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Risk Management Treatise for Engineering Practitioners

Edited by Chike F Oduoza

RISK MANAGEMENT TREATISE FOR ENGINEERING PRACTITIONERS

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http://dx.doi.org/10.5772/62812
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First published in London, United Kingdom, 2018 by IntechOpen
eBook (PDF) Published by IntechOpen, 2019
IntechOpen is the global imprint of INTECHOPEN LIMITED, registered in England and Wales, registration number: 11086078, The Shard, 25th floor, 32 London Bridge Street
London, SE19SG – United Kingdom
Printed in Croatia

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Additional hard and PDF copies can be obtained from orders@intechopen.com

Risk Management Treatise for Engineering Practitioners
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p. cm.

Print ISBN 978-1-78984-600-3

Online ISBN 978-1-78984-601-0

eBook (PDF) ISBN 978-1-83881-237-9

Meet the editor

Chike F. Oduoza is a Professor of Process and Manufacturing Engineering at the University of Wolverhampton, UK. He is a chartered engineer and a fellow of the Institution of Chemical Engineers.

His research interests are in the areas of chemical and manufacturing engineering with focus on electroplating and corrosion protection, engineering materials, reactor design, risk management, sustainability and life cycle engineering, and manufacturing processes engineering. He is a regular consultant for industry and has successfully managed several Engineering and Physical Sciences Research Council (EPSRC) industry case studentship awards, EU (Brite-Euram) and EU FP7 funded projects. He has authored and co-authored 200 research publications including books and book chapters, and belongs to several networks of scientific and technical committees responsible for international conferences.

Contents

Preface

Most engineering projects, especially in the construction sector, face risks which occur with different levels of likelihood and impact. The risks associated with the construction sector can generate severe consequences for the organisation if not properly managed. Generally, risk in project management is typically referred to as a variable in a process whose occurrence results in uncertainty as to the final cost, duration and/or the quality of the project. To try to mitigate or eliminate the impending risk, we deploy risk management, which is an integral part of project management. Risk management therefore reduces the likelihood and impact of unsatisfactory consequences to the project in its different stages, such as design, manufacture/construction, operations and maintenance. Hence, the main purpose of risk management is to identify, evaluate and control the risk to achieve project success. Overall, the process includes the following steps: (1) risk identification; (2) risk assessment (qualitative and quantitative) and (3) risk response.

This book "Risk Management Treatise for Engineering Practitioners" has been published by academic researchers and experts on risk management concepts mainly in the construction engineering sector. It addresses basic theories and principles of risk management backed up in most cases with case studies. The contributions for this treatise came from authors based in Europe, the Far East and Africa, and it is hoped that the contents of this book will be useful to anyone interested in understanding the principles and applications of risk management, especially within the construction engineering sector.

The decision to write this book was based on a four-year research project (RiMaCon) funded by the European Union under the call for Marie Curie Industry Academia Partnerships and Pathways in which the partners (University of Wolverhampton, UK, University of West Bohemia, Czech Republic, Vettorazzo, Italy and Computors, UK) were tasked with developing a risk management software program to support SMEs operating especially in the construction sector. Some of the rich experiences gained from this project have been shared by some of the participants in this book, and this should make for interesting reading.

Overall, there are four chapters based on extracts from the RiMaCon project, while the remaining five chapters were contributed by other authors researching similar research topics in other universities from around the world.

The book has been broken down into two sections: with section one contributions addressing risk management background, theories and principles, and section two backing up the theme with case studies to illustrate the applications of risk management to enterprise business performance.

Within section one, Odimabo, Oduoza and Suresh presented an insight into the process, tools and techniques available to support risk management in construction projects. They recommend a comprehensive appraisal of the cost of tools and techniques and the timeliness of their adoption during each stage of the project life cycle prior to deployment.

Gorecki in his submission described the significance of big data as a project risk management tool and concluded that it is a new source of valuable information that will enhance enterprise project objectives, especially in these days of massive data collection, analysis and use in the business arena.

Machac, Steiner and Tupa studied product life cycle risk management and highlighted the need to manage risk separately at each phase of the life cycle. Their view is that product life cycle risk management should be deployed and prioritised based on customer's needs and requirements.

Kikwasi shortlisted the nine critical success factors out of a list of twenty five that organisations should focus on to achieve project objectives and effective risk management.

Within section two, the author used elaborate case studies to illustrate the application of risk management during project management.

Sandanayake, Dissanayake and Oduoza researched the construction supply chain resilience during catastrophic events and developed framework / strategies to minimise their impact. They concluded that impacts due to supply chain catastrophes are diverse with potential unique effects applicable for each case.

Wibowo, Hatmoko and Diponegoro reviewed risk management in Indonesia construction projects and used a toll road project as illustration. They applied some form of risk management to toll road project reviewing the impacts from different stakeholder (including contractors, clients, owners, etc.) perspectives. They concluded that the risks faced by each stakeholder were unique depending on their interest and level of participation on the project.

Simota, Tupa and Steiner studied risk management to enhance business performance in the construction sector focusing on the SME experience. They presented a methodological framework matching key performance indicators with key risk indicators, thereby producing an effective management system that recognises risks that could affect performance.

Suresh, Oduoza and Suresh described leadership initiatives for health and safety risk management, especially applicable to SMEs. In their case study, they used a diagnostic toolkit to demonstrate the importance and role of leadership in the management of risks associated with health and safety in SMEs. Overall, eight out of thirty eight risk factors identified had an influence on financial, client, business process and learning growth related performance.

Svalova discussed geological landslide risk management focusing on urbanised territories using Moscow and Taiwan as case studies. The author defined a methodology for landslide risk assessment and summarised the action points that should be focused on during risk management of landslides.

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Section 1

Risk Management: Theory and Principles

An Insight into the Process, Tools and Techniques for Construction Risk Management

Onengiyeofori O. Odimabo, Chike F. Oduoza and Subashini Suresh

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79459

Abstract

Investing in construction projects is not without risks. Risk management is considered an important aspect when making decisions in the construction industry—as it determines whether the construction project will be successful or will fail. Effective decisions are made based on certain predetermined criteria such as investigating the construction project in detail, generating good alternatives to manage risk, exploring the best options, etc., whereas, decisions can fail when the best suitable alternatives to manage risk are not made clear at the onset of a construction project, or logical assessment of project-specific criteria are not considered part of the process. As a result, risks can possibly have an adverse effect on the delivery of construction projects with respect to its objectives. Therefore, this chapter will present the numerous tools and techniques that are available to support the various phases of the risk management process in construction projects.

Keywords: risk management, risk identification, risk analysis, construction projects

1. Introduction

Generally, construction projects around the world are developing at a rapid rate both in terms of technology and organisation. Apparently, the construction industry earns its reputation from its perceived performance in terms of the value it produces and also plays a key role in the economy of any nation, which is a vital contributor to the gross domestic product (GDP) growth and produces the built environment that supports other sectors of the economy in most part of the world [1].

However, an investment in construction projects is, of course, not without risks. Construction organisations constantly face issues such as poor management, poor resource management, information unavailability and lack of communication between parties involved in the construction project [1]. These issues often give rise to delayed completion of construction project, exceeding budget, loss of productivity, third-party claims and abandonment or termination of contract for the project. The construction sector in most cases does not quickly respond to the needs of its clients or customers and they constantly fail to meet the target technical performance of the construction project [2]. At the same time, distortions in prices and the shortage of materials and other inputs tend to cause allocative inefficiencies, which make the works in hand economically costlier than they should be [3].

Risk management is an important part of project management that if done effectively will result in construction projects been successful. It allows identifying risk variables, anticipating events that could adversely affect construction projects by determining likelihood of occurrence and to define actions that could reduce their impacts. Project managers in construction projects bear the main responsibility of dealing with risk or uncertainties that occur continuously during construction works. This role is particularly complex and inefficient if risk management has not been performed or supported adequately from the start of the project [4]. For construction projects that are vital to the economy of any nation, a risk management system will have to be in place to ensure that the entire task on the project plan have been performed successfully and the project objectives have been achieved.

It is important that project managers do not only perceive the risk management process as only the creation of previously unknown information, but also need to share information and knowledge while also having basic administrative and technical competencies, business skills, customer relations skills, political skills and be results-oriented self-starters with a high tolerance for ambiguity [5]. Shortcomings in any of these aspects can cause project failure. When risk management process is implemented effectively, it will result to the successful completion of construction projects, and thereby making the project more profitable and keep stakeholders satisfied. Consequently, an effective risk management process will have to be dynamic in nature than the identified risk; otherwise, there are chances it may not blend well into the culture of an organisation and other company practices [2].

2. Construction sector risk and uncertainty

According to Heerkens [6], risk and uncertainty are avoidable in construction project life cycle and it is dangerous to ignore or deny their impact. Uncertainty is described as the absence of information, knowledge, or understanding regarding a situation, condition, action, decision or event [6]. Project managers constantly suffer from an absence of information, knowledge and understanding. A common view of risk is that it can be thought of in terms of variability or uncertainty. Risk can also be interpreted as referring to a lack of predictability about outcomes or consequences in a management decision situation. Risk is, therefore, related to the outcomes and the concepts of chance such as the probability of loss or probability of gain. Hence, Abujnah and Eaton [7] highlights that risk comprises three essential elements:

http://dx.doi.org/10.5772/intechopen.79459

- the number of possible outcomes
- the value (magnitude) of each outcome
- the probability of the occurrence of each outcome

Managing risk is to minimise, control and share risk and not merely passing them off unto another party Project in controlled environment [8] defines risk as the chance of exposure to the adverse consequences of future events. Consequently, Eaton [9] defines construction risk as a potential event, either internal or external to a project that, if it occurs, may cause the project to fail to meet one or more of its objectives. Odeyinka et al. [10] define construction risk as a variable in the process of construction whose occurrence results in uncertainty as to the final cost, duration and/or the quality of the project. **Figure 1** provides a holistic view of project risk.

2.1. Construction risk management

Project management facilitates the use of clear procedures and techniques, which includes risk management in construction projects. The Project Management Institute [12] includes risk management as one of the 10 areas of project management (i.e. integration, scope, time, cost, quality, human resource, communications, risk, procurement and stakeholders). The Australian/New Zealand standard [13] describe risk management as the culture, processes and structures that are directed towards realising potential opportunities while managing

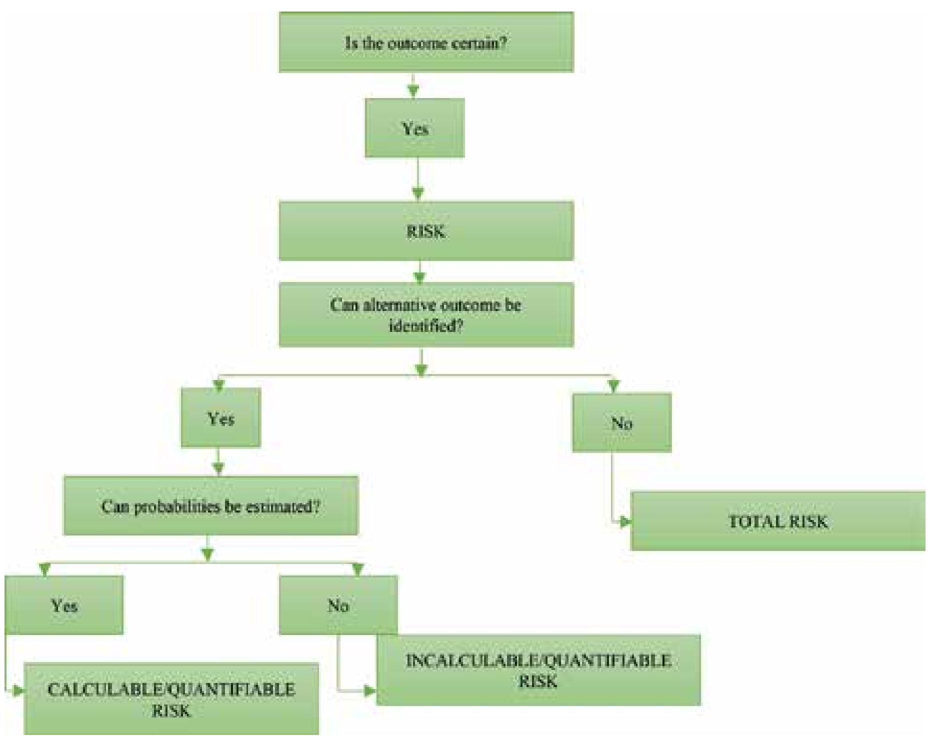

Figure 1. A holistic view of project risk [11].

adverse effects, while Zou et al. [14] describe risk management in the construction project management context as a systematic way of identifying, analysing and dealing with risk as associated with a project with a goal to achieve the objectives of the project. Consequently, the British standard 31100 [15] reports that risk management is a procedure whereby decisions are made to accept a known or assessed risk and/or the implementation of actions to minimise the impact or likelihood of occurrence. An awareness of project risks facilitates strategic decision-making. As a result, Smith et al. [16] report that project organisations and clients have an overall risk management strategy and policy included in their strategic documents and quality management system. The effective management and implementation of these elements enhances the achievement of project goals and the successful delivery of construction projects.

3. The risk management process in construction projects

When managing risk in construction projects, a number of processes have been proposed [17, 18]. However, the process of risk management encompasses defining the risk management scope; uncovering risk and uncertainties; understanding the significance and prioritisation of risks and defining actions, which when implemented will result to construction project success [19]. Kendrick [20] highlights that the successful implementation of risk management facilitates effective communication, mitigates stakeholders' uncertainty, builds trust among parties involved in the project and facilitates informed decision-making so that future actions contribute to the success of organisations.

Mainstream risk management provides four basic or conceptual steps, namely; risk identification, risk assessment, risk response, and risk review and risk monitoring. However, these steps may vary depending on individual or organisational use. For example, the INSEAD team introduced their terminology—identify, classify, manage and embed—into the system [21]. Meanwhile, Cooper et al. [22] adopted a different approach, dividing the process into three key elements for effective management of risks: the core process, which consisted of identifying, analysing, assessing, developing plans to manage them; the allocation of responsibility to risk owners, the party that can manage the risks well; and the assurance that the costs incurred to manage the risks were proportionate to the importance of the project. According to Jia et al. [23], **Figure 2** illustrates six processes and their relationships. Among these processes, risk management planning is the first stage of the risk management process, where the scope and objectives of project risk management are defined. It is achieved through the production of a risk management plan, a tool specifying how risks will be managed in the context of the project throughout the lifecycle. As a result, it regulates and promotes four successive processes in the core risk management cycle. Risk management reporting is the final stage of the entire risk management process, where planned actions are actualised and also ensuring that if a risk emerges it will have minimum adverse effects on the achievement of the construction project objectives.

Figure 2 also agrees with the definitions of other construction institutions which includes but is not limited to the Association of Project Management [24], Institution of Civil Engineers [25], Construction Industry Research and Information Association [26], etc. These construction institutions recognise that the initiation, identification, assessment and response of risks are achieved through a structured and systematic risk management process which enables communication and invariable awareness throughout the construction project lifecycle.

http://dx.doi.org/10.5772/intechopen.79459

3.1. Definition of risk management objectives

The first stage of the risk management process clearly defines the scope and objectives. Within this phase of risk management, a feasibility study is carried out, in order to ensure that risks which may have adverse effect on key project deliverables are well-defined and assessed [27]. According to the APM [24], a key output at this stage is the development of a risk management plan which gives details of how identified risk variables will be managed throughout the construction project lifecycle. The risk management plan provides a medium to communicate the existing risks to interested stakeholders. Consequently, at this phase, a general impression of the risk appetite is also established. The project manager must arrive at a consensus on defining risk in such a way it is tailored to the construction project. This exercise allows the project manager to measure the risk appetite of stakeholders, the project team and the construction project. The Project Manager has to ensure the risk management strategy employed by the project team is compatible with key stakeholders' appetite to receive it [24].

3.2. Risk identification

It is almost certain in construction projects that some events will not be completed in line with their duration estimates and budgets. Some might exceed their estimates, while others could be finished early and cost less than expected [28]. The risk management process is figuring out what you are up against. According to Tchankova [29], it should start with the basic question of:

- How can the project resources be threatened?
- What adverse effect can prevent the project from achieving its goals?
- What favourable possibility can be revealed?

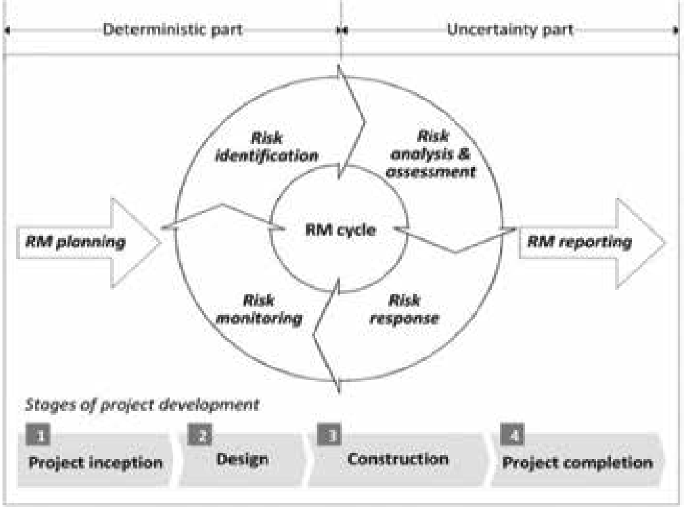

Figure 2. Risk management process for construction projects [23].

Table 1 lists some of the most common areas of uncertainty that exist on many construction projects. These problems can develop from these sources of uncertainty and they need to be uncovered.

Risk identification develops the basis for the next steps of analysis, assessment and control. If this is done correctly, it ensures risk management effectiveness. Risk identification must be seen in a broader way, and not just be seen as what can be insured or mitigated [29].

During this stage, all potential risk affecting the estimates of future outcomes should be identified by considering the factors shown in **Figure 3**.

Risk identification occurs throughout the construction project lifecycle; however, most risks are documented in a risk register. The process of risk identification helps project managers to study activities and areas where the construction project is exposed to risk. As reported by Tchankova [29], risk identification can be described based on the following elements:

- *Sources of the risk*: these are variables which occur in a project environment that can result to positive or negative outcome. Numerous researchers have different definitions and classifications of risks used in a project environment. For instance, Tchankova [29] used a general risk breakdown structure to classify risk as physical, social and economic sources. However, a detailed investigation of risk identification may need classification that can cover all types of risk in more detail within a construction project environment [29]. **Table 2** lists some common problems encountered on projects.
- *Hazard*: these are conditions or circumstances that have the tendency of increasing the chances of losses in construction projects.

Area	Description
Scope	Projected amount of work done, ambiguous planning, defective designs and omissions, scope change by client
Time	Projected duration of the project, projected duration of task, time-to-market, introduction date, timing of organisation appraisals and approval
Cost	Estimated cost of the project, cost of downstream manufacturing, cost of downstream maintenance, inaccurate estimates, exchange rate fluctuation, limitations in budget
Technology	Client expectations, likelihood of success, ability to scale-up, manufacturability of product, success in design.
Resources	Quantity, quality, availability, skill match, ability to define roles and responsibilities
Organisational	Priorities and knowledge of clients, coordination among departments of the organisation
Marketability	Expectations of the users, volume of sales, pricing, share, location, quality, geography, economy.
Outside factors	Actions or reactions of competitors, regulations in the industry.

Table 1. Typical areas of uncertainties on projects [6].

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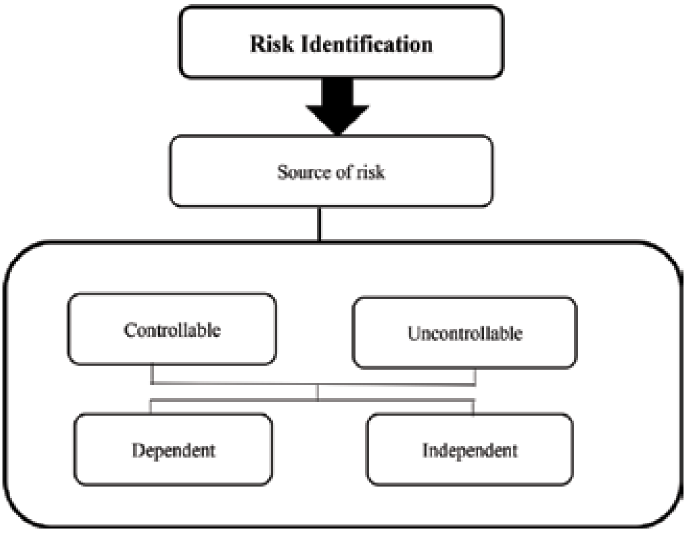

Figure 3. Risk identification process.

- *Peril*: these are circumstances that cause loss and have negative, non-profitable results in construction projects. It is important to state that peril can happen at any time in a construction environment and cause unknown, predictable losses.
- *Exposure to risk*: this is a situation facing possible loss or gain in a construction project. The project will be affected if the risk occurs.

  The problem of risk identification may need classification that can cover all types of risk in more detail [29].

The stage of risk identification is a non-stop process in the life cycle of a construction project. The identification of risk is not a one-off activity [29]. Practically, different risk identification techniques are used to thoroughly capture significant risks factors affecting construction projects. These techniques include but are not limited to:

1. *Brainstorming*: this is the commonly used technique in risk identification. Brainstorming involves the process of bringing together all relevant parties in the construction project to identify possible risk that might affect the construction project. The main purpose of this technique is to provide a free and open approach that encourages everyone on a project team to generate a large quantity of potential risks affecting the project. Consequently, this technique encourages risk identification concerns in a non-critical way and not attributing blame to the identified risk [31]. In order to make the brainstorming session to be effective, the process must include individuals who have a vast knowledge, experience and expertise in risk management especially within construction project environment [32, 33].
2. *The Delphi technique*: this technique can be utilised by involving a panel of experts in risk management to identify risks or estimate the impact and probability of previously

Physical • Supplies of defective materials • Low productivity of equipment • Fluctuation of material prices	Logistics • Low productivity of labour • Delay in equipment delivery • Undefined scope of working	Construction • Unsuitable leadership style • Improper construction methods • Improper quality, health and safety management
Environmental • Environmental factors (e.g. flood) • Rain effect on construction activities • Hot weather effect on construction activities	Financial • Delayed payment in contracts • Unmanaged cash flow • Inflation and sudden changes in price • Financial failure of the contractor	Political • Lack of transparency • New governmental acts or legislation • Political orientation • Instability in project governance.
Design • Defective design • Inaccurate quantities • Uncoordinated design (Structural, mechanical, electrical, etc.) • Awarding design to unqualified designers	Legal • Delayed dispute resolution • Legal disputes during construction phase among the parties of the contract • Frequent changes and modification in law	Management • Poor resource management • Poor site management and supervision • Poor communication between involved parties

Table 2. Checklist of specific potential problems [30].

identified specific risks through questionnaires. The key features of this technique are the anonymity of group members, statistical group response, and controlled feedback. The risk manager summarises the responses gotten and elicits estimates based on the outcomes. This information is redistributed in order to undertake the session again. The procedure will continue until a firm judgement is reached [31]. This technique is time consuming and expensive when compared to the method of brainstorming [32]. Another disadvantage to this technique is the lack of collaboration and communication, the respondents may encounter challenges in interpreting the questions and results.

3. *Interviews*: this technique is mostly used to follow-up the brainstorming and Delphi techniques. Experts in risk management are interviewed to assess risk parameters, identify possible mitigation, contingency measures and to elicit information. This is a predecessor to any quantitative analysis that maybe required later [31]. This technique is very time consuming. Due to the time limitations, the questions must be appropriately organised in order to successfully gather the required data. Ambiguous and unclear questions should be avoided so that the feedback gained from respondents is not confusing [34]. Another downside of this technique is that the data acquired is based on the subjective judgement of risk management experts that may not be free from bias.

4. *Experiential knowledge*: this technique involves individuals obtaining information through past experiences in the construction industry [35]. It is vital to state that in this technique, knowledge-based information attained must be appropriate and applicable to the current construction project.

5. *Outputs from risk-oriented analysis*: as reported by Clear Risk report [35], there are numerous kinds of risk-oriented analysis. For example, fault tree analysis and event tree analysis. These top down analysis approach identifies the event, conditions or faults that will lead to an undesirable or unacceptable event. These events may be associated to a risk in a construction project.
6. *Risk register*: the risk register contains a standard format which is used to document risk information, and actions to manage the risk. It logs in several information for individual risk factors, including a description, potential causes, ownership, probability, impacts, mitigation and fall-back plans and status [31]. In a more detailed format, it includes an identification of secondary risks, contingency plans and quantitative parameters [31]. Nonetheless, it is not advisable to use checklists to initiate the risk identification process as it may constrain the identification of new risks [25].

3.2.1. Controllable and uncontrollable risk

Controllable risks are those risks which the decision maker voluntarily undertakes and the outcome is within their direct control. This contrasts with uncontrollable risks, which the decision maker cannot influence.

For example, the outcome of a construction workers' performance is controlled by exercising the personnel skill of the project manager or decision maker. By contrast, weather conditions which can be categorised as risk that is uncontrollable and as a result, is completely beyond the control of the decision maker or project manager. Nevertheless, the adverse effect of this risk factor can be integrated into the project plan and taking necessary actions in scheduling and in the project sites of the organisation. There is a wide difference between controllable and uncontrollable risk in a construction project environment and it is important to take note of this. For example, in the aspect of controllable risk, a project manager or decision maker can voluntarily accept the risks that are associated with modern technologies in construction. These risks might be performance risks, where the technical capability of the technology is uncertain, or financial risks, resulting from uncertain installation or support costs. However, these risk factors can be tolerated if favourable benefits like prestige, accumulation of expertise or favourable financial outcomes have the likelihood of occurring. Through careful planning and exploiting available expertise, a project manager or decision maker can control the eventual outcome of the project. On the other hand, uncontrollable risks usually originate from factors such as the external environment, social, political or economic scope. As a result, the project manager cannot influence risk factors associated with them. However, the degree of exposure can be minimised. For example, in a case where there is an increase in gas prizes, this risk factor can be minimised by designing more efficient gas plants.

3.2.2. Dependent and independent risk

When undertaking any risk evaluation, the question of dependence, or otherwise, between the risks has to be considered and assumptions have to be made.

3.3. Qualitative risk assessment

In the risk management process, qualitative risk assessment is regarded as the most useful part of the process [33]. At this stage, qualitative risk assessment allows for risk comparison and prioritisation. Hence, attention has to be focused on the most significant risks in order to reduce their negative impact of the objectives of the construction project. At this stage, two considerations are made on risk; the anticipated impact on the project and the likelihood if it occurs. Using these measures as a common set of criteria allows for the comparison and prioritisation of risks. Qualitative risk assessment techniques includes:

1. *Probability-impact (P-I) grids or RAG report*: the probability-impact (p-i) grids or the RAG (red, amber and green) status are tabular format for assessing and ranking risks. The 'RAG status' is used to indicate confidence, stability or quality of a process in a construction project. For example, green indicates that the project objectives are proceeding as planned and no issues or problems are foreseen; amber/yellow indicates there are issues that could potentially affect the construction project and requires caution and management intervention, while red indicates that there are known issues which are impacting the construction project and as a result, management intervention is required to remedy the issues. On the other hand, probability-impact (p-i) grids has two attributes of the likelihood of the risk occurring and the impact on the construction project. These attributes form the rows and columns of the grid as seen in **Table 3**. One of the benefits of using the P-I grids is its simplicity. It allows risk to be conveniently assessed without precisely specifying their impacts and probabilities of occurrence [36]. For any identified risk factor on the construction project, their estimates of likelihood on the project and the impacts can be assigned qualitatively, for example: high, medium, and low, as shown in **Table 3**. The score for each cell in the P-I grid can be determined as the result of the multiplication of likelihood and impact scale values or an arbitrary value [36]. Subsequently, it is essential to achieve a consistent quantification of risk likelihood and impact by using a common language in describing them as been suggested by Tah and Carr [37].
2. *Qualitative cause and effect (Fishbone)*: the Ishikawa fishbone diagrams are used to evaluate failures or project performances. When using it in a construction project environment, it starts by identifying possible causes of risks in the construction project, and then assesses their probable effects on the project [28].

Impact	V High					
	High					
	Med					
	Low					
	V Low					
		V Low	Low	Med	High	V High
		Probability				

Table 3. Example of a P-I table [17].

3. *Failure mode and effect analysis* (*FMEA*): FMEA is an analytical technique that supports decision-making and quality planning in different planning and management phases of a construction project [38]. The FMEA is helpful to project managers because it starts by considering possible risk events (failure modes) and then proceeds to predict all their possible effects. **Table 4** shows a simple FMEA chart.

3.3.1. Risk exposure

As reported by Fraser and Simkins [39], risk exposures are the degree to which a project is exposed to risk (or a portfolio of risks). It is the estimates of the likelihood of occurrence and the potential impact on the construction project. As a result, these risk factors can have an adverse effect on the objectives of the construction project [39]. In addition, if there are more than two events occurring, risk exposure is used to quantify, compare and decide how to manage to them.

Lock [28] demonstrates the use of four main quadrants for risk exposure which are:

- High likelihood—High impact
- High likelihood—Low impact
- Low likelihood—High impact
- Low likelihood—Low impact

Low likelihood—low impact is the least important type of risk while high likelihood—high impact is the most important type of risk. Also, when determining the probability of risks occurring and its impact on the project qualitatively, Hillson [40] reports that the P-I Matrix is useful because it involves rotating the opportunity half as shown in **Figure 4**. It allows significant threats and opportunities to be envisaged by concentrating on the so-called *'Arrow of Attention'*. The size of this wedge can be increased if the project organisation is risk-adverse.

When using the probability-impact matrix as shown in **Figure 4**, each identified risk factor is assessed against defined scales, and plotted on a two-dimensional grid. The positions on the P-I matrix signifies the relative importance of the risk factor. As a result, indicators such as high/medium/low may be well-defined, allowing risks to be ranked.

Item	Failure mode	Cause of failure	Effect	Remedy: recommended action
Building project	Building construction collapses during installation of heavy equipment	Errors in floor loading calculations	Personal injuries, project interruptions and loss of reputation	Triple check structural calculations
	Building construction collapses during installation of heavy equipment	Floor slabs incorrectly poured	Personal injuries, Project interruption, Loss of reputation	Ensure operatives get good training and instruction. Employ competent project manager

Table 4. Part of a failure, mode and effect matrix (FMEA) [28].

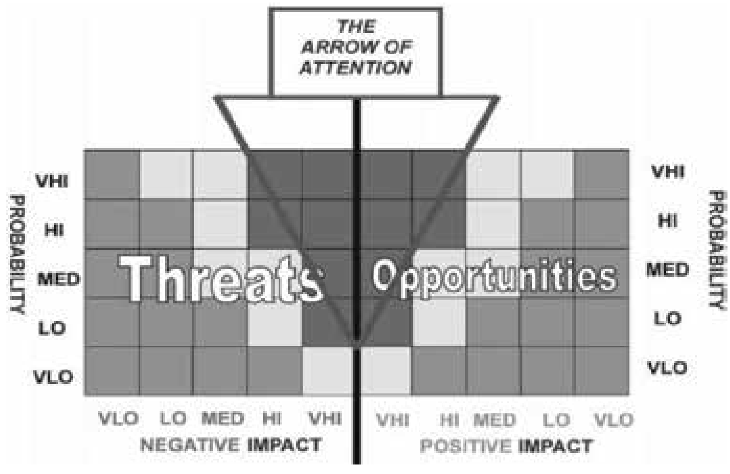

Figure 4. Probability-impact matrix for opportunity and threat [40].

3.3.2. Risk acceptability

Risk acceptability is about the decisions a project manager can make in accepting risk. In other words, it is the residual risk that a project organisation is willing to take. For example, identified risk factors in a construction project can be classified as unacceptable (intolerable must be eliminated or transferred), undesirable (To be avoided if reasonably practical, detailed investigation of cost justification is required, top level approval is needed, monitoring is essential), acceptable (can be accepted provided that the risk is managed) and negligible (no further consideration needed) as suggested by Godfrey [41]. Risk acceptance depends on Risk Criteria.

