The current issue and full text archive of this journal is available on Emerald Insight at:
www.emeraldinsight.com/0263-5577.htm

Managing supply chain risks and delays in construction project

Received 25 September 2017
Revised 23 February 2018
Accepted 29 April 2018

Yulia Panova
Department of E-Commerce, Luoyang Normal University, Luoyang, China and Department of Logistics and Supply Chain Management, National Research University Higher School of Economics, St Petersburg, Russia, and
Per Hilletofth
Department of Industrial Engineering and Management, School of Engineering, Jönköping University, Jönköping, Sweden and Department of Industrial Engineering and Management, University of Gävle, Gävle, Sweden

Abstract

Purpose – The purpose of this paper is to investigate models and methods for managing supply chain risks and delays in construction projects.
Design/methodology/approach – The study mainly employs quantitative analysis in order to identify disruptions in construction supply chains. It also uses paradigms of simulation modeling, which are suitable for risk assessment and management. Both qualitative and quantitative data were collected through a literature review and details of specific construction projects, respectively. A dynamic modeling method was used, and the model was provided with an event-based simulation. Simulation modeling was used to measure the performance of the system.
Findings – The study shows the benefits of applying the dynamic modeling method to a construction project. Using event-based simulation, it was found that construction delays influence both the magnitude and the probability of disruption. This method contributes to the existing theoretical foundations of risk management practices, since it also considers the time factor. This method supplements the Monte Carlo statistical simulation method, which has no time representation. Using empirical analysis, the study proposes increasing the safety stock of construction materials at the distribution center, so as to mitigate risks in the construction supply chain.
Research limitations/implications – The research considers a single case of a hypothetical construction project. The simulation models represent a simple supply chain with only one supplier. The calculations are based on the current economic scenario, which will of course change over time.
Practical implications – The outcomes of the study show that the introduction of a safety stock of construction materials at the distribution center can prevent supply chain disruption. Since the consideration of risks at all stages of construction supply chain is essential to investors, entrepreneurs and regulatory bodies, the adoption of new approaches for their management during strategic planning of the investment projects is essential.
Originality/value – This dynamic modeling method is used in combination with the Monte Carlo simulation, thus, providing an explicit cause-and-effect dependency over time, as well as a distributed value of outcomes.

Keywords Risk management, Construction projects, Construction delays, Simulation modelling
Paper type Research paper

1. Introduction

Construction projects are inevitably related to a future period of time so that it is problematic to predict the results of their implementation. They depend on how accurately the amount of material and their associated flows during the project are forecasted. Insufficient information is a problem, and stochastic materials flow through the value stream likewise hinder the universal application of lean principles to the construction supply chain (Fearne and Fowler, 2006; Forsman *et al.*, 2012; Eriksson, 2010). In essence, the lean concept focuses substantially on the process flow, and a synchronization of

Industrial Management & Data Systems
Vol. 118 No. 7, 2018
pp. 1413-1431
© Emerald Publishing Limited
0263-5577
DOI 10.1108/IMDS-09-2017-0422

demand and production. Therefore, it is difficult to implement this in the construction industry, due to its inherent uncertainty and complexity, both of which cause disintegration in its supply chains (Voordijk *et al.*, 2006; Briscoe and Dainty, 2005; Fearne and Fowler, 2006). Hence, the construction supply chain should be developed within the framework of the "agile paradigm" (Vrijhoef and Koskela, 2000). Nevertheless, this study supports the idea of using a material inventory to avoid supply chain disruption in the construction industry.

Difficulties in planning construction projects result in the work flow variability causing inefficiency in downstream processes that result in delays and the associated costs. Accordingly, it is crucial to consider all possible outcomes and the influence of risk factors due to disruptions in the construction supply chain. Risk factors affect the value of investment in construction projects, by inducing a deviation of future cash flows from the expected flow within the project, which results in firms exceeding their budget goals. For so-called "megaprojects", risks may result in cost overruns during the process of their implementation with more than 100 percent overspending from the expected budget appraisals, and the incurring of additional costs even before the construction begins.

The actual financial cost of the longest underwater railway, the Channel Tunnel, was sharp 140 percent higher than the estimated investment cost (Flyvbjerg *et al.*, 2003). The increase in cost by 55 percent of the Great Belt Bridge (Denmark) was noted three years before the expected date of completion of the project, while the change in the cost (+10 percent) of the Öresund Bridge (Sweden) was recorded even before the start of its construction (Bruzelius *et al.*, 2002). The underestimation of risk factors for projects, especially capital-intensive ones, at the stage of their feasibility study, leads not only to unexpected financial losses, but also delays in projects commissioning. However, the number of studies that address the delays and cost overrun issues simultaneously in construction projects is not sufficient. Previous studies focus on the delays alone and not on cost overruns or both (Ramanathan *et al.*, 2012).

A risk-free asset is a case of hypothetical construction, which is widely used in the theory of finance, however, in the real life is impractical to achieve (Black *et al.*, 2012; Shapkin and Shapkin, 2013). It is essential to restrain the previously mentioned types of risk, which have numerous causes, primarily construction delays (Ramanathan *et al.*, 2012). Some authors note that the cause of these risks is rooted in close deadlines due to changes in construction schedules, incorrect forecasts of traffic volumes, an easing of bidding rules and possibly corruption as well. Other authors emphasize that failure factors are rooted in inaccurate data and irrational research methods (Panova and Hilmola, 2016; Bruzelius *et al.*, 2002; Flyvbjerg *et al.*, 2003). From this point of view, the development of methods and models that consider and assess construction risks in terms of their initial cost estimate is a fundamental task from both a practical and theoretical points of view.

The probabilistic nature of risks is difficult to consider on the basis of analytical formulae. The inappropriateness of some methods for assessing the investment in infrastructure projects has led to a combination of different methods (e.g. deterministic and stochastic approaches using the Monte Carlo analysis (MCA); Esipova *et al.*, 2010; Salling, 2013; Lorenzo *et al.*, 2012; Ambrasaite *et al.*, 2011). The Monte Carlo test is one of the most suitable methods of quantitative risk assessment, since it can deal with the greatest possible number of risk factors (Panova and Hilmola, 2016). However, the method has no explicit time representation and aims to solve the deterministic problem probabilistically. Therefore, in order to describe the dynamic system, which is represented by the construction project, the application of dynamic modeling is proposed. In particular, by means of an event-based simulation of construction delay issues, the magnitude and the probability of the disruption can all be explained explicitly.

The aim of this research is to investigate models and methods for managing supply chain risks and delays in construction project. The specific research questions are:

RQ1. What models and methods are suitable for the economic appraisal of construction project delays?

RQ2. How can construction delays regarding time and cost risks be assessed and mitigated by a combination of different methods?

Both qualitative and quantitative methods were used to address these questions. The qualitative data were collected through a literature review, in order to explore various possible disruptions in construction supply chains, and to identify simulation modeling and risk assessment methods. The quantitative data were collected through the detailed hypothetical construction project and was subjected to simulation modeling techniques.

The remainder of this paper is structured as follows. To begin with, an overview of relevant models and modeling methods and specifically those for managing delays in construction projects is provided in Section 2. The research method for this research is then described in more detail in Section 3. Thereafter, the simulation models and their outcome are discussed in Section 4. Finally, the research is concluded and venues for further research are proposed in Section 5.

2. Models and methods for managing construction delays

2.1 Lean concept in construction supply chains

The lean concept has been widely applied in manufacturing to reduce waste that restricts process efficiency. However, the development of production processes by adopting lean principles in the construction supply chains is still in its infancy (Forsman *et al.*, 2012). The peculiarities of this industry prevent the elimination of all waste in its supply chain.

Out of the seven wastes in the lean concept (Forsman *et al.*, 2012); inventory waste is hardly eliminated at all from the construction supply chain. In many instances, inventory is essential for companies, because of imbalanced demand and production capabilities, long distances between suppliers and customers, low delivery reliability and speculative intentions as well as inflation expectations (Lukinskiy and Panova, 2017).

