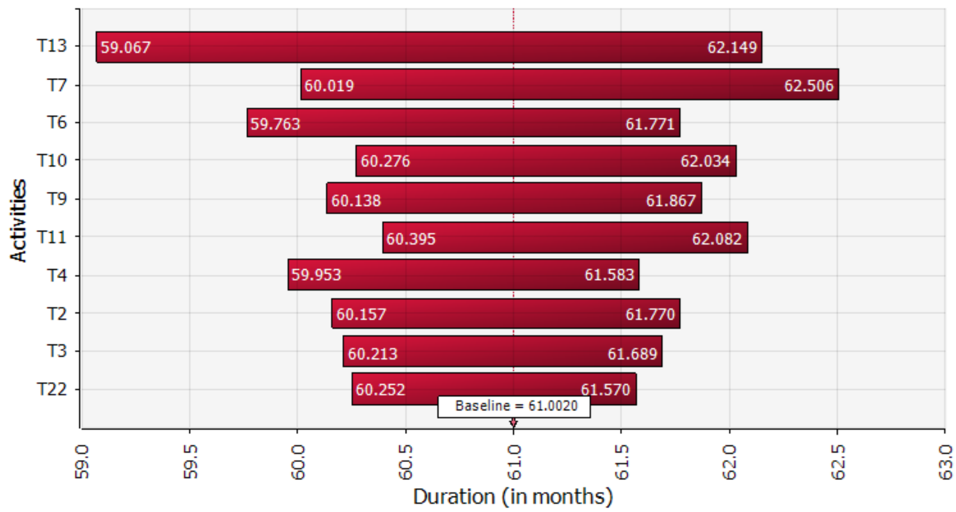

Figure 10: *Effects of the main activities on the project schedule.*

4 Integrated cost/schedule risk analysis

Cost and schedule are important facets of the total quality of defence acquisition projects. Cost indicates if the project is within budget. Schedule indicates how long the project takes [44]. Integrating these two elements is crucial to a successful analysis of large-scale defence acquisitions projects with long durations and interrelated activities.

In integrated cost/schedule risk analysis, project schedule is constructed within the limited amount of resources available [10]. These resources can be divided into two main categories: time-independent and time-dependent resources. Time-independent resource is the resource that does not cost more if it works longer (e.g., procured raw materials, some equipment). Time-dependent resource is the resource that will cost more if its activity takes longer (e.g., labour, rented equipment) [11]. This chapter suggests a novel integrated cost/schedule risk assessment approach that combines cost risk and schedule risk analyses within a single mathematical model.

4.1 Integrated cost/schedule risk analysis methods

A growing body of literature recognizes the integration of cost and schedule risk analysis as an important analytical technique to effective risk analysis. This literature has adopted various scheduling objectives. Its streams of research can be divided along methodological lines into six main methods: (1) Time-cost trade-off problem, (2) Net Present Value (NPV) maximization, (3) Resource leveling, (4) Resource availability cost problem, (5) Work continuity optimization, and (6) Time minimization ([10], [45], [46]).

4.1.1 Time-cost trade-off problem

The objective in the time-cost trade-off problem is to maximize the amount of time compression for the least incremental cost. To reduce project completion time, Liberatore and Pollack-Johnson (2006) [47], for example, investigated the impact of crashing as well as the removal and modification of precedence relationships. Crashing is a time-cost trade-off technique for completing an activity in the minimum possible time for the minimum additional cost. The authors found that doing more tasks concurrently, or overlapping them, in addition to compressing task times would accelerate the project completion.

4.1.2 NPV maximization

The Net Present Value (NPV) maximization is used as a criterion of scheduling activities when the financial aspect of project management is of interest [48]. In this approach, both negative and positive cash flows are discounted towards the beginning of the project ([14], [49]). Kazaz and Sepil [50], for example, used activity profit curves to show how sensitive the net present value of each activity is to the different activity finish times.

4.1.3 Resource leveling

The resource-leveling problem considers how to make the resource consumption as efficient as possible within a predefined project deadline. Ponz-Tienda et al. [51], for example, used the Weibull distribution to establish an estimation of the global optimum as a termination condition. The proposed algorithm is implemented using VBA for Excel to enable practitioners to choose between different feasible solutions to a problem in realistic environments.

4.1.4 Resource availability cost problem

The resource availability cost problem links the cost of a resource to its availability and minimizes the total cost of the necessary resources, premising that the project duration is acceptable. Qi et al. [52], for example, developed a method to directly solve this problem. The method adjusts the start time of each activity of the yielded schedule to further reduce the total cost.