3.4. Quantitative risk analysis

Quantitative risk analysis requires that sufficient information is made available regarding the construction project. As reported by Rossi [42], if the project information is available, the benefits of its application are; the determination of the probability of accomplishing a construction project objective; determining risks that require the most attention by quantifying their comparative influence on construction project risk; recognising realistic and viable costs, schedule, or scope targets and then risk responses are then implemented. This process is made easier with the creation of a model. When creating the model, it is modified to quantify the impacts of risk on the construction project using qualitative techniques [31]. General, uncertainty on the construction project is also explained in the quantitative risk analysis [31]. Quantitative risk models can be developed based on a spread sheet, diagrammatic tool or activity network. All elements such as task, cost, duration, etc., which are relevant to the quantitative risk analysis must be included in any modelling methods used [7]. Against these elements, uncertainty variables can be entered instead of deterministic variables, in order to reflect areas of critical uncertainty [7]. The following techniques are used to evaluate risk quantitatively. They include, but is not limited to,

1. *Decision trees*: a decision tree is represented graphically when modelling risk in a construction project. Within the model it shows the possible effects of identified risks factors that

require project decisions and immediate-planned courses of action to the overall outcome [7]. Each of the outcomes is assigned a likelihood of occurrence allowing the most probable outcome to be determined. Also, alternative actions are explored within the model to identify the most beneficial outcome of the construction project or activity [31].

2. *Influence diagrams*: in earlier times of its development, the influence diagram was used to formulate problems prior to decision-making [31]. Modelling using the influence diagrams graphically represents relationship between risk factors and they affect the construction project goal or objectives. Influence diagram models expose key influences and allow the effect of uncertainty to be determined. These models are sometimes very complex and can lead to the need for effective graphical presentation as well as mathematical and computational efficiency [24].

3. *Probabilistic analysis*: this is a statistical method, which calculates the impact of every single risk factor, or the impacts of all risk factors on the project [43]. In this technique, Optimistic, Most Probable, and Pessimistic time and cost estimates are given for each activity, or for the project as whole [7].

4. *Sensitivity analysis*: sensitivity analysis or what-if analysis as it is sometimes called is a technique that seeks to determine which task variable in a project (for example, cost, time, quality etc.) has the greatest impact on project parameters [31]. In construction projects, project managers seek to determine how uncertainties and risks on specific task correlate with variance in the construction project. For example, sensitivity analysis allows a project manager to identify which activity schedule risk has the strongest correlation with the completion time of the construction project. Sensitivity analysis answers specific question like, which project task inputs have the greatest impact on the key project goals. This in turn helps the project manager in decision-making.

5. *Monte Carlo simulation*: this technique involves examining the impact of identified risk factors by running simulations to identify a range of possible effects on a number of construction project scenarios [31]. In using this technique, a random sampling is undertaken using uncertain risk factors to generate a wide range of possible outcomes. This is usually done by creating a mathematical model and then running simulations on the model to determine the impacts of identified risks on a construction project. The Monte Carlo techniques aid project managers in forecasting the likely outcome of a risk event and informs on decision making.

6. *Simple assessment*: the simple assessment technique is a mathematical method that examines important risks separately by determining their probable effect on total construction project cost and schedule [43].

7. *Failure mode effect and criticality analysis* (FMECA): the FMEA (see Section 3.3), when used in a prioritisation of failure modes, is referred to as the Failure Mode Effect and Criticality Analysis (FMECA). The FMECA is a technique much like a product or process analysis. It identifies potential failures in a construction project that could affect the client expectations and/or the project goals. The tool is useful in preventing adverse conditions on construction projects. Some of the benefits of using the FMECA tool includes; it assists in communication between project managers and suppliers who work closely during the concept and design stages of the construction project; it improves the knowledge and understanding of the behaviours

of the construction project; if it is done appropriately, it will ensure that the construction project is delivered on time and all the deliverables of the project are achieved; and finally, it provides proof to the extent of care that has been taken to ensure that the construction project meets the clients expectations. It is important to state that when using the FMECA, a Risk Priority Number (RPN) for ranking the failure modes is used which can be seen in **Table 5**. The Risk Priority Number is generally calculated as the product of occurrence (O), severity (S) and non-detection (D) of the failure modes. O is represented as the frequency of occurrence of the failure mode, S is represented as the level of damage the particular failure mode having occurrence O can do on the construction project and D represents the probability of not detecting the failure mode with frequency of occurrence O, and severity S [44].

Table 5 shows an example of the possibility and potential seriousness of building collapse as illustrated by Lock [28]. Within Lock's scenario, a building is developed as part of a project, and the collapse in question might happen during the installation of heavy machinery or office equipment on upper level floors. If the floors have been incorrectly designed, they might not be sufficiently strong to carry the weight of the machinery or equipment. The assessors clearly think this is unlikely to happen because they have ranked 'Chance' at the bottom end of the 1–5 scale. There is no doubt, however, that if this event did occur it would be extremely serious, so severity is ranked as 5. Detection difficulty means perceived difficulty of noticing the cause of the risk in time to prevent the risk event. Here, there is a considerable element of judgement, but the assessor thinks that although the chance of a design error is very low, the difficulty of spotting a mistake if it did occur would be higher (3 on the scale of 1–5). The product of the three parameters, 1 × 5 × 3 gives a total ranking number of 15.

Limitations of using the FMECA range from; different evaluation of occurrence, severity and non-detection can lead to identical RPN values even if their risk implications are totally different; conversion of the scores is different for the three risk factors; the three risk factors are difficult to be precisely evaluated, etc.

Item	**Failure mode**	**Cause of failure**	**Effect**	**Remedy: recommended action**	**Occurrence**	**Severity**	**Detection difficulty**	**Total ranking**
Main building	Building collapses during installation of heavy machinery	Errors in floor loading calculations	Personal injuries, project delays and loss of reputation	Triple check structural calculations	1	5	3	15
	Building collapses during installation of heavy machinery	Floor slabs incorrectly poured	Personal injuries, Project delay, Loss of reputation	Ensure operatives get good training and instruction. Employ competent site manager	1	5	2	10

Table 5. Part of a failure, mode effect and criticality analysis matrix (FMECA) [28].

According to Sodhi and Tang [45], in the quantitative risk analysis phase, risk models are used to define construction project expectations and outcomes of identified risk. Consequently, other benefits of the quantitative risk model includes but is not limited to the following:

- It can aid and support project managers to understand the nature of threats and ways to manage them.
- It can support risk measures for informing their stakeholders,
- It can help project managers to focus on specific risk areas and
- Support allocation of risk management efforts and budget to different risk mitigations such as to answer the question of who should make such an investment (contractors, subcontractors or its clients) in construction industries.

Any quantitative risk management model adopted should be able to provide the outcomes which can fulfil the defined purposes of the construction risk analysis [46].

3.5. Risk response and monitoring

After the identification and assessment of risk, they are not left unattended in the development phase of a construction projects. Risk responses are implemented. Apparently, the planning of responses to construction risk can happen at all phases of the project; however, it is predominantly done in the development phase of the project. This is because the development phase of a construction project is where a project manager can practically implement the most effective and beneficial response to an identified risk factor as result, ensure the successful delivery of the construction project. As reported by the APM [24], the response plan includes strategies such as avoid, transfer, mitigate, exploit, share and enhance. In other words, appropriate responses must be applied for identified risk factors in the construction project which can vary from avoidance, transferring the risk elsewhere, reduction through mitigating threats and realising the opportunities and acceptance the risk.

Some project organisations cope with risk by applying different strategies and this can affect the performance of a construction project. For instance, this can happen if planning and implementation of responses are not being effective due to unclear lines of communication between the risk manager and the project team. If the responses are ineffectively managed, actions after assessment of the identified risks factors may not be fully captured and communicated which will therefore, result to ineffective mitigation and in turn impact on the performance of the construction project.

Vose [17] has clearly explained mitigating actions that can be applied even in a construction project especially in terms of implementing different risk mitigation strategies as seen in **Figure 5**.

The responses for threats in construction project are:

1. *Risk avoidance*: in applying this strategy in a construction project, the project manager aims to prevent an adverse effect from impacting or occurring in the project. For example, it may

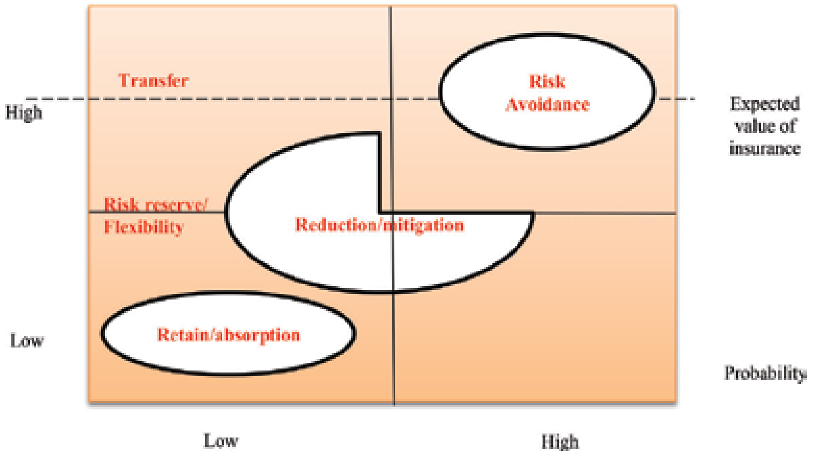

Figure 5. Mapping risk mitigation with level of probability and consequence [17].

involve the project manager changing the project design so that the circumstance under which a particular risk factor might occur cannot arise, or so that the risk factor will have little impact on the construction project if it does happen.

2. *Risk transfer*: in applying this strategy, the project manager seeks to shift the responsibility for risk to a third-party. This is done in order to eliminate the threats to the construction project. What this implies is that the project manager is passing the risk to another party who is better equipped to manage the risk, resulting in the construction project successfully achieving its objectives. In risk transfer, common strategies used are contract, insurance, warranties, outsourcing, etc.

3. *Risk reduction*: this strategy involves the use of one or more reinforcing actions by a project manager designed to reduce a threat to a construction project by mitigating the probability of occurrence and/or the impact before the risk is realised. The goal of applying this strategy by the project manager is to ensure that a risk factor does not occur in the construction project or if it does the impact can be contained in a low level.

4. *Risk reserve/flexibility*: this approach allows for more time, money or human resource on a construction project. When undertaken estimates for a construction project, a risk reserve is included in order to ensure the successful delivery of the construction project. For example, if a WBS (work breakdown structure) has been developed for a construction project and resources has been budgeted; then in applying this strategy, a reserve is then established to prevent future problems from arising. As a result, this reserve can then be used by the project manager to manage risk that may arise in the life cycle of the construction project.

5. *Risk acceptance*: this strategy involves using a range of passive and active responses. To passively accept a risk is to recognise the risk exists but choose to do nothing about it other than monitor the status of the risk in the construction project. This approach is appropriate if the risk threat is low and the risk source is external to the construction project. On the

other hand, the threat may be real to the construction project, however there is not much that can be done about the threat until it materialises in the construction project. As a result of this case, contingencies can be established to manage the event when or if it occurs. Examples of contingencies that can be implemented includes; provision of extra funds, a detailed action plan that can be implemented when the issue arises.

And the responses for opportunities are:

1. *Exploit*: in applying this strategy, the project manager ensures that opportunities are realised. Opportunities can arise in completing an ongoing construction project on time in order to bid for a similar project. This strategy is the opposite of risk avoidance.
2. *Enhance*: this is an approach where the project manager seeks to increase the chances of risk happening in a construction project in order to realise the benefits of the risks.
3. *Reject*: this is when a project manager takes a deliberate decision not to exploit or enhance an opportunity.
4. *Share*: this strategy is used when project organisations are unable to realise opportunities by themselves; as result, they team up with another project organisation and work together to realise the opportunity. For example, if a project organisation lacks some certain technical capabilities in bidding for a construction project, team up with another project organisation that is capable of doing the task and jointly bid for the construction project.

In practice, risk response strategies are effective in providing possible options that can be considered by a project manager to managing threats that are associated with a construction project [17]. Consequently, knowledge creation is useful in reducing the likelihood and impact of risk effectively [47].

Through a careful study and adoption of the results of other researches such as those of Seo and Choi [48], Aloini et al. [49] and Karim [50], a summary of the risk management processes, including the clear purposes and activities within each step is developed and shown in **Figure 6** [51–54]. The summary is intended to assist construction professionals to better undertake each process.

4. Conclusion

The construction risk management process starts by defining the risk management objectives before proceeding to identifying risks. This will increase the understanding of the scope, responsibilities, environment, and the project objectives. The assessment and analysis stages are interpreted and implemented differently across various standards and guidelines. However, with this theoretical construction risk management process presented in **Figure 6**, each step is a stand-alone; the activities to be conducted are clearly specified. The next steps are response and monitor/review. Peter Campbell in Hillson [55] criticised risk management as being talked about more than implemented, whereby people are overly optimistic about the future event, lacking clear understanding and philosophy behind each of the steps in the risk management process. The focus is towards identifying more pros than cons; more benefits over costs; and being optimist that risk will be managed successfully. People are biased towards the optimism that risk could be managed simply by allocating financial contingencies to account for the eventuality of something that could go wrong. Such biases can

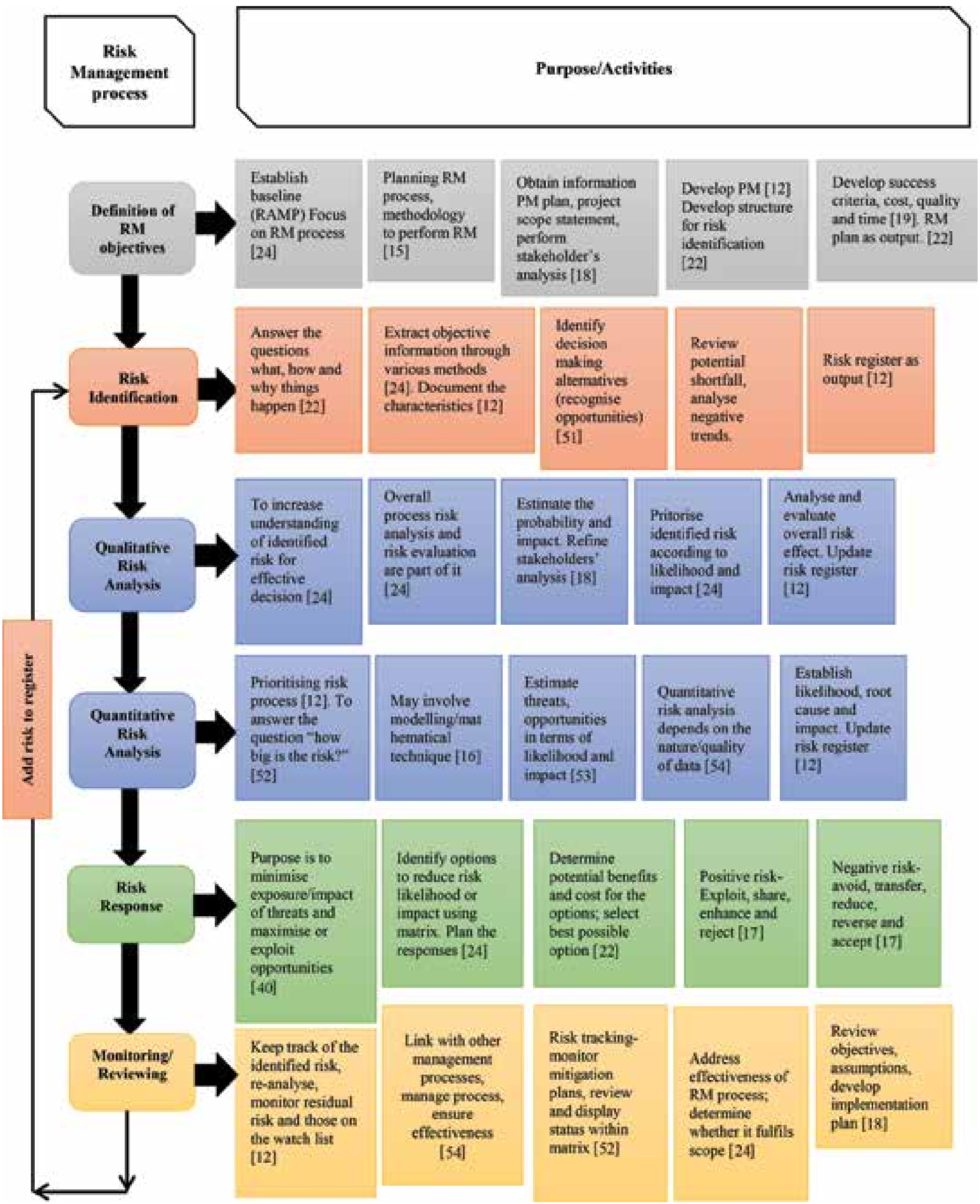

Figure 6. Summary of the conceptual processes of managing construction risks (developed by the researcher).

http://dx.doi.org/10.5772/intechopen.79459

be overcome through the use of a structured and well explained framework for risk management. This summarised framework presented in **Figure 6** can therefore address this problem and provide a better understanding of how risk can be managed.

Tools and techniques are used to assist the construction risk management process. Tools are commonly known as generic software products used to carry out the techniques efficiently, while techniques are methods of carrying out particular elements of the process. Besides considering the costs of the tools and techniques, their selection must also be appropriate to the particular stages, as some of them may only be suitable during the earlier stages, others may be used later. However, understanding of the process is more vital than over reliance on tools, models or systems.

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Chapter 2

Big Data as a Project Risk Management Tool

Jarosław Górecki

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79182

Abstract

Risk management plays a key role in project management methodology. Nowadays, it is quite common to manage projects with the use of digitally collected data. The Big Data (BD) analysis can enhance the quality of information taken from these records and be used for project management. Moreover, it can be a project risk management tool. Some examples of BD application can be found in the investment and construction projects which use both physical and virtual data derived from controlling, bids for tender, schedules from sub-contractors or some other specific information. An accurate analysis of all that data (BD) makes it possible to discover new phenomena characteristic for the project. Getting to know them can be helpful in reducing the risk of accomplishing the project objective. The chapter is intended to arouse the readers' interest in this new source of valuable information, required to improve a course of projects. An awareness of utility of Big Data was presented on the basis of the recent anonymous survey among Polish construction entrepreneurs at the turn of years 2016 and 2017. The research has been the first step towards the broad analysis of the propensity of construction companies for using BD in project risk management. Moreover, it points out some capabilities in this matter.

Keywords: project, risk, Big Data, management, construction industry

1. Introduction

Risk can be most generally defined as a diversion of the course of events from the expected ones. The risk stands for the probability of a lack of success in terms of the actions taken [1]. It should be associated mostly with the measure of deviation from the pre-planned values. It is usually defined as the probability of those deviations. Attempts at its parametrization refer to the estimation of the probability of achieving the objectives of the planned actions and the effects of the failure to accomplish them, expressed in physical or financial units [2].

In more detail the term of risk is also presented by the Project Management Institute (PMI) which defines the project risk as an event which is difficult to predict which, if exists, affects at least one project objective (e.g. quality, cost and time) [3]. Thus sensitivity to risk of a specific area of activity can be perceived as its vulnerability to the effect of disturbing factors. It can be objective or subjective. Objectively the susceptibility to risk can be determined as the exposition to risk. It mostly refers to the susceptibility to changes in objects or systems due to various factors. Subjective vulnerability to risk is related to the perception of risk factors and the scope of their effect by the work entities.

Risk management, on the other hand, is of fundamental importance for achieving the project objectives, not only minimizing bad results but also acting as a guide to maximize the positive results. Analysing the state of knowledge on risk management, one can state that the opinion about a necessity of considering risk in project management has been well established [4]. However, management tools have been still imperfect. In risk management heuristic models are still of dominant importance. Attempts at modelling mostly refer to the evaluation of the behaviour of some parameters exposed to random effects. An insight into the nature of phenomena affecting the risk level and diagnosing the extent of risk based on empirical research are, however, still an open research field.

The risk analysis can provide the grounds for building the security of accomplishing the objectives of a given project. One has to think not only about the weak links of primary nature, which occur in its respective processes, but also about a consequent risk which is the effect of mutual relations of those processes, developing dynamically. In project risk management one must also factor in the threats which can occur in the future. They are still constantly changing challenges faced by project managers, contributing to changes in project management. Such an approach facilitates orienting the actions in the project compliant with its objectives. For example, one can note that including the risk analysis to estimate the project cost is a chance for bringing those estimates closer to the reality [5].

With the development of IT the data in analogue format lose its importance since the computer is unable to process it. In response to that problem the digital technology emerged and the amount of data saved in that format is continuously growing. It has already been so high that it exceeded the technological possibilities of its collection. Besides, according to the International Data Corporation [6], each year it increases by 40% and from 2011 to 2016 it increased nine-fold. This phenomenon is referred to as Big Data (BD).

2. Problems of gathering the data for the purpose of Big Data analysis

2.1. General context

Database is an IT term. It is defined as the collection of digitally recorded data, which are appropriately specified and describe a chosen reality. Databases are able to store all the structures of data enumerated in the previous point, starting from numbers up to sound, including immeasurable features.

The key role in making available such big collections of data so that they could fulfil the BD criteria is played by the governments. Thanks to the efforts of the former President of the United States Barack Obama, in the USA, the database Data.gov, within which open access may be granted to the data from the government sources, was created [7]. In June 2013, at the meeting of G8 Group, its countries concluded agreements with reference to making public of their database in accordance with five rules: default open data, quality and quantity, usable for everybody, releasing the data for better management and releasing the data for innovations [8]. During the same year, the government of Japan made available its collections on the website: data.go.jp. The pioneers were followed by France (data.gouv.fr), China, who published commencing of the work on making available government data, and many others countries. More details can be found in the magazine "The Bridge" [7]. The countries mentioned above make available the data from the branches of economy selected thereby. However, there are also pure construction databases, for instance, the German database, created by German BKI [9]. This organization every year publishes well-organized and exhaustive data on the costs of construction projects; the structure of the report divides the buildings into different types, allocating a specific example to each of them. Then, it presents the standard deviation for price data, taking into account the localization (prices differ depending on the region) [10].

In spite of the fact that data collections from other countries or regions could be applied, it must be noticed that not all branches of the economy are highly globalized (as, for instance, construction). Thus, it is not always possible to use "foreign" collections without cleaning and adapting the data [10].

Taking into account the earlier, construction companies more and more often decide to create their own databases, especially big enterprises, implementing many projects yearly, are in a position to generate BD.

To introduce BD for the management of the risk of projects, the manner of data gathering must change. Based on visual inspections, measurements carried out with the tape, documentation relating to the transportation of material and talks to the workers or managers are not sufficient. The collections of data obtained in this manner are too small and therefore it is not possible to recognize general dependencies and connections with other cases [11]. Gathering of data is a huge challenge as technologically advanced sensors generating the data, their transfer and storage are necessary for that purpose.

2.2. Data collection

One of the possibilities of collection of data is the procedure suggested by Son and his team [12]. It consists of surveying the key units of the construction project (for instance: architect, investor, project manager and construction site manager) during face-to-face meetings. These persons have access to detailed information relating to the progress of works both at the stage of designing and at the stage of implementation. The questionnaire should be designed in such a manner as to picture the differences between adopted assumptions at the design stage and the results during the implementation of construction projects. The survey may be oriented on aspects of costs and time, and the conclusions relating to deviations should serve the future projects at every stage of implementation [12].

The suggestion of the system to assess the offer of the construction project given by Zhang with his team [13] may be also quoted. The data necessary to perform the analysis relate to costs. The main three sources of gathering thereof were presented. The first refers to the cumulated experience of the researchers relating to the implemented projects. The second source is the agreement concluded between the construction enterprises which obliged themselves to make available their data. The companies included customers, contractors, subcontractors and so on. The third source is the agreement on the cooperation that concluded with the government, giving the authorization to analyse the government collection of data. Combing the three, abovementioned, sources, one source was achieved which generates the sufficient amount of data to fulfil the conditions of BD. To ensure the timeliness and the reliability of sources, the data relating to the costs from all the units were connected to the system. It enables the quickest transfer thereof, which, in result, leads to their number growing constantly. The content of the abovementioned data is basic information on the project that includes the number and name of the project, date, localization of the contractor and total duration time of each stage of the project. Then, characteristic information depending on the type of project, for instance, in case of the underground station construction, is presented: type of station, depth of the excavation, surrounding environment, shape of station, geotechnical and geological conditions, construction methods and so on. Next, subsequent information of each cost that includes the total cost, cost of single units, costs and amounts of material and so on is presented. All these data, after being gathered, are subject to integration and consolidation [14].

Next possible way to collect data is using the global positioning system (GPS) receiver. The data gathered in this manner may deliver necessary information which may be used to minimize the risk relating to the safety of building sites, to improve the processes of new investment planning and to choose better their localization as well as to optimum architectural solutions fulfilling the needs of the users. The methods of collecting the data which are based on GPS receivers [14] include, among others:

- Data gathered from the vehicles of public transport, taxis in particulars: Public transport has a fleet of vehicles constantly crossing the town, which are in the position to deliver the most current data relating to, for instance, traffic intensity. Geographic coordinates, speed, time of drive and its directions allow one to learn the transport structures, templates of travels and size of traffic.
- Data from the personal devices of physical persons: The individual users deliver the data concerning the use of urban spaces and the traffic roads. Additional data such as age, gender, education or individual templates of behaviour may help to optimize the architectural solutions of the buildings and public spaces.
- Data from the receivers of the workers at the building site: The workers, wearing the receivers attached to their helmets, generate the data relating to their activities and localization at the moment of performing the activities of increased risk. The data are helpful to determine the safety zones and inflict real influence on the improvement of life and health of employees.

The disadvantage of the global positioning system (GPS) is that it loses the signal inside the buildings and therefore may only be applied in case of outside works—in the open area [14].

The solution to this problem may be a Polish technical novelty—Beacon, a small transmitter based on Bluetooth technology (radio waves), which may be attached to any place on the building site. It can monitor the activities of the employees in the range up to 70 m.

The real mine of information is also the effect of not removing the data from the construction projects implemented in the past. In spite of the fact that the projects differ in many macro-conditions, for instance, requirements of the customer, localization of the implementation or the content, there are similarities in the micro-scale, such as tools, technologies, workers' skills, structure of the team and so on. Therefore, the knowledge obtained during solving the problems should be preserved in the format allowing to manipulate thereof and to disseminate it in the forthcoming projects [15].

It is not possible to enumerate all sources of data. Apart from those mentioned above, monitoring may be distinguished (for instance, at the construction site), sensors (to control the operation of machines), pictures of the employees - to register dangerous behaviour, etc. All methods of generating and gathering data involve the challenge which is their format. Text data may be stored on a PC, tabular data, pictures, recordings and many other data recorded on paper, which require different processings. Therefore, the best manner is the transformation of the unstructured data into semi-structured or structured. They must be transformed manually, sorting the documents or automatically applying algorithms based on artificial intelligence (automatic scanning of the text and recognizing texts and pictures) [13].

2.3. Computer-aided data analysis

Presently, there are enough techniques and technologies to face BD. However, the choice of the proper ones is the most important. As a branch report indicates [16, 17], the application of the unsuitable programmes leads to the fact that the implementation of BD becomes unprofitable or significantly difficult for the organizations [18].

For BD to correspond to purposes and expectations the time between the gathering of data and the results obtained from their analysis is of unusual significance. The priority is to strive towards real time. The closest to that aim is cloud computing. Cloud computing is a big database which contains lots of supporting technologies and algorithms. It was introduced in 2006 by Google. The development of various internal applications relating to BD is supported by a series of tools, which integrate cloud computing with a platform called Hadoop [14]. Hadoop became a complete ecosystem, which contains a module such as database (H Base, Cassandra), file system (HDFS), the processing of data (MapReduce) and others. To some extent, it can be claimed that Hadoop became a standard application having the necessary tools to face BD [13].

Introducing the cloud as an analytical solution for an enterprise, the following models of implementation should be taken into account [19]: private, public and hybrid.

Private models are deployed in a private network, managed by enterprise or by external units. Private cloud is recommended for the companies which require the highest control over the data, their safety and privacy. Using this model, data and services provided by the cloud may be used more effectively by all departments of big enterprises.

Public models may be located in the Internet and be accessible for the public. Public clouds offer high efficiency and low costs. The supplier deals with analytical services and managing the data, and the degree of safety, privacy and accessibility is written in the contract. Organizations may use this model to carry out the analysis against lowered costs and to share the observations relating to the results of the analysis of public data.

Hybrid models join two models, where the additional source of data may be added to private collection. The users may develop and implement analytical applications with the use of private surroundings and, in the same way, take advantage of the flexibility and higher level of safety than in the case of public model.

Due to latest progress, the technologies like cloud, Hadoop and MapReduce enable the collection of large amounts of co-structured and non-structured data within reasonable, close to real, time [7]. More information relating to technologies, mechanisms and the construction of the systems to store and process the data can be found in the literature, see [20].

2.4. Quality of data

Poor data quality leads to poor results of analysis. The key challenge is how to improve the quality of data in relation to reliability, completeness, consistence and resolution. Two main reasons of the lack of high quality data are lack of generally accepted templates identifying parameters which should be monitored and lack of suitable sensors which would ensure the generation of reliable data of high resolution [21]. Generally speaking, when the size of data increases, their quality remains the same. However, proportionally to the scale of the size of data increase, the amount of problems related thereto increases as well. If the size of data was multiplied by 10, 10 times more hindrances would appear in the collections of data [22]. The quality of data is defined by detailed principles depending upon the branch they are used in. These principles determine specific requirements relating to collection of data in the dimensions of precision, preciseness, coherence, metrics, timeliness and meaning, the breach of one of the abovementioned principles constitutes the insufficient quality of data [22]. It must be taken into account that depending on the context and use, the quality of data should correspond to other requirements.

According to NASA [23], the errors generated by humans are the most difficult to detect, understand and correct. They are semantic in their nature; however, they are practically undetectable for the machines. The ratio of their occurrence is from 5 to 10%, significantly more often than any other type of errors. It is a red zone. Automation of the data sources significantly increases their quality, whereas, by replacing humans, it increases the effectiveness of work as well as eliminates the errors generated manually. The advantages of automation data generating include also their precision and the ease of detection of possible errors. It is characterized by high regularity, due to which it is possible to create appropriate algorithms which would easily detect and repair irregularities. It is a green zone. In spite of that, these are the situations in which the errors in data may be ignored. Everything depends on the required level of the quality of data. If the user searches exclusively for templates or trends they need not pay special attention to errors, which will be shown in the results of analysis as outliers. Thus, it is very important to precisely know the level of the data quality on which one works.

It may turn out that the same collection of data would fulfil the quality criteria for one user and would not for the other [22].

To improve the quality of data it is necessary to implement the management of meta-data (data about the data) and master-data (collection of trusted data disseminated in the organization between different branch systems, for instance, customers files) [24]. Both in the collection of data of traditional size and in BD the proper management of meta-data and master data are crucial. The errors contained therein have disproportionally big influence on the quality of data with which they are connected. One error in the fraction of meta-data would make a perfect collection of data completely useless [22].

Also the use of too many sources does not serve to improve the quality of data. The more the sources, the less the probability of the analysis success. This happens due to technological problems. The merger of several dozens of data sources nearly always creates the difficulties relating to the transformation of formats and data structures. Besides, the unification of the gathered data often takes too much time [22]. The challenge relating to the quality of data is also the lack of their consistency. Four types of consistencies may be distinguished [25]: time, space, text and the consistency of functional dependencies breach. Time inconsistency occurs when in databases containing the time attribute, the data components overlap in time or are contrary with the circumstances. Space inconsistency may result from the geometric representation of the object (object having many localizations), space relations between the objects (breaking of space relations) or their connections. Text inconsistency occurs in non-structured texts written by a human. Inconsistency resulting from the breach of functional dependencies causes the inconsistency within the data and information.

The manner to improve the data inconsistency consists of the identification of the cause of inconsistency and introducing the heuristic procedures, which aim at solving the problem at its source [25]. For instance, if the inconsistency arises out of improper features, the algorithm is introduced and it replaces the improper features with the proper ones [26]. Also the history of carried-out analysis may deliver lots of information. In the BD era the leaving of errors detected in the collections of data while performing the activities relating to the improvement of their quality is possible and significant. All corrections and other interferences performed should also be left. This serves to create the templates which may prove to be helpful in the detection and correcting of data [27].