Unlike other supply chains, for example, vehicle manufacturing or retail distribution industrial sectors, which are highly integrated, the realization of truly integrated construction supply chains is problematic and difficult to achieve (Briscoe and Dainty, 2005). Therefore, lean principles cannot be fully applied. Many authors stress that in construction sector, fragmented integration stems from supply chain complexity (Voordijk *et al.*, 2006; Briscoe and Dainty, 2005; Fearne and Fowler, 2006). In particular, Voordijk *et al.* (2006) provide multiple case study evidence on the modularity of construction supply chain, that it exhibits low proximity and being represented by geographically dispersed actors, is characterized by autonomous managerial and ownership structures, diverse cultures and low electronic connectivity (in contrast to supply chains in other sectors which have a high degree of integrality).

Briscoe and Dainty (2005) also stress the existence of various different companies supplying materials, components and a wide range of construction services, as well as a large subcontracted workforce, which limit opportunities for process integration. Moreover, the construction projects themselves are treated as a series of sequential and predominantly separate operations, for which the individual participants are not particularly committed to the common goals, e.g., long-term success of the final construction (Briscoe and Dainty, 2005; Fearne and Fowler, 2006).

Of critical importance is uncertainty, a characteristic of most construction projects (Fearne and Fowler, 2006; Oparin, 2015; Flyvbjerg *et al.*, 2003; Bruzelius *et al.*, 2002). In order to respond to this feature, responsibility and flexibility are essential. For this reason, construction supply chains should be developed within the framework of the agile paradigm, rather than that of lean thinking (Vrijhoef and Koskela, 2000). Even though lean thinking reduces variability and buffer stocks, which make the supply chain efficient, it is stripped off its capacity to respond to adverse specifications and to change in the operating environment (Fearne and Fowler, 2006). In fact, authors underline that the ubiquitous and indiscriminate usage of lean thinking may result in sub-optimization or so-called local efficiency (Fearne and Fowler, 2006; Forsman *et al.*, 2012) that can reduce the project's overall effectiveness.

Adoption of the lean concept is limited and depends on the extent to which it is really required. For example, Eriksson (2010) found that lean-related aspects have been broadly utilized in projects, when they focus on cooperation and serve as the starting point for a fully-fledged utilization of the lean concept. Thus, informal collaborative efforts have been used explicitly as an aspect of the lean concept in the specific case (Eriksson, 2010; Khalfan *et al.*, 2007).

Meanwhile, other aspects of the lean concept, like just-in-time (JIT) deliveries, and joint IT tools that relate to waste reduction, were as above only implicitly used to some extent (Eriksson, 2010). This favors the idea that the complete elimination of inventory, supported by JIT operations, are difficult to achieve in the construction sector. Many authors point out the slow growth in efficiency of construction industry, compared to the aerospace and automotive industries where the productivity improved substantially during the last few years (van Lith *et al.*, 2015; Tookey *et al.*, 2005).

Therefore, substantial research has been done to solve the problems that arise in construction supply chains. Considering the above difficulties in planning construction projects, this study addresses the formal methods and models of the construction supply chain management.

2.2 Models for estimation of construction delays

Ameyaw and Chan (2013) present a comprehensive analysis of risks related to specific infrastructure projects including transportation, telecommunications, power and energy plants. The breakdown of risks includes 81 factors. Based on the varied classification of risks, it was found that the most frequent ones were political, construction and operational, including land acquisition and financial/market risks. The review study of Ramanathan *et al.* (2012) identified 113 factors responsible for delays, which were classified into 18 groups.

According to Ramanathan *et al.* (2012), the groups responsible for the success of project realization have been ranked as: Owner (Rank 1), Contractor (Rank 2). In this regard, it is necessary to take into account the assessment and mitigation of risks related to the contractor (e.g. delays in assets transfer, material supply delay and of other resources; timeliness of loading and shipment of goods during the transportation stage).

Beyond the identification of causes and disruptions in construction supply chains, it is important to evaluate the associated risks, since they affect the estimated return on investment of the project. The concept of risk is also linked to uncertainties associated with events. In the context of construction projects, risk is commonly associated with an uncertain event or a condition that leads to a positive or a negative outcome with respect to the project's objectives. The concepts of risk and uncertainty in the literature are not always identical. Uncertainty is the incompleteness and inaccuracy of information about the conditions of project implementation (Oparin, 2015). Authors in the area stress that risk is the possibility of occurrence during the project implementation, of conditions, which will or may lead to negative consequences for all or individual project participants. When there is a risk, each alternative generates a probability distribution over possible consequences, and the decision-maker has to choose on the basis of this probability of distributions (Black *et al.*, 2012). If the probability is unknown, then the choice is made under uncertainty, which is the perceived inability to make accurate predictions and calculations (Milliken, 1987; Knight, 2012).

In this paper, the realization of an investment project for a container terminal which undergoes the delay of material supply to the construction site, and as a result, the overall delay in commissioning phase is being analyzed. Accordingly, the assessment of the construction risks is considered as a prerequisite for their mitigation. For the estimation of those risks, one of the most important capital-budgeting models is applied, for example, net present value (NPV) and discounted payback period (DPP). The statistical mean of the NPV and DPP is used to determine the expected cumulative profit and payback time for the investment respectively, while the standard deviation determines the risk, with respect to the budget and timing of the construction project.

Two capital-budgeting models are proposed because NPV, first, is perceived as a superior technique (Keown *et al.*, 2003; Dymowa, 2011; Pyles, 2014), despite the fact that economic appraisal of construction projects relies on a stream of capital-budgeting techniques such as payback period, profitability index, internal rate on return, modified internal rate of return and DPP. Also, NPV can recognize the time value of money, which differs from the payback period (Pyles, 2014).

Second, the use of the payback period as a decision-making criterion has its own benefits, such as that it is easy to visualize, is understandable, easy to calculate and can indicate the projects' liquidity (Keown *et al.*, 2003). Moreover, the DPP can be adjusted for the time value of money. Bhandari considers six capital budgeting decision criteria, of which the discounted payback satisfies ten characteristics (e.g. simple to understand, measures profitability, ensures liquidity, etc.). None of the six criteria meet all the requirements of an ideal criterion like DPP and NPV.

It should be noted that the NPV rule ensures profitability, but not liquidity. In other words, decision-making on the acceptance of the project on the basis of a positive NPV does not take into account the time period, or a project's useful life that is exposed to risks, due to the disruption in construction supply chain. These peculiarities can be easily indicated with the use of DPP. For this reason, the DPP is not a less important criterion than NPV, and is more effective for use as a decision-making technique for construction delays in the investment projects. Its benefits are indicated through its application in economically assessing the construction project (container terminal). The benefits of both analytical models, such as NPV and DPP, for the assessments of delays of infrastructure projects, can amplify if these models are be calculated by using simulation platforms (e.g. Panova and Hilmola, 2016).

2.3 Qualitative and quantitative methods for risks assessment

There are various methods for assessing the probability of failure, and risks on the performance criteria, e.g., based on expert estimations, method of analogies (qualitative methods), simulation techniques, MCA (quantitative methods) or semi-quantitative approaches.

Risk assessment is a technical and scientific process by means of which the risks of a given situation for a system are modeled and quantified. For the development of a container terminal, risk estimations can facilitate its successful implementation. However, not all assessment methods can be beneficial for construction project delay assessment, due to various shortcomings.

Qualitative risk analysis employs judgment and sometimes expert opinion to evaluate probability and consequence values, while quantitative analysis relies on probabilistic and statistical methods. To increase the reliability of expert estimates, the pairwise comparison method, also known as analytic hierarchy process (AHP) is often used in decision support systems. Dey (2009) identifies construction project risk levels in an AHP framework, while Gaudenzi and Borghesi (2006) apply the method for assessing risk in supply chains. Thus, the AHP supports managers in demonstrating the relationships of the overall goal, as well as supply chain objectives, in identifying risks and assessing their potential impact within the chain.