4.1.5 Work continuity optimization

Work continuity optimization minimizes the total cost of projects by minimizing idle time of spatial resources between the first and last tasks of similar activities. Spatial resources are a resource type that is not required by a single activity but rather by a group of activities such as dry docks in a ship yard [53]. Vanhoucke [54], for example, described the scheduling of a real-life tunnel project and showed that work continuity is the main issue during the scheduling phase.

4.1.6 Time minimization

In time minimization, the start time of the dummy end activity is minimized subject to the limited availability of resources. In its basic formulation, this approach assumes that activities have a fixed duration and are not allowed to be split (pre-empted). Vanhoucke and Debels (2008) [55], for example, relaxed this assumption and investigated its impact on the project completion time and the efficiency of resource use. The authors analyzed three different situations: (1) the variation of activity durations, (2) the presence of pre-emption, and (3) the fast tracking (parallel execution of subparts of activities). Their results indicated that the variation of activity durations and/or fast tracking has a significant impact on both the project completion time and the resource utilization. The extra effect of pre-emption is found to be negligible.

The existing literature covers different formulations of the time–cost problem, i.e., linear, nonlinear, and discrete [47]. Integrated cost/schedule risk analysis analyzes the risks to the project and identifies how they may affect the project cost and schedule. More specifically, this approach specifies the impact of schedule risk on cost risk and cost contingency reserves [11]. This chapter offers a comprehensive methodology that takes into account not only time-dependent resources, but also time-independent resources in integrating cost and schedule risks.

4.2 An integrated cost/schedule risk analysis approach for the defence project

This section suggests a stochastic approach to conduct an integrated cost and schedule risk analysis for new large-scale projects. The suggested approach captures the effect of schedule uncertainty on cost. It incorporates project duration with time-dependent and time-independent resources to provide more accurate project cost and cost contingency estimates. It also provides useful indicators about the potential critical path and schedule buffer. The approach involves eight steps as summarized in the flow diagram in Figure 11.

In Step 2, costed resources are assigned to activities and a distinction is made between time-dependent and time-independent costs in the schedule [11]. As stated in [8], the cost of activity *j* can be expressed as

$$c_j = a_j + b_j d_j, \tag{6}$$

where d_j is the duration of activity j and the constants a_j and b_j are respectively the time independent cost and the cost per unit time of activity *j*. Equation (6) states that the direction of influence is from schedule to cost in this approach. The project total cost is given by

$$C = \sum_{j=1}^{n} \left(a_j + b_j d_j\right), \tag{7}$$

where *n* is the total number of activities.

The other steps are conducted in the same manner as in Chapter 3 [7]. In Step 1, a work breakdown structure is used to present the causal dependencies between all activities required to complete the project. In Step 3, a probability distribution is applied for the variables a_j, b_j, and d_j. A three-point estimate approach may be used to assess the likely fluctuation of each variable. In Step 4, a Monte Carlo simulation is used to generate multiple schedules and costs. In Step 5, the critical path ranking probabilities from Monte Carlo simulation are estimated and organized using a ranking probability matrix. This step is basically similar to Step 3.2.4 in Section 3. In Step 6, the risk-adjusted critical path is derived by optimization in the same way as in Step 3.2.5 (Section 3). In Step 7, an integrated cost/schedule risk profile is generated and presented using the CDFs of the overall cost in Equation (7). In Step 8, a sensitivity analysis using stochastic simulation is conducted to evaluate the robustness of the risk profile.