It may be noticed that data generating, gathering and storing are not easy tasks. These processes are very complicated and are accompanied by many challenges, on every stage of processing. One of the more important problems is the quality of data, which depends on the manner of their generation and gathering; however, this can be seen only at later stages. The solution that would significantly improve the quality of data and enable the detection of possible errors is replacing work of a human by sensors and automatic technologies of gathering. Thanks to it, the errors difficult to be detected which are generated by the semantic nature of people are avoided. However, these errors produced by the machines are easy to be detected and repaired. The data may be stored in private, public and hybrid databases. If an enterprise has at its disposal the collections of huge value, the application of private databases is recommended. It is the safest manner of storing, whereas proper protecting measures are to be preserved, that is, data encryption and the policy of responsibility and the access authorization. The level of possibility of interference in the data gathered should be dependent on the position in the company. Based on visual inspections, measurements carried out with the tape, documentation relating to the transportation of material and talks to the workers or managers are not sufficient. Storing of any, even apparently not significant, data is recommended including, most of all, accomplished projects, recordings from the monitoring cameras, readings form GPS receivers or pictures. Since the governments have at their disposal the collections that are several teen times bigger, the collection of the whole construction industry making them public is also recommended. This would revive and increase the productivity of all segments of the economy.

3. Project management ontology

3.1. Theoretical framework

Each project is characterized by [28]:

- clearly specified objectives, the accomplishment of which closes the project,
- specific time frameworks (commencement and completion dates),
- use of resources (people, money, materials, machines, etc.),
- a number of interrelated processes (tasks) affecting the course and costs of the projects.

Thus the project, next to its innovativeness and untypical nature, has also a few other characteristic features: it is oriented on a specific objective (a specific result is expected), it has specific commencement and completion dates (it is limited in time), during its execution various resources (human, financial, etc.) are used, it is organizationally separated from other actions performed within a given organization, it has a specific organizational structure, it is a vast and complex project, it varies depending on the execution phases, it is related to investments, it is an interdisciplinary issue (it requires an involvement of specialists of many fields) and it requires an ongoing cost control. The risk of the actions taken is also the project's essential feature. However, there are no two such projects: one can always find at least one aspect which differentiates them: commercial, administrative or physical [29].

The term "project management" stands for all actions related to the preparation and execution of the decisions. However, it does not refer to the activities which directly refer to the project execution, especially with specialist aspects of solving it but to problem-solving process management [30]. Yet the term "problem" can refer to a threat of danger, an emerging chance as well as unsatisfactory situations or favourable situation in the course of project execution. The problems which need solving as part of project management are inseparably risk related.

Project maturity in project management is seen in the project team members' competencies, including the project manager. Project manager's project maturity can be defined as an ability of professional project management.

Searching for effective project management, the managers use risk management tools. It is necessary to assume the measures referring to the same risk of the project and accomplishing its objectives. One must also determine the size of any potential project losses in reference to the occurrence of independent risk areas. And independent risk is a risk which does not depend on the project manager's decision. The project risk factor analysis allows for defining and accounting for the events which can heal the project and it helps in defining possible strategies of counteracting such situations. The systematic approach to risk management stands for a global perception of the project via the role of each element of the whole, especially future effects of the decisions taken. Risk management mostly refers to a series of actions to reduce the risk effects. It thus seems that respective risk areas affect the accomplishment of project objectives to various extents, and some risk factors come from its environment. Risk management effectiveness is guaranteed by a systemic approach fully integrated with all the processes in the project. Practical risk management in the project appears mostly in a form of risk diversification.

It is also necessary to create a project risk management plan and risk capital facilitating the coverage of potential losses related to the project execution. Project maturity in project management is perceived mostly in potential possibilities of a competent project team selection, considering mostly planned risk management skills, including a search for methods on how to secure yourself from various risks, identified for the project or defining the active risk control methods. Risk management strategy in the project should foresee the necessity of creating reserves (risk capital) which can have a decisive effect on project profitability and which are important for decision-making about project execution. The key element of the strategy of securing yourself from risk is investing in the projects for which the expected rate of return is higher than the costs of the capital increased by the risk-related mark-up.

In project management there is a need for intergenerational management which requires understanding the differences in understanding values, the style of work and leadership as well as employee attitudes between the representatives of generations X and Y, as well as generation Z emerging in the market (persons born after the year 1995). The young generation articulates their willingness to participate in projects. Enterprises, willing to use their potential, formulate a number of their tasks as projects. Currently project managers are mostly representatives of generation Y (also referred to as the millennium generation), the persons born in the early 1980s. Their specific nature is related to a considerable acceleration of globalization processes accompanied by IT development and building the information society. Young people almost around the world feel like residents of the global village, from their childhood familiar with state-of-the art communication tools.

Interestingly, they usually have strong competencies of creative thinking, they adapt to changes easily, they are ready to face new challenges and ready to cooperate. Such features are especially needed for today's project managers, facing the need for implementing the system information modelling (SIM) ideas, see [31]. SIM, which refers to modelling information on the subject of the project, facilitates a permanent and immediate access to information on costs, schedules of actions and so on. One must note that the technical elements of that model have been, to much extent, operating already. Computers are powerful enough and the Internet is a huge communication tool. Specialist software does not only facilitate an efficient performance of each element of multi-sector documentation but also supports the actions of the investor, contractors as well as the users of objects in which their life cycle is accompanied by SIM.

The competencies of project managers as the tools developed in terms of SIM make it possible to improve project management together with the process of operation and liquidation of the objects existing as part of the project.

3.2. Research results

Objects with the long cycle of operation are investment and construction project products. The opinions of managers executing projects in the construction sector are thus interesting. To acquire opinions on managing such projects, project managers in 29 Polish construction companies of the Kujawsko-Pomorskie region have been surveyed. The study was carried out in the first quarter of 2017. It showed that the risk of exceeding the essential project parameters, namely the project execution time, budget and the scope, shows varied intensity.

As for complying with the planned project execution time, exceeding the deadline was most often reported as ranging from 76 to 100%, which was the most frequent (48% respondents). Exceeding the planned budget was most often reported to fall within 0–25% (45% respondents) and 48% of the respondents pointed to the occurrence of exceeded project scope accounting for 26–50%. The studies also covered the evaluation of the level of project management complexity in the respective perspectives of essential project parameters, namely: project time, budget and scope as well as the construction workmanship quality.

As shown in **Figure 1**, the respondents see the highest level of complexity in project time and budget management.

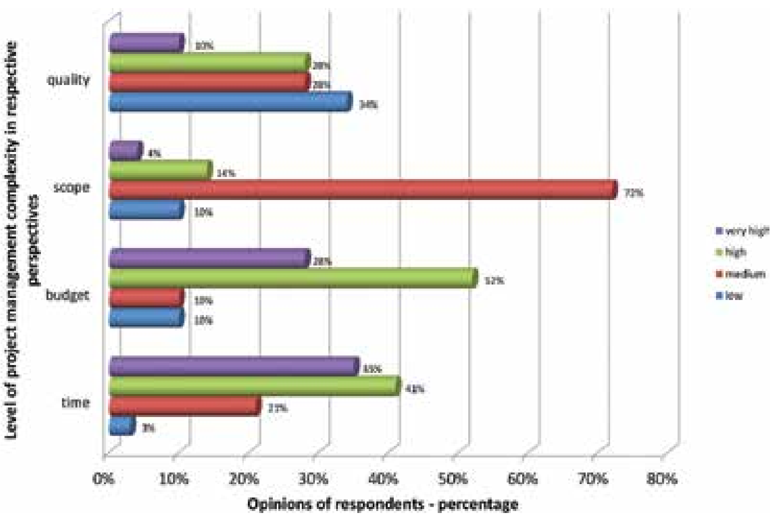

Figure 1. Opinions of respondents on the level of complexity in project management in terms of time, budget, scope and quality. Source: own study.

4. Essence and development of Big Data (BD) analysis

According to the National Science Foundation [32], Big Data (BD) is "a big varied, complex and/or dispersed set of data generated from devices, sensors, Internet transactions, e-mails, films and/or other digital sources available at present and in the future" (own translation). Gartner, in the report of 2001, indicated that BD is characterized by a 3 Vs formula (volume, velocity, variety) [33].

"*Volume*" refers to generating, collecting and accumulating big, continuously increasing, amounts of data. It strongly depends on the existing equipment infrastructure which, if not continuously improved, can lead to data analysis becoming very quickly invalid [20].

"Velocity" is the speed, the data are produced and processed with.

Only when it is high, a maximum use of the value coming from BD is possible [19].

"Variety" points to various types of data: structured (data ready for analysis, e.g., spreadsheet data), semi-structured (not organized enough to be directly analysed) and non-structured (data which, before being processed to structured, cannot be analysed, e.g., sound, video) [20].

With time the 3Vs formula got transformed into 5Vs. It was considered that BD should also correspond to such features as: veracity and value.

"Veracity" refers to the source of data, whether it is trustworthy and whether the data quality is sufficient.

"Value" is most crucial of all "Vs". It is related to the difficulty in foreseeing whether the dataset is adequately adjusted to the question asked in the analysis [18].

All the "Vs" are both the features which describe BD and a challenge faced by the analysts. A missing success in any of the attributes results in a failure of the entire analysis [18].

The research reported by The Data Warehouse Institute shows that only 12% of the companies which had introduced BD were successful, 64% with a moderate success and 24% failed [17]. However, one must note that such BD analysis implementation experiences calls for further improvement.

BD uses a set of data of extreme sizes which exceed the possibilities of manual techniques and commonly applied computer programmes for capturing, management and processing in a tolerated time range [22]. Due to its size, BD requires brand new analytical tools. It is necessary to transform the semi-structured to structured data [7]. Structured data is adequate for a direct analysis and semi-structured data must be first adequately processed. Nevertheless the processing speed is essential. Datasets show some complexity and uncertainty. Complexity is due to a large amount and variety of data, whereas uncertainty comes from ongoing changes in nature. According to [34] the challenge is to determine how to acquire essential knowledge from complex and uncertain surface of data.

One should note the relations of non-homogenous data, non-homogenous knowledge and non-homogenous decisions. Decision-making depends on the knowledge acquired, while knowledge depends on data. If the knowledge of the project manager who draws on his experience mixes with the knowledge acquired from automatically generated non-homogenous data, then we deal with non-homogenous knowledge. Due to non-homogenous knowledge the manager takes a non-homogenous decision. Manager's knowledge represents a group of non-structured data and thus it is difficult to use it in the analysis. There is also an inconsistency of data which is shown in various kinds of human behaviours and decision-making processes. We face it when one source describes a problem in another way than the other one [25].

Despite the above problems one faces while implementing BD, one must consider the advantages of the BD analysis. It allows for discovering some "hidden knowledge" [35] or "information providing grounds for actions" [36], which helps the decision-making process. Next to the technical and methodological difficulties, there is a premise that applying BD can eliminate the partiality of smaller datasets and ensure a more accurate image of the reality studied in the course of its objective assessment [37].

One must indicate the BD applicability in the course of project management and one can even assume a statement that being successful in investment and construction projects is conditioned by the access to data in a structured form, especially in a form of BD. At the same time one shall stress an innovative nature of BD as a project-management supporting tool [38].

The BD analysis can be included in the system information model (SIM), usually built with an object-oriented approach [39].

System information modelling (SIM) is a general term applied to describe the process of modelling complex information carrier systems. System information modules are digital representations of connected systems, such as, for example, tooling, power supply, control and communication systems. The objects modelled on the SIM card are closely related with the objects in the physical system. Components, connections and functions are defined and connected just like in the real world [40].

The BD application examples can be found in the investment and construction projects which use both physical and virtual data derived from controlling, building information modelling (BIM), bids for tender, schedules, from subcontractors and information from the construction site, to mention just a few. An accurate analysis of all that data (BD) makes it possible to discover new phenomena characteristic for the project. Getting to know them can be helpful in reducing the risk of accomplishing the project objective [41]. Currently on the construction market there appear centres dealing with data capturing, storage, protection and analysis [11].

5. Project risk management

Project risk must undergo a permanent control. The essence of risk is the occurrence of potential possibilities of unexpected events resulting in a change of the situation, people, objects, systems (e.g. economic systems, ecological systems, etc.), phenomenon and so on. Therefore foreseeing their future, made a priori, diverges from the reality. At the same time the expectations of the planning entities do not come true, which is a definite planning failure. The factors of that failure, or rather the probability of their execution, are defined as risk.

The term risk itself thus has a definitely negative connotation. With the above in mind, it is hardly possible to agree with the views claiming a dualism of the term risk itself. The effects of the events, however, can already assume the form of both a loss or a profit as compared with the preliminary assumptions. Losses occur if the foreseen situations, referred to as the threats to planned objectives of the actions taken, come true. However, profits have a chance to appear if actions are taken contrary to the speculations about the threats which, however, will not come true or if there happens to be a confluence of circumstances making their occurrence not have a significant effect on accomplishing the objective of the challenges taken up.

Risk management, as an art of taking rational decisions, runs in a standard way in the following (basic) stages [4]:

- risk identification,
- risk assessment,
- risk control,
- risk financing,
- control of the actions taken.

Identifying risk involves defining what kinds of risk and to what extent the project is threatened. An analysis of respective processes from the point of view of their threat of risk and then their classification are necessary.

A detailed analysis covers external events which threaten the project from the outside and those which can emerge as part of the project and threaten others.

Risk estimation involves defining the probability of a possibility of the occurrence of damage and the loss size. An adequately performed risk evaluation allows for taking up the projects, reducing the level of project exposure to its objective accomplishment failure.

Risk control involves taking up actions limiting the risk to the assumed admissible size. Limiting the risk often becomes contrary to the other project objectives, including mostly meeting the desired parameters of project effectiveness.

The basic risk control objective is to determine the measures of prevention eliminating or limiting the risk evaluated. Each time the selection of adequate measures is a result of a detailed analysis of the effectiveness or costs of their introduction. The costs of limiting the risk cannot exceed the value of the damage which can happen (material and non-material damage). One must note that an increase in profit is often possible by increasing the size of risk related to project execution. Most often risky projects are related to high incomes. However, above a certain limit a risk of loss can threaten profit generation.

Similarly, an enhanced profitability is contrary to maintaining liquidity. Limiting the risk is also related to bearing additional costs. Determining the size of the admissible risk is necessary.

As part of risk control, two types of actions can be taken:

- actions affecting the causes of the occurrence of risk, the objective of which is to limit risk; they are defined as an active strategy of counteracting risk,
- actions influencing the effects, the objective of which is to reduce a negative effect of unexpected losses on the level of accomplishing the project objective; they are referred to as a passive strategy of counteracting risk.

Risk financing considered as a stage of risk management comes from the fact that all the risks which are not eliminated with preventive measures must be financed. The basic forms of risk financing are:

- self-insured retention:
  - without applying preventive measures,
  - applying preventive measures,
- transferring risk to other entities (e.g., suppliers, recipients, subcontractors, insurance companies):
  - complete,
  - partial (franchising, liability limit, exclusion of the subject and the scope of insurance, etc.).

Control of the actions taken is the last stage of risk management. Its objective should be to investigate the effectiveness of actions aiming at limiting the risk. A big role in risk control and limiting is played by internal control procedures.

The rationally performed risk management process allows finding optimal solutions, a compromise between insurance and self-insurance retention. That compromise constitutes an insurance programme. Risk management is also a professional approach to insurance.

The division of risk analysis into the qualitative and quantitative stimulates two different approaches to building risk measures. The project's qualitative risk analysis facilitates creating a risk matrix. Based on the forecasts, a project threats catalogue is made. Then the threats are attributed with the levels of probability of their occurrence and the effects for the project at the assumed scale, described verbally. Such an analysis is made originally for respective projects [42].

The quantitative project risk analysis aims at determining the probability of a failure to accomplish the project's objective or its phase and the consequences of such a situation. The quantitative sizes of the risk are shown by risk value $VaR(t)$, calculated as a product of risk probability $R(t)$ and value exposed to risk Va. One must note that each action implies risks in many areas. The total risk value is a sum of products of risk probability in a given area "i" ($Ri(t)$) and value exposed to risk in that risk area (Va_i):

http://dx.doi.org/10.5772/intechopen.79182

$$VaR(t) = \sum_{1}^{n} R_i(t) \cdot Va_i \tag{1}$$

where: VaR(t), risk value; Ri(t), risk probability in given area "i"; Va_i, value exposed to risk in given area "i".

More and more frequently one points to the necessity of a systemic approach to risk. Such an approach to risk management in the organization requires an interdisciplinary perception of the phenomena related to it. The necessity of a dynamic and interdisciplinary approach to risk problems is also indicated by [43].

The risk phenomenon has become the focal point of taking economic decisions and in project management the project scope risk, cost risk, time risk and the quality risk are of capital importance [44]. They must be treated as a probability of a failure to accomplish the planned level of respective project attributes and they are always a planning failure.

The project risk determinants are both in the specific nature of the trade the project refers to, most often sensitive to the variation in the economic environment, and they also have an inner nature as they are sensitive to the assumed technological and organizational solutions for the course of the processes in the project.

Project decision-making is often related to the settlement of problems in terms of costs [44, 45], quality and time. An efficient project management requires simultaneously obeying those three factors, covering the actions in the directions of:

- "cheaper and cheaper" strategy as a pursuit of making right decisions in terms of costs,
- "better and better" strategy as a pursuit of making right decisions in terms of quality,
- "faster and faster" strategy as a pursuit of making right decisions in terms of time.

Such perspectives, despite an apparent contradiction, determine contemporary tendencies in search of the optimal solutions for the course of projects. They are subject to compromise in project management and they constitute the basic determinants of their success.

The term "risk management" covers all the actions towards identifying, evaluating and approaching risk, namely its reduction, diversification or using the phenomenon of risk. Currently there is much interest observed in risk management which translates to applying good practices in project management and which helps in accomplishing the project objectives. The conditions of an effective risk management are created by a systemic approach which considers all areas of the organization holistically.

The project risk management (PRM) system should be based on the knowledge and skills of the employees willing to use them to achieve the project's objective. It should include tracking down all the sources and paths of the exposure of the processes which occur in the project, the circumstances generating risk and determining their effects. Respective risk types can be grouped into single-name risk teams (e.g. costs, quality, environment, security), and detailed problems should be served by their adequate subsystems. The system information modelling (SIM) can be a subsystem supporting project cost risk management.

6. Big Data in construction projects

6.1. Background

Currently, the construction industry has been generating and storing more and more data. The reports with reference to the progress of the works, data from different types of sensors and equipment or pictures and recordings from the building site and so on may serve as examples. However, without an appropriate tool these data would be of no value. But, when the adequate tool to process the data is used, it is possible to reveal unique conclusions. The bigger the database, the more precise information extracted thereof.

The pioneers to use BD in the construction industry are the companies from the United States: Case Inc. and Terabuild USA. They process BD with the aim to, among others, monitor in real time the costs of project and to optimize the process of planning of investment and construction enterprises. However, the potential contained in BD is still not used properly. That is why, a research question should be asked on whether BD is a helpful tool to minimize the risk arising from the implementation of construction projects.

In the world literature from the end of twentieth century, a need to improve the management of risk in the construction projects is noticed as the research proved that less than a half of such projects were accomplished without exceeding the assumed budget [46].

6.2. Research results

In the search of the influence of BD onto the minimization of the risk of construction projects, the opinions of the Polish construction entrepreneurs were quoted. It was necessary to become familiar with the level of computerization of entrepreneurs, the type of their business and whether they use the systems supporting data mining. Furthermore they were asked if BD was used to manage the risk or if the enterprises intend to use it in future.

An anonymous Internet survey was used to carry out the poll. The questionnaires were sent via email to Polish construction entrepreneurs in the break of years 2016 and 2017. In total 739 questionnaires were sent.

A total of 32 replies were received and they represented different types of enterprises, including those acting in the domestic, international and local markets, dealing with construction, design works or trade, including micro-, small, medium and big enterprises. The ratio of respondents amounted to 4.3%, which is significantly below the norm of the reply to the questionnaires in the construction industry (20–30%) [47]. The low number of replies may testify to the confidentiality of the information but mostly to the low awareness of the need to use data on the level of BD.

http://dx.doi.org/10.5772/intechopen.79182

Among the respondents there were 40.6% of the entrepreneurs performing the construction works at the building site, 25% dealing with design works, 15.6% dealing with trading in construction material, 9.4% dealing with production of construction material and 6.3% dealing with urban designing and 3.1% dealing with investor supervision. The respondents answered the question concerning the innovative management systems and IT systems currently implemented in the enterprises. They gave their assessment in the 5-grade scale, where "1" denominated a very low level and "5" very high. A total of 21.9% of the respondents graded their enterprise with very high level—level 5. Most of the answers were given to grade 4, that is, 34.4% of all respondents. Level 3 was indicated by 25% of the respondents, and level 2 was chosen by 15.6% of respondents, and 3.1% of the assessments had fallen to level 1.

As indicated in **Figure 2** only 3.1% of the respondents have installed the IT systems serving to mine data. In the examined group of enterprises nobody sees the possibility of implementing such IT systems in the nearest future.

The respondents assessed also the degree of utility of BD in the management of the risk of the construction investment project, which is illustrated in **Figure 3**.

The results of the poll carried out indicate a very low interest in the implementation of BD analysis in the Polish construction enterprises. The reasons of such conditions may be found in the structure of enterprises, among which small and medium enterprises dominate. The strategies of these enterprises refer to short-term periods and their role in the implementation of the construction project is usually seen as that at the level of subcontractors. Thus, increasing interest in the application of BD would be more visible on the side of big enterprises or organized groups of small and medium enterprises—which unite in clusters or around the regional centres of innovativeness.

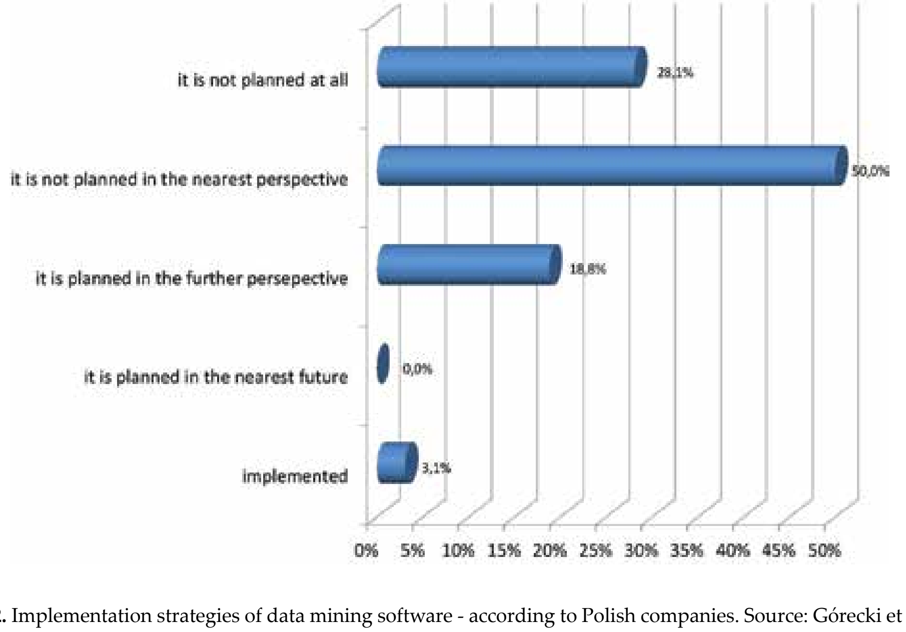

Figure 2. Implementation strategies of data mining software - according to Polish companies. Source: Górecki et al. [38].

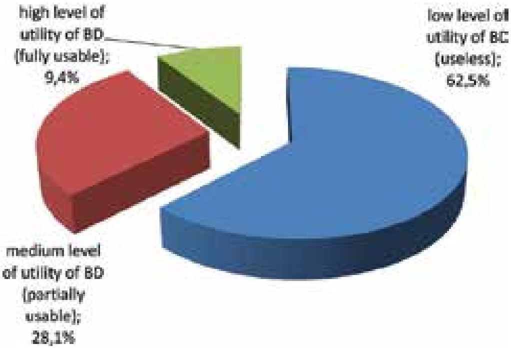

Figure 3. Level of utility of the Big Data – according to Polish respondents. Source: Górecki et al. [38].

7. BD as PRM tool: case studies

Examples of the real projects implemented in some Asian countries testify to the fact that BD has a significant influence on minimizing the risk during the implementation of construction projects. In the further part of this chapter such a relation was presented and it was described in the context of the choice of the most advantageous tender offer, the systems to ensure the safety at work at the building site and managing the construction waste during building works. The decisions which have the most influence on the success of the project (mainly in the aspect of costs) are adopted at its beginning stage. The control over the costs during the implementation of the construction projects may only be limited to preventing the exceeding of the established budget. It is not possible to correct the fundamental errors made at the beginning [10]. Thus, the effective assessment of the tender offer is the most significant in minimizing the risk relating to costs but also to quality and time.

7.1. Pre-contract stage

The pre-contract stage usually includes the following: inception, feasibility study, scheme and detail design, tendering arrangements and other pre-contract planning activities. In this part, one specific process of choosing the best offers with use of BD was taken into consideration.

The evaluation of the tender price of construction projects based on BD gathered at the building site was initially implemented in some of the projects of the underground in the Chinese town of Wuhan [14]. The system of evaluation of tender price decreases the risk resulting from poor quality, delays and exceeding budget. It consists of determination of the price frames for a given project. The enterprise taking part in the tender has the possibility of comparing their offer with the limits denominated by the system. If the offer proves to be lower than the bottom limit, the risk to exceed the budget is very high. Whereas, if the offer would be higher than the upper limit, the risk of failure in the tender rises. The system serves also for the units responsible for the selection of the tender offer. Thanks to it, they may reject the offers which, by too low a price, expose the building works to poor quality or increase the probability of company bankruptcy. Possible insolvency would involve the delays in the implementation of construction projects. BD influences also positively the number of accidents at the building site and increases the self-control of the workers.

The effects of its operation were assessed as good but requires the improvement of the accuracy. It consists of the determination of the price frames for a given project with the use of the following information: type of station, the depth of excavation, shape, hydrological conditions, geotechnical conditions, the surrounding environment and the parameters of accomplished projects, together with the history of their costs. When the participant of the tender logs in, stating the tender data, the programme would automatically calculate the price frames and would set off the alarm should they be exceeded [14].

It is a promising system, which is helpful for the units responsible for the choice of the best tender offer, it does not need to take up decisions based on the criterion of the lowest price but also based on its justification. Furthermore, it may become also useful for the entrepreneurs taking part in the tender.

In the case of customers, it influences the minimization of the risk of the insufficient quality of performance, inadequate high costs and time. The choice is based on the marginalization of too high and too low offers. It limits the probability of bankruptcy of companies implementing construction projects; thus, there is no need to open new tenders, which would generate delays in the implementation of investment.

In turn, in case of the enterprises taking part in the tender, the system allows to minimize the risk of bankruptcy and to maximize the profits. It is worth noticing that it must be adjusted to differing construction standards in different countries or regions. For instance, because of the higher degree of seismic risk, Japan has adopted more stringent construction standards than in many other countries and, what follows, the costs of the construction projects significantly increased [46].

7.2. Operational stage

7.2.1. Occupational hazards

Significant number of the accidents at the building site is caused by inappropriate behaviour of the employees, which threatens their safety. Thus, focus would be put on human aspects. Therefore, the gathering of data from monitoring cameras (which have the ability to follow and detect the objects moving against the adopted rules) and setting off mobile application which allows the employees to register the dangerous behaviour are recommended. In consequence of the analysis of the data gathered, the safety zones, which change depending on the progress of work, are to be designated (in real time) and the employees must be made aware of specific examples of behaviour. In the same way, the level of self-control of the workers increases.

During the construction of the underground in China, the system of monitoring of the employees' behaviour was implemented for safety reasons. BD analysis was used for the implementation of the safety system at the building site of two underground lines (3 and 6) consisting of 15 stations and 8 tunnels, in the Chinese town of Wuhan. The data were generated from the monitoring cameras, equipped with the abovementioned capacity to follow and detect the objects moving against the adopted rules, from mobile applications and from GPS receivers. It gave the possibility to take photos of dangerous behaviour by the employee. The mobile application itself generated 150,000 pictures registering the behaviour threatening safety. The analysis of data allowed one to create safety zones and to automatically capture the behaviour which may create threats and warn the employees. Additionally, they provided the building site manager with the access to information which was useful to optimize the schedule to include the safety component and gave the possibility of warning the employees in person in case of specific behaviour. All this was allowed to react in real time [48].

No matter how automated construction process or how complex the managing system is, people cannot be separated therefrom totally. The employees must constantly control the production processes and intervene in the case of unplanned events. It must be underlined that the accidents are caused in 50–90% by human error [49]. To decrease the number of incidents and to improve the efficiency of safety management at the building site it is necessary to pay particular attention to the dangerous behaviour of the employees [50]. The analysis of this behaviour is significant as it turns out that dangerous behaviour may be controlled by appropriate resources or even by the employees themselves [51]. Thus, it is worth knowing what influence the adopted measures inflicted on the employees.

Apart from the behaviour of employees the risk of preserving of their safety is also influenced by the schedule of construction works. The experts noticed certain phenomena occurring at the building site: the more tense the schedule is the more works overlap due to insignificant delays. This causes shrinking of the working space for the employees which, in turn, generates the danger. The safety of the workers at the building site decreases with their distance from construction material, equipment or other danger [14, 52, 53]. Besides, building site is a very dynamic environment where the working space relating to the performance of different tasks is subject to constant changes. The implementation of advanced automation would limit overcrowding while performing different construction activities, which often leads to threats to safety [54].

7.2.2. Waste management

Construction industry is the branch, which is not environment friendly. The waste that is generated thereby often makes up a huge portion of all communal wastes, which contribute to the degradation of the environment [55, 56]. Together with the constant increase of the pressure on sustainable development, taking up steps aiming at limiting the amount of generated waste by the construction industry is exceptionally important [11]. The comparative analysis described by Lu and his team in their papers may be of help [11, 37]. It presents the waste generation rate (WGR), which is used as the ratio of efficiency of construction waste management (CWM). BD is created by three joined databases. The first of them contains the registers of waste utilization, which include the information, among others, related to the dumping vehicle bringing the waste (for instance, number of the vehicle) or the amount of waste and name of the landfill. The second base contains, among others, the name of the project, category, location, technology and so on. The third base includes the information on waste.

The contractor may compare its achievements in CWM to its equivalents or based on its earlier achievements and denominate its practices as “good”, “medium” or “not too good”.

This allows one to optimize practices related to CWM. Furthermore, the government or the office responsible for the management of the waste may encourage the enterprises which were denominated as" not too good" in the analysis to increase the efficiency of CWM by, for instance, imposing fines thereto. What is more, this allows us to encourage the companies denominated as "good" to improve their achievements by rewarding them. In the analysis carried out, all outliers also deliver the information, on, for instance, the possibility of illegal disposing of waste in the case of unusually low results.

8. Conclusion

Currently the world faces the challenge of a growing inflow of digitally generated data, which is due to the technological advancement, becoming a new tool in human hands to optimize human actions and aims. The economy segments, such as banking, healthcare or insurance, already for some time have been benefiting from BD. Although the awareness of the need of project risk management is common and the tools to identify, evaluate and to manipulate risk are not a novelty, a great majority of project managers draw only on a deterministic approach to risk management.

Interestingly, the data derived from various sources, collected digitally in datasets with a high numerical amount, allows for building project risk management tools in terms of quantity. It is highly probable that already in the near future the state of the project managers' awareness will be drifting towards a greater use of digital data, including BD systems. It is also purposeful to publish the experience of the execution of projects applying BD as a recommendation for building and using BD-like data in project management. In search of effective project management methods, it is essential to inspire new actions and an ongoing search for innovative solutions. BD, next to BIM, SIM or Internet of Things, is one of those areas the development of which is worth monitoring, especially the applications supporting project risk management.