Apart from expert estimations, no less common in the qualitative assessment of investment risk is the method of analogies or estimation by analogies, EBA, or analogy based estimation. The main difficulty with this method is in achieving the correct selection of the analogy, because there are no formal criteria for establishing the degree of similarity of situations. Decision-makers on less familiar terrain must look to other industries for comparisons. For example, a company shifting from a product-based to a service-based business model might consider IT companies that have already made this shift (Courtney *et al.*, 2013). Consequently, although business leaders frequently use analogies to inform their decisions, many fail to do so in a rigorous, systematic manner (Courtney *et al.*, 2013).

Meanwhile, expert judgments are quite often used to describe risks so that the uncertainties in expert judgment, as well as the resulting variance of the risk calculation cannot be entirely eliminated (Pluessa *et al.*, 2013). In general, qualitative methods offer analysis without detailed information, and the intuitive and subjective process may result in imbalanced outcomes by those who use them. Because qualitative methods do not allow determining the numerical magnitude of the risk associated with the investment project, this can be the basis for further research using quantitative methods.

The latter methods are widely based on the mathematical apparatus of probability theory, that is, mathematical statistics. The main objective of the quantitative approach is to determine the impact of risk factors on efficiency criteria of the investment project. Accordingly, quantitative analysis is more desirable for container terminal project economic assessment, in terms of obtaining accurate results.

The most widely used method in the risk assessment of investment projects (especially productive investment) drew on several quantitative methods, such as that of adjusting the discount rate, sensitivity analysis (method of variation of parameters), scenario method (the method of formalized description uncertainties) and the Monte Carlo method (Popova, 2011).

The use of quantitative methods enables to obtain a numerical estimate of the riskiness of the project, thus determining the degree of influence of risk factors on its effectiveness. In particular, Monte Carlo simulation enables researchers to evaluate the accuracy of the sampling risks (Carlos and Fernández, 2013). In the Monte Carlo simulation method, the computer generates hundreds of possible combinations of parameters (factors) of the project with regard to their probability distributions. Each combination gives a value of the performance criteria, and in the aggregate, the analyst obtains a probability distribution of possible project outcomes.

Thus, MCA is frequently used for calculating the discounted cash flow (DCF) and free cash flow (value-based management models). With the use of MCA, the evaluation value of the DCF approach amplifies, because MCA allows taking into account the probabilistic environment, which increases the accuracy of the DCF approach (Amédée-Manesme *et al.*, 2013). More specifically, Monte Carlo is applied to calculate NVP from a probabilistic perspective (Bannerman, 1993; Amédée-Manesme *et al.*, 2013; Piranfar and Masood, 2012; Samis and Davis, 2014). This research is also geared toward a proliferation of the use MCA for calculating the DPP, in order to assess risks in the container terminal project from the probabilistic perspective.

At the same time, it should be noted that in the statistical simulation method of Monte Carlo, which aims to solve the deterministic problem probabilistically, there is no explicit time representation. Therefore, the list of quantitative methods for risk assessment

(Popova, 2011) can be complemented by the method of dynamic modeling, which takes into account the time factor (Panova and Hilmola, 2016). To describe a dynamic system, which includes the development of an infrastructure project in phases with construction delays, dynamic modeling can be used in combination with the Monte Carlo method. The combination can be enabled by the use of modeling tools. Specifically, to solve the problem, it is preferable to employ the simulation systems described below.

3. Research methodology

This present research describes methods of assessing the risks associated with delays in construction projects through comparative analysis. It also explains the stochastic nature of risk factors in construction projects. A literature review was used to determine the risk factors (e.g. time and cost), as well as approaches for their management. An experimental analysis was used to empirically validate the findings from the literature, conducted using visual simulation modeling experiments with the help of AnyLogic and Vensim computer packages.

3.1 Research strategy

This research employs both qualitative and quantitative methods. The former used is a literature review, in order to explore the various disruptions in construction supply chains. The literature review also enabled collecting background information on the topic. The paper selection was from four databases: EBSCO Business Source Complete, Emerald Insights, ProQuest and E-library (Russian database). Works in English and Russian were included. To ensure research quality, only papers published in peer-reviewed journals were considered.

The quantitative data were gathered from a hypothetical construction project. Dynamic modeling was used, and the model was provided with an event-based simulation. Simulation modeling was used to measure the performance of the system. The complex system was divided into different parts for an experimental analysis. A finite number of parts were identified. The financial flows were divided into revenue, taxes, profit, operational cost, initial investments, etc., as these were convenient to incorporate in the first model. By contrast, in the second model, the system was represented by a finite number of events, such as the generation of demand for materials for a construction project, ordering of materials and update of inventory.

3.2 Data collection

To answer the research questions, both qualitative and quantitative data were used, which led to a better understanding of both the objects and subject of the investigation. The objects are the construction delays and associated risks, which were assessed in the context of the investment project, while the subject(s) are the financial flows affected by risk factors.

An in-depth review of the relevant literature was used to ensure the content validity of the research. The first part of the literature review yielded in the qualitative data from various sources, while the second part of the literature review concerned the quantitative data. This was in addition to the qualitative data, which helped to conduct the feasibility study on risk mitigation, with respect to delays in the delivery of materials to the construction sites (the secondary qualitative data were mainly in the form of analytical formulas).

3.3 Data analysis

Vensim and Anylogic were used as simulation environments for data analysis. The first computer package provides the simulation with the help of a systems dynamics approach

(Forrester, 1958). System dynamics concentrates on dynamic complexity, which is created by multi-loop feedback (Sterman, 2000). In the present study, the relationship in the causal financial diagram is simple, without considering looping, described with the help of Excel. However, this causal financial diagram requires an MCA. In Excel, it is less extended, without a sophisticated graphical representation of the model outcome (unlike the Vensim package, where MCA is built into the program, and can be applied to any model designed there). Moreover, the sensitivity test itself was more important in the current research than the feature of the Vensim environment for building complex models.

Moreover, an area of interest is the analysis of changes which occur during different time periods, also referred to as the scope of dynamic complexity (Hilletofth and Lättilä, 2012; Hilletofth *et al.*, 2009; Hilletofth, Aslam and Hilmola, 2010; Hilletofth, Ujvari, Lattila and Hilmola, 2010). In particular, the Vensim environment was used to explore the simple system in time, under the impact of risk. This system was represented by the financial flows related to the construction project, developed in phases subject to risk. These risks were assessed by the superior capital-budgeting model, NPV.

The Vensim program contains the built-in dynamic function for computing the NPV of the project. This dynamic function of the program returns the NPV of the stream, computed using the discount rate. The computation assumes that the stream is valued at the end of the period and that the discount rate is considered as a discrete period rate. This is the same set of assumptions that Excel uses, although, Vensim allows a simultaneous MCA and representing the results in the form of a sensitivity graph.

Unlike the Vensim program, AnyLogic contains a lesser number of built-in dynamic functions and tools for representing Monte Carlo outcome, despite the fact that systems- dynamic models are supported by AnyLogic. This is because Vensim is used specifically for analyzing the systems dynamics of complicated environments (e.g. how corporate produce successes and failures). On the other hand, AnyLogic is suitable not only for the application of systems dynamics, but also for agent and event-based approaches, either separately or in combination within one model. This provides the opportunity for pure coding, as well as a reasonable level of detail and off-the-shelf functionality, which makes Anylogic a good toolset for creating hybrid models (Lättilä *et al.*, 2010; Hilletofth, Ujvari, Lattila and Hilmola, 2010).

In the current study, it would be possible to create a hybrid model, if the AnyLogic software had more extended Monte Carlo analyses (possibility to represent the outcomes in the form of statistics, sensitivity graphs, tables, etc.). However, it would take a long time, since not all of the simulation paradigms are easily matched. For example, SD models are continuous by nature, and have difficulty coping with discrete events (Lättilä *et al.*, 2010). Due to these reasons, the second model was built in Anylogic.