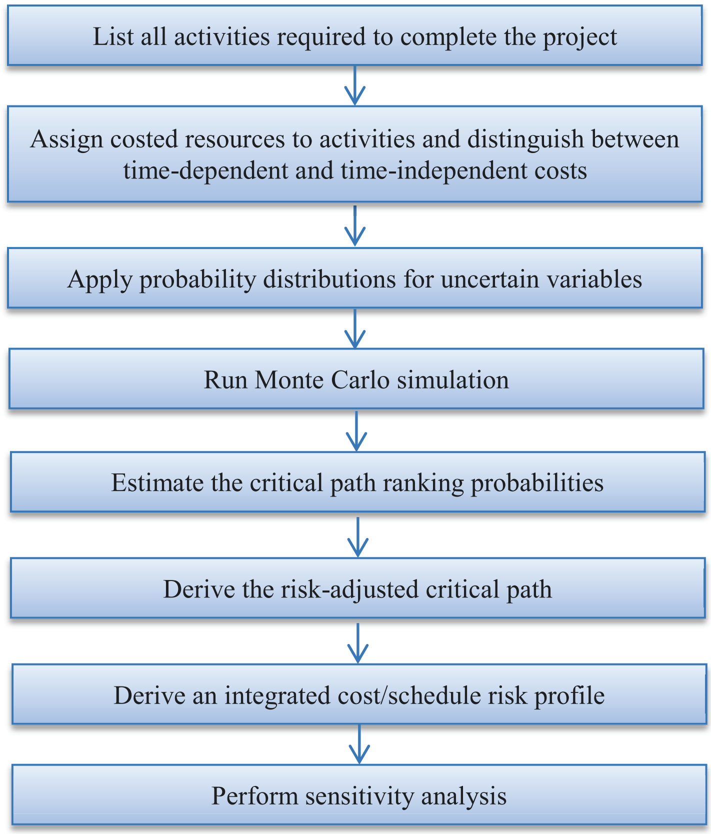

Figure 11: *Cost/schedule risk analysis approach steps.*

4.3 Illustrative example

The approach presented in Section 4.2 is applied to a military aircraft replacement project. In this illustrative example, the set of tasks contains 22 standard tasks such as the preparation of the procurement documents. Table 5 summarizes the first three steps described in Figure 11. (1) It provides the set of tasks and their interdependencies; (2) assigns time-dependent and time-independent costs to activities; and (3) applies a probability distribution for each risk impact using a three-point estimates approach. Monte Carlo simulation is used to combine the input distributions. The critical path ranking probabilities and the corresponding risk-adjusted critical path are derived in the same way as in Section 3. Figure 12 presents the resulting risk profile. Figure 12 depicts the CDFs of the cost estimate when only cost varies, when only schedule varies, and when cost and schedule vary. It displays the benefit of integrating cost and schedule risk within the same model and provides a more complete and accurate profile of cost risk. This graph confirms that when the schedule risk is not involved, the cost risk is underestimated [11]. The sensitivity analysis can be conducted in the same way as in the previous sections.

Table 5: *Task, costs, durations, and dependencies.*

Task	Successors	Duration (months) (d_j)			Time independent Cost (a_j)			Time dependent Cost (b_j)			Only cost varies	Only time varies	Cost & time vary
		Min	ML	Max	Min	ML	Max	Min	ML	Max			
T1	T2	0	0.5	1	99	101	103	0	0	0	101	101	101
T2	T3,T5	1	1.5	2	38	40	45	40.0	43	44.0	105	105	105
T3	T4	2.5	3	3.5	77	80	81	51.0	55	55.5	243	245	243
T4	T6	0.5	1	1.5	6	8	10	19.5	20	22.0	28	28	28
T5	T10	18	20	22	148	150	152	47.0	48	49.0	1110	1110	1110
T6	T7	6	7	8	0	0	0	73.5	75	76.0	524	525	524
T7	T10	6	7	8	100	102	104	44.0	45	46.0	417	417	417
T8	T10	0.5	1	1.5	48	50	52	0.0	0	0.0	50	50	50
T9	T10	1	2	3	37	40	42	37.0	38	38.5	116	116	116
T10	T11	0	0.5	1	4	5	6	49.0	51	52.0	30	31	30
T11	T12,T13	0.5	1	2	15	18	21	34.5	36	37.0	54	56	57
T12	T14	1	3	5	38	40	42	60.0	62	62.5	225	226	225
T13	T22	33	35	37	348	350	352	51.0	55	57.0	2263	2275	2263
T14	T15,T20	2	4	6	66	75	77	31.0	33	33.5	205	207	205
T15	T18	3	4	5	20	25	30	0.0	0	0.0	25	25	25
T16	T18	1	3	5	67	71	73	41.0	43	44.0	199	200	199
T17	T18	2	3.5	5	25	30	35	29.5	30	30.5	135	135	135
T18	T19	1	2	3	0	0	0	24.0	25	27.0	50	50	50
T19	T22	1	2	3	69	70	75	73.5	74	74.0	219	218	219
T20	T21	4	6	10	148	150	152	63.0	65	66.0	539	562	561
T21	T22	0.5	2	3.5	43	45	50	0.0	0	0.0	46	45	46
T22	T23	1	2	2.5	60	65	75	62.0	64	65.5	194	188	188

Note that we have derived the integrated cost/schedule risk profile, assuming that the time-cost trade-off problem has already been solved. As shown in Table 5, we assume that the following variables are known:

- activity durations,
- activity time-independent costs, and
- cost per unit time.