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Product Life Cycle Risk Management

Jan Machac, Frantisek Steiner and Jiri Tupa

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68797

Abstract

Every new product coming to the market usually brings with a certain amount of doubt concerning the likelihood of its success. In particular, hidden problems and risks which might appear later in the product's service life could cause producers' difficulties, costing them a lot of money. This might even result in product phaseout and a consequent loss of the company's reputation. Hence, it is necessary to manage all product risks. Unfortunately, no comprehensive methodology, managing the entire product life cycle, has been developed so far. This paper presents a new risk management methodology that covers the entire product life cycle. The product life cycle and its management have become a present standard and an important element of the information structure of modern enterprises. A product life cycle comprises several phases; this helps make risk management easier because it is feasible to manage risk for each phase separately. Generally, this phase structure creates a closed and unceasing rotation of risk management tasks and is an important element in universal process improvement. The methodology is focused on prioritizing risks according to the customer's needs and requirements. It can be applied to a large number of different products and industries.

Keywords: risk management, product life cycle, risk analysis, product risk

1. Introduction

Nowadays, risk management is an integral part of every state-of-the-art enterprise. This is because engaging in an enterprise always involves various kinds of risk. Thus, it is necessary to develop methods for risk management system integration into enterprise processes. Risks shall be controlled on all levels of an organization and exist in terms of costs and environmental and occupational safety. As far as manufacturing enterprises are concerned, it is also required to possess a strategy of the risk management related to the finished products. Every product has its product life cycle, and it is necessary to consider the various spectra of issues which may occur during the product life cycle and manage the risks related to them. The product life cycle management (PLM) has become a standard: widely recognized element of the information structure of modern enterprises. In order to promote comprehensibility and definiteness, it is seen as consisting of several phases. The aim of this is to make the risk management more tractable because it is, in fact, feasible to manage risks for each phase separately. Unfortunately, no comprehensive methodology managing the entire product life cycle has so far been developed. Some methodologies attempt to combine a number of known methods, but they are unsatisfactory in most cases. There is a need for a comprehensive, sophisticated method which would cover all possible risks throughout the entire product life cycle. This chapter deals with the primary life cycle phases—of conceiving, designing, realizing, and servicing a product. The risk management, especially at the beginning of the product life cycle, is a very important management task since this measure may be beneficial for following phases and save a considerable cost, the company's reputation, and even human health.

2. Product life cycle risk management

The product life cycle model is based on the idea of a biological cycle, i.e., the process from birth to death. The pattern holds good for a commercial product, and it can also be understood as a process embedded within all the other processes of an enterprise. In risk management, all participating subjects must understand the relationship between the project management processes and the other enterprise processes. The product life cycle is a natural framework for the investigation of relationships and processes in the product management. It can be described as a means to define the start and end of a product and all phases in between. The way that defines the life cycle varies from industry to industry, but it also varies within the same industry in relation to different organizations and businesses. In product life cycle management, the risk approach changes once different phases are reached. This change depends on how much information is available and project progress. A typical product life cycle description covering all phases is shown in **Figure 1**.

The product life cycle or product life cycle management (PLM) is a control process maintained from conception through design and production to service and disposal. PLM includes people, data, processes, and business systems and represents the main information flow within companies. At the same time, PLM systems help organizations to cope with increased complexity and new engineering tasks related to new product developments for global competitive markets [1]. Low-quality data generated in the product conception phase may mean

Figure 1. Product life cycle phases.

considerably higher costs in the subsequent phases [2]. The number of components involved with most of today's products, along with their complexity, increases. This trend can evidently be seen in all industries. It is not exceptional for the number of product components to be in the hundreds of thousands or even in six figures (automotive, aerospace, and marine industry) [3]. Thus, it is necessary to take extreme care, to prevent the risk of failures, from the very beginning of the life cycle of each product. The potential existence and detection of nonconformities throughout the product life cycle are shown in **Figure 2**.

The risk management aim is to add the highest permanent value to all company's processes. It contributes to a better understanding of all the possible advantages and disadvantages of all the factors affecting the project or organization. It increases the probability of success and decreases the probability of failure and of uncertainty as regards achieving general objectives. The final output of the risk management process should be a decision about whether and how to treat risks. If there is an unacceptable level of risk, it may be necessary to stop the current process(es) and accept certain countermeasures which will abate the risk level. Residual risks that cannot effectively be abated by such countermeasures may be processed using crisis plans [4]. Risk priority assessment shall be performed whether the risk is acceptable or not. Risk management should be a continuous and ever-improving process integrated into the strategy of the organization and the enforcement of this strategy.

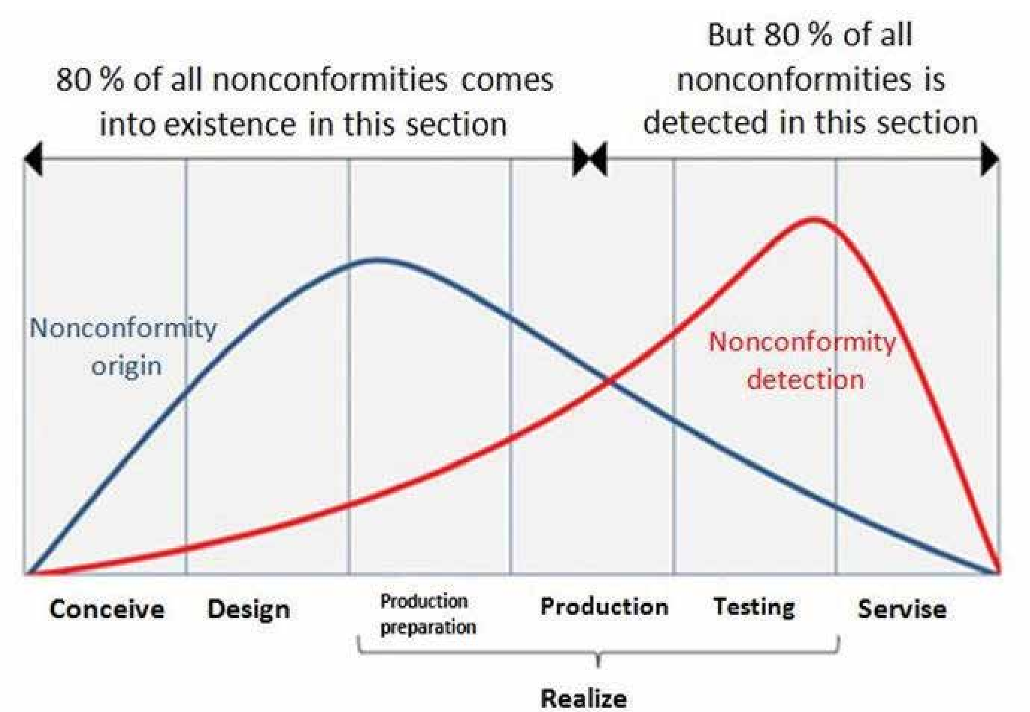

Figure 2. Existence and detection of nonconformities during the product.

2.1. Baseball field diagram

This method of risk analysis has been developed uniquely for the assessment of risks identified by utilizing a combination of different tools within the product life cycle. The use of this unique assessment method guarantees a unified system for the entire product life cycle. There is a priority attached to each identified risk, according to its risk value. Risk priority may change during the life cycle.

For priority risk assessment, the basic principle of the method from Dr. Hsia [5], as customized for this particular situation, was used. The diagram is applied once all risks associated with a given product life cycle phase have been identified. Risk value R is divided into five priority areas, from A to E. Risk value R combines the probability index RP and the impact index RI. With one index as the horizontal axis and the other as the vertical axis, a diagram (which is reminiscent of a sector of a baseball field) can be drawn. The bottom left corner represents the lowest coordinates (0,0), and the upper right corner represents the largest coordinates (1,1), as shown in **Figure 3**.

There are five priority areas outlined in the diagram. Priority area A represents risks of the highest priority for which it is necessary to carry out immediate countermeasures. The area designated as B represents risks of the next highest priority. Thus, the risks have the next highest priority to call on resources for management, and so on, down to the E priority area where risks may be neglected.

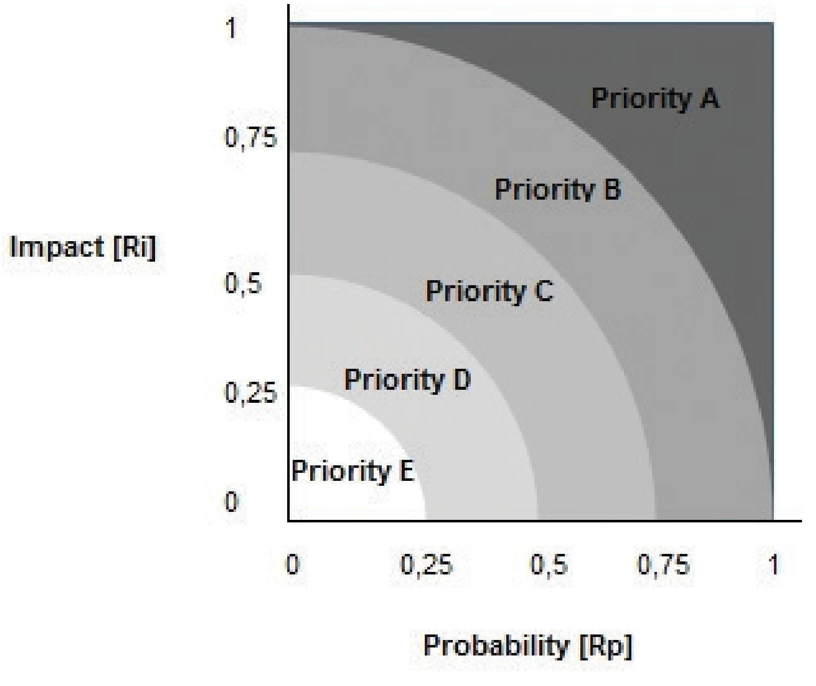

Figure 3. Baseball field diagram.

http://dx.doi.org/10.5772/intechopen.68797

2.1.1. Probability and impact level

The probability value is categorized into five levels: very likely, likely, possible, unlikely, and very unlikely. The relative descriptions of these probabilities are shown in **Table 1**. Furthermore, the impact event level is also categorized into five levels: very serious, serious, moderate, minor, and negligible. The exact criterion description depends on the particular product, as seen in **Table 2**. The higher level of either, the more serious the issue.

When assessing or calculating a probability level, these three approaches may be used, individually or in a combination.

2.1.1.1. Historical data

The use of appropriate historical data, for example, data from previous, similar, projects (the Lessons Learned database), provides the ability to extrapolate an approximate probability of occurrence of certain effects or failures. The historical data must be in regard to the same system, equipment, or operational concept. If there is only a low frequency of occurrence (of a particular situation), then any estimate based on historical data is very uncertain.

2.1.1.2. Predictive techniques

For probability prediction, a number of "predictive techniques" can be used, for example, fault tree analysis, event tree analysis, or Markov chains. When historical data are unavailable or unsuitable, it is then necessary to determine probabilities from the system or equipment

Level	Description	Probability (%)
5	Very likely	1–0.1
4	Likely	0.1–0.01
3	Possible	0.01–0.001
2	Unlikely	0.001–0.0001
1	Very unlikely	Less than 0.0001

Table 1. Probability level.

Level	Description	Criterion
5	Very serious	
4	Serious	
3	Moderate	Depends on the event
2	Minor	
1	Negligible	

Table 2. Impact level.

operation analysis in terms of fault or failure conditions. Numerical data for equipment, people, and systems come from experience or from other data sources, and it is used in order to estimate the probability of the top event. Simulation techniques that generate probabilities of component, equipment, and system failures caused by degradation or aging may also be used here.

2.1.1.3. Expert estimate

In systematic and structured processes, it is possible to use expert estimates in order to assess probabilities. There are many formal methods designed to obtain relevant expert estimates; these help in forming proper, pertinent questions. Available methods are Delphi, What If?, category classification, and absolute probability estimates.

When determining or calculating the impact level of a risk, the criteria (character and type) must be stated. The impact of risk factors can be determined from previous, similar, projects, or they can be estimated by an expert. The analytic hierarchy process (AHP) method facilitates determination of the priority of risk factors when multiple criteria in relation to specific impacts are available. AHP has attracted the attention of many researchers because of its logical and mathematical approach and because the input data for the method are easily attainable. The method is a decision-making tool that can be used for the solution of complex problems. More details can be found in Thomas L. Saaty's work [6].

2.1.2. Risk value

After the identification of all the possible risk events, it is necessary to determine the probability and impact index of each given event and its consequent risk value *R*, as provided by Eq. (1). The calculation of the probability and impact indexes are shown in Eqs. (2) and (3):

$$R = \sqrt{R_I^2 + R_P^2} \tag{1}$$

where

$$R_P = \frac{\mu_P - \min}{R_{FP}} \tag{2}$$

$$R_I = \frac{\mu_I - \min}{R_{FI}} \tag{3}$$

From Eq. (2), μ_p refers to the level of probability. From Eq. (3), μ_I refers to the impact level and min refers, in both cases, to the minimum of the k – level table, set to 1. R_{FP} and R_{FI} refer to the full distance of k – level table minus 1; both values are 4 ($R_{FP} = R_{FI} = 4$). All calculated indexes and values are recorded in the table. An example is seen in **Table 3**.

Item	Event	Probability level	Impact level	Probability index	Impact index	Risk value
1.	Risk	1–5	1–5	0–1	0–1	0–1.41

Table 3. Example of a table with assessed risks.

3. Method of risk management for the entire product life cycle

The first phase of the product life cycle, called conception, has a number of risk factors and influences associated with it. These risks must be treated immediately once identified, if possible. However, this is not always feasible, and so it becomes necessary to transfer the risk to the next product life cycle phase (again, where this is possible). All risks which are identified must be recorded in order not to be forgotten in the later product phases. Some risks may not be possible to eliminate but can only be mitigated to a certain level. These cases must also be transferred to the next product phase. Risks present at the conception phase which were not totally mitigated there, so that there is still a residual risk or a risk which was not possible to treat at that phase, are then inputs to the design phase. At the design phase, identified design risks are added to these inputs. Together, these risks make up the risk input to the design phase. All risks discovered at or before the design phase which have not been totally mitigated, so there is still a residual risk or risks which were not possible to treat in that phase, become inputs to the third phase: the phase of realization. The procedure is then the same as for previous phases. Risks originating at the realization phase are added to these input risks and treated together here. Risks relating to the service phase consist of risks identified in previous product phases, but not completely mitigated, plus risks particular to the service phase. It should be noted that most of these identified risks, associated with these phases, are predicted risks only. Thus, it is not possible to determine their precise probability; it is only possible to make a qualified estimate.

All risks identified in the fourth phase become the feedback for the life cycle of the new generation product—if it is impossible to treat them. The same applies to all risks which weren't predicted but which were subsequently identified when investigating an incident—but also could not be treated. Generally, it may be said that the method leads to a closed, unceasing cycle of the risk management tasks and forms the continuous process of improvement. The entire process is displayed in **Figure 4**. The detailed description of the risk management method, as it pertains to each individual phase, follows.

3.1. Risk at the conception phase

At the beginning of each product's life cycle, there is always a customer who expresses his needs; these needs must be heard. There is no universal voice of the customer (VOC), each is unique, and they are very diverse. Customers have many different requirements. Even within a single purchasing unit, various different requirements may appear [7]. All these voices must be considered and balanced in order to develop a successful product. For a better understanding of the customer's needs, a discussion with them should be held; it is important at this point to identify the basic customer's needs. First, it is needed to define requirements, answer the questions raised by developers, and then advise and criticize the process of the actual product development or the evaluation of the prototype design. General requirements should be split into more specific detailed requirements—the customer should be urged in order to clarify and express thoroughly his demands until they make perfect sense from the supplier's perspective.

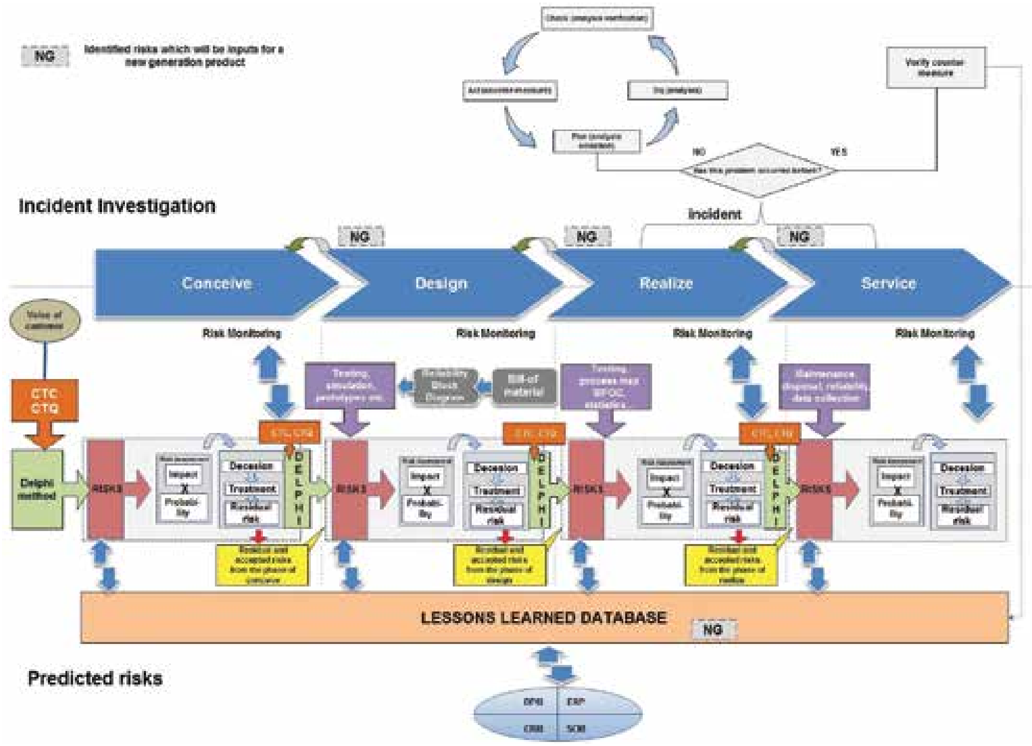

Figure 4. Entire process of risk management for the entire product life cycle.

Voice of customer is usually the input for critical to customer (CTC). Critical to customer (CTC) are measurable standards of product performance which has been determined essential to its customers. CTC is generally defined in the process of the voice of customer assessment by methods ranging from survey or interview to focus groups. CTC provides a straightforward method for the prioritization and selection of appropriate input requirements for the whole process. CTC items are internally reflected in critical-to-quality (CTQ) criteria as shown in **Figure 5**.

Further, CTC and CTQ are used as inputs for risk analysis techniques like the Delphi method. Another input for the preliminary risk analysis of the entire product life cycle is the Lessons Learned database, as it is termed: recommendations based on experience, from which others can learn in order to improve their performance. This may be supplied in the form of knowledge from data product management (DPM), enterprise resource planning (ERP), customer relationship management (CRM), and supply chain management (SCM). It is necessary to consider whether a similar product has already been developed in the past and what risks occurred and how they were treated. Hence, the same countermeasures may be applied to the current product (possibly with adjustments or improvements). As was mentioned above, the inputs to the very first risk analyses should be CTC, CTQ, and the Lessons Learned database, as shown in **Figure 6**.

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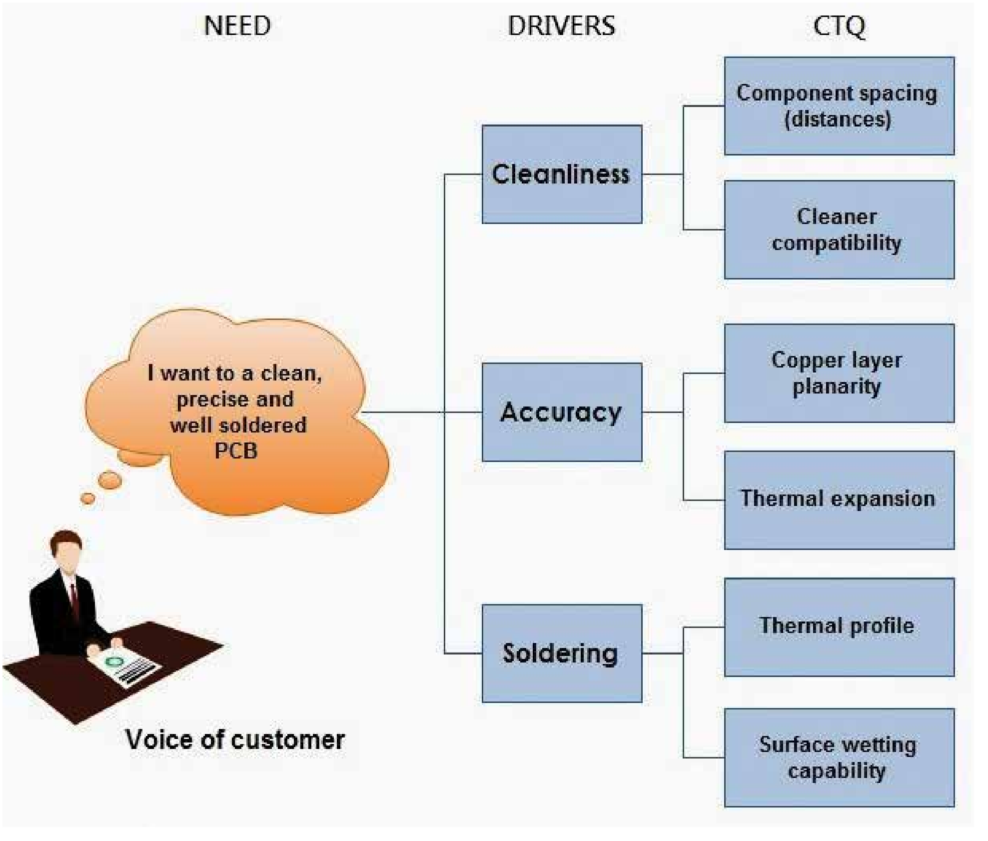

Figure 5. Example of critical to quality criteria.

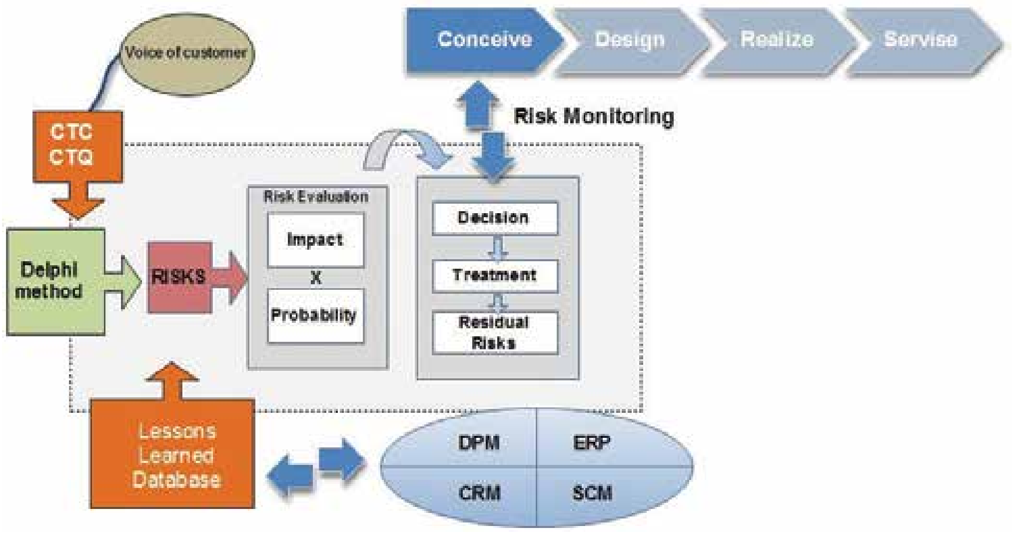

Figure 6. Risk process management at the conceptual stage.

It is always difficult to assess risks, especially in the initial product life cycle phases, when no or only very minimal data is provided. Despite this, the risk analysis is important and an integral part of any new product development. Every risk analyst starts with risk identification. The means by which proper risk identification can be accomplished may differ. Delphi, What If?, preliminary hazard analysis, and just a simple brainstorming are all recommended tools. Risk estimation and measurement for the early phases of a product's life cycle are complicated. Since no real-time data are available, methods like the analytic hierarchical process, for impact, and Markov chains, for probability estimation, should be utilized. Also, specific countermeasures or treatments from the Lessons Learned database can be accessed. Subsequently, risk values are calculated in order to determine the priorities of the various risks. If a priority dictates that a risk be treated, the risk must, in most cases, be reduced, avoided, or transferred. In exceptional cases, the risk is accepted. After this treatment, all countermeasures must be verified, and all risks must be measured again in order to discover whether there is any residual risk. Subsequent risk monitoring is essential. Sometimes, it is not possible to treat certain risks or residual risks in this phase. Consequently, these risks are transferred to the next product life cycle phase along with all the accepted risks identified due to proper risk monitoring. The whole process is shown in **Figure 7**. This process is identical for the conception, design, and realization phases.

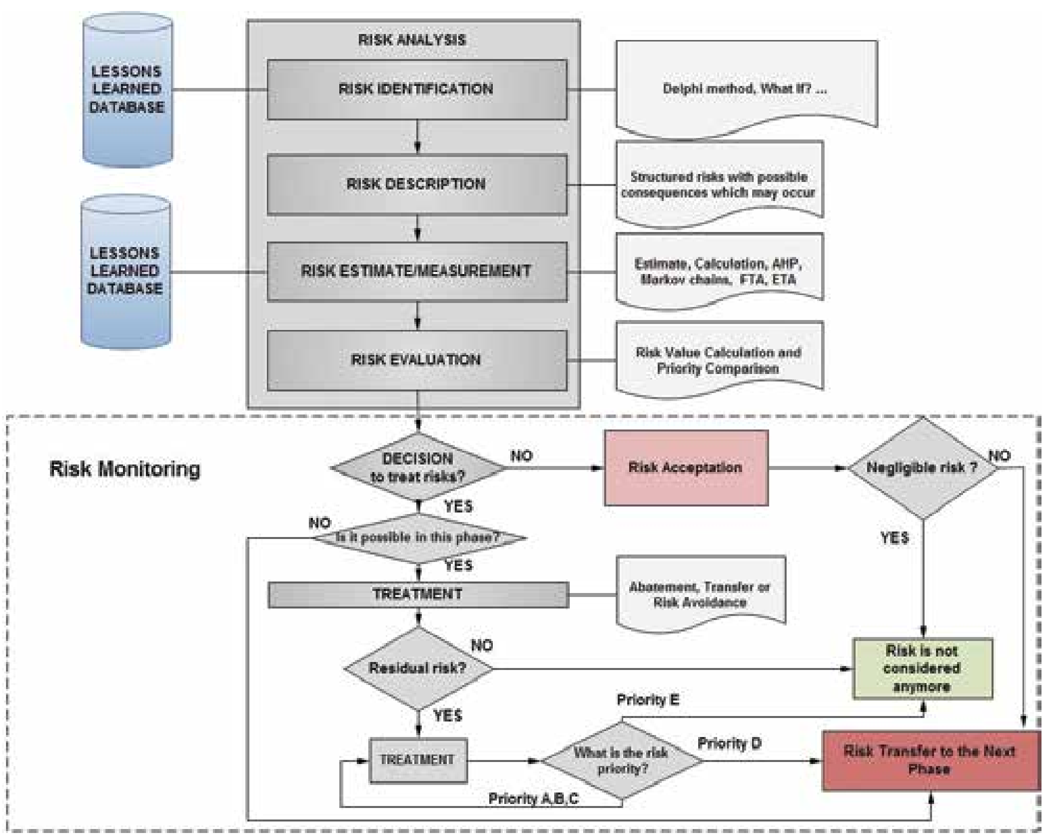

Figure 7. Process of risk treating at early product life cycle phases.

In the (conception) phase, it is relatively easy to make changes. In the subsequent product phases, the ease, and indeed possibility, of any change decreases, and the costs of changes rapidly grow over the time since the product is committed to a certain technology, configuration, and performance. Therefore, it is highly desirable to identify all risks during the first two phases—while it is still feasible to make changes and take countermeasures with certain ease. Unidentified risks in the realization and service phases may endanger the overall financial viability of the product.

3.2. Risk at the design phase

This product life cycle phase is also very likely to produce a large number of nonconformities which may cause trouble in subsequent phases. A design risk assessment is the act of determining the potential risks in the design process, either in the detailed design, in subsequent analysis or simulation, or in validation or possible tool design [8]. It provides a broader evaluation of the design—beyond just CTQs—and enables the elimination of possible failures and reduces the impact of potential failures. Thus, it is possible to categorize these risk factors into groups and manage risks for each group separately according to their severity (see **Table 4**).

The process of risk management for the design phase is shown in **Figure 8**. Accepted risks and residual risks with accepted risk values from the conception phase are transferred and evaluated again at the design phase, in order to determine possible increases in risk.

The identification of new risks in the design phase usually starts with the bill of materials and its list of components. These can assist in constructing a block reliability diagram, whereby weaknesses and risks can be identified. Building of a prototype and simulations can also help considerably in the identification of new product risk areas. Then, a simulation relating to the treatment of the product and its placement into the working environment are important. For the better understanding of customer's requirements, it is appropriate to set an appointment with the customer, introduce the prototype, and afterward possibly customize it according to the customer's stated considerations. It is likely that other possible risks will be observed from the way the customer deals with the prototype. A simple brainstorming session with customers is often essential. Further, it is still necessary to follow CTQ, CTC, and VOC as inputs for the Delphi method. At this phase, knowledge management is easier to apply, and the knowledge from DPM, ERP, CRM or SCM, and the Lessons Learned database should be used to deliberate about risks from previous similar projects or from the past generally. It is necessary to start planning the preventative maintenance of a product.

	Identification		**Analysis**								**Decision**
No.	Risk	Description	Category	Treating in this phase?	Probability level	Impact level	Probability index	Impact index	Risk value	Priority	Accepted
1.				Yes/no	1–5	1–5	0–1	0–1	0–1.41	A–E	Yes/no

Table 4. Table for the risk analysis.

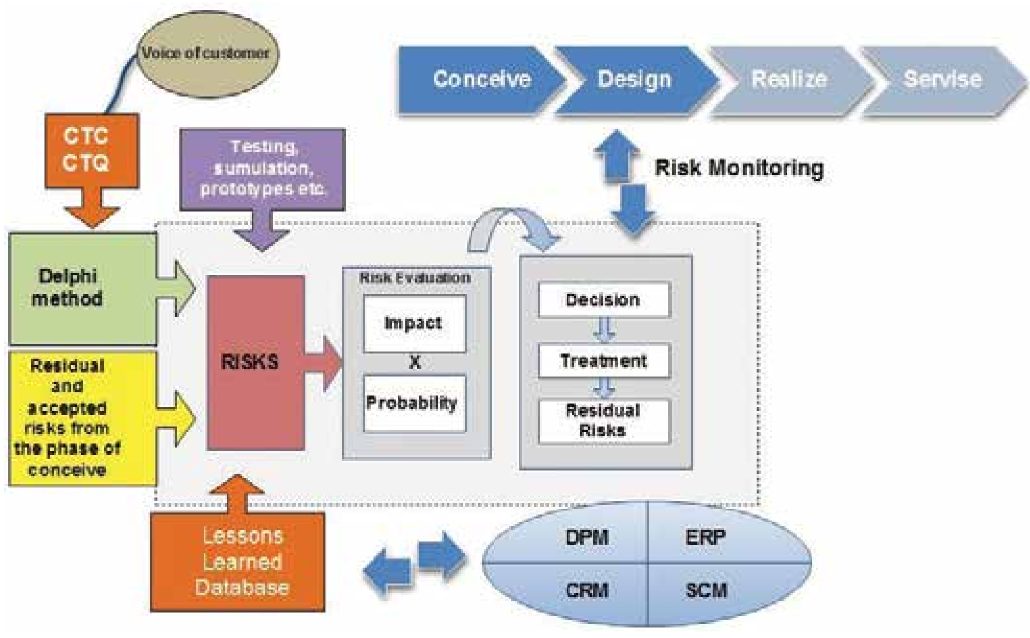

Figure 8. The process of risk management for the design phase.