It should be noted that the interaction between different simulation programs was provided manually. For instance, the data outcome was obtained from the Anylogic model, and applied to the model developed in Vensim. In Anylogic, there is a built-in feature for converting the models developed in Vensim, so as to access them in the Anylogic. However, Vensim does not provide such an ability to serve the needs of the current research.

The event-based simulation was applied in order to build the second model with information on construction delays in the supply chain. As the structure of the system tends to be fixed in the system dynamics paradigm, it is easier to use the other paradigm to study systems, which tend to evolve through time (supply networks are a good example; Lättilä *et al.*, 2010). In the built model, the event was the simplest way to plan actions. Overall, events are often used to model delays.

The behavior of the second system was modeled by action charts and three types of event. The first event occurs after the timeout, which was used when there was a need to schedule the execution of some action at a certain point in time. An event type that occurs after the timeout was used in combination with additional option of the cyclic mode (e.g. for the generating demand for materials at the construction sites). The second event, triggered by timeout, was used in combination with other modes (occurring ones). It was applied for the computation of stockout costs at the end of the simulation period. The third timeout event was complemented by the managed manually mode. It was triggered by the action chat and simulated the completion of a new order of construction materials and simultaneous update of the stock level at the warehouse.

In conclusion, it should be noted that the simulation models were used for explanatory purposes, providing an overall understanding of the system, rather than a normative one. Unlike a normative system, for which simulation models are normally validated with historical data, the other models might yield suggestions that are far from optimal (Lättilä *et al.*, 2010). Thus, the computer simulation merely helped to explain how the construction delays occur and influence the disruption, rather than yield normative results.

4. Findings

4.1 Base scenario of the system dynamics model for financial flow analysis

In order to analyze and assess the risks associated with the project of creating a container terminal, it is necessary initially to calculate, in a risk-free environment, indicators such as income, expenses, gross and net profits, taxes, etc. for the entire period of the project realization (from 2017 to 2022). The calculations mainly employed analytical formulas from Panova and Hilmola (2016). It was assumed that the center is planned to perform logistical services, such as cargo and container handling, warehousing, organization of cargo delivery by trucks, customs clearance, etc. The computation of the financial plan was based on data from the Russian companies providing a similar complexity of logistics services to the project under consideration. For the economic appraisal of the hypothetical container terminal project, which was exposed to various risks, the initial value of capital investments was estimated at approximately 10 ML EUR (Table I).

The income and expenses were associated with by provision of logistics services. Indirect expenses were calculated with allowance for the wages payment fund and administrative costs. For the calculation of the NPV and DPP, the interest rate was taken at 11.8 percent, allowing for the key refinancing rate of 8.5 percent provided by the Central Bank of Russia (since September 18, 2017) and the level of inflation of 3.3 percent (Cbr, 2017). To foresee the growth of income, as well as expenses over the settlement period of six years, a chain price index (also known as consumer price index for the UK and USA; Black *et al.*, 2012) was taken into consideration. It should be noted that the whole financial plan was calculated the investor point of view.

To calculate NPV and DPP in a risk-free environment (so-called base-scenario), the simple model was developed in the Vensim program (Figure 1).

Based on the output of the model, the NPV and DPP were determined. In particular, the accumulated profit equals 7.248 ML EUR, while the investments will pay off in three years and 3.8 months (Figure 2).

4.2 Discrete-event model for the analysis of delays in the supply of materials

For the analysis of construction delays during realization of the project, it was proposed to focus on the risks related to the contractor, particularly untimely delivery of the materials

			Expenses			
Capital investment	Taxes	Income	Direct	Indirect	Gross profit	Net profit
10,000,000	125,530	9,480,900	5,266,000	1,185,000	3,029,900	2,904,369

Table I. Financial plan (in EUR)

(e.g. rolled metal products) to the rent warehouse. To estimate the influence of delays, the second model was developed according to discrete-event approach in AnyLogic program (Figure 3).

By using the simulation model, it is possible to analyze how the supplier, whose services the constructor company has been using for a period of one year, influences the activities of the organization. As in the first model, it is necessary to look first at the risk-free scenario (without construction delays). To perform this scenario, the following parameters were formed: per day, from the leased warehouse, eight tons of rolled metal products, with a standard deviation of three tons, are consumed. These parameters can be observed from

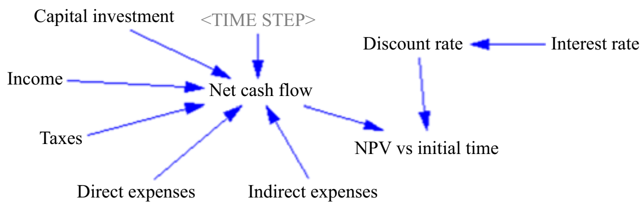
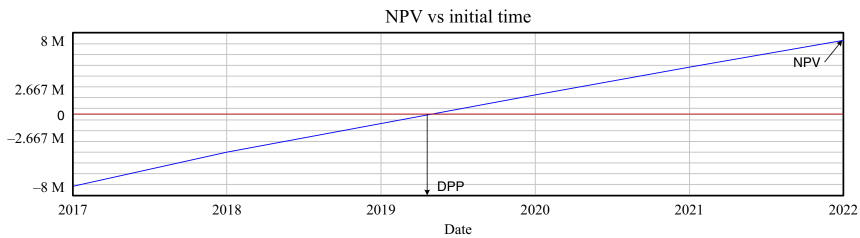


Figure 1.
The system dynamics model for appraisal of investment in the container terminal



Table

Date	2017	2018	2019	2020	2021	2022
"NPV vs initial time" Runs:	Current					
"NPV vs initial time"	–7.096 M	–3.737 M	–923.500	1.891 M	4.616 M	7.248 M

Figure 2.
The deterministic output of the model (in ML EUR)

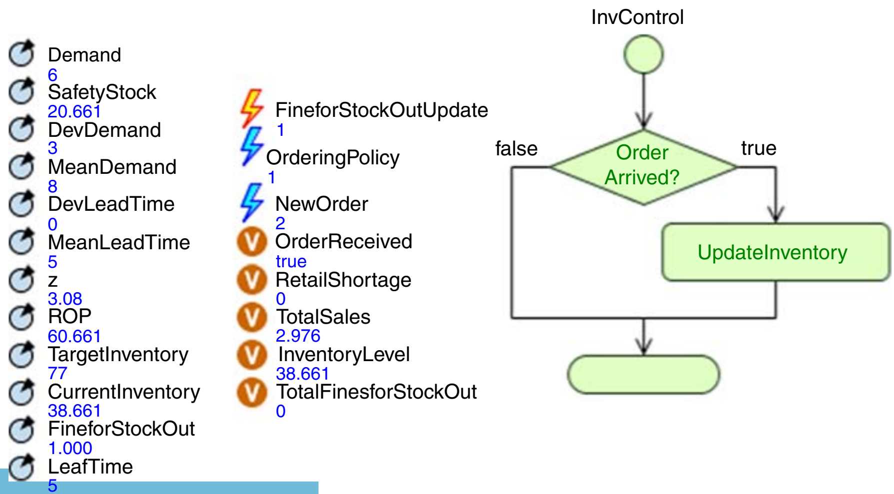


Figure 3.
The discrete-event model for the assessment of delays in supply of materials

Figure 3 ("MeanDemand" and "DevDemand"). The daily demand was calculated dynamically via the function of normal distribution over the simulation period of the experiment, which equals 365 days. This figure was represented by the demand parameter. The list of all parameters can be seen on the left of Figure 3 (in the form of gray circles).