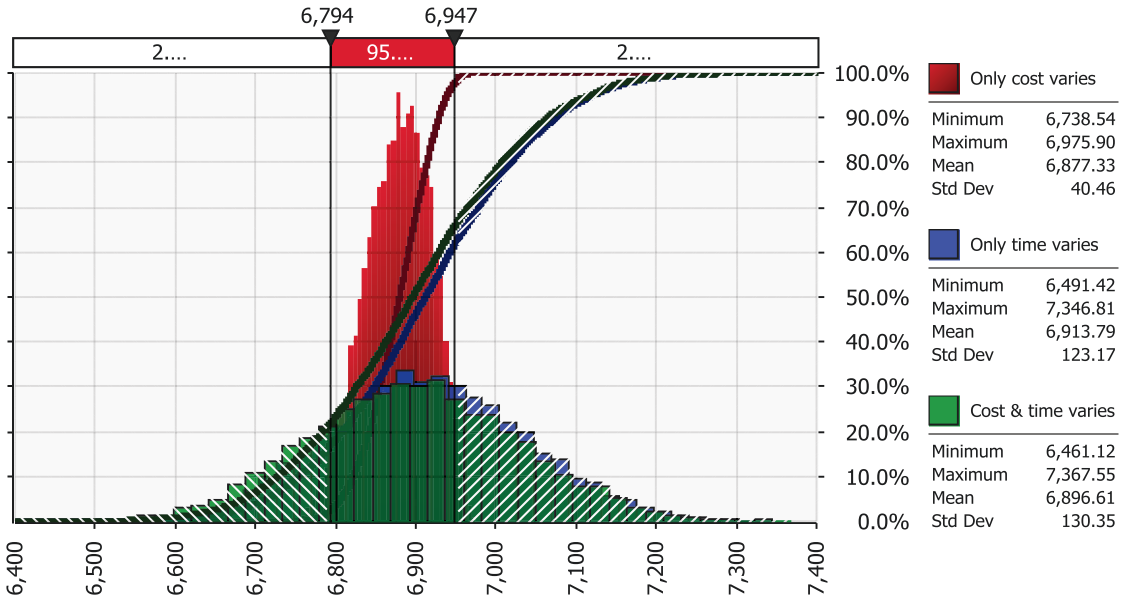

Figure 12: *Distributions of the cost estimate.*

5 Conclusion

Handling uncertainty in defence acquisition projects has been an ongoing challenge for military forces. The ability to accurately define a cost and a schedule for these projects is challenged by their large scale and uncertainties in their interrelated activities. This report presents state-of-the-art methods for analyzing cost risk, schedule risk as well as integrated cost/schedule risk. The proposed approach would provide decision makers with useful indicators about the potential critical activities and the expected cost contingency and schedule buffer. It would also enable them to better handle common causal risks and minimize the consequences of adverse events.

5.1 Cost risk

Various quantitative and qualitative cost risk analysis methods were discussed and a simulation-based risk analysis approach was proposed for defence acquisition projects. In general, qualitative methods are useful when there is little historical data available or when the project requirements have not yet been established. They are most appropriate for assessing risk at the earliest stages of project conception when even subjective opinions are difficult to elicit. Quantitative methods, however, provide more detailed cost risk analysis results and would be applied when probability distributions on cost elements or drivers can be estimated from historical data or deduced from expert opinion. A DRL metric could be used to determine whether a qualitative or quantitative analysis has to be undertaken. A high DRL, for example, represents situations where sufficient data is available to perform a detailed quantitative risk analysis using simulation methods, for example.

5.2 Schedule risk

A literature overview of analytical methods for project schedule risk analysis was conducted. Depending on the availability and quality of project data, two main approaches for schedule risk analysis were identified: phase driven approach and event driven approach. The phase driven approach is a high level method that divides the project schedule into a number of phases with different distributions of completion times and combines the probability distributions of all the phase completion times to determine a confidence interval around the mean schedule. The event driven approach, however, provides a detailed assessment of the project schedule risk using CPM. As for cost risk analysis, a DRL metric could also be used to select an appropriate method for schedule risk analysis.

Building on this review, a novel schedule risk analysis approach for defence acquisition projects was proposed. The approach combines optimization and stochastic simulation techniques to conduct schedule risk analysis. Optimization was used to objectively identify the most likely critical path and simulation was applied to derive a schedule risk profile.

5.3 Integrated cost/schedule risk

A familiar approach to quantitative risk analysis for small projects (e.g., involving short schedules and small budgets) is to conduct analyses of the risks and uncertainties as separately applied to the schedule and to the cost. However, there will be some line items in the cost analysis to account for project overruns; this will necessarily be a crude and clumsy approximation of the true impact. For complex acquisition projects (e.g., involving extended schedule and large budgets), a more realistic approach to quantitative risk analysis is to integrate all aspects of the analysis into a single model. As such, the interactions between cost, time, risk and certainty can be modelled to represent the real-world situation. In this way, time-dependent costs may be individually modelled and related to their particular schedule drivers.