There are specific parts and systems determined in a bill of materials at the design phase: the systems, subsystems, and components which form the final product are defined here. This also forms an input to the reliability analysis: from analyses of single components to the reliability analysis of the entire system. For the correct understanding of the entire system reliability, it is necessary to make a detailed reliability diagram of the product. This may help to uncover product weaknesses. The reliability block diagram is a diagrammatic method to scheme how the reliability or otherwise of individual components contributes to the failure of the complete, complex system. This method is also known as the dependency diagram.

The reliability block diagram is usually produced as a group of blocks connected in a parallel and serial configuration. The example is shown in **Figure 9**. Each block represents a system component with a certain failure rate. There are often parallel paths, meaning that all of them must fail for system breakdown to happen. They are in contrast to the serial paths where a failure of any component leads to the system breakdown.

3.2.1. Reliability

At the design phase, it is necessary to plan the maintenance focused on reliability. Identified risks from this phase will serve as inputs for the maintenance plan. The successful application of the reliability program demands good product understanding as well as a good knowledge of operational conditions, context, associated systems all together with possible failures, and their consequences. Maintenance is a common way of treating less severe risks. The initial maintenance program should be formed in cooperation between supplier and user. A possible reliability program application is shown in **Figure 10**.

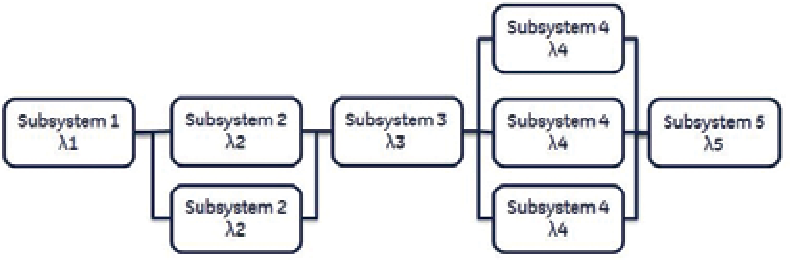

Figure 9. The reliability block diagram.

3.2.2. *Disposal*

During product development and production, it is essential to think of product disposal and related risks. Some of the customer's requirements might be concerned with various regulations regarding the usage of restricted and hazardous substances. Directives dealing with the use and handling of hazardous substances, waste, and its collection are as follows:

Waste electrical and electronic equipment (WEEE)—concerning the collection, recovery, and processing of electrical waste

Restriction of the use of certain hazardous substances (RoHS)—concerning the restriction of the use of hazardous substance in products

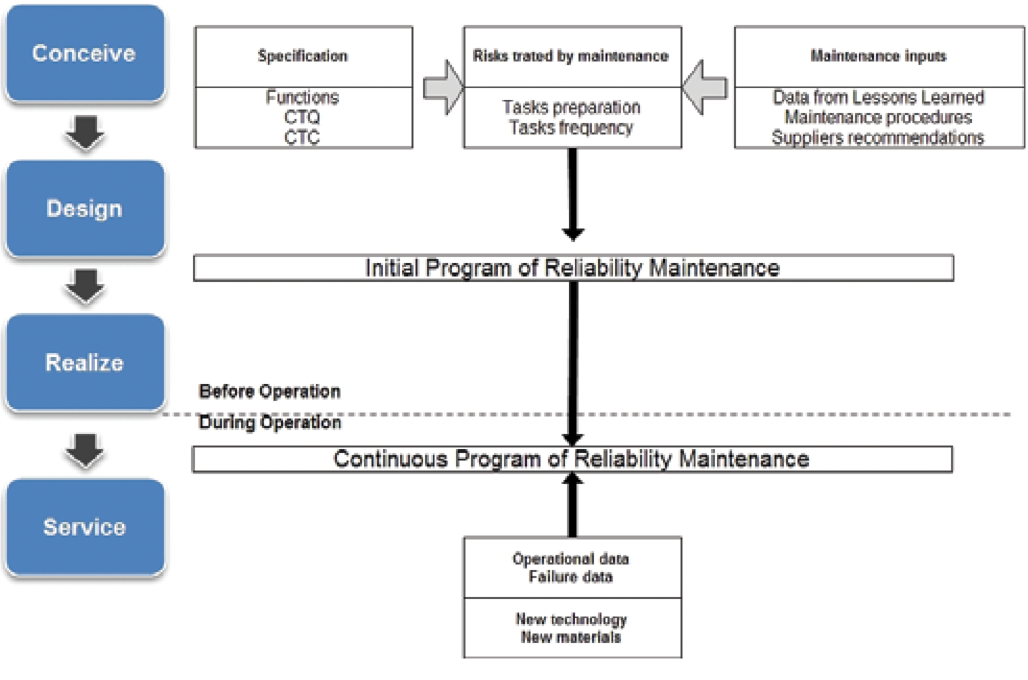

Figure 10. Reliability program application example.

3.3. Risk at the realization phase

CTC and CTQ requirements are the basis of the risk management at the phase of realization. Accepted risks and residual risks with accepted risk values from the design phase are transferred and evaluated at the phase of realization again in order to verify their possible increase. Prior the production start, there is a need for a thorough simulation, tests, and planning. The process of the risk management at the phase of realization is shown in **Figure 11**. Once all the tests and simulations [computer-aided production engineering (CAPE), computer-aided production planning (CAPP)] are done, risks are identified and the design is validated; it should be made sure that already specified CTQs define strict quality standards in the production. These can contain tolerances, procedures, performance, and safety tests which should be done prior the product delivery to customers. All these instructions should be stated in so-called control plans and refer to prior quality planning and tests. All production processes shall be tracked and monitored in a process map.

It is also recommended to use quality management tools for risk identification at the phase of realization. Most of the seven quality basic tools are quantitative methods that contribute to better process control, process monitoring, process understanding, including diagnostics, troubleshooting, and generally better process operation [9].

The entire production process must be mapped in order to identify weak and risky spots. The example of a process map at the realization phase is shown in **Figure 12**.

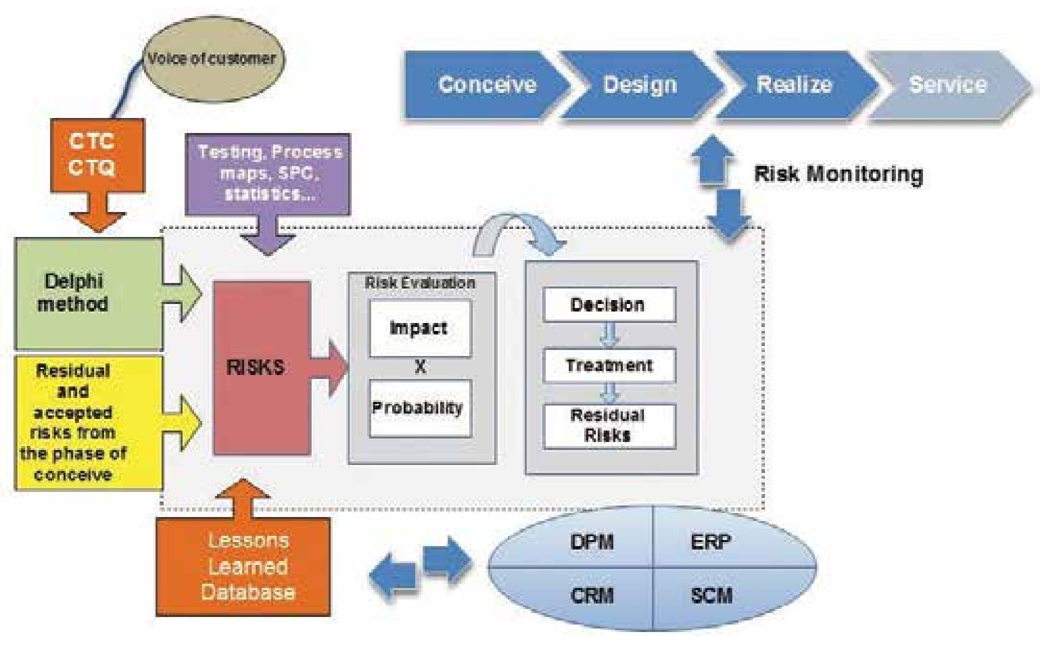

Figure 11. The process of the risk management at the phase of realization.

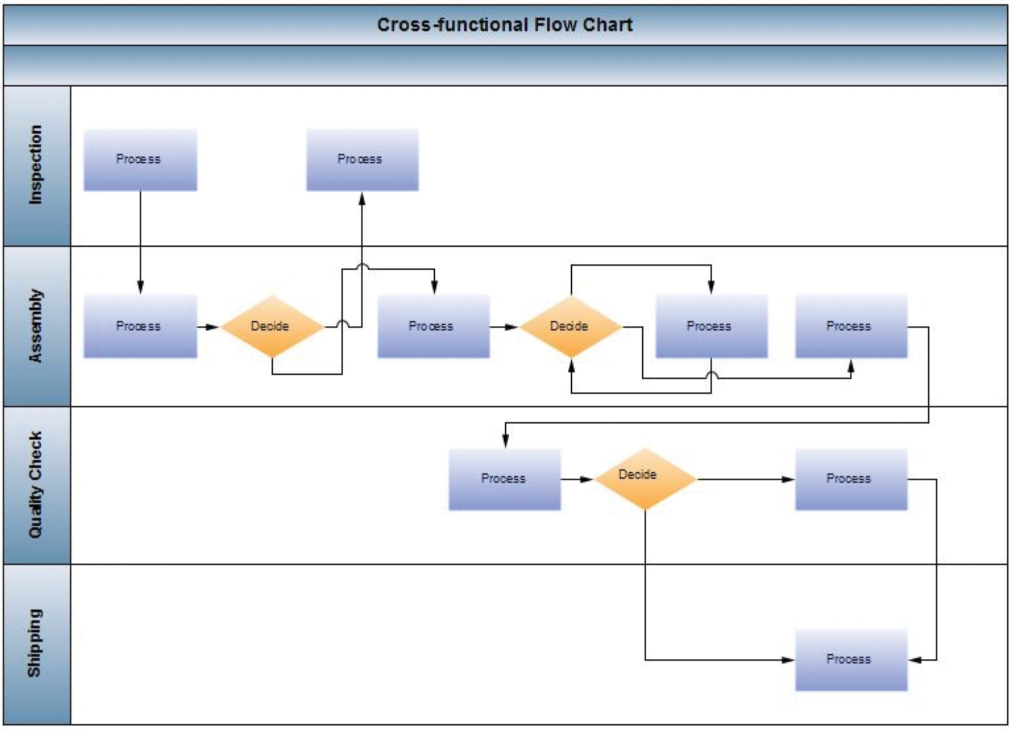

Figure 12. Example of a process map.

3.3.1. SIPOC

For identification of factors and elements entering the process, the SIPOC method is highly recommended. The general SIPOC process map is a chronological representation of the most significant steps (up to 6), events, or operations in a process. It provides the basis for identification of the process inputs and outputs, and hence it shows possible risks affecting the process. It also gives a simplified view of the entire process. Inputs, outputs, and also suppliers and customers (internal or external) are identified in this diagram. The SIPOC example is shown in **Figure 13**.

Figure 14 shows a production process. It is possible to see a certain pattern in the graph. Based on observation, it is possible to find out root causes or define a certain period when an event occurred. The run chart shows a production process during a specific part of the year. Here, a steep value which increases in the month of July can be observed and a subsequent sharp fall in the month of August. A period of interest is defined by this observation: it is necessary to find out what happened or what changed at that time. There are a few possibilities of the usage, and the method application is mostly user-friendly.

3.4. Risk at the service phase

By this phase, there should already be a minimal amount of risks, and all significant risks should have been identified at prior phases as no design changes are possible at this phase.

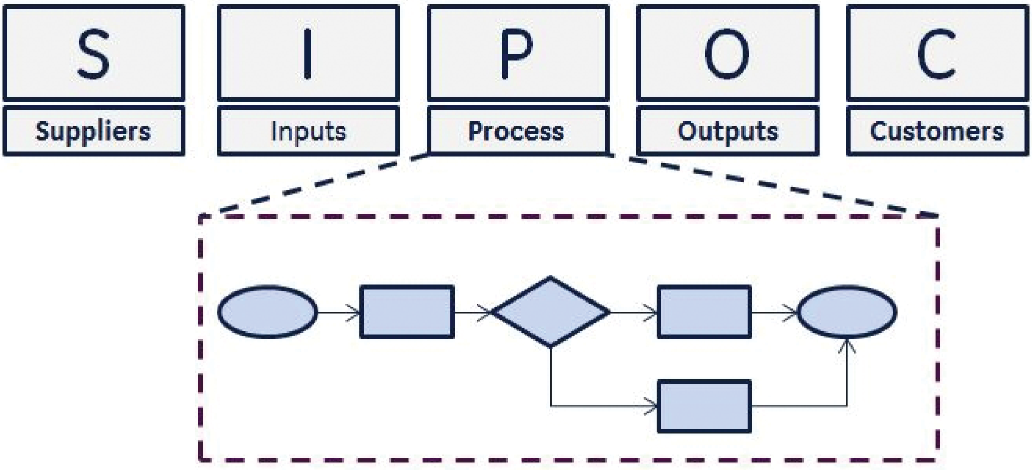

Figure 13. The SIPOC diagram example.

CTC and CTQ are also very important for the final phase of the product life cycle and need to be considered. Accepted risks and residual risks with accepted risk values from the realization phase are transferred to the service phase and evaluated again in order to determine whether they might increase. The entire process is shown in **Figure 15**.

Most of these risks can only be treated by preventive maintenance, customer support, or product manual. Risks involved at this phase are usually related to stocking, transportation, or disposal. Detailed feedbacks from customers, service experience, claims, and reports are recorded in the Lessons Learned database and used for the development of the next-generation product. The process of the risk management at the service phase is shown in **Figure 16**.

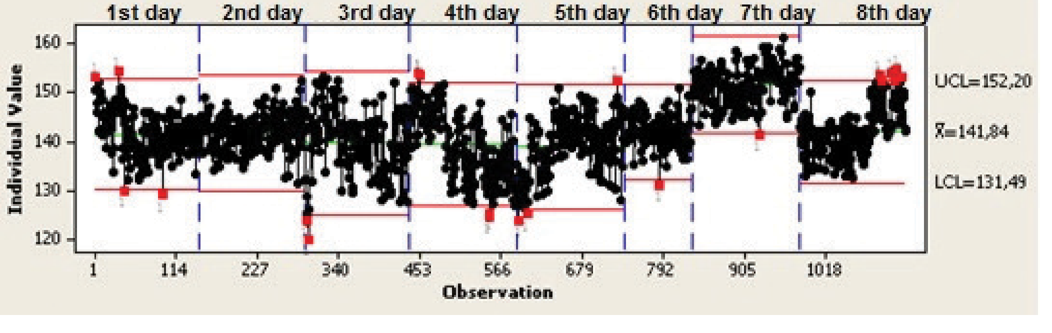

Figure 14. Example of a production process.

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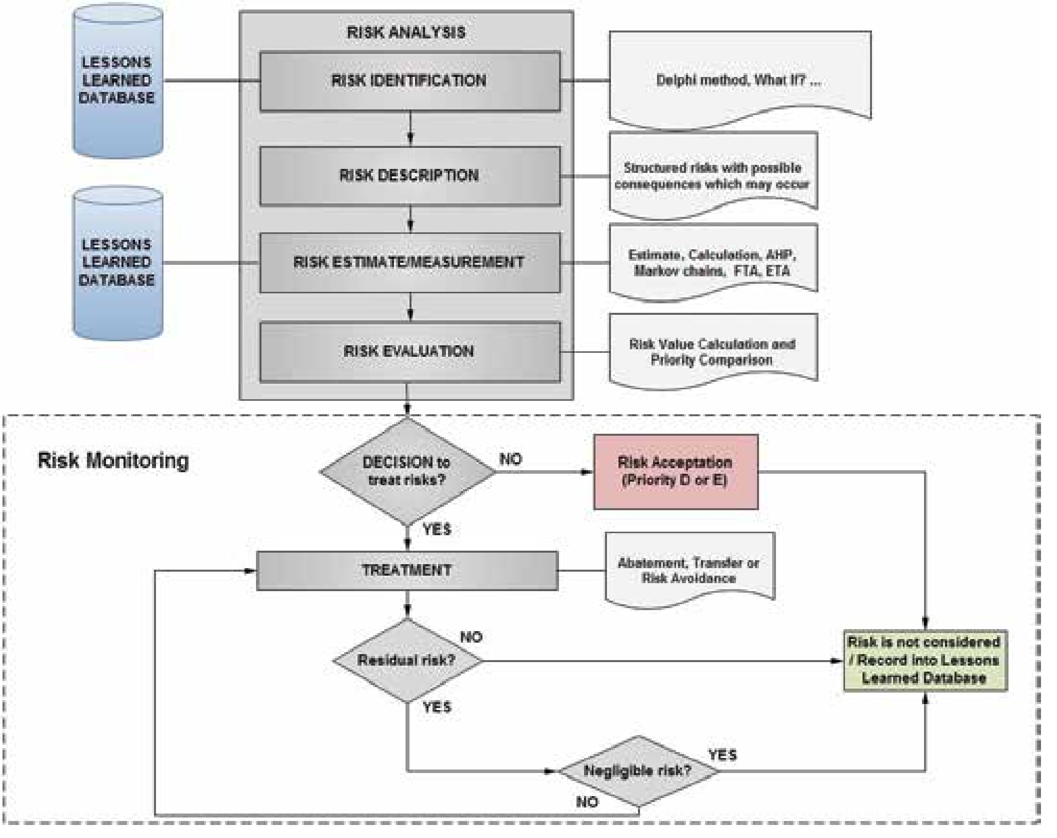

Figure 15. Process of risk treating at the final product life cycle phase.

There are various methods of interpretation in relation to life test data or operational data. Many of these interpretation methods use theoretical statistical distributions which model the lifetime of monitored components (time before failure). Hence, quantification of reliability uses methods involving mathematical statistics, and the theory of probability for which the proper theoretical distribution usage is essential.

When analyzing the reliability of electronic and other components, Weibull distribution is often used. Weibull analysis is applied when addressing the following kinds of questions: How many failures should be expected in certain conditions? How reliable is the current construction or technology in comparison with the innovated technology? How to quantify the product reliability? The advantage of Weibull distribution is its ability to approximate other distributions (e.g., exponential, normal, or log-normal). On the basis of a small sample of data, it is also capable of determining the distribution shape suitable for modeling the time to failure [10].

When analyzing reliability, complications may arise from the occurrence of censored data (i.e., if failure does not occur in all monitored components in the monitored time interval) and

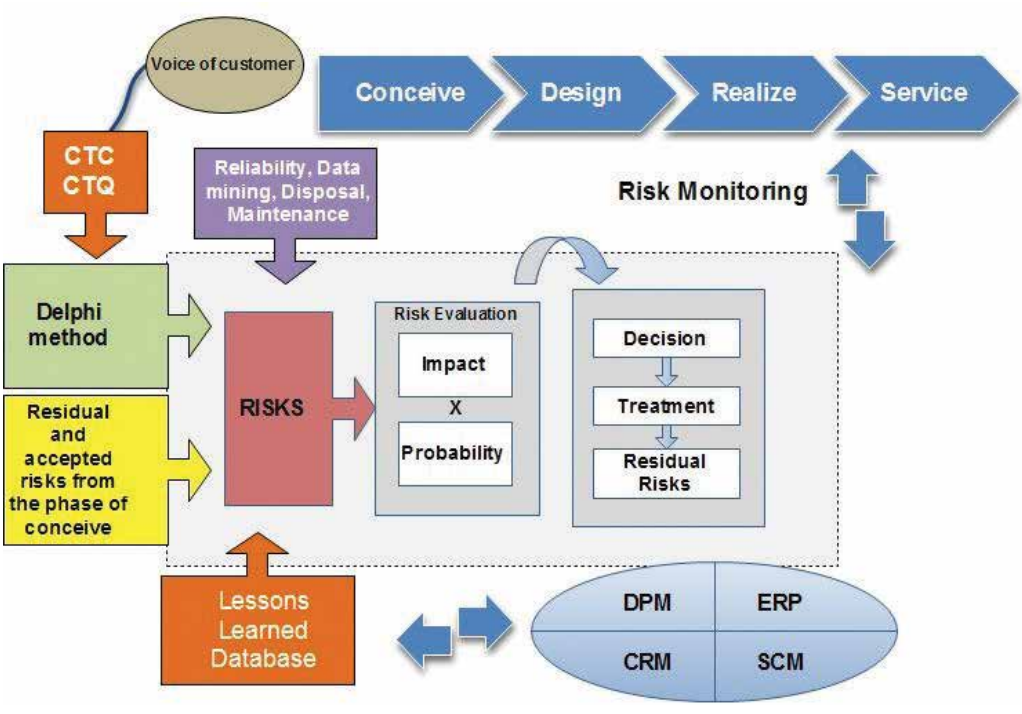

Figure 16. The process of the risk management at the phase of realization.

also when performing rapid tests. The analytical procedures of modern software tools allow to perform reliability analyses with respect to these complications and thus the prediction of failures on the qualitatively higher level [11].

3.5. Risk monitoring and root cause investigation

When monitoring risks, failed countermeasures or even new risks may be identified. When this happens, it is necessary to take action against the newly uncovered risk immediately. First, it is essential to find out whether this problem has already been observed in the past and, if so, what kind of countermeasure was used there. In this case, the countermeasure clearly must be reviewed and then improved or replaced. If the situation appears to be entirely new, however, the process of incident investigation must be initiated. Finally, not all risks can be predicted. The investigation process is based on the PDCA (Plan-Do-Check-Act—Deming cycle) cycle as shown in **Figure 17**.

A list of the best incident investigation methods is set out in **Table 5**. In addition, this table indicates whether the method is qualitative, quantitative, or combined. It also indicates the phase of the life cycle for which each method is useful and its character. Subsequently, it describes whether it is a combination of methods and option of applicability only by one analyst.

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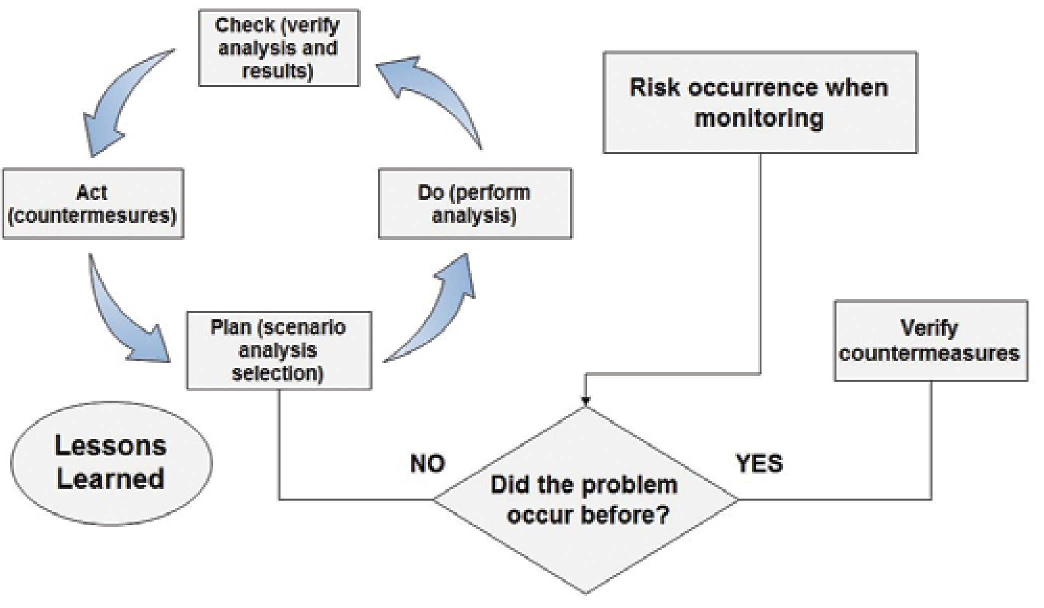

Figure 17. The investigation process.

Analysis	Quantitative	Qualitative	Design	Realize	Service	Method's character	Combination of several methods?	Can it be applied by a single analyst?
Fault tree analysis	X	X	X	X	X	Supporting		X
Event tree analysis	X	X	X	X	X	Supporting		X
Causes and consequences analysis	X	X	X	X	X	Supporting	X	X
Current reality tree		X		X	X	Supporting	X	
Multiple event sequencing		X		X	X	Supporting		
Sequentially timed events plotting procedure		X		X	X	Supporting	x	
Schematic report analysis diagram		X		X	X	Supporting		X

Analysis	Quantitative	Qualitative	Design	Realize	Service	Method's character	Combination of several methods?	Can it be applied by a single analyst?
Tripod beta analysis		X		X	X	Investigating		
Root cause analysis		X	X	X	X	Supporting	X	X
Root cause failure analysis		X		X	X	Supporting	X	X
Events and causal factor charting		X		X	x	Supporting	X	X
Savannah river plant root cause analysis		X		X	X	Supporting	X	X
Tap root		X		X	X	Investigating	X	X
Event root cause analysis procedure	X	X		X	X	Investigating	X	X
HSYS	X	X		X	X	Supporting	X	
Assessment of safety significant teams		X	X	X	X	Supporting	X	X
Safety through organizational learning		X	X	X	X	Supporting		
Causal tree method	X	X		X	X	Investigating	X	
Systematic accident cause analysis	X	X	X	X	X	Supporting	X	X
Systematic cause analysis technique		X	X	X	X	Supporting	X	X
Six sigma	X	X	X	X	X	Investigating	X	
Management oversight and risk tree	X	X		X	X	Investigating	X	
Technique of operation		X		X	X	Investigating	X	
Change analysis		X	X	X	X	Supporting		X

Table 5. The list of best incident investigation methods.

4. Conclusion

The methodology comprises the risk analysis that combines with methods for the incident investigation where the results serve as the input risks for the new-generation products. Further, the methodology suggests to exploit the knowledge database which comes to light when managing incidents or already exists, and it is used for the purpose of the risk prevention. By recording of information of the origination, progress, and the way of previous incident solutions, the solution of a new or similar incident can be accelerated. The purpose of the knowledge base creation is also the objectification of probabilities and impacts of recorded risks. These records must be, in most cases, estimated, especially for completely new products, but thanks to the knowledge base, it is possible to refine the estimates. The methodology brings a new methodological approach that endeavors not only to prevent failures but also to remove the root cause as fast as possible and minimize its consequences. The use of the methodology can be customized for all kinds of industry.

Acknowledgements

This research has been supported by the Ministry of Education, Youth and Sports of the Czech Republic under the RICE—New Technologies and Concepts for Smart Industrial Systems, project No. LO1607, by the European Commission under Marie Curie action FP7, project Risk Management Software System for SMEs in the Construction Industry (RiMaCon), project No. FP7-2012-IAPP-324387 and by the Student Grant Agency of the University of West Bohemia in Pilsen, Grant No. SGS-2015-020 "Technology and Materials Systems in Electrical Engineering.

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Chapter 4

Critical Success Factors for Effective Risk Management

Geraldine J. Kikwasi

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.74419

Abstract

Risk management is extremely important in achieving overall organizational goals and objectives. Achieving organizational goals amid risks entails determining and implementing critical success factors (CSFs). This chapter presents composite CSFs which organizations can focus on to achieve their overall goals and objectives by portraying a case study of the construction industry. Using this case study reveals statistical significance of impact of risk management on the project as reduction in design/production time, improved public perception, and improved team morale and productivity. Similarly, CSFs mostly implemented are awareness of risk management processes, appreciating that risk management practice is viable in the construction industry, organizations have policies to support the development of risk management and organization deal with internal/external environment that influences risk management in their organizations. The chapter also presents nine composite CSFs determined by the case study namely: management approach; goals and objectives of the organization; risk management policy and experts; information technology and culture; environment and usage of tools; teamwork and commitment of the top management; communication and training; awareness of risk management process and legal requirements; and risk monitoring and review. Lastly, the conclusion is drawn on nine composite CSFs for effective risk management.

Keywords: construction, critical success factors, management, organizations, risks

1. Risk management

Formal risk management is extremely important in achieving overall organizational goals and objectives. Risk management involves actions of identifying, analyzing, and controlling risks by organizations. Organizations undertake risk management to maximize opportunities and minimize consequences of events that may arise when implementing activities geared to achieving their goals and objectives. PMI [1] defines project risk management as the processes of conducting risk management planning, identification, analysis, response planning, and controlling risk on a project. Other explanations of risk management are found in the work of Berg [2] and Harry et al. [33]. Berg [2] explains that risk management is a systematic approach to set the best course of action under uncertainty by identifying, assessing, understanding, acting on and communicating risk issues. Harry et al. [33] point out that risk management is a continuous process where the sources of uncertainties are systematically identified, their impact assessed and qualified and their effect and likelihood managed to produce an acceptable balance between the risks and opportunities. Smith [3] explains that although there are inconsistencies between the definitions, there are noted similarities such as: it is a formal process; employs systematic and scientific methods; aims to identify risks in an operation or business; evaluates the importance or impact of those risks on the operation or business; provides mechanisms to control the individual risk to provide an acceptable level of overall exposure; and is not a one-off event. PMI [1] states that the objectives of project risk management are to increase the likelihood and impact of positive events and to decrease the likelihood and impact of negative events in the project. Generally, the risk management process mainly involves risk planning, assessment (identification and analysis), ranking, treatment and monitoring. The risk management process has been expanded by Berg [2], AbouRizk [31] and PMI [1] to include establishing goals and context (i.e., the risk environment) and preparation for risk analysis. Techniques for risk identification, analysis and handling are traced in risk management books and chapters, as well as researches conducted by Cagliano et al. [4], Chinenye et al. [5] and PMI [1]. Techniques for risk identification include but not limited to:

a. Documentation reviews

b. Information gathering techniques

c. Brainstorming

d. Delphi technique

e. Interviewing

f. Root cause analysis

g. SWOT analysis (strength, weakness, opportunities and threats)

h. Checklist analysis

Techniques for risk analysis both quantitative and qualitative include but not limited to:

a. Brainstorming

b. Sensitivity analysis

c. Monte Carlo

d. Decision tree analysis

e. Decision theory

f. Probability analysis

g. Delphi technique

h. Expected monetary value (EMV) analysis

i. Simulation

j. SWOT analysis (strength, weakness, opportunities and threats)

k. Historical data

Risk handling techniques normally adopted during risk management are:

a. Risk avoidance

b. Risk reduction (mitigation)

c. Risk transfer (sharing)

d. Risk retention (acceptance/assumption)

In addition, Habib & Rashid [6] present another approach of risk handling techniques used in their study such as shape and mitigate (SMT), shift and allocate (SAT), influence and transfer (ITT) and diversify through portfolio (DTP) which they related to project outcomes. PMI [1] classifies risk handling options into risk strategies for dealing with negative risks or threats and those for dealing positive risks. While strategies for dealing with negative risks remain to be those listed in other studies, strategies for dealing with positives risks are exploit, enhance, share and accept. The use of any of these handling measures depends on the outcome of the analysis and rating of the risk. Qualitative and quantitative analyses determine the probability of occurrence of risk and its potential severity. **Figure 1** summarizes a generic risk management process and **Table 1** presents severity matrix used by organizations to decide on the handling option to follow.