Mean lead time for the delivery of materials from the producer is five days (parameter "MeanLeadTime", which is identical to the "LeadTime" in a risk-free scenario without delays ("DevLeadTime" = 0, Figure 3). In addition to the already defined parameters, other static parameters were introduced to the model: *Z* value to define the service level of 99.9 percent, which corresponds to 3.08, and "FineforStockOut", which equals EURO 1,000 and helped to calculate the risk of stockouts in the warehouse. The parameters "SafetyStock", target inventory and "CurrentInventory" were updated during the experiment with the help of respective events ("OrderingPolicy", "NewOrder", described in Section 3.3) and the action chart.

The created events and the action chart were also used for real-time variable changes and for accumulating of the required information during the simulation experiment (e.g. the volume of "Retailshortage", "TotalFinesforStockOut", "TotalSales", which was generated by the daily demand). One variable "OrderReceived" served as the supportive one in the action chart. It had a Boolean value and was used in defining of the replenishment rule at the warehouse. In particular, for the management of inventory at the warehouse, the "Minimum-maximum" policy, with a continuous review of inventory levels (ILs), was employed as the most flexible, in turns of stochastic demand (Lukinskiy *et al.*, 2016, 2017; Lukinskiy and Panova, 2017).

Relying on the more or less timely delivery of materials, the space for storing the rolled metal products at the contractor warehouse was calculated with an allowance for the safety stock levels and re-order point (ROP), defined by the formula (with the demand variable, and the lead time constant; Lukinskiy *et al.*, 2017):

$$\mathrm{ROP} = d \times L + z \times \sigma_c \times \sqrt{L}, \quad (1)$$

where *d* is the average demand, which determines the decrease in the IL, L the lead time, *Z* the number of standard deviations (i.e. the normal distribution parameter, which corresponds to the probability of stockouts, 3.08, corresponds to 99.9 percent service level from the standard normal distribution function), σ the value of the standard deviation of demand during lead time.

The formula of ROP was set in the simulation model and computed dynamically computed during the experiment. According to the logic of inventory policy, if the IL reaches ROP and there are no other orders in transit, which is defined by the variable "OrderReceived", the new order for the replenishment of the inventory is generated. It arrives in five days, which is defined by the "LeadTime" parameter. Once the order arrives, the IL increases, as seen in Figure 4(a).

The outcome of the model with the parameters that describe the risk-free environment, show that materials are always in stock and inventory is kept at the minimum level (Figure 4(a)).

The second scenario is not free from risks. Delays in the supply of material from the producer were modeled by the parameter ("DevLeadTime"). For this purpose, the input data of the model was corrected (i.e. the value of parameter "DevLeadTime" was set to 3 days instead of 0, as used in the first risk-free experiment). Since the lead time was not constant, the delays caused an IL with stockouts (Figure 4(b)): in the hypothetical model, the ILs were fixed even below the zero line, so as to calculate the total fines related to the cases of stockouts. Specifically, the stockouts resulted in fines that the supplier would pay to the contractor of the project. Each ton of material, which was not delivered on time to the constructor warehouse was estimated at a value of EURO 1,000 (defined by the parameter "FineforStockOut").
To a greater extent, the stockouts at the warehouse result in delays in constructing the project. In fact, the owner/designer of the project encounters postponements that entail

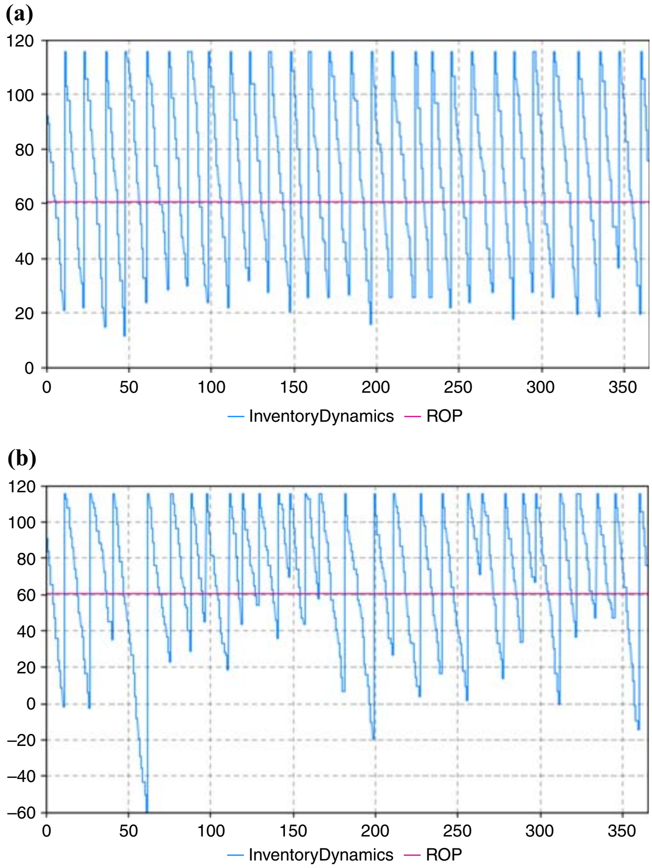


Figure 4.
The dynamics of inventory level

Notes: (a) Risk free environment; (b) with delays in supply chain

unproductive hours of both the workforce and equipment, as well as fines due to deviations from the planned period of construction of the container terminal and the corresponding lost income. The lost income per day due to the delay in commissioning the project can be defined from the yearly expected income (Table I).

Payment of forfeit (fines) due to deviation from the planned period of construction is regulated by a special rule of law. The amount of the penalty is calculated as a percentage of the contract price for each day of delay. The interest is calculated as 1/300 of the refinancing rate of the Central Bank of the Russian Federation on the day of fulfillment of the obligation. For example, the conditional refinancing rate on the day of consideration is 8.5 percent, the conditional price of the project: EURO 10,000,000 and the length of the delay is the 1 year (365 days, in the worst-case scenario). The forfeit amount can easily be determined 10,000 000 $\times$ 365 $\times$ 1/300 $\times$ 8.5/100 $=$ 1,034,167 EUR/year.

The idle time of the workforce was calculated from the assumption that the salary of workers in a month is EURO 60,000, when the salary per day is EURO 2,000 for the workforce. The average number of people in construction brigade is 20. By knowing the delays, it is possible to calculate that the amount of money that the company spends on wages for workers on days of idle time (simply by multiplying those figures). Similarly, the idle time for equipment can be calculated. The work value of the crane per day is estimated at EURO 15,000 and trucks at EURO 8,000. Hence, by multiplying by the number of days of delays, it is possible to calculate the cost to the owner.

In order to calculate the additional financial flows due to the delay of materials delivery from the supplier to the construction sites, it is necessary to determine the number of stockouts at the contractor warehouse. Just one run of the model with constant risk parameters (i.e. deviation in the lead time, which equals to three days) is insufficient. The reason is that during the run of the model, random probability samples were used. Hence, the output from one experiment would be the only individual result of a random variable with a large variance. Therefore, in order to obtain more reliable data on the number of days of stockouts in the warehouse, further 10 runs of the model were provided, in order to find mean values and standard deviations of the considered variable (Table II).

On the basis of ten values obtained from the normal distribution of the random variable, one can find the mean values and define a confidence interval. In particular, the mean value for the days of stockouts is 13, with the standard deviation of three days; thus, at a 95% confidence interval, the limits are [16, 10], and the average stockout volume is 179 with the standard deviation of 54 or [233, 145].

4.3 Adjusted financial model for the assessment of risks related to time and cost

In order to estimate the impacts of the material supply delays on the project, the financial flow model was adjusted (Figure 5). It was assumed that the days of stockout result expenses for the owner, which was discussed in the previous section.

For this reason, additional constant parameters, such as daily expenses, were added to the model. Meanwhile, the days of stockouts were set as a variable with the help of a normal distribution (Table III).

During the Monte Carlo experiment (with 20,000 runs), the delay parameter was varied, while the other parameters were set as constant. The output of the model can be analyzed via the sensitivity graph and generated statistics (Figure 6).