5.4 Other considerations

This study focused primarily on the cost and schedule risks, as they are the most common risks in defence acquisition projects. Future research should consider other risk factors such as technical and operational performance risks. Technical risk is the probability of loss incurred through the execution of a technical process in which the outcome is uncertain. Untested engineering, technological or manufacturing procedures entail some level of technical risk that can result in the loss of time and resources. Operational performance risk is the consequence of the military system not performing well enough in a warfighting environment to fully accomplish its mission or task, resulting in undesirable outcomes or effects. These risks could be viewed as risk drivers in the risk analysis approach presented in this report.

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List of symbols/abbreviations/acronyms/initialisms

ADM (Fin)	Assistant Deputy Minister Finance
AOPS	Arctic Offshore Patrol Ships
BN	Bayesian Networks
C	Incremental Cost
CAD	Canadian Dollar
CCM	Critical Chain Methods
CFD	Cumulative Distribution Function
CPM	Critical Path Method
CRS	Chief Review Services
CSC	Canadian Surface Combatant
DND	Department of National Defence
DRDC	Defence Research and Development Canada
FWSAR	Fixed Wing Search and Rescue
GAO	Government Accountability Office (United States)
JSS	Joint Support Ship
KPMG	Klynveld Peat Marwick Goerdeler
MSVS	Medium Support Vehicle System
NGFC	Next Generation Fighter Capability
PERT	Program Evaluation and Review Technique
SAS	System Analysis and Studies Panel
SM	Simulation Model
USD	United States Dollar

DOCUMENT CONTROL DATA (Security markings for the title, abstract and indexing annotation must be entered when the document is Classified or Designated)	
1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g., Centre sponsoring a contractor's report, or tasking agency, are entered in Section 8.) DRDC – Centre for Operational Research and Analysis Defence Research and Development Canada 101 Colonel By Drive Ottawa, Ontario K1A 0K2 Canada	2a. SECURITY MARKING (Overall security marking of the document including special supplemental markings if applicable.) CAN UNCLASSIFIED 2b. CONTROLLED GOODS (NON-CONTROLLED GOODS) DMC A

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

Risk Analysis of Defence Acquisition Projects : Methods and Applications

4. AUTHORS (last name, followed by initials – ranks, titles, etc., not to be used)

Sokri, A.; Ghanmi, A.

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
October 2017	40	55

7. DESCRIPTIVE NOTES (The category of the document, e.g., technical report, technical note or memorandum. If appropriate, enter the type of report, e.g., interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Scientific Report

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

DRDC – Centre for Operational Research and Analysis
Defence Research and Development Canada
101 Colonel By Drive
Ottawa, Ontario K1A 0K2
Canada

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.) DRDC-RDDC-2017-R124	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

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Risk analysis is an integral part of the risk management process for defence acquisitions. It provides a means to examine the impact of individual risks on the overall project objectives to determine the probability of concluding the project on a given budget (cost risk analysis) or on a given time (schedule risk analysis). While there is an extensive literature on risk management for defence acquisition programs, there are limited research studies and critical gaps in cost and schedule risk analysis methodologies and techniques. This Scientific Report synthesizes the work conducted by the authors during the past few years on risk analysis research. It provides a literature overview of analytical methods for project risk analysis, and suggests quantitative methods for analyzing cost risk, schedule risk, and integrated cost/schedule risk of defence acquisition projects. The proposed approach would provide defence leadership with useful indicators about the expected cost contingency and schedule buffer.

L’analyse du risque fait partie intégrante du processus de gestion des risques liés aux acquisitions militaires. Elle permet d'examiner l'impact des risques individuels sur les objectifs globaux d’un projet. Elle détermine la probabilité de réaliser un projet en temps requis (analyse du risque d’échéancier ou de calendrier) et sans dépasser un budget donné (analyse du risque de coût). Malgré la richesse de la littérature sur la gestion des risques, il y a encore des lacunes dans les méthodologies et les techniques d'analyse des risques liés aux acquisitions militaires. Ce rapport scientifique synthétise les travaux menés dernièrement par les auteurs dans ce domaine. Il fournit une vue d'ensemble de la littérature existante et suggère des méthodes quantitatives pour analyser le risque de coût, le risque d’échéancier, et le risque intégré de coût et d’échéancier. L'approche proposée fournirait aux décideurs des indicateurs utiles sur les réserves de coûts et de temps.

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