1.1. Risk framework and risk register

Recent developments in audit services have led to certain public organizations in Tanzania to develop risk management frameworks and registers. Risk management frameworks and risk registers are the vital tools for an organization to implement risk management activities. The risk management framework is the document that guides the implementation of risk management activity. The risk management framework covers:

a. Purpose

b. Objectives

c. Scope in terms of organizational activities and stakeholders

d. Risk policy and appetite statements

e. Roles and responsibilities of various organs, top management and staff in risk management in an organization

f. Risk management procedures

g. Templates for risk identification and analysis sheet, risk register, risk treatment schedule and action plan and risk treatment implementation report

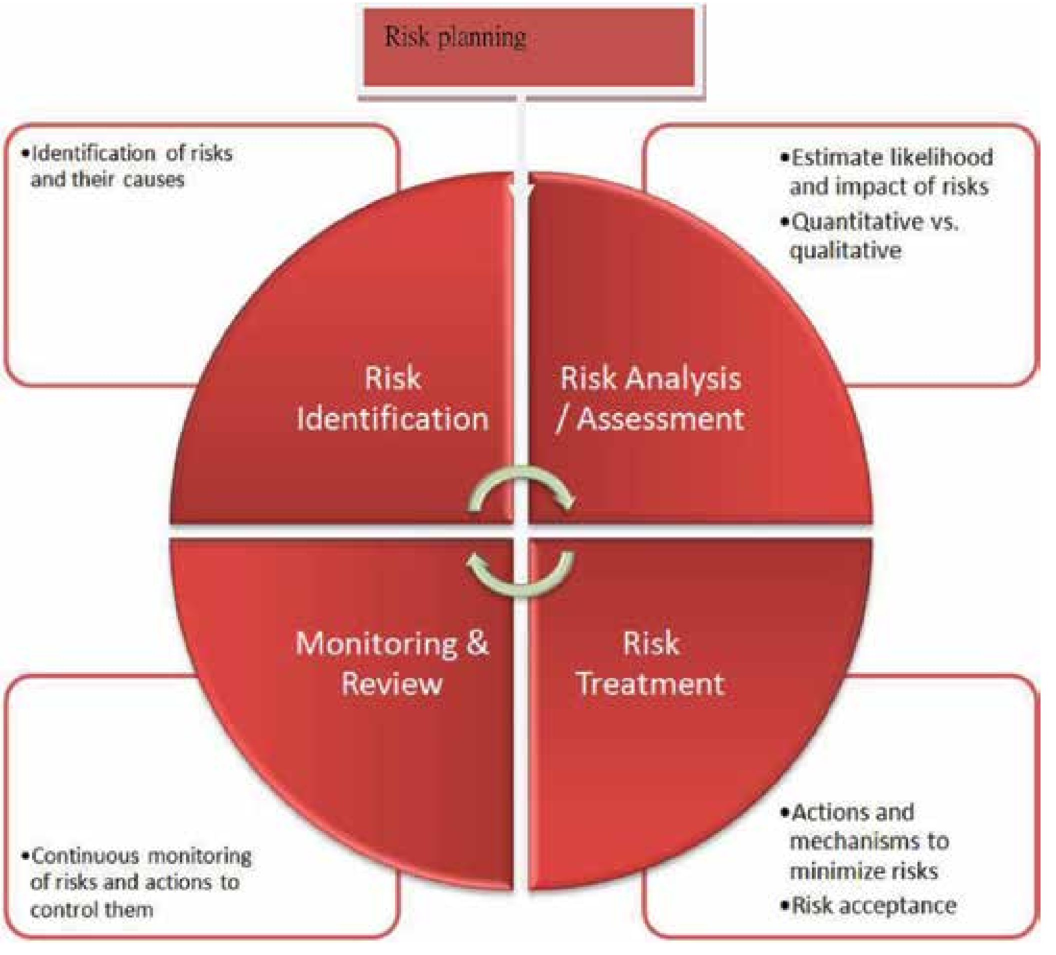

Figure 1. Risk management process (adapted from Naphade & Bhangale [30]).

	Significance		Consequences				
			1 Trivial impact	2 Minor impact	3 Moderate—Minor impact	4 Major impact	5 Catastrophic
Probability	1	Rare	Low	Low	Moderate	High	High
	2	Unlikely	Low	Low	Moderate	High	Very high
	3	Moderate	Low	Moderate	High	Very high	Very high
	4	Likely	Moderate	High	High	Very high	Extreme
	5	Almost certain	Moderate	High	Very high	Extreme	Extreme

Source: Adapted from Berg [2].

Table 1. Risk severity matrix.

<table>
<tr><td colspan="4">Risk title: provide a brief title of the risk</td><td colspan="3">Risk ID: provide a unique identity</td></tr>
<tr><td colspan="7">Overview</td></tr>
<tr><td colspan="4">Risk</td><td colspan="3">Provide a brief description of the risk</td></tr>
<tr><td colspan="4">Principal risk owner</td><td colspan="3">Include title of the person managing the risk and the area where the risk falls</td></tr>
<tr><td colspan="4">Supporting owner(s)</td><td colspan="3">Provide title of other persons affected by the risk</td></tr>
<tr><td colspan="4">Risk category</td><td colspan="3">Is it a financial, technical etc.</td></tr>
<tr><td colspan="4">Objective/plan</td><td colspan="3">List the objective impacted by the risk</td></tr>
<tr><td colspan="7">Details</td></tr>
<tr><td colspan="4">Causes: provide the causes that may lead to the risk materializing</td><td colspan="3">Consequence(s): Provide description of what will happen if the risk will materialize</td></tr>
<tr><td colspan="7">Inherent risk analysis (tick the appropriate ratings basing on the scenario that current controls do not exist or completely fail)</td></tr>
<tr><td>Inherent risk</td><td>Impact</td><td>Very high</td><td>High</td><td>Moderate</td><td>Low</td><td>Very low</td></tr>
<tr><td>Likelihood</td><td colspan="2">Very high</td><td>High</td><td>Moderate</td><td>Low</td><td>Very low</td></tr>
<tr><td colspan="3">Risk rating</td><td colspan="2">Impact × likelihood</td><td colspan="2">□ Multiply the ratings from impact and likelihood.
□ Shade this area with appropriate color</td></tr>
<tr><td colspan="7">Key risk mitigation/controls currently in place and their weaknesses: briefly describe the current controls existing to reduce the inherent risk, also point out the main weaknesses for the current controls.</td></tr>
<tr><td colspan="7">Residual risk analysis (tick the appropriate ratings basing remaining risk levels after the above existing controls)</td></tr>
<tr><td>Residual risk</td><td>Impact</td><td>Very high</td><td>High</td><td>Moderate</td><td>Low</td><td>Very low</td></tr>
<tr><td>Likelihood:</td><td colspan="2">Very high</td><td>High</td><td>Moderate</td><td>Low</td><td>Very low</td></tr>
<tr><td colspan="2">Risk rating</td><td colspan="3">I × L:</td><td colspan="2">□ Multiply the ratings from impact and likelihood.
□ Shade this area with appropriate color</td></tr>
<tr><td colspan="7">Actions/mitigating controls to be taken: (propose feasible treatment actions to be put in place to reduce the risk at tolerable levels, including resources required for each treatment action—financial, physical assets or human)</td></tr>
<tr><td colspan="3">Treatment:
1.
2.
3.</td><td colspan="4">Resource required
1.
2.
3.</td></tr>
</table>

Table 2. Template for risk identification and analysis sheet.

A risk register is a tool used in the risk management process to keep record of all identified risks and their respective corresponding mitigations or counter measures. It comprises of:

a. Purpose

b. Organizational goals and objectives

c. Risk assessment methodology

d. Overall risk profile of an organization

e. Summary of risks

f. Details of risks in each organization objective

g. Risk assessment sheets indicating causes, consequences, rating and mitigations measures

Tables 2–5 show templates of risk identification and analysis sheet, risk register, risk treatment schedule and action plan and risk treatment implementation report adopted by some organizations.

Objective	**Risk title**	**Type of risk**	**Risk ID**	**Risk assessment**		**Risk rating**	**Principal risk owner**
				Impact (I)	Likelihood (L)	I × L	

Table 3. Template for risk register.

Date of review: ……………………………… Compiled by: …………………………………… Date: ……………………… Reviewed by: ………………………………… Date: ………………………………………………					
Risk title and ID (from risk register in priority order)	Proposed treatment/control options (from risk identification sheet)	Results of cost-benefit analysis (A = accept, B = reject)	Person responsible for implementation of treatment options	Timetable for implementation (give specific start and end dates)	How will this risk and treatment options be monitored

Table 4. Template for risk treatment schedule and action plan section/unit.

Risk management quarterly implementation report for the quarter ending………………………………….. Prepared by: ………………………………… Date: ………………………………………………						
Risk title and ID (from risk register in priority order)	Proposed treatment/ control options (from risk identification sheet)	Person responsible for implementation of treatment options (as in the risk identification sheet)	Timetable for implementation (give specific start and end dates)	How will this risk and treatment options be monitored	Status of implementation (completed, ongoing, not done)	Remarks and/or comments

Table 5. Template for risk treatment implementation report section/unit.

2. Critical success factor (CSFs)

CSFs are selected key result areas that can facilitate achievement of organizational goals and objectives including risk management. CSFs were first defined by Rockart ([35] cited in Chen [7]) as the limited number of area in which results, if they are satisfactory, will ensure successful competitive performance for the organization. Later on, a number of CSFs definitions were given by various researchers. CSFs are certain rules, executive procedures and environmental conditions (Pinto & Covin, [36]). CSFs are the critical areas which organizations must accomplish to achieve its mission by examination and categorization of their impacts (Oakland [37] cited in Salaheldin, [34]). Deros et al. [38] defined CSFs as a range of enablers which, when put into practice, will enhance the chance for successful benchmarking implementation and adoption in an organization.

2.1. Critical success factors for effective risk management

Effective risk management entails doing the right thing with respect to risk management process. Top management needs to embark on CSFs as means of minimizing or eliminating risks in their organizations. Studies worldwide have documented CSFs which serve as a cornerstone for managing risks. For example, Grabowski and Roberts [8] identify the four important factors for risk mitigation that are organizational structuring and design, communication, organizational culture and trust. Hasanali [9] categorizes five critical success factors into: leadership; culture; structure, roles, responsibilities; information technology infrastructure; and measurement. Na Ranong and Phuenngam [10] determined seven CSFs for the financial industry namely: commitment and support from top management, communication, culture, information technology (IT), organization structure, training and trust. Studies of Agyakwa-Baah & Chileshe [11] identified 10 CSFs for the construction industry which are: management style, awareness of risk management process (RMP), cooperative culture, positive human dynamics, customer requirements, goals and strategic objective, impact of environment, usage of tools, teamwork and communication and availability of specialist in risk management. Chileshe and Kikwasi [32] assessed the 10 CSFs and determined that awareness of risk management processes, team work and communications and management style were the top three for Tanzania. Zhao et al. [12] determine top three CSFs as commitment of the board and senior management, risk identification, analysis and response and objective setting. Tsiga et al. [13] reveal initiation, identification, assessment, response planning, response implementation and risk communication and attitude, monitoring and review as CSFs for the construction industry. The study by Renault et al. [14] reveal drivers for ERM implementation namely legal and regulatory compliance requirements, nonmandatory reports, credits rating agencies' requirements, reduced earnings volatility, reduced cost and losses, increased profitability and earnings. Hosseini et al. [15] determine support from managers, inclusion of risk management in construction education and training courses for construction practitioners, attempting to deliver projects systematically and awareness and knowledge of the process for implementing risk management as factors for implementing risk management systems in developing countries. Chen [7] suggests four composite CSFs for the bank industry namely: bank operation management ability, developing bank trademarks ability, bank marketing ability and financial market. Collectively, CSFs identified in these studies can serve as key result areas which construction enterprises and other stakeholders can bank on to enhance risk management in their locality.

The manner that the chosen CSFs influence the performance of a certain organization or sector has been a subject of discussion in researches conducted worldwide. Commitment and support from top management has been found an important aspect in achievement of organizational goals. For example, Ifinedo [16] investigated the impact of contingency factors such as top management support, business vision and external expertise and established that top management support influences the success level of the organizational system. Similarly, Zwikael [17] argues that the high importance of top management support is considered to be among the CSFs for project management. Renault et al. [14] determine that lack of support from top management and management priorities are among key obstacles to enterprise risk management (ERM). Risk management happens to be a process that an organization has to assume. Awareness of risk management process has been identified by Chileshe and Kikwasi [32] as one of the barriers to adoption and implementation of risk assessment and implementation practices (RAMP). Likewise, Agyakwa-Baah and Chileshe [11] point out that awareness of risk management processes within an organization is paramount to the sound success of the project.

Communication is the backbone of any successful endeavor. Effective communication between the teams that are working on the project will enhance project success including mitigation of risks. Clutterbuck & Hirst [18] argue that communication ensures that the team members understand and support not only where the team is now but also what they want to be. Grabowski & Roberts [8] stress that communication plays an important role in risk mitigation and that provides opportunities for clarification, for making sense of the organization's progress, and for members to discuss how to improve the organization and the impact of using different risk mitigation strategies. Culture has an influence on how organizations manage risks. This is echoed by Grabowski & Roberts [8] that risk management requires the combination of several cultures that make the system into a cohesive whole in which the deep assumptions and espoused values of each of the member organizations can be built around the need for melding a culture of reliability. Training is important in equipping trainees with knowledge on emerging issues including risk management. Carey [19] points out that the ability to respond to changing conditions in an organization's operations relates to a range of activities including the development of risk training courses and the involvement of staff in responding to early warning systems. Advancement in technology and changing in clients' requirements calls for embarking on information technology. Hasanali [9] points out that an organization is on such a large scale that it would be difficult for members to communicate and share information without an information technology infrastructure.

3. A case study: risk management in the construction industry

3.1. Overview of the case study

The construction industry in Tanzania like in many other countries contributes drastically to the national growth through gross domestic product (GDP), gross fixed capital formation, creation of employment and industrial productivity. The National Bureau of Standards

(NBS) [20] reveals that in volume terms, the construction industry accounted for an average of 6.8% of GDP in the 2003–2010 periods. The contribution of the industry to gross fixed capital formation in 2011 was over 50% (URT, [39]). In 2016, data indicate the construction sector contribution to GDP was about 12%, the second single sector with highest growth rate preceded by agriculture. The general outlook of the contribution of various sectors of the economy is shown in **Figure 2**.

Construction being one sector of the economy is prone to risks. These include technical, social, construction, economic, legal, financial, natural, commercial, logistics and political risks. These risks are also classified into internal and external risks. Internal risks emanate from activities performed within the organizations such as technical, social and construction. External risks are risks which originate outside of the organization's undertakings and these include economic, natural and political risks. Accordingly, the construction industry needs to adopt a sound risk management system to maximize opportunities and minimize negative events in its operations for it to contribute effectively to national growth.

3.2. Risk management in construction

The risk management as part of project management is extremely important in achieving project objectives of time, cost, quality, improved health and safety and no disputes. Changes in technology and more sophisticated clients' requirements attract more risks in construction projects which call for formal risk management process. Although there have been remarkable efforts toward risk management in construction projects, implementation of risk management process is still inadequate. Studies [5, 21–25] have documented risk management practice in the construction industry. Akintoye & MacLeod [23] found that risk analysis and management in construction depend mainly on intuition, judgment and experience. They also cited the reasons to be lack of knowledge coupled with doubts on the suitability of these

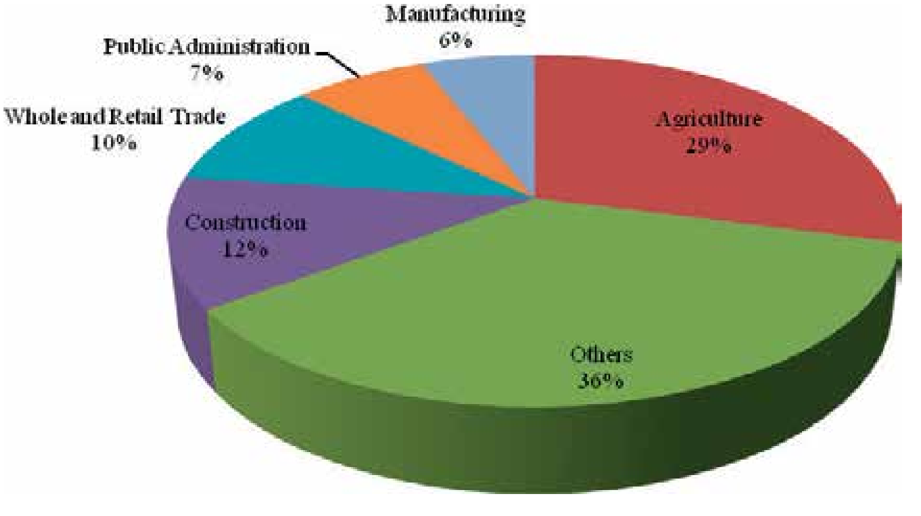

Figure 2. Contribution of various sectors of the economy to GDP.

techniques for the construction industry. Ahmed & Azhar [22] established that risk analysis and management techniques are rarely used by the general contractors due to a lack of knowledge and expertise. This is echoed by the study by Chinenye et al. [5] which established that organizations within the construction industry do not work with risk management in such a structured manner due to additional cost to be incurred when performing risk management on construction projects and lack of knowledge in the area of risk management. Mahendra et al. [25] determined that the participants used to handle the risks with an informal approach because of less knowledge and awareness among the construction industry stakeholders. Similarly, Abdul-Rahman et al. [21] found that the implementation of risk management process in Malaysian construction industry is still at a low level, due to the fact that most of the construction employees involved in risk management are not fully aware of the available risk management techniques that can be applied in construction projects. Kikwasi [24] also noted inadequate risk management knowldege among consultants and determines that most consultants use document reviews and assumptions to identify risks and contingency sum method to quantify risks. A survey by Yusuwan et al. [26] also reveals low level of awareness of risk management in the clients' organization and that they have implemented risk management in their operations on a small scale.

Previous studies in the construction industry reveal poor implementation of risk management process, as well as CSFs for effective risk management. This calls for the need to review the impact of risk management on project outcomes, assessment of implementation of previously identified CSFs and determination of a new set of CSFs.

3.3. Methodology

The study drawn a sample of 200 practitioners from the construction industry comprised of consultants, clients and contractors. The study adopted a descriptive research type that attempts to provide an insight on categories of CSFs that can enhance effective risk management in the construction industry. Data were collected using literature review and questionnaires. Two hundred questionnaires were distributed to randomly selected respondents through emails and hand delivery. Out of 200 distributed questionnaires, 100 were returned, out of which 67 were fairly filled for analysis equating to a response rate of 33.5%. A list of critical success factors for effective risk management used in the study was extracted from previous studies. Previous studies also aided in establishing gap to be filled by the current study. The collected data were analyzed using the Statistical Package for Social Sciences (SPSS) version 20. Descriptive statistics were used to compute mean scores for project outcomes and CSFs and principal component analysis (PCA) was used to compute composite CSFs. A 5-Likert scale was used, i.e., 5 = Strong agree, 4 = Agree, 3 = Neutral, 2 = Disagree and 1 = Strong disagree.

3.4. Results

3.4.1. Respondents' profile

The participation of the intended groups namely consultants, client and contractors was 36.4, 21.2 and 42.4%, respectively. The three groups comprised of 13.4% architects, 23.9% engineers, 33.5% quantity surveyors, 17.9% project managers and 9% others. Furthermore, majority (83.9%) of these respondents have experience of more than 5 years. Majority of respondents (91%) have indicated that they worked on projects that have gone over budget.

3.4.2. Impact of risk management on project outcomes

Risk management has an influence on both the risk management process and project success. This is echoed by Junior and de Carvalho [27] that risk management practices have an impact on project success. Similarly, Kishk & Ukaga [28] through their case study concluded that there is a direct relationship between the effective risk management and project success. The influence on the risk management process includes: creation of a risk sensitive organization, formalized risk reporting, improved focus and perspective on risk, efficient use of resources and compliance matters. The impact on project outcomes is aligned with fulfilling objectives of the project, mainly time, cost, quality, health and safety and no disputes.

Table 6 presents assessment of impact of risk management on project outcomes. Results reveal three significant outcomes of risk management in construction which can be adopted in other sectors namely: reduction in design/production time, improved public perception and improved team morale and productivity. The case study therefore underlines that risk management has positive results toward achievement of organizational goals and objectives.

3.4.3. Selected areas of CSFs implementation in construction organizations

Figure 3 indicates selected areas of CSFs implementation. Among the areas assessed, the areas that seem least implemented are: understanding the risk management guideline or policy,

S/N	Outcome	t	df	Sig. (2-tailed)	Mean difference	95% Confidence interval of the difference	
						Lower	Upper
1	Project completed on time	−1.697	47	.096	−.271	−.59	.05
2	Project completed within budget/ major cost saving	−1.855	46	.070	−.234	−.49	.02
3	Product to the required budget	−.535	45	.596	−.065	−.31	.18
4	Reduced accidents on site	1.273	46	.209	.170	−.10	.44
5	Reduction in design/production time	−3.207	44	.003	−.400	−.65	−.15
6	Improved public perception	−3.076	46	.004	−.447	−.74	−.15
7	Reduction in contract claims	−1.430	45	.160	−.217	−.52	.09
8	Improved team morale and productivity	−2.141	46	.038	−.298	−.58	−.02

Table 6. Impact of risk management on project outcomes.

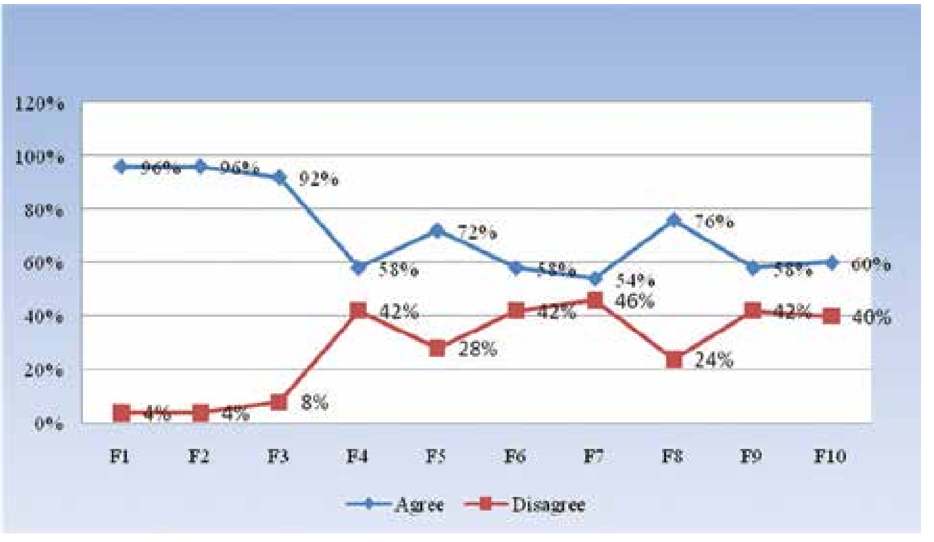

Figure 3. Implementation of selected aspects of CSFs. Key: F1 = Aware of risk management processes. F2 = Risk management practice viable in the construction industry. F3 = The organization has a policy to support the development of risk management. F4 = Understand the risk management guideline or policy. F5 = The organization has a documented risk management guideline or policy. F6 = The organization has guideline to support the goals and objectives of risk management. F7 = The organization conducts training to new employees. F8 = Internal/external environment influences risk management in your organization. F9 = The organization has established procedures for keeping up-to-date and informed with changes in regulations. F10 = Organization use methods and tools to manage risk.

organization has a documented risk management guideline or policy, the organization has guideline to support the goals and objectives of risk management, the organization conducts training to new employees, organization has established procedures for keeping up-to-date and informed with changes in regulations and organization use methods and tools to manage risk. This implies that organizations rarely formulate policy or guidelines for risk management and conduct training to new employees and the use of methods and tools to manage risks is at a low level.

3.4.4. CSFs effective risk management in construction

Several CSFs have been listed by researchers in the financial, construction and other sectors. Most of CSFs are associated to actions by top management, communication within organizations, organization structures, policies, risk management experts and knowledge.

Table 7 below presents 25 CSFs. Using descriptives, results reveal top seven CSFs for effective risk management which are training, communication, commitment and support from top management, awareness of risk management process, teamwork, clear objectives and guidelines for risk management and management styles. Generally, there are 23 CSFs that have scored a mean score greater than 3.5 indicating a fair agreement of respondents. This result calls for further analysis to scale down the number of CSFs and thus the use of principal component analysis (PCA).

S/N		N	MS	Std. Dev
CSF 1	Training	68	4.25	.760
CSF 2	Communication	68	4.19	.697
CSF 3	Commitment and support from top management	67	4.15	.680
CSF 4	Awareness of risk management process	67	4.10	.741
CSF 5	Teamwork	67	4.10	.873
CSF 6	Clear objectives and guidelines for risk management	67	4.03	.904
CSF 7	Management style	67	4.01	.879
CSF 8	Availability of specialist risk management consultants	67	3.93	.804
CSF 9	Risk monitoring and review	66	3.92	.882
CSF 10	Having documented risk management policy or guidelines	67	3.87	.886
CSF 11	Consideration of internal and external environment	67	3.82	.869
CSF 12	Trust	65	3.80	.905
CSF 13	Effective usage of methods and tools	67	3.75	.927
CSF 14	Cooperative culture	67	3.72	.982
CSF 15	Management priorities	67	3.70	.835
CSF 16	Impact for environment	67	3.66	.808
CSF 17	Risk identification, analysis and response	66	3.62	.837
CSF 18	Customer requirements	67	3.61	.870
CSF 19	Goals and objectives of the organization	67	3.58	1.002
CSF 20	Information technology infrastructure	67	3.55	.942
CSF 21	Positive human dynamics	67	3.54	.959
CSF 22	Organizational structure	65	3.52	.868
CSF 23	Objective setting	67	3.51	1.021
CSF 24	Allocating adequate resources	66	3.38	.837
CSF 25	Legal and regulatory compliance requirements	67	3.34	.845

Table 7. CSFs mean scores (MS).

Further, principal component analysis reveals nine factors of CSFs for effective risk management. **Table 8** reveals that about 74% of the total variance is explained by the first nine factors. The factors are arranged in decreasing order of total variance explained. To allow for flexibility in the results, the Eigen value greater or equal to 1 was assumed implying that that only factors that account for variances greater or equal to 1 are included in the factor extraction. On the coefficient display format, small coefficients with absolute value below 0.5 were suppressed. Consequently, only factor scores greater than 0.50 are shown on the rotated component matrix in **Table 10**.

Component	Initial Eigen values			Extraction sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
CSF 1	5.238	20.950	20.950	5.238	20.950	20.950
CSF 2	2.895	11.580	32.530	2.895	11.580	32.530
CSF 3	2.236	8.944	41.474	2.236	8.944	41.474
CSF 4	1.761	7.043	48.517	1.761	7.043	48.517
CSF 5	1.684	6.738	55.255	1.684	6.738	55.255
CSF 6	1.421	5.685	60.940	1.421	5.685	60.940
CSF 7	1.307	5.229	66.168	1.307	5.229	66.168
CSF 8	1.082	4.329	70.498	1.082	4.329	70.498
CSF 9	1.037	4.147	74.644	1.037	4.147	74.644
CSF 10	.933	3.733	78.377			
CSF 11	.885	3.541	81.918			
CSF 12	.772	3.090	85.007			
CSF 13	.752	3.009	88.016			
CSF 14	.538	2.153	90.169			
CSF 15	.444	1.775	91.944			
CSF 16	.392	1.567	93.511			
CSF 17	.347	1.389	94.900			
CSF 18	.301	1.205	96.105			
CSF 19	.298	1.190	97.296			
CSF 20	.223	.890	98.186			
CSF 21	.173	.694	98.879			
CSF 22	.134	.538	99.417			
CSF 23	.069	.275	99.692			
CSF 24	.040	.161	99.853			
CSF 25	.037	.147	100.000			

Table 8. Total variance explained.

In **Table 9**, some of the variables are more highly correlated with some factors than others. In order to make it easier to assign meaning to the factors, it is ideal to see groups of variables with large coefficients for one factor and small coefficients for the others. The component matrix is therefore rotated to achieve simple structure, where each factor has large loadings in absolute value for only some of the variables, making it easier to identify.

		Component								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
CSF 1	Risk identification, analysis and response	.783								
CSF 2	Customer requirements	.735								
CSF 3	Allocating adequate resources	.654								
CSF 4	Having documented risk management policy or guidelines	.632		.549						
CSF 5	Objective setting	.611				−.501				
CSF 6	Teamwork	.610								
CSF 7	Consideration of internal and external environment	.586								
CSF 8	Availability of specialist risk management consultants	.573		.511						
CSF 9	Impact for environment	.554								
CSF 10	Clear objectives and guidelines for risk management	.521								
CSF 11	Effective usage of methods and tools									
CSF 12	Organizational structure		.771							
CSF 13	Information technology infrastructure		.705							
CSF 14	Cooperative culture		.688							
CSF 15	Trust		.594							
CSF 16	Training									
CSF 17	Management style			.663						
CSF 18	Communication				.703					
CSF 19	Commitment and support from top management									
CSF 20	Goals and objectives of the organization	.544				.616				
CSF 21	Management priorities									
CSF 22	Legal and regulatory compliance requirements									
CSF 23	Awareness of risk management process									
CSF 24	Positive human dynamics									
CSF 25	Risk monitoring and review									.526

Extraction method: principal component analysis; 9 components extracted

Table 9. Component matrix.

Table 10 shows the rotated component matrix after varimax rotation and after the variables have been sorted by the absolute values of the loadings with nine components. Five variables are highly correlated to factor 1; variables 6 and 7 are highly correlated to factor 2; variables 9 and 10 are highly correlated to factor 3; variables 11 to 13 are highly correlated to factor 4; variables 14 and 15 are highly correlated to factor 5; variables 16 to18 are highly correlated to factor 6; variables 19 and 21 are highly correlated to factor 7; variables 22 and 24 are highly correlated to factor 8; and variable 25 is highly correlated to factor 9.

In summary, the following are categories of CSFs for effective risk management:

a. CSF 1 Management approach: Comprise of five CSFs with management style scoring high followed by allocating adequate resources and risk identification, analysis and response

b. CSF 2 Goals and objectives of the organization: Comprise of two CSFs all with high scores

c. CSF 3 Risk management policy and experts: Comprise of two CSFs all with high scores

d. CSF 4 Information technology and culture: Comprise of three CSFs with information technology infrastructure scoring high followed by trust.

e. CSF 5 Environment and usage of tools: Comprise of three CSFs with consideration of internal and external environment scoring high followed by effective usage of methods and tools.

f. CSF 6 Teamwork and commitment of the top management: Comprises of two CSFs all of them scoring fairly.

g. CSF 7 Communication and training: Comprise of three CSFs with communication scoring high followed by management priorities.

h. CSF 8 Awareness of risk management process and legal framework: Comprise of three CSFs with legal and regulatory compliance requirements scoring high followed by awareness of risk management process

i. CSF 9 Risk monitoring and review: Comprising of risk monitoring and review with high scores

Collectively, the nine categories of CSFs have yielded the top eight CSFs with component loading of between 1 and 0.8:

a. Goals and objectives of the organization (0.924);

b. Having documented risk management policy or guidelines (0.918);

c. Availability of specialist risk management consultants (0.899);

d. Consideration of internal and external environment (0.881);

e. Objective setting (0.878);

f. Risk monitoring and review (0.878);

g. Management style (0.823);

h. Information technology infrastructure (0.805).

http://dx.doi.org/10.5772/intechopen.74419

		Component								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
CSF 1	Management style	.823								
CSF 2	Allocating adequate resources	.788								
CSF 3	Risk identification, analysis and response	.737								
CSF 4	Clear objectives and guidelines for risk management	.725								
CSF 5	Customer requirements	.563								
CSF 6	Goals and objectives of the organization		.924							
CSF 7	Objective setting		.878							
CSF 8	Positive human dynamics									
CSF 9	Having documented risk management policy or guidelines			.918						
CSF 10	Availability of specialist risk management consultants			.899						
CSF 11	Information technology infrastructure				.805					
CSF 12	Trust				.765					
CSF 13	Cooperative culture				.673					
CSF 14	Consideration of internal and external environment					.881				
CSF 15	Effective usage of methods and tools					.789				
CSF 16	Impact of environment					.669	.			
CSF 17	Teamwork						.634			
CSF 18	Commitment and support from top management						.630			
CSF 19	Communication							.752		
CSF 20	Management priorities							.609		
CSF 21	Training							.595		
CSF 22	Legal and regulatory compliance requirements								.717	
CSF 23	Awareness of risk management process								.629	
CSF 24	Organizational structure								.608	
CSF 25	Risk monitoring and review									.878

Extraction method: principal component analysis
Rotation method: varimax with Kaiser normalization; Rotation converged in 12 iterations

Table 10. Rotated component matrix.

3.5. Discussion

The case study has underlined that risk management in construction projects has positive results such as reduced accidents on sites, product to the required budget, reduction in contractual claims, project completed within budget and project completed on time. This finding is partly in line with the study by Al-Shibly et al. [29] on aspects of time. On the other hand, this finding supports the work of Kishk and Ukaga [28] that the conventional view of project success based on cost, time and quality objectives is not sufficient. They argue that the project success has to base on the predetermined and preagreed success criteria set by all stakeholders.