Table II. Output of the experiments, representing delays and stock outs

Experiment	1	2	3	4	5	6	7	8	9	10
Days of stock outs	22	8	12	16	14	14	8	5	19	13
Stock out, tons	304	64	120	226	176	206	134	56	350	156

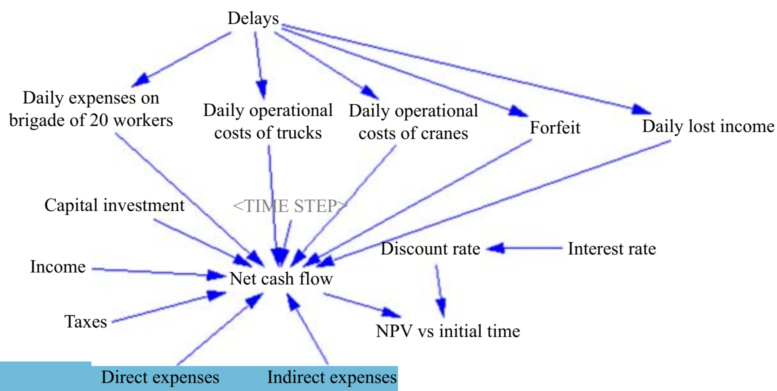


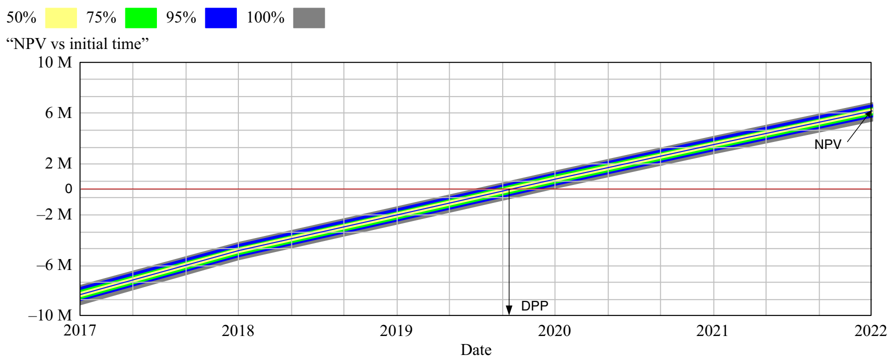
Figure 5. Adjusted model of financial flows on the construction project

In Figure 6, the sensitivity graph shows various confidence bounds. The Vensim program allows entering up to eight confidence-bound regions (in any order) and the corresponding color that should be used to display them. For example, for a confidence bound at 50, 1/4 of the runs will have a value exceeding than the maximum of the confidence bound, and 1/4 will have a value lower than the minimum. With regard to the sensitivity graph, the investments will pay off over an average time frame of 3 years 8.5 months (DPP). However, the DPP can deviate from the average figure by ±1.3 months with a probability of 75 percent or might be ±2.1 months (with a probability of 95 percent). On the whole, the risks of delays resulted in an increase of the DPP by almost 5 months, compared to the risk-free scenario (3 years and 3.8 months).

The risk of delays also affected the NPV. On average, NPV decreased by 17 percent from the base scenario of the risk-free environment. The mean, minimum and maximum values of NPV were 6.156, 5.406 and 6.828 ML EUR, respectively, with StDev 0.246 ML EUR and a low unitized risk value also known as the coefficient of variation of 4 percent (Figure 6). With respect to the confidence intervals, which were installed during the simulation experiment, and the table of cumulative probability (or table of normal distribution), the following assumptions were made. A rate of 75.18 percent corresponds to a satisfaction level $Z=1.15$. Thus, the probability value of obtaining an NPV, which belongs to the boundaries [6.156–0.246 × 1.15; 6.156 + 0.246 × 1.15] ML EUR equals 75.18 percent. Since our random variable (NPV) has a normal distribution, it is possible to use the rule of three σ (Figure 6). Following this rule, which states that the probability of a random variable falling within the confidence interval [M–3σ; $M+3\sigma$] is close to 1, it is possible to conclude that, with a probability of 99.8 percent, the largest possible amount of losses under the project is EURO 0.739, while, with a probability close to 0, and the NPV of the container terminal project could be below 5.406 ML EUR.

Table III. Additional input parameters for the model

Parameter	Units
Daily expenses on brigade of 20 workers	EURO 40,000
Daily operational costs of trucks	EURO 8,000
Daily operational costs of cranes	EURO 15,0000
Forfeit	0.028333 (1/300 × 8.5)%
Daily lost income	EURO 25,975
Delays	13±3, Days



Statistics

Variable	Count	Min	Max	Mean	Median	StDev	(Norm)
NPV vs initial time sensitivity results at time 5 Runs: Current							
"NPV vs initial time"	20,000	5.406 M	6.828 M	6.156 M	6.156 M	246,300	0.04001

Figure 6. The distributed assessment of construction risks from Monte Carlo experiment

4.4 Proposal for the mitigation of construction risks

In order to mitigate the risks of delay in materials supply that result in the postponement of commissioning the whole construction project, the contractor may increase the levels of safety stocks (SS) and correspondently targeted IL. In particular, if it is possible to estimate average deviations in the lead time from the supplier, the SS and ROP for IL in the warehouse of the contractor can be calculated by the formula (i.e. for the case when both demand and lead time are variables; Lukinskiy *et al.*, 2017):

$$\mathrm{ROP} = d \times L + x\sqrt{L \times \sigma_c^2 + d^2 \times \sigma_B^2}. \qquad (2)$$

It should be noted that the use of this formula, which includes safety stock, in a "minimum-maximum" policy with a continuous review of ILs, helps to prevent project delay. However, it is only suitable for routine materials, when the mean demand is quite stable, but entails uncertainty in terms of quantity and lead time. If the delay is caused by unique materials that are only needed in a few projects, such an approach would not be appropriate.

Moreover, it is important to note that in the case using inventory control policies with ROP, i.e., when the replenishment order is made, if IL reaches ROP, the probability of stock deficit is very low, and with a continuous review system, it is excluded. Accordingly, for the calculation of the safety stock levels, included in both formulas of ROP, the deviation in the demand should be taken into account only during the lead time (L), and not the whole period (Lukinskiy *et al.*, 2017).

By setting this formula in the discrete-event model, the circumstances of the deviation in the lead time (three days from the mean of five days) was considered (Figure 7).

As can be seen from Figure 7, the SS and targeted IL increased to 77 and 170 tons, respectively, from the risk scenario (SS = 21 and IL = 116). This enables the owner to avoid risks of stockouts (Figure 8) and, therefore, the risk relating to time and cost for the construction project.

For the contractor, this means that the warehousing expenses grow, on the one hand, but on the other hand, the fines due to undelivered material to the construction sites would decrease. In particular, if we assume that the contractor leases the warehouse and the cost of leasing 1 square meter is EURO 460, and that 1 ton of stored material corresponds to 3 square meters, then the expenses of the contractor increase by 74,520 EUR/year

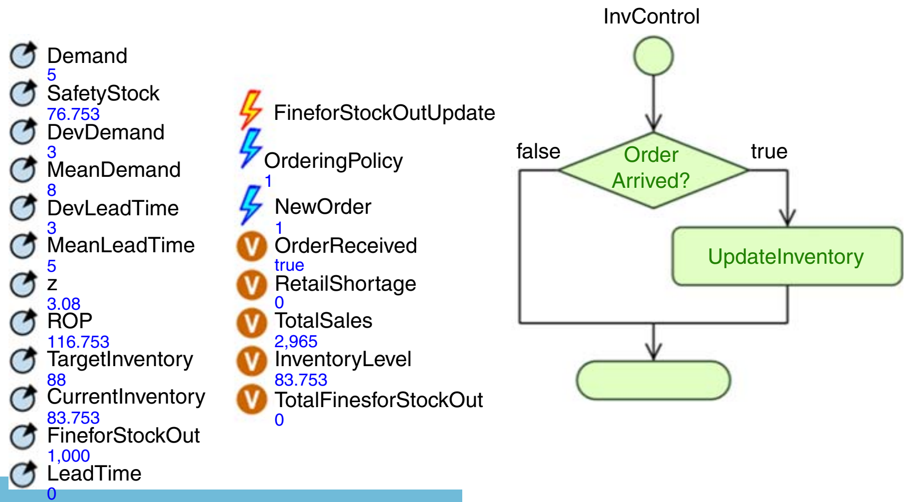


Figure 7. The model with the mitigated risks of stock outs

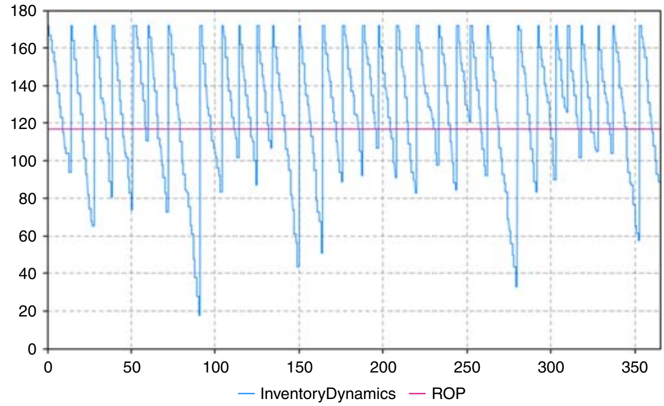


Figure 8.
The output of the model with the mitigated risks of stock outs

((170−116) × 3 × 460). At the same time, if we consider that due to stockouts, the contractor experiences the same level of fines as the supplier (EURO 1,000 per undelivered ton of material to the construction site), its expenses will decrease by EURO 179,000±54 (as stockouts, calculated from Table II will be eliminated).

5. Conclusion

At the beginning of construction project, it is necessary to consider supply chain risks, such as possible delays in the supply of materials and other resources, overcapacity or deficiency warehouse, on-time loading and shipment of goods. These risks can be divided between the owner and the contractor, but no rigid line can be drawn. The participants are interdependent, and both can benefit economically from the success of the project.

Both qualitative and quantitative methods were used. In the present study, a combination of MCA with dynamic simulation was performed, using Vensim and AnyLogic programs. This answered the first research question:

RQ1. What models and methods are suitable for the economic appraisal of construction project delays?

Dynamic simulation helped to portray the dynamic nature of the delays in the delivery of materials to the construction sites and the probability of the disruption in the construction supply chain. By contrast, the Monte Carlo method would not have been as effective, since it does not have an explicit time representation. The MCA, in turn, was thus used to calculate the parameter of NPV and DPP, as decision-making criteria corresponding to changes in the environment during the project realization. Its exposure to the construction risks was accessed by computing standard deviations from both capital-budgeting models (NPV and DPP).

With the help of a statistical analysis of models output, distributed values of NPV and DPP were obtained, rather than point values. Such an approach is especially suitable in the field of the construction, where there is uncertainty of information and material flows, resulting in inaccurate predictions and calculations. Moreover, difficulties in planning construction projects bring variability to the information and material flows, causing inefficiency in downstream processes. This results in delays, increases costs and restricts the use of lean principles.

The outcomes of the financial flow model, the minimum, mean and maximum possible NPV and DPP, were duly obtained. For this construction project of a container terminal, in the given scenario with risks, the NPV was 6.156, 5.406 and 6.828 ML EUR, respectively, with a standard deviation of 0.246 ML EUR. Applying the rule of three-σ to the simulation results, it was found that when the probability is close to zero, the NPV is below 5.406 ML EUR.

The second critical capital-appraisal decision-making criterion (DPP) showed that, in the high-risk scenario, the investment will pay off in 3 years and 8.5 months. However, with a probability of 95 percent, the planned time can deviate from the average figure by $\pm$2.1 months or within the confidence interval (3 years 6.4 months; 3 years 10.6 months). Thus, the analyses stress that by ignoring the risk scenario in the feasibility study for a construction project, investors and contractors can misjudge the future situation and face an over-expenditure of time and exceed the allocated budget.

For the owner, it is necessary to assess the risks inherent to the economic appraisal, in order to reduce cost overruns and avoid postponement of the project commissioning. Once the risk- is measured in the feasibility studies, they can be managed in advance. The risks management aspects are addressed in the second research question:

RQ2. How can construction delays regarding time risks and cost risks be assessed and mitigated by a combination of different methods?

In order to mitigate the risks from construction delays, it was proposed to increase the safety stock of construction materials at the distribution center, which otherwise led to barrier disruption in the supply chain. In terms of practical implications (especially, for the contractor), it is necessary to find the right level of safety stock and the corresponding target ILs, allowing a reduction of stockouts and untimely delivery of the material to the construction site.

From the findings, it is evident that the overall outcomes were indeed largely generated by using suitable methods. This is an important theoretical implication of this study. Such an approach enabled excluding the maximum number of shortcomings of each method. However, the benefits of using both approaches, with respect to the research problem, were applied only to one research setting (i.e. for the hypothetical project). Thus, empirical data from similar and other research settings should be gathered to reinforce and confirm the validity of the reported findings. Another limitation is that the developed simulation models consider a simple supply chain with a single supplier. In a real scenario, multi-tier suppliers are involved in a construction project.

Therefore, in future studies, it would be useful to extend this model by including additional actors and factors that incur in the context of construction risks. At the same time, other groups of construction risks should be considered, in order to propose solutions for their mitigation. Another area of study could entail the distribution of risks over different project participants, especially if developed within the framework of public-private partnership investments.

References

Ambrasaite, I., Barfod, M.B. and Salling, K.B. (2011), "MCDA and risk analysis in transport infrastructure appraisals: the Rail Baltica case", *Procedia – Social and Behavioral Sciences*, Vol. 20 No. 11, pp. 944-995.

Amédée-Manesme, C.O., Barthélémy, F., Baroni, M. and Dupuy, E. (2013), "Combining Monte Carlo simulations and options to manage the risk of real estate portfolios", *Journal of Property Investment & Finance*, Vol. 31 No. 4, pp. 360-389.

Ameyaw, E.E. and Chan, A.P.C. (2013), "Identifying Public-Private Partnership (PPP) risks in managing water supply projects in Ghana", *Journal of Facilities Management*, Vol. 11 No. 2, pp. 152-182.

Bannerman, S. (1993), "Sensitivity analysis for property appraisal", *Journal of Property Valuation and Investment*, Vol. 11 No. 3, pp. 248-256.

Black, J., Hashimzade, N. and Myles, G. (2012), *Dictionary of Economics*, 4th ed., OUP, Oxford.

Briscoe, G. and Dainty, A. (2005), "Construction supply chain integration: an elusive goal?", *Supply Chain Management: An International Journal*, Vol. 10 No. 4, pp. 319-326.

Bruzelius, N., Flyvbjerg, B. and Rothengatter, W. (2002), "Big decisions, big risks", *Improving Accountability in Mega Projects, Transport Policy*, Vol. 9 No. 2, pp. 143-154.

Carlos, J.P.-G. and Fernández, A.J. (2013), "Classical versus Bayesian risks in acceptance sampling: a sensitivity analysis", *Computational Statistics*, Vol. 28 No. 3, pp. 1333-1350.

CBR (2017), "The refinancing rate of the Central Bank of the Russian federation", available at: www.cbr.ru/ (accessed September 8, 2017).

Courtney, H., Lovallo, D. and Clarke, C. (2013), "Deciding how to decide: a tool kit for executives making high-risk strategic bets", *Harvard Business Review*, Vol. 91 No. 11, pp. 63-70.

Dey, P. (2009), "Managing risks of large scale construction projects", *Cost Engineering*, Vol. 51 No. 6, pp. 23-27.