Through description, the study identified top seven CSFs; however, about 23 CSFs were generally within acceptable limits based on the mean score. These CSFs were further reduced using PCA and nine composite CSFs for effective risk management were determined. This approach also was used by Chen [7] to suggest four composite CSFs for the banking industry. These CSFs are management approach, goals and objectives of the organization, risk management policy and experts: information technology and culture, environment and usage of tools, teamwork and commitment of the top management, communication and training, awareness of risk management process and legal requirements and risk monitoring. Collectively, the nine CSFs have yielded the top eight CSFs namely: goals and objectives of the organization, having documented risk management policy or guidelines, availability of specialist risk management consultants, consideration of internal and external environment, objective setting, risk monitoring and review, management style and information technology infrastructure. To a great extent, this finding supports the works of Grabowski and Roberts [8], Hasanali [9], Agyakwa-Baah and Chileshe [11], Chileshe and Kikwasi (2014), Zhao et al. [12] and Tsiga et al. [13]. The current study supports the work of Hosseini et al. [15] on issues of management support, training and awareness of risk management process. The study also noted lack of understanding of risk management guideline or policy, organizations lacking documented risk management guideline or policy and guideline to support the goals and objectives of risk management, organizations not conducting training to new employees, organizations lacking established procedures for keeping up-to-date and informed with changes in regulations and organizations not using methods and tools to manage risks.

4. Conclusion

The chapter sought to explore theories on risk management and using the construction industry as a case study establishes CSFs for effective risk management. The case study also has explored the impact of risk management to project outcomes and the status of implementation of selected previously identified CSFs. Generally, risk management in organizations has positive results to the risk management process as well as achievement of organizational goals and objectives. Similarly, organizations at certain levels have been implementing previously determined CSFs. From a list of 25 CSFs determined previously, a new set of 9 composite CSFs have established for effective risk management. The findings of the current study provide snapshot on the composite CSFs that can be assumed by organizations in achieving their goals and objectives. The limitation of this which is worth to be acknowledged is that the study has drawn 9 composite CSFs from only 25 CSFs.

Conflict of interest

The author declares that there is no conflict of interests regarding the publication of this chapter.

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Section 2

Selected Case Studies Illustrating Risk Management

Construction Supply Chain Resilience in Catastrophic Events

Yasangika Gayani Sandanayake,
Tharaka Bandara Dissanayake and Chike Oduoza

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79963

Abstract

In the wake of a number of catastrophic events, construction supply chain (CSC) vulnerability has become a major issue in the industry. Construction organisations today focus on strategies to minimise the impact of catastrophic events and manage risk by creating more resilient supply chains. However, there is lack of a mechanism to minimise the impact of catastrophic event on CSC. Therefore, this chapter focuses on the impact of catastrophic events on CSC and proposes a strategic framework to minimise their ultimate impact on the construction organisations. This aim is achieved through a comprehensive literature review, preliminary investigation and structured questionnaire survey. According to findings, most likely catastrophes that disrupt CSC are non-terrorist events and in fact are not always the most severe catastrophes. The aggregate effect of likelihood and severity revealed that disruption to transportation has the extreme risk level on CSC, while the most significant impact of catastrophic events is business failure and least significant impact is loss of focus to work. Thus, the catastrophic event risk minimisation strategic framework presented in this chapter will assist construction organisations to identify most suitable strategic actions to minimise the impact of catastrophic events on CSC in order to create resilient construction industry.

Keywords: construction supply chain (CSC), construction supply chain management, catastrophic events, risk analysis, severity, likelihood, strategic framework

1. Introduction

Heightened challenges due to series of catastrophic events that have disrupted economies around the world have prompted academics and practitioners to investigate new strategies to minimise their impact on supply chain. Supply chains are increasingly vulnerable to catastrophic events and a diverse set of risks [1]. According to Atley and Ramirez [2], there are evidence that failure to manage supply chain risks effectively may lead to a significant negative impact on organisations. Such impacts include not only financial losses but also reduction in product quality, damage to assets and loss of reputation [3]. Developing strategies to mitigate disruptions has become a necessity as systems become more complex and increasingly more vulnerable to experiencing supply chain disruptions [4]. According to Stecke and Kumar [5], it is difficult to find strategies that best suit an organisation or industry due to the nature and severity of catastrophes.

The construction industry consists of certain peculiarities such as one-of-a-kind nature of project, temporary multi-organisation, on-site production and regulatory intervention preventing the attainment of flows as efficient as in manufacturing [6]. Vrijhoef and Koskela [7] argued that due to construction peculiarities, supply chain management (SCM) has specific roles in construction. The construction supply chain (CSC) basically represents a series of serial and parallel connections between clients and suppliers leading to the delivery of one or more products to one or more end clients [8].

Some researchers have introduced strategies that can be implemented both before and after a catastrophic event in order to minimise or prevent the impact of such an event in manufacturing industry [1, 5, 9, 10]. However, there is a lack of research on the impact of catastrophic events on CSC and strategies to ensure a resilient CSC. Consequently, there is no evidence in the literature of any mechanism to minimise the impact of catastrophic event on CSC. There is therefore a necessity to investigate the impact of catastrophic events on this sector and to propose an action plan with strategies to face such events with resilience in future.

The structure of this chapter begins with a review of supply chain management, construction supply chain management, supply chain risks, impact of catastrophic events on CSC and strategies to minimise the impact of catastrophic events on supply chain. The next section presents the research methodology and conceptual framework. Research findings are presented in Section 7 followed by concluding discussions.

2. Supply chain management (SCM)

Supply chain management (SCM) originated and flourished in the manufacturing industry. Although supply chains exist in any type of organisation, the complexity of the chain seems to vary greatly from firm to firm and also from industry to industry depending on the size of the business, type of products and intricacy of the industry. The supply chain starts and ends with the customer. Despite the popularity of SCM, both in academia and industry, there is a considerable confusion as to its meaning and lack of a universally accepted definition. **Table 1** shows typical definitions of supply chain and SCM given by various authors in their publications.

References	Supply chain	Supply chain management (SCM)
Monczka et al. [11]	Supply chain is a set of three or more organisations linked directly by one or more of the upstream or downstream flows of products, services, finances and information from a source to a customer	SCM endorses a supply chain orientation and involves proactively managing the two-way movement and coordination of goods, services, information and funds from raw materials through to end user
Coyle et al. [12]	Supply chain can be viewed as a series of integrated enterprises that must share information and coordinate physical execution to ensure a smooth, integrated flow of goods, services, information and cash through the pipeline	SCM is involved with integrating three key flows across the boundaries of the companies in a supply chain: product/materials, information and financials/cash
Handfield and Nichols [13]	Supply chain encompasses all activities associated with the flow and transformation of goods from the raw materials stage, through to the end user, as well as the associated information flows. Material and information flow both up and down the supply chain	SCM is the integration of these activities through improved supply chain relationships, to achieve a sustainable competitive advantage
Lambert et al. [14]	Supply chain is not a chain of businesses with one-to-one, business-to-business relationships, but a network of multiple businesses and relationships	SCM is a philosophy which integrates key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders
Thomas and Griffin [15]	There are three traditional stages in the supply chain: procurement, production and distribution and supply chain for a particular product will cross functional or corporate boundaries	SCM is management of material and information flows both in and between facilities such as vendors, manufacturing and assembly plants and distribution centres
Ayers [16]	Life cycle processes supporting physical, information, financial and knowledge flows for moving products and services from suppliers to end users	Design, maintenance and operation of supply chain processes for satisfaction of end user needs
Mentzer et al. [17]	Supply chain is a set of three or more entities (organisations or individuals) directly involved in the upstream and downstream flows of products, services, finances and/or information from a source to a customer	SCM is the systemic and strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole

Table 1. Definitions of supply chain and supply chain management.

Although the definitions of supply chain appear similar across authors, the definition of SCM could differ. Tyndall et al. [18] and some authors defined SCM in operational terms involving the flow of materials and products, some viewed it as a management philosophy and some others viewed it in terms of a management process. Mentzer et al. [17] and Mohanty and Deshmukh [19] identified three degrees of supply chain complexity, that is, "direct supply chain," "extended supply chain," and "ultimate supply chain" as presented in **Figure 1**.

SCM integrates all organisations across supply chain, through upstream and downstream linkages. Many past researchers applied the generic concepts, methods and lessons learnt from SCM in manufacturing industry to the construction industry. The next section presents the review on construction supply chain management.

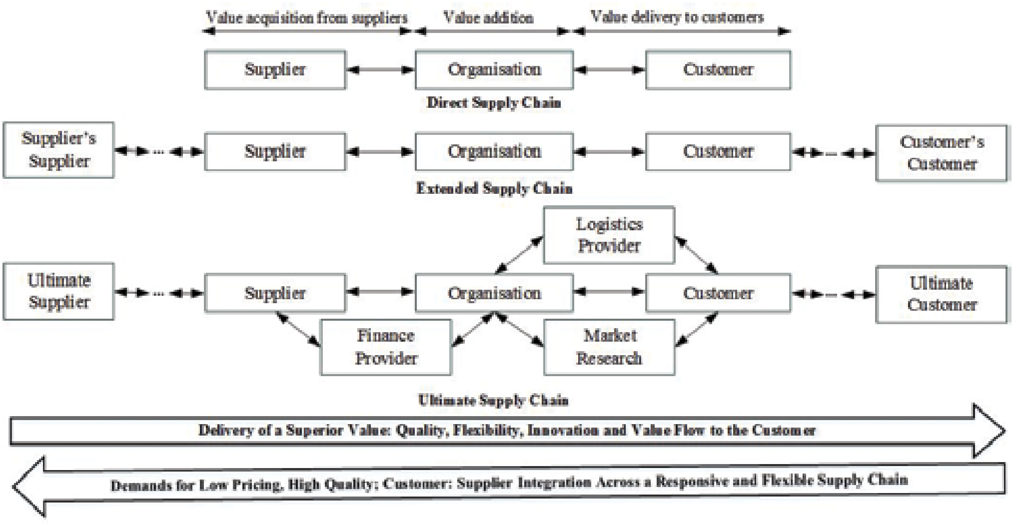

Figure 1. Types of supply chain relationships (adapted from [17, 19]).

3. Construction supply chain management (CSCM)

A major distinction between construction and manufacturing is that the construction industry is project based and of discontinuous nature, while manufacturing industry involves continuous processes and relationships [20]. The construction industry is one of the most complex industries because the total development of a project normally consists of several phases requiring a diverse range of specialised services and involvement of numerous participants. Therefore, it is difficult to control and manage construction projects effectively [21]. Production in construction is relatively disconnected and fragmented due to how demand and supply systems in construction have traditionally been organized [8]. Vrijhoef and Koskela [7] further identified four major roles of SCM in construction, dependent on whether the focus is on the supply chain, the construction site, or both. **Figure 2** presents the four areas of focus as pointed out below.

Supply chain in construction consists of all the construction business processes initiated from the demands by the client as conceptual design and construction to maintenance, replacement and eventual decommission of building [22]. According to Xue and co-workers [22], CSC is not a chain of construction businesses with business-to-business relationships, but a network of multiple organisations and relationships, which includes the flow of information, materials, services or products, and funds between client, designer, contractor and supplier. Based on three case studies conducted in the Netherlands and Finland, Vrijhoef and Koskela [7] developed a typical supply chain and make-to-order construction process as shown in **Figure 3**.

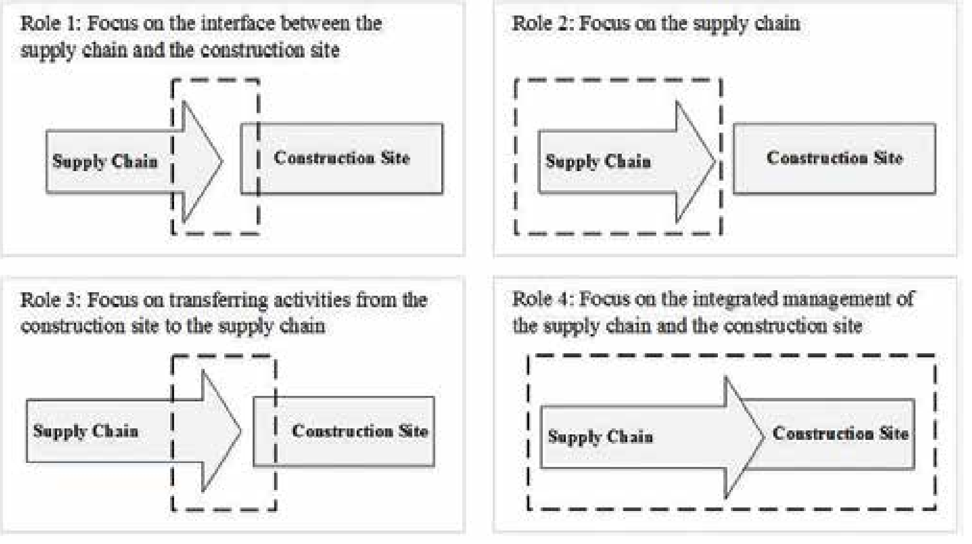

Figure 2. The four roles of supply chain management in construction (source: [7]).

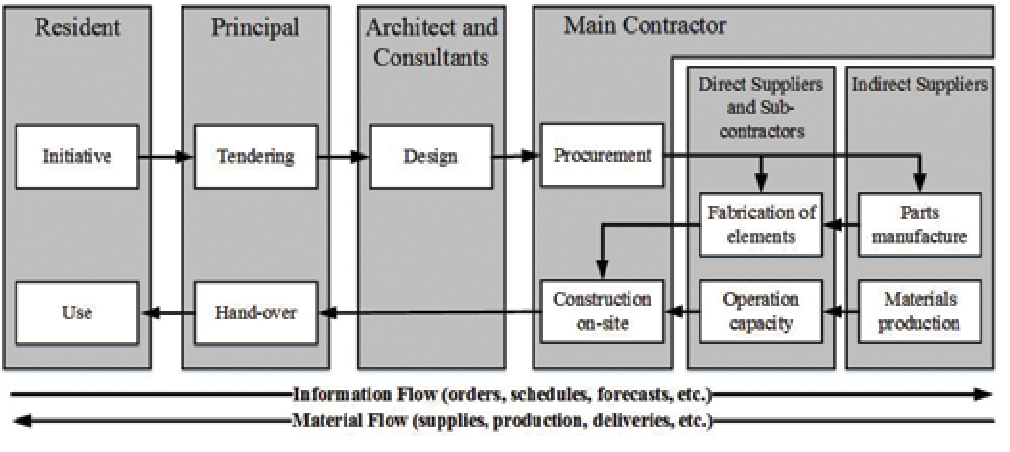

Figure 3. Typical configuration of a traditional construction supply chain (source: [7]).

According to Vrijhoef and Koskela [7], in a typical construction process as shown in **Figure 3**, principle (or client's representative) initiates the construction project and establishes a construction project organisation with the consultant, since the resident/client is not an expert. Based on the principles' instruction, architect and other consultants prepare drawings and tender documents. Once contracts and formalities are ready and information is available, contractor starts the physical execution of the construction project. Construction process includes extraction of materials, manufacture of parts, engineering and assembly of elements and final construction on site. Normally, the main contractor takes care of employment of subcontractors and procurement of materials from suppliers.

Hence, CSC consists of all the construction business processes, from the client's initiation, briefing, conceptual and subsequent design and construction to maintenance, replacement and eventual decommission of building, where several stakeholders such as client, architect, consultant, contractor, subcontractor, supplier, etc. are involved [22]. Therefore, Xue and his co-authors stated that "CSC is not a chain of construction businesses with business-to-business relationships, but a network of multiple organisations and relationships, which includes the flow of information, the flow of materials, services or products, and the flow of funds between client, designer, contractor and supplier" [22]. The authors further defined CSCM as "the integration of key construction business processes, from the demands of client, design to construction, and key members of construction supply chain, including client/owner, designer, contractor, subcontractor and supplier" [22].

Today's global supply chains are highly complex networks and are increasingly vulnerable to disruption, which can have significant impact on company performance and shareholder's value. Due to the unique nature of the CSC, construction organisations face complex supply chain risks, and firms are under increasing pressure to manage, mitigate and transfer risks effectively. Hence, the following section presents the risks on supply chain.

4. Risks on supply chain

Supply chain risks and disruptions can be materialised either inside or outside of a supply chain and can be highly divergent [23]. Chopra and Sodhi [24] divided supply chain risks into nine categories, namely disruptions, delays, systems, forecast, intellectual property, procurement, receivables, inventory and capacity. Further, Kleindorfer and Saad [25] introduced two broad categories of risks affecting supply chain design and management. First category consists of problems of coordinating supply and demand and second category includes risks arising from disruptions to normal activities. Finch [26] classified supply chain risk into three broad categories, that is, application level, organisation level and inter-organisational level. Application level risks include natural disasters, accidents, deliberate acts, data/information security risks and management issues. Organisational level risks consist of legal and strategic changes in decision-making, while at the inter-organisational level, there is a possible uncertainty from the outside of the organisation, which could be risky. Wagner and Bode [23] considered five different classes of risks, namely demand side, supply side, regularity/legal and bureaucratic, infrastructure and catastrophic events. Vanany et al. [27] classified supply chain risks into three categories such as operational accidents, operational catastrophes and strategic uncertainty. While operational accidents are those affecting the operational processes or resources related to logistics/supply chain, operational catastrophes are risks associated with rare and difficult to predict events, but once occurred, have severe impact on the company. Strategic uncertainty is the type of risk that is generally difficult to address and affect the company not at the operational level, but strategically.

Reviewing different types of classifications of supply chain risks, it is obvious that some researchers have identified catastrophic event as one of the major potential risks in supply chain. This chapter therefore focuses on the impact of catastrophic events on the CSC.

5. Catastrophic events and supply chain management

Companies all around the world are increasingly vulnerable to high impact/low probable events [28]. Stecke and Kumar [5] showed that there has been a marked increase in the frequency and economic losses from natural and man-made catastrophes. But, Vanany et al. [27] highlighted that catastrophic events have received relatively less attention in the SCM literature. Catastrophic events have been identified under supply chain risks in various ways. The next sections of this chapter review literature on catastrophic events, their impact on supply chains and strategies introduced by past researchers to minimise their impact on supply chains.

5.1. Catastrophic events

Gilbertson et al. [29] defined catastrophic events as events that are beyond the ordinary or routine and are characterised by being of low probability but high consequence. Brindley [30] categorised potential supply chain risk based on probability and severity perspectives, and according to **Figure 4** developed by the author, catastrophic events are located in the bottom right corner.

Mitroff and Alpaslan [31] identified seven categories of catastrophes such as economic crises (recessions, hostile takeovers), physical crises (industrial accidents, product failures), personnel crises (strikes, exodus of key employees, workplace violence or vandalism), criminal crises (product tampering, act of terrorism), information crises (theft of proprietary information, tampering with company records), reputation crises (logo tampering, rumour mongering) and natural disasters (floods, fires). Wagener and Bode [23] recognised natural hazards,

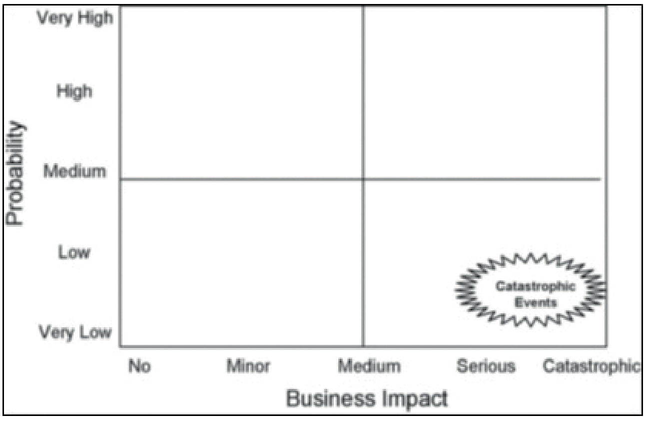

Figure 4. Risk categorisation scheme (source: [30]).

socio-political instability, civil unrest, economic disruptions and terrorist attacks as catastrophic events. Stecke and Kumar [5] broadly classified catastrophes into two main parts: man-made and natural catastrophes and further divided them into other sub groups as shown in **Figure 5**.

Gilbertson et al. [29] identified several catastrophic events that could occur during construction phase: structural collapse of permanent structure, collapse of temporary works and collapse of plant and equipment such as cranes, major fire, tunnel collapse and disruption of underground services. Further to Gilbertson et al. [29], the most significant factor, which could affect the probability of a catastrophic event in construction industry, is the failure to recognise hazardous scenarios and influencing events. Other important factors include lack of site control, interface problems with various parties, lack of checking and competent reviewing and lack of designer's involvement on site.

5.2. Impact of catastrophic events on supply chain

From time to time, frequent as well as rare catastrophes disrupt supply chain operations, and every firm's supply chain is susceptible to a diverse set of risks [1, 5]. Atley and Ramirez [2] found evidence to prove that failure to manage supply chain risks effectively may lead to a significant negative impact on organisations. Stecke and Kumar [5] found that business losses constitute a major percentage of the total losses caused by catastrophes. Cousins et al. [32] identified the wider consequences of failure to manage risks effectively. These include not only financial losses but also reduction in product quality, damage to property and equipment, loss of reputation in the eyes of customers, suppliers and the wider public and delays in delivery days. Knemeyer et al. [1] stated that if, for instance, a facility is lost due to a catastrophic event, the consequences affect supply chain operations, financial flows and possibly information flows too.

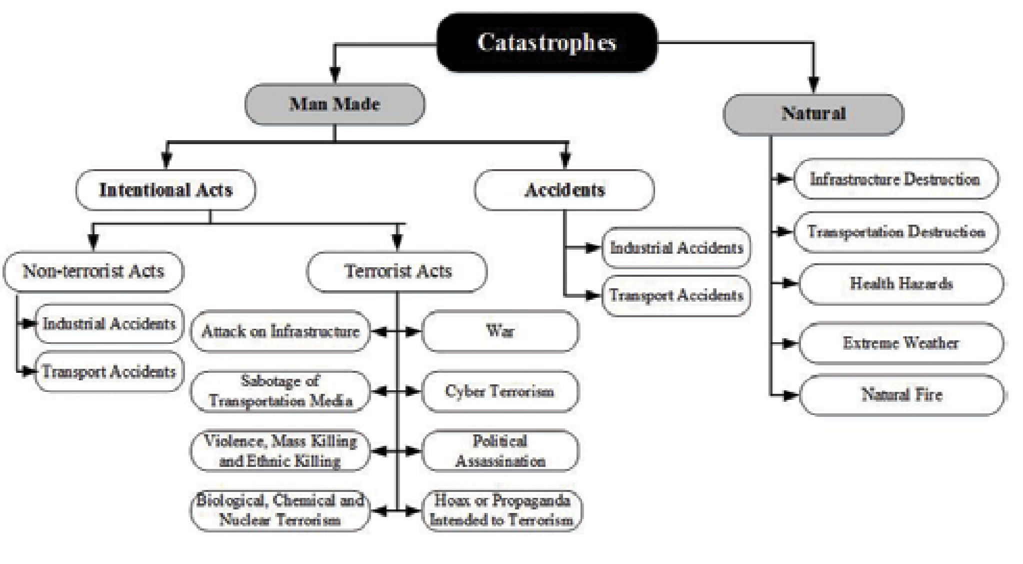

Figure 5. Classification of catastrophes (adapted from [5]).

Construction industry is also highly vulnerable to catastrophic events. The impacts of catastrophic events on construction industry include construction supply chain breakdowns, information and communication breakdowns, significant damages to property and infrastructure, increased demand for reconstruction, injuries and deaths. The aforementioned impacts lead to increase project cost and time, reduce quality and devote more management time for crisis handing. Catastrophic events may have wider implications such as extensive delay or project failure, significant business failure, loss of money and loss of reputation for all concerned [29]. Extreme weather events such as floods, hurricanes and storms have significant effects on CSC, and according to Wedawatta et al. [33], supply chain disruptions due to extreme weather events can create a substantial impact on a construction enterprise. Therefore, potential consequences of catastrophic events on CSC are wide ranging and long-lasting.

5.3. Strategies to minimise the impact of catastrophic events on supply chain

Marley [4] stated that developing strategies to mitigate disruptions has become a necessity as systems become more complex and increasingly more vulnerable to experiencing supply chain disruptions. In fact, several recent books and articles have directly focused their attention on the vulnerability of supply chains and assert the need for companies to perform a more systematic analysis of their vulnerability [1]. While many firms developed plans to protect against recurrent, low impact risks in their supply chains, there are many who ignored high-impact low-likelihood risks [24]. **Table 2** summarises the strategies introduced by researchers to minimise the impact of catastrophic events on supply chain both in manufacturing and construction industries.

Journal article	Proposed strategies
Knemeyer et al. [1]	• Identify key locations and threats • Estimate probabilities and potential loss for each key location • Evaluate alternative countermeasures for each key location • Select countermeasures for each key location
Stecke and Kumar [5]	• Proactive strategies • Advanced warning strategies • Coping strategies • Survival strategies
Tang [9]	• Postponement • Develop a strategic stock • Employ a flexible supplier base • Make and buy • Offer economic supply incentives • Flexible transportation • Revenue management via dynamic pricing • Assortment planning • Silent product rollover
Norrman and Jansson [10]	• Identify the risk • Assess the probability of risks • Assess the impact of risks • Develop strategies to implement before and after an incident

Table 2. Strategies to minimise the impact of catastrophic events on supply chain.

Norrman and Jansson [10] identified the requirement of action plan to ensure continued operations in case of a catastrophic event. Knemeyer et al. [1] proposed a proactive planning process for addressing catastrophic risks in supply chains. Researchers revealed that this method could help managers to identify key locations in their supply chain, systematically measure the risk of suffering catastrophic events at each key location and then select effective countermeasures to be adopted at selected key locations.

Stecke and Kumar [5] introduced the following four strategies to make supply chain components robust.

a. Proactive strategies—Help a company to avoid or decrease the impact of possible types of future disruptions.

b. Advanced warning strategies—Gain benefits from advance information (forecast) of a catastrophe.

c. Coping strategies—Flexibility and redundancy in various supply chain components to mitigate catastrophe.

d. Survival strategies—Aid companies to reduce losses and duration of disruptions.

Stecke and Kumar [5] stated that proactive strategies can help a company to avoid or decrease the possibility of certain types of disruptions. Researchers further emphasised that well-developed and implemented proactive strategies can reduce the need of mitigating strategies. Stecke and Kumar discussed strategies that can help in forecasting a catastrophe under the advanced warning strategies. The researchers highlighted that these advanced warning strategies can provide valuable preparation time to align its capabilities to minimise disruption effects or may allow complete prevention of a disruption. Flexibility and redundancy in various supply chain components help in defining coping strategies, which help to mitigate catastrophes [5]. A severe catastrophe and/or lack of proactive and coping strategies may result in supply chain breakdowns, which can make a company inoperative. Survival strategies can be used by companies in such situations [5]. Researchers confirm that survival strategies can be implemented in two stages: immediate response to a catastrophe (i.e. save life and property) and steps taken to recover (i.e. reorganise resources to restart supply chain operations).

Tang [9] described nine different robust supply chain strategies that aim to improve a firm's capability to manage supply and/or demand better under normal circumstance and to enhance a firm's capability to sustain its operation when a major disruption hits. The nine strategies include postponement, develop a strategic stock, employ a flexible supplier base, make and buy, offer economic supply incentives, flexible transportation, revenue management via dynamic pricing, assortment planning and silent product rollover. Tang [9] further stated that although robust supply chain strategies enable companies to deploy the corresponding contingency plans when disruption occur, these companies would become less vulnerable if they could reduce their exposure to risk. Hence, researchers proposed several possible ways to reduce the impact of disruption on the supply chain operations such as proactively form strategic alliances with other suppliers in different countries; reduce the lead time by redesigning the supply chain network and establish a recovery planning system to gain visibility of inventories, sales and shipments.

Gilbertson et al. [29] identified key factors to prevent or reduce catastrophic events in construction industry. The most effective control in reducing catastrophic events is the presence on site of knowledgeable, fully qualified, trained and competent individuals who could recognise and act upon any hazards. Another significant control is to be proactive about hazards, since many projects are complex, requiring effective teamwork, careful management and coordination. Other key controls identified by Gilbertson et al. [29] include managed interfaces, communication and cooperation and adequate resources (time and money). Researchers further confirmed that processes for diagnostic check on site as another key control factor. Most of the above controls play a significant role in minimising the impact of catastrophes [29].

In summary, the strategies developed by Stecke and Kumar [5], Tang [9] and Norrman and Jansson [10] minimise the impact of catastrophic events on supply chain in the manufacturing industry, while the strategies identified by Gilbertson and his co-workers [29] reduce the impact of catastrophic events on whole construction industry rather than construction supply chain. There is therefore a necessity to identify the strategies to minimise the impact of catastrophic events on CSC. Having considered the strategies identified by aforementioned authors, those of Stecke and Kumar [5] were used as a basis to develop a strategic framework to minimise the impact of catastrophic events on construction supply chains.

6. Research methodology

This section presents the methodology used to achieve the following objectives:

a. Identify likelihood and severity of catastrophic events and their level of risk on CSC.

b. Investigate the impact of catastrophic events on CSC and its performance.

c. Develop a strategic framework to minimise the impact of different catastrophes on CSC.

The research started with an extensive review of literature to develop a research framework to gather data for an empirical study. Different types of catastrophes affecting CSC, their impact and strategies to minimise the impact were initially identified using a literature review. The study then conducted a preliminary investigation with five construction industry experts to evaluate the applicability and suitability of literature findings to CSC context in order to develop a detailed questionnaire. Five construction project managers who have more than 20 years of experience in managing CSCs were interviewed during the preliminary investigation.

Subsequently, a research framework was developed for the empirical study incorporating the aforementioned three objectives, literature review findings and feedback given by experts during the preliminary investigation. The research framework is shown in **Figure 6**.

Catastrophic events, their impacts and impact minimisation strategies identified through literature review and preliminary investigation are summarised in **Figure 6**. Further, a detailed list of strategies identified under the aforementioned four different strategic dimensions is tabulated in **Table 3**.

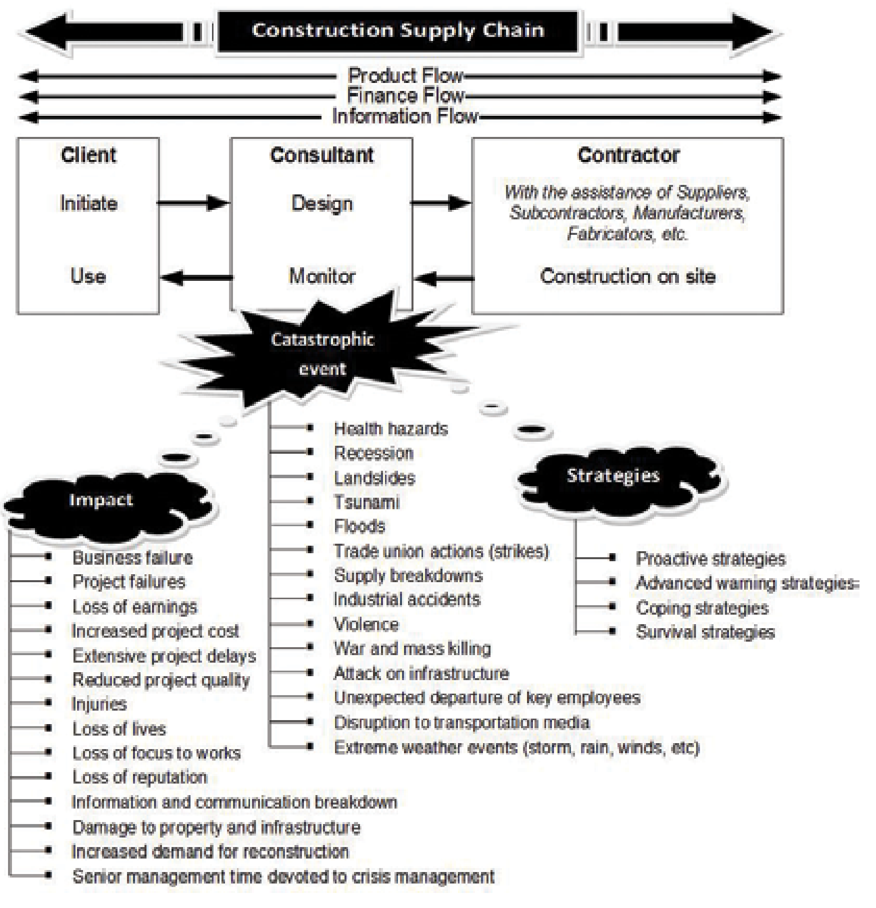

Figure 6. Research framework.