Dymowa, L. (2011), *Soft Computing in Economics and Finance*, Springer Verlag, Berlin.

Eriksson, P.E. (2010), "Improving construction supply chain collaboration and performance: a lean construction pilot project", *Supply Chain Management: An International Journal*, Vol. 15 No. 5, pp. 394-403.

Esipova, E.V., Oparin, S.G. and Gurova, Yu.E. (2010), "Evaluation of the effectiveness of investments in transport construction, taking into account uncertainty and risk", *Scientific and Technical Statements of SPbSPU*, Vol. 4 No. 102, pp. 60-65.

Fearne, A. and Fowler, N. (2006), "Efficiency versus effectiveness in construction supply chains: the dangers of 'lean' thinking in isolation", *Supply Chain Management: An International Journal*, Vol. 11 No. 4, pp. 283-287.

Flyvbjerg, B., Bruzelius, N. and Rothengatter, W. (2003), *Megaprojects and Risk: An Anatomy of Ambition*, Cambridge University Press, Cambridge.

Forrester, J.W. (1958), "Industrial dynamics – a major breakthrough for decision makers", *Harvard Business Review*, Vol. 36 No. 4, pp. 37-66.

Forsman, S., Björngrim, N., Bystedt, A., Laitila, L., Bomark, P. and Öhman, M. (2012), "Need for innovation in supplying engineer-to-order joinery products to construction: a case study in Sweden", *Construction Innovation*, Vol. 12 No. 4, pp. 464-491.

Gaudenzi, B. and Borghesi, A. (2006), "Managing risks in the supply chain using the AHP method", *International Journal of Logistics Management*, Vol. 17 No. 1, pp. 114-136.

Hilletofth, P. and Lättilä, L. (2012), "Agent based decision support in the supply chain context", *Industrial Management & Data Systems*, Vol. 112 No. 8, pp. 1217-1235.

Hilletofth, P., Aslam, T. and Hilmola, O.-P. (2010), "Multi-agent based supply chain management: case study of requisites", *International Journal of Networking and Virtual Organisations*, Vol. 7 Nos 2/3, pp. 184-206.

Hilletofth, P., Lättilä, L. and Hilmola, O.-P. (2009), "Agent-based decision support in manufacturing supply chain", in Håkansson, A., Nguyen, N.T., Hartung, R.L., Howlett, R.J. and Jain, L.C. (Eds), *Agents and Multi-Agent Systems: Technologies and Applications*, Springer Verlag, Berlin, pp. 677-686.

Hilletofth, P., Ujvari, S., Lattila, L. and Hilmola, O.P. (2010), "Agent-based decision support for maintenance service provider", *International Journal of Services Sciences*, Vol. 3 Nos 2-3, pp. 194-215.

Keown, A.J., Martin, J.D., Petty, J.W. and Scott, D.F. (2003), *The Logic and Practice of the Financial Management*, 5th ed., Pearson Prentice Hall, Upper Saddle River.

Khalfan, M.M., McDermott, P. and Swan, W. (2007), "Building trust in construction projects", *Supply Chain Management: An International Journal*, Vol. 12 No. 6, pp. 385-391.

Knight, F.H. (2012), *Risk, Uncertainty and Profit*, Courier Corporation, Boston, MA.

Lättilä, L., Hilletofth, P. and Lin, B. (2010), "Hybrid simulation models–when, why, how?", *Expert Systems with Applications*, Vol. 37 No. 12, pp. 7969-7975.

Lorenzo, D.L., Pilidis, P., Witton, J. and Probert, D. (2012), "Monte-Carlo simulation of investment integrity and value for power-plants with carbon-capture", *Applied Energy*, Vol. 98 No. 8, pp. 467-478.

Lukinskiy, V.S. and Panova, Y. (2017), "Simulation modelling of inventory management strategies", *Imitatsionnoe i kompleksnoe modelirovanie morskoy tekhniki i morskikh transportnykh sistem [Simulation and complex modelling in marine engineering and marine transport systems], Materials of IV International Scientific Conference*, *St Petersburg, June 28*, pp. 71-75.

Lukinskiy, V.S., Panova, Y. and Soletskiy, R. (2016), "Simulation modelling of supply chain with allowance of reliability", *Russian Journal of Logistics and Transport Management*, Vol. 3 No. 2, pp. 49-60.

Lukinskiy, V.S., Lukinskiy, V.V., Pletneva, N.G., Vorobyeva, N.I. and Maevsky, A.G. (2017), *Upravlenie zapasami v tsepyakh postavok (Inventory Management in Supply Chains)*, In 2 parts, textbook and workshop for undergraduate and graduate students, Yurayt Publishing, Moscow, p. 1.

Milliken, F.J. (1987), "Three types of perceived uncertainty about the environment: state, effect, and response uncertainty", *Academy of Management Review*, Vol. 12 No. 1, pp. 133-143.

Oparin (2015), *Risk Management in the Economy: Problems and Solutions*, Publishing of Polytechnic University, St Petersburg.

Panova, Y. and Hilmola, O.-P. (2016), "Risk mitigation strategies for doing terminal and warehousing businesses: Russian case study", *Logistics and Supply Chain Management*, Vol. 3 No. 74, pp. 60-79.

Piranfar, H. and Masood, O. (2012), "Measuring risk and financial support for NPPs using Monte Carlo simulation", *The Journal of Risk Finance*, Vol. 13 No. 2, pp. 160-170.

Pluessa, D.A., Grosob, A. and Meyer, T. (2013), "Expert judgements in risk analysis: a strategy to overcome uncertainties", *Chemical Engineering Transactions*, Vol. 31 No. 1, pp. 307-312.

Popova, A.Y. (2011), "Assessment of risk of the investment project", *Scientific Journal of KubSAU*, Vol. 74 No. 10, pp. 1-26.

Pyles, M.K. (2014), *Applied Corporate Finance Questions, Problems and Making Decisions in the Real World*, Series: Springer Texts in Business and Economics, New York, NY.

Ramanathan, C., Narayanan, S.P. and Idrus, A.B. (2012), "Construction delays causing risks on time and cost-a critical review", *Construction Economics and Building*, Vol. 12 No. 1, pp. 37-57.

Salling, K.B. (2013), "A new approach to feasibility risk assessment within transport infrastructure appraisal", *Procedia – Social and Behavioral Sciences*, Vol. 74 No. 5, pp. 468-477.

Samis, M. and Davis, G.A. (2014), "Using Monte Carlo simulation with DCF and real options risk pricing techniques to analyse a mine financing proposal", *International Journal of Financial Engineering and Risk Management*, Vol. 1 No. 3, pp. 264-281.

Shapkin, A.S. and Shapkin, V.S. (2013), *Economic and Financial Risks: Assessment, Management, Investment Portfolio*, 9th ed., Dashkov and Co Publication, Moscow.

Sterman, J.D. (2000), *Business Dynamics: Systems Thinking and Modelling for a Complex World*, McGraw-Hill, New York, NY.

Tookey, J.E., Bowen, P.A., Hardcastle, C. and Murray, M.D. (2005), "Concurrent engineering: a comparison between the aerospace and construction industries", *Journal of Engineering, Design and Technology*, Vol. 3 No. 1, pp. 44-55.

van Lith, J., Voordijk, H., Matos Castano, J. and Vos, B. (2015), "Assessing maturity development of purchasing management in construction", *Benchmarking: An International Journal*, Vol. 22 No. 6, pp. 1033-1057.

Voordijk, H., Meijboom, B. and de Haan, J. (2006), "Modularity in supply chains: a multiple case study in the construction industry", *International Journal of Operations & Production Management*, Vol. 26 No. 6, pp. 600-618.

Vrijhoef, R. and Koskela, L. (2000), "The four roles of supply chain management in construction", *European Journal of Purchasing & Supply Management*, Vol. 6 No. 3, pp. 169-178.

Corresponding author
Yulia Panova can be contacted at: panovayulia87@gmail.com