Above identified catastrophic events, impacts and strategies were used to develop a structured questionnaire for this study. The structured questionnaire was subsequently distributed among the construction industry experts in order to identify the likelihood and severity of the catastrophic events that disrupt CSC. The questionnaire survey was extended to identify significant impact of catastrophes and strategies that can be implemented to mitigate the impact of each identified catastrophes.

Construction industry experts were selected from among CS1 and CS2 grade contracting organisations in Sri Lanka, due to the complex nature of supply chain activities carried out by those companies. CS1 and CS2 are the two highest grades that can be achieved by a contractor according to the categorisation of Construction Industry Development Authority (CIDA), the regulating authority of construction in Sri Lanka. During the study, researchers requested assistance from the initial respondents to identify professionals with similar experience and/or expertise. The questionnaire was distributed among new respondents nominated by existing experts. Hence, snowball sampling method is used for this study. The questionnaires

Main strategies	Sub strategies
Proactive strategies	Identify and avoid vulnerable locations and threats Assess probabilities and impacts of risks Choose robust suppliers and manage communication and cooperation Enforce security Maintain efficient human resource management practices Maintain adequate and suitable resource base
Advanced warning strategies	Enhance visibility and coordination of supply chain Increase transportation visibility Monitor weather forecasts Monitor catastrophic trends (e.g., terrorist threat levels, strikes, recession) Monitor the progress of on-site processes
Coping strategies	Maintain flexible and alternate sourcing arrangement Choose flexible transportation Keep standardised and well-documented processes Insure against various risks Maintain redundant critical components
Survival strategies	Implement organisational emergency plans Maintain communications Keep control of the organisation at all times Identify needs to resume operations

Table 3. Strategies to minimise the impact of catastrophes on construction supply chain (adapted from [1, 5, 29]).

Designation	Number of questionnaires distributed	Number of responses received	Response rate (%)
Senior managers	7	7	100
Project managers	18	15	83.3
Planning engineers	6	6	100
Purchasing managers	4	4	100
Total	**35**	**32**	**91.4**

Table 4. Composition of participants.

were given to 35 construction industry experts and 32 responded. Composition of participants and their response rates are shown in **Table 4**.

The questions in the questionnaire were based on Likert scale format and mean weighted rating was calculated for each catastrophic event in order to identify the likelihood and severity level of catastrophic events. Furthermore, same calculation was conducted to investigate the significance of the impacts of catastrophes on CSC and to identify the strategies to mitigate the identified impact.

7. Research findings

The key findings of the survey are summarised in the discussion section, supplemented by a series of tables. Severity and likelihood of different catastrophic events that affect CSC are discussed first, followed by risk analysis of catastrophic events and the results pertaining to the impact of those events. Finally, strategies to minimise the identified impact are presented.

7.1. Likelihood of catastrophic events

All catastrophes do not pose the same type or amount of risk to CSC. For example, war may have severe consequences such as large number of human and facility losses, while a disruption to transportation media may only affect supplies. Catastrophes such as extreme weather events and landslides may have different consequences on CSC making it difficult for construction organisations to plan their projects to face different catastrophes. Therefore, identification of severity and likelihood of catastrophes may facilitate the construction project planning process.

First part of the questionnaire is focused on the identification of likelihood and severity of catastrophic events that threaten or disrupt the CSC. The likelihood and severity corresponds to "how likely" and "how much" a catastrophe might affect the CSC.

The questionnaire used Likert scale to receive the opinion of respondents regarding the likelihood of each catastrophic event that disrupts CSC. In the particular question, respondents were asked to give their opinion about the level of likelihood based on the scale that indicates most likely—4, very likely—3, somewhat likely—2, little likely—1 and unlikely—0. The data range of this five point Likert scale is 4. Therefore, the researcher set the cut-off point at intervals of length 4/5, which is 0.8. The new guide to indicate the likelihood of a catastrophic event is unlikely (0.00–0.80), little likely (0.81–1.60), somewhat likely (1.61–2.40), very likely (2.41–3.20) and most likely (3.21–4.0). Likelihood survey findings are given in **Table 5**.

Catastrophic event	Mean	p-value	Rank	Likelihood
Unexpected departure of key employees	3.094	1.000	1	Very
Floods	2.906	1.000	2	Very
Trade union actions (strikes)	2.719	1.000	3	Very
Disruption to transportation media	2.688	1.000	4	Very
Supply breakdowns	2.531	1.000	5	Very
Health hazards	2.250	0.946	6	Somewhat
Recession	2.250	0.946	6	Somewhat
Landslides	2.000	0.500	8	Somewhat
Tsunami	1.625	0.002	9	Somewhat
Extreme weather events (storm, rain, wind, etc.)	1.625	0.002	9	Somewhat
Industrial accidents	1.594	0.001	11	Little
Violence	1.531	0.000	12	Little
War and mass killing	1.406	0.000	13	Little
Attack on infrastructure	1.313	0.000	14	Little

Table 5. Likelihood of catastrophic events that disrupt construction supply chain.

http://dx.doi.org/10.5772/intechopen.79963

According to the survey findings given in **Table 5**, unexpected departure of key employees, floods, trade union actions, disruption to transportation media, supply breakdowns, health hazards, recession and landslides received p-values greater than 0.05. Therefore, the aforementioned catastrophic events are identified as likely catastrophic events that disrupt CSC. Most of the likely catastrophes that disrupt CSC are non-terrorist events, except disruption to transportation media. The most likely catastrophe that affects the CSC is unexpected departure of key employees followed by floods, trade union actions, disruption to transportation media and supply breakdowns. According to the ranking list, it is evident that terrorist events have very low likelihood to disrupt the CSC. Further to respondents, catastrophes such as violence, war and mass killing and attack on infrastructure are unlikely events in many countries.

7.2. Severity of catastrophic events

The survey used 1–5 Likert scale to get the respondents' opinions on the severity level of the identified catastrophic events. In the particular question, respondents were asked to give their opinion about the severity level based on the scale that depicts very high severity—5, high severity—4, average severity—3, little severity—2 and very little severity—1. This Likert scale has five severity levels and the range of the data is 4. In order to prepare a guide for indicating the severity of catastrophic events, the researchers set the cut-off point at intervals of 4/5, which is 0.8. Therefore, the severity of catastrophic events are categorised based on the guide as very little severity (1.00–1.80), little severity (1.81–2.60), average severity (2.61–3.40), high severity (3.41–4.20) and very high severity (4.21–5.00). Severity survey findings are given in **Table 6**.

Catastrophic event	Mean	p-value	Rank	Severity
Disruption to transportation media	4.406	1.000	1	Very high
War and mass killing	4.375	1.000	2	Very high
Attack on infrastructure	4.000	1.000	3	High
Tsunami	3.844	1.000	4	High
Supply breakdowns	3.719	1.000	5	High
Violence	3.656	1.000	6	High
Floods	3.625	1.000	7	High
Trade union actions (strikes)	3.625	1.000	7	High
Recession	3.563	1.000	9	High
Health hazards	3.188	0.882	10	Average
Unexpected departure of key employees	3.031	0.585	11	Average
Extreme weather events (storm, rain, wind, etc.)	2.938	0.380	12	Average
Landslides	2.844	0.096	13	Average
Industrial accidents	2.781	0.177	14	Average

Table 6. Severity of catastrophic events that disrupt construction supply chain.

All the p-values shown in **Table 6** are greater than 0.05. Therefore, all the catastrophic events that were identified from literature survey and preliminary investigation remained as severe catastrophic events that disrupt CSC. According to the ranking, terrorist events such as disruption to transportation media, war and mass killing and attack on infrastructure are moved to top of the list. It is obvious that those terrorist events have very high potential of disrupting the CSC than any other. Among the natural catastrophes, tsunami is the only catastrophe that has been selected as the severe catastrophe within the top five severe catastrophes. Industrial accident is the least severe catastrophic event that disrupts CSC.

7.3. Risk analysis of catastrophic events

Risk levels of aforementioned catastrophes are different due to the combined effect of likelihood and severity of the event. Risk analysis matrix is a way to focus managerial attention on the high priority catastrophic events that have a high possibility to occur and a high severity, if disrupt construction supply chain. The study used risk analysis matrix introduced by Scottish Government under the NHS Scotland Model for Organisational Risk Management as shown in **Figure 7** to analyse the combined effect of likelihood and severity of catastrophic events.

Table 7 shows the aggregate effect of severity and likelihood of catastrophes. This table helps to identify the risk level of each catastrophic event on CSC. The risk analysis matrix identifies suitable actions to mitigate the impact of a catastrophe based on the risk level of a catastrophe.

When comparing the rankings of likelihood and severity, it is obvious that catastrophes which have high severity are not all the time likely catastrophes that disrupt the CSC. For an example, although war and mass killing, tsunami and recession ranked among highly severe catastrophes, they are little/somewhat likely catastrophes that disrupt the CSC. According to **Table 7**, disruption to transportation media has an extreme risk level on CSC. Supply breakdown, trade union actions, floods, war and mass killing, tsunami, recession and unexpected departure of key employees have high risk level on CSC, where all the other catastrophes have medium risk level. Key catastrophes that require managerial attention are the events that ranked top of both the

	SEVERITY				
	Very Little	Little	Average	High	Very High
Most Likely	Medium	High	High	Extreme	Extreme
Very Likely	Medium	Medium	High	High	Extreme
Somewhat Likely	Low	Medium	Medium	High	High
Little Likely	Low	Medium	Medium	Medium	High
Unlikely	Low	Low	Low	Medium	Medium

Figure 7. Risk analysis matrix (source: [34]).

Event	Likelihood	Severity	Risk level
Disruption to transportation media	Very	Very high	Extreme
Supply breakdowns	Very	High	High
Trade union actions (strikes)	Very	High	High
Flood	Very	High	High
War and mass killing	Little	Very high	High
Tsunami	Somewhat	High	High
Recession	Somewhat	High	High
Unexpected departure of key employees	Very	Average	High
Health hazards	Somewhat	Average	Medium
Extreme weather event (storm, rain, wind, etc.)	Somewhat	Average	Medium
Landslides	Somewhat	Average	Medium
Violence	Little	High	Medium
Attack on infrastructure	Little	High	Medium
Industrial accidents	Little	Average	Medium

Table 7. Risk analysis matrix for catastrophes.

catastrophes, which are likely to disrupt a CSC and have a severe impact. Stecke and Kumar [5] established this idea by stating that managers should focus on mitigating catastrophes that have a high possibility and severity of affecting critical components of a supply chain. Nevertheless, it does not mean that management should not look into other catastrophic events.

7.4. Impact of catastrophic events on construction supply chain

The second objective of this research is to investigate the impact of catastrophic events on CSC. Respondents' opinions regarding the significance of the impacts of catastrophic events were collected using the 0–4 Likert scale. Survey findings are given in **Table 8**.

According to **Table 8**, all p-values are greater than 0.05, except for two impacts, that is, information and communication breakdown and injuries, which are not significant. Therefore, all the other impacts that were identified from the literature survey and preliminary investigation have significant effect on CSC. The highest significant impact that could make by a catastrophic event is a business failure followed by loss of earnings and extensive project delays.

According to **Table 8**, the impacts of catastrophic events on CSC are not only limited to financial losses. The other impacts such as senior management time devoted to crisis management, damage to property and infrastructure, increased demand for reconstruction, reduced product quality and loss of reputation are identified as significant impacts on CSC. This confirms the findings of Cousins et al. [32], where they concluded that wider consequences of a failure to manage catastrophe risks not only include financial losses.

Impact	Mean	p-value	Rank
Business failure	3.031	1.000	1
Loss of earnings	2.906	1.000	2
Extensive project delays	2.875	1.000	3
Project failures	2.875	1.000	4
Senior management time devoted to crisis management	2.781	1.000	5
Damage to property and infrastructure	2.688	1.000	6
Increased project cost	2.625	1.000	7
Increase demand for reconstruction	2.594	0.998	8
Reduced project quality	2.500	0.999	9
Loss of lives	2.406	1.000	10
Loss of reputation	2.156	0.904	11
Loss of focus to work	2.156	0.904	12
Information and communication breakdown	1.688	0.012	13
Injuries	1.438	0.000	14

Table 8. Impact of catastrophic events on construction supply chain.

7.5. Strategic framework to minimise the impact of catastrophic events on CSC

The last objective of this research is to investigate strategies and develop a framework with actions to successfully face catastrophic events to minimise their impact on CSC. The impact of catastrophes can mitigate using different strategies. Therefore, construction organisations must concentrate on different strategies to overcome the impact of different catastrophes on their supply chain. In order to develop a strategic framework, the respondents were asked to give their opinion about the effective level of each identified strategy to minimise the impact of each identified catastrophic event. Responses were based on the scale of 0—4 where 0 is very low/no effect and 4 is very high effect, and the results are given in **Table 9**.

In preparation of strategic framework to indicate the effectiveness of a strategy, the researcher set the cut-off point at intervals of length 4/5, which is 0.8. The guide to effectiveness of a strategy is very low/no effect (0.00–0.80), low effect (0.81–1.60), medium effect (1.61–2.40), high effect (2.41–3.20) and very high effect (3.21–4.00). The strategic framework developed to minimise the impact of each identified catastrophic event on CSC is shown in **Table 10**.

Depending on the type and nature of catastrophe that a company faces, managers in the construction organisations can use the findings summarised in **Table 10** as a guide to choose strategies that best fit their needs to minimise the impact of those catastrophic events on CSC. For an example, construction organisations can adopt strategies such as enhancing visibility and coordination of CSC, maintaining flexible and alternative sourcing arrangements and identification of needs to resume operations to minimise the impact of disruption to transport media caused by catastrophes on CSC. Further, construction organisations can implement (a) proactive strategies such as maintain adequate and suitable resource base, (b) advanced warning strategies such as enhance visibility and coordination of supply chain, (c) coping strategies such as maintain flexibility and alternate sourcing arrangement and maintain redundant critical components and (d) survival strategies such as identify needs to resume operations to minimise the impact of catastrophes on construction supply breakdowns.

Construction organisations can further strengthen their CSCs with advanced warning strategies such as monitoring weather forecasts on extreme weather events, floods, landslides and tsunami to successfully face disasters or minimise the post disaster impact on CSC. As coping strategies, this study highly recommends the construction organisations to obtain insurance policies to minimise the impact of catastrophes such as attack on infrastructure, war and mass killing, violence, tsunami, extreme weather events, floods, landslides and industrial accidents and to recover quickly the aftermath of disasters. Further, advanced identification of basic needs to resume construction operations aftermath of a disaster can be recognised as a highly effective survival strategy, which construction organisations must concentrate in order to successfully commence their businesses after catastrophes.

Strategies	Catastrophic Events													
	Attack on infrastructure	War and mass killing	Violence	Disruption to transportation media	Health hazards	Tsunami	Extreme weather events	Floods	Landslides	Industrial accidents	Trade union actions	Recession	Supply breakdown	Unexpected departure of key employees
Identify and avoid vulnerable locations and threats	2.50	3.13	3.00	2.25	2.50	2.50	1.75	2.50	3.50	2.50	1.06	1.28	2.25	1.69
Assess possibilities and impacts of risks	2.75	2.00	2.00	1.75	1.75	1.50	1.25	1.50	0.75	1.25	1.59	1.75	2.28	1.78
Choose robust suppliers & manage communication & corporation	1.75	1.75	1.75	2.00	0.63	1.25	1.06	0.41	0.25	1.06	2.00	1.75	2.06	2.00
Enforce security	3.25	2.75	3.38	1.25	0.13	0.19	0.16	0.16	0.13	1.25	1.50	0.13	0.16	0.16
Maintain efficient human resource management practices	0.28	0.16	0.72	0.13	2.00	0.09	0.25	0.25	0.22	0.59	3.28	0.53	0.28	3.63
Maintain adequate and suitable resource base	1.81	0.31	0.22	1.75	1.94	0.94	0.75	0.53	0.41	1.28	2.00	3.00	3.25	2.63
Enhance visibility and coordination in a supply chain	0.13	0.19	0.22	3.38	0.38	0.19	0.19	0.19	0.16	0.19	0.16	0.19	3.75	0.16
Increase transportation visibility	0.00	0.00	0.00	2.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.06	0.00
Monitor weather forecasts	0.00	0.00	0.00	0.38	0.91	3.66	3.81	4.00	3.09	0.00	0.00	0.00	1.25	0.00
Monitor catastrophic trends	0.00	0.00	0.00	1.22	0.00	0.00	0.00	0.00	0.00	0.00	0.38	1.50	1.68	0.75
Monitor the progress of on-site processes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.09	1.38	0.16	1.50	0.47
Maintain flexible and alternate sourcing arrangement	2.34	1.75	1.75	3.25	3.75	1.25	1.59	1.59	1.25	1.75	3.63	2.19	3.84	3.84
Choose flexible transportation	0.25	0.97	0.41	3.03	0.09	0.66	0.50	1.06	1.00	0.25	0.00	0.00	2.59	0.00
Keep standardised and well documented processes	1.00	0.75	0.75	2.72	2.00	0.41	0.50	0.38	0.25	1.75	1.25	1.25	1.47	2.50
Insure against various risks	3.75	3.78	3.72	1.63	2.75	3.78	3.78	3.78	3.75	3.75	1.16	0.75	1.50	0.03
Maintain redundant critical components	1.31	0.00	0.00	3.72	1.06	0.00	0.00	0.06	0.00	0.91	2.31	2.00	3.88	1.13
Implement organisational emergency plans	2.75	2.88	2.63	1.75	2.50	2.25	2.16	2.47	2.22	3.00	2.84	1.91	2.56	2.44
Maintain communications	2.81	2.50	2.50	1.66	0.34	2.75	2.06	2.56	1.72	1.66	1.25	1.38	1.69	1.25
Keep control of the organisation at all times	0.25	0.50	0.53	1.75	1.50	0.44	0.44	0.44	0.41	3.00	3.25	1.81	2.25	3.41
Identify needs to resume operations	2.25	3.47	3.31	3.25	3.41	3.59	3.47	3.56	3.28	3.88	3.88	3.09	3.41	2.84

Table 9. Mean values of effectiveness of the strategies to mitigate the impact of catastrophic event on construction supply chain.

			Catastrophic events													
			Attack on infrastructure	**War and mass killing**	**Violence**	**Disruption to transportation media**	**Health hazards**	**Tsunami**	**Extreme weather events**	**Floods**	**Landslides**	**Industrial accidents**	**Trade union actions**	**Recession**	**Supply breakdown**	**Unexpected departure of key employees**
Strategies	Proactive strategies	Identify and avoid vulnerable locations and threats	H	H	H	M	H	H	M	H	VH	H	L	L	M	M
		Assess possibilities and impacts of risks	H	M	M	M	M	L	L	L	VL	L	L	M	M	M
		Choose robust suppliers & manage communication & corporation	M	M	M	M	VL	L	L	VL	VL	L	M	M	M	M
		Enforce security	VH	H	VH	L	VL	VL	VL	VL	VL	L	L	VL	VL	VL
		Maintain efficient human resource management practices	VL	VL	VL	VL	M	VL	VL	VL	VL	VL	VH	VL	VL	VH
		Maintain adequate and suitable resource base	M	VL	VL	M	M	L	VL	VL	VL	L	M	H	VH	H
	Advanced warning strategies	Enhance visibility and coordination of supply chain	VL	VL	VL	VH	VL	VL	VL	VL	VL	VL	VL	VL	VH	VL
		Increase transportation visibility	VL	VL	VL	H	VL	VL	VL	VL	VL	VL	VL	VL	M	VL
		Monitor weather forecasts	VL	VL	VL	VL	L	VH	VH	VH	H	VL	VL	VL	L	VL
		Monitor catastrophic trends	VL	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	L	M	VL
		Monitor the progress of on-site processes	VL	VL	VL	VL	VL	VL	VL	VL	VL	M	L	VL	L	VL

http://dx.doi.org/10.5772/intechopen.79963

		Catastrophic events													
		Attack on infrastructure	War and mass killing	Violence	Disruption to transportation media	Health hazards	Tsunami	Extreme weather events	Floods	Landslides	Industrial accidents	Trade union actions	Recession	Supply breakdown	Unexpected departure of key employees
Coping strategies	Maintain flexible and alternate sourcing arrangement	M	M	M	VH	VH	L	L	L	L	M	VH	M	VH	VH
	Choose flexible transportation	VL	L	VL	H	VL	VL	VL	L	L	VL	VL	VL	H	VL
	Keep standardised and well-documented processes	L	VL	VL	H	M	VL	VL	VL	VL	M	L	L	L	H
	Insure against various risks	VH	VH	VH	M	H	VH	VH	VH	VH	VH	L	VL	L	VL
	Maintain redundant critical components	L	VL	VL	VH	L	VL	VL	VL	VL	L	M	M	VH	L
Survival strategies	Implement organisational emergency plans	H	H	H	M	H	M	M	H	M	H	H	M	H	H
	Maintain communications	H	H	H	M	VL	H	M	H	M	M	L	L	M	L
	Keep control of the organisation at all times	VL	VL	VL	M	L	VL	VL	VL	VL	H	VH	M	M	VH
	Identify needs to resume operations	M	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH	H	VH	H

Effectiveness guide: Very low/no effect (VL), low effect (L), medium effect (M), high effect (H), and very high effect (VH).

Table 10. Strategic framework to minimise the impact of catastrophic event on construction supply chain.

8. Conclusions and recommendations

Catastrophic events are unique among other supply chain risks due to low probability of occurrence, difficulty in prediction and severity of impact. Vulnerability of CSC for various types of catastrophic events has been substantiated in the literature.

Majority of the catastrophes, which were ranked among the most likely catastrophes to disrupt CSC, are non-terrorist events. Findings corroborated the fact that most likely catastrophes to disrupt the CSC are not always the most severe catastrophes. Among the likely catastrophes, unexpected departure of key employees in construction organisations was identified as the most likely catastrophic event to disrupt CSC, and disruption of transportation media was identified as the most severe catastrophic event, which has high impact on CSC. The aggregate effect of likelihood and severity revealed that disruption to transportation media has the extreme risk level on CSC, whereas violence, attack on infrastructure and industrial accidents have medium risk level. All the other catastrophes have high risk level on CSC.

The study further identified that the impact of such catastrophes is highly diverse and has different effects on CSC performance. According to the findings, the most significant impact of catastrophic events is a business failure and least significant impact is loss of focus to work.

The research finally established the need to implement strategies not only after catastrophe occurs but also before the catastrophe in order to avoid severe consequences on construction organisations. This chapter hence presented the strategic framework developed with four strategic dimensions: (a) proactive strategies, (b) advanced warning strategies, (c) coping strategies and (d) survival strategies in order to minimise the impact of each identified catastrophic event on CSC of construction organisations. The catastrophic event risk minimisation strategic framework developed in this study would be useful for construction organisations to identify suitable strategic actions according to the risk level that they faced. The organisations in construction industry can use the proposed strategic framework to minimise the impact of future catastrophic events on CSC for creating resilient construction industry.

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Risk Management in Indonesia Construction Project: A Case Study of a Toll Road Project

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79457

Abstract

While project risks are generally acknowledged merely from owner and contractor perspectives, other parties also play important roles in the project. The aim of this study is to analyze the application of risk management in the toll road project from stakeholders' perception, such as contractor, owner, design consultant, supervisory consultant, and community surrounding the project. Data of risk factors were collected through interviews with each stakeholder, including the probability of occurrence and their impacts. Risk Breakdown Structure (RBS) has been adapted to breakdown project risks from various stakeholders. Risk level of each risk factor is obtained by multiplying the probability and the impact. The overall results of risk analysis show various risks as perceived by each stakeholder due to different roles and interests in the project. This research provides an understanding of how project risks need to be fully comprehended for the success of the project.

Keywords: risk management, construction risk, project stakeholders, risk breakdown structure, toll road project

1. Introduction

Indonesia's economic growth continues showing improvement over the last 9 years (2009–2017 period) with the latest rate of 5.05% in 2017. One of the challenges faced in escalating Indonesia's economic growth and improving economic competitiveness is the development of infrastructure. The rapid infrastructure development has been running in various sectors, from energy systems, road transport, office buildings and schools, telecommunications, and water supply networks, all of which require reliable infrastructure support [1].

Risks are closely linked to infrastructure projects, and toll road projects are no exception. Risk is a consequence of an uncertain condition which quite often cannot be predicted accurately. It is therefore necessary to have risk management from the beginning of the construction project, to reduce the impact of possible risks. PMBOK Guide 5th edition (2013) describes the stages of risk management, that is, risk identification, risk analysis, risk response, risk monitoring, and control.

Risks in construction projects are actually borne by many parties that involved in the project. Generally, risks are identified just from the owner and contractors perspectives; however, some other parties are also involved in the project. The aim of this study is to analyze the application of risk management in the toll road project from stakeholders' perception, such as contractor, owner, design consultant, supervisory consultant, and community surrounding the project.

2. Reviewing risk management framework

2.1. Risk management at construction project

Risks of the project can be defined as an elaboration of unfortunate consequences, both of finance and structure of project, as a result of decisions taken or due to environmental conditions on the project location. Risks in construction projects are the matter that cannot be eliminated, but their impact can be minimized [2].

A construction project is unique, specific, and dynamic, and therefore projects have different levels and combinations of risks, hence different responses are taken to minimize those risks and different consequences affect the project performance. Risk categories in building projects

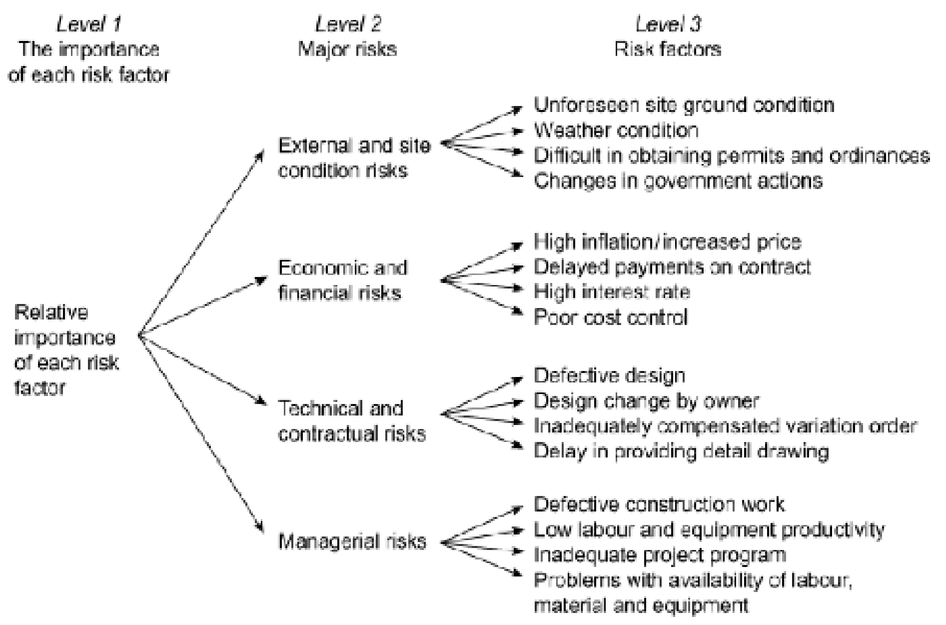

Figure 1. Hierarchy of risk at building project in Indonesia. Source: Wiguna and Scott [3].

are external risks, economic and financial risks, technical and contractual risks, and managerial risk [3]. This risk identification can be seen in **Figure 1**.

It is important to manage the multifaceted risks associated with international construction projects, in particular in developing countries, not only to secure work but also to make profit [4]. To effectively manage risks in construction projects, it is crucial to correctly identify the important risks and properly allocate them to the contractual parties. Stakeholders' perceptions of risk vary due to different interests in the project [5].

Figure 1 shows risk category and risk identification on a construction project. Risks are identified in each risk category. The risk category in the construction project can be within the scope of financial risk, time risk, physical risk, personnel risk, design and technical risk, contractual risk, political and regulation risk, and safety risk [6]. The risk categories for construction projects are determined based on several considerations, including the types of construction works, the parties involved, the construction methods, the project resources, the construction issues, and others.

2.2. Risk management of toll road projects

Basically, risk management of toll road projects goes through several stages such as risk identification, risk analysis, and risk response. What distinguishes toll road projects from other projects is the identified risks. Risks will vary depending on the stakeholders' perceptions on the project.

The identified risk on toll road construction projects was [7]:

2.2.1. Major risk

- Traffic risk: traffic during the construction process. Inconvenience for the commuters to travel.
- Toll risk: due to the lower traffic density, the collection of toll reduced. Toll risk lead to the failure in recovery of construction cost. Total construction cost increased.
- Constructional risk: the project is to be completed in certain costs and time, hence the risk in the increase of material cost increased.
- Operational and maintenance risk: due to the delays of the project, the operational and maintenance cost increased which affected the commencement of operation to cover the estimated maintenance expenditure.
- Land acquisition: delay in the project due to land acquisition lead to increase in the estimated construction cost.

2.2.2. Minor risks

- Utilities: nonavailability of fuel, electricity, and utilities not relocated on time causing delays to some works.

- Noise: repetitive, excessive noise causes long-term hearing problems in labour and can be a dangerous distraction.
- Material and manual handling: materials and equipment are being constantly lifted and moved around on a construction site, whether manually or by the use of lifting equipment. Different trades will involve greater demands, but all may involve some degree of risks.

The risks of toll road projects in Indonesia from the perception of owners are categorized into seven categories as below [8]:

a. Political risks, such as discontinuation of concession, tax increase, inappropriate tariff implementation, inappropriate tariff increase, new government policy enforcement, etc.

b. Construction risks, such as inappropriate design, land acquisition, project delay, project site condition, contractor's failure, etc.

c. Operation and maintenance risks, such as toll network condition, operator's incompetence, construction quality, etc.

d. Legal and contractual risks, such as concession time warranty, flawed/inconsistent contract document, etc.

e. Income risks, such as inaccurate traffic volume estimate, inaccurate toll tariff estimate, construction of a competing alternative road, etc.

f. Financial risks, such as inflation, devaluation, interest rate, changes in monetary policies, limited capital, etc.

g. Force major, such as weather condition, war, natural disasters, etc.

Risks of toll road projects will be different when viewed from different stakeholder perspectives. From the investor point of view, the most risk in toll road projects is related to land acquisition. Other major risks are related to government policy [9].

2.3. Concepts of risk and risk management

The risk arises because of the uncertainty of an event that has not happened yet. In such an uncertainty, risk will always be inversely proportional to profit. Uncertainty can usually increase the risk factors that can be seen from potential occurrence of an undesirable negative state of an event [10]. In many cases, the greater the likelihood of risk, the greater the likelihood of profit. But there are also some cases where the level of risk is small, but the likelihood of profits is great. The ability to understand one's risks and benefits is not always the same will depend on the experience and knowledge.

Analyzing risk is an important thing in a business. In construction, risks can be seen in every aspect of the job, such as work location, resources, or project execution schedule [11]. Risk analysis aims to determine from the beginning of the possibility of losses and benefits.

Risk management can be defined as the identification, measurement, and control of the economic perspective of the risks that threaten the assets and income. Risk management aims to identify the source of risk and uncertainty, determine its influence and determine its response appropriately. The goal of risk management is not just to reduce risk. Risk management can be used by a decision maker in estimating risks and benefits that can turn a risk into a large income. The risk management divided into five stages, that is, risk classification, risk identification, data elicitation, risk analysis, and risk response [10].

In the book, A Guide to The Project Management of Body of Knowledge 5th edition, a more detailed description of the risk management process consists of more than five steps as shown in **Figure 2**. In the following diagram, it is shown that the risk management process consists of six stages, that is, risk management planning, risk identification, risk analysis that divided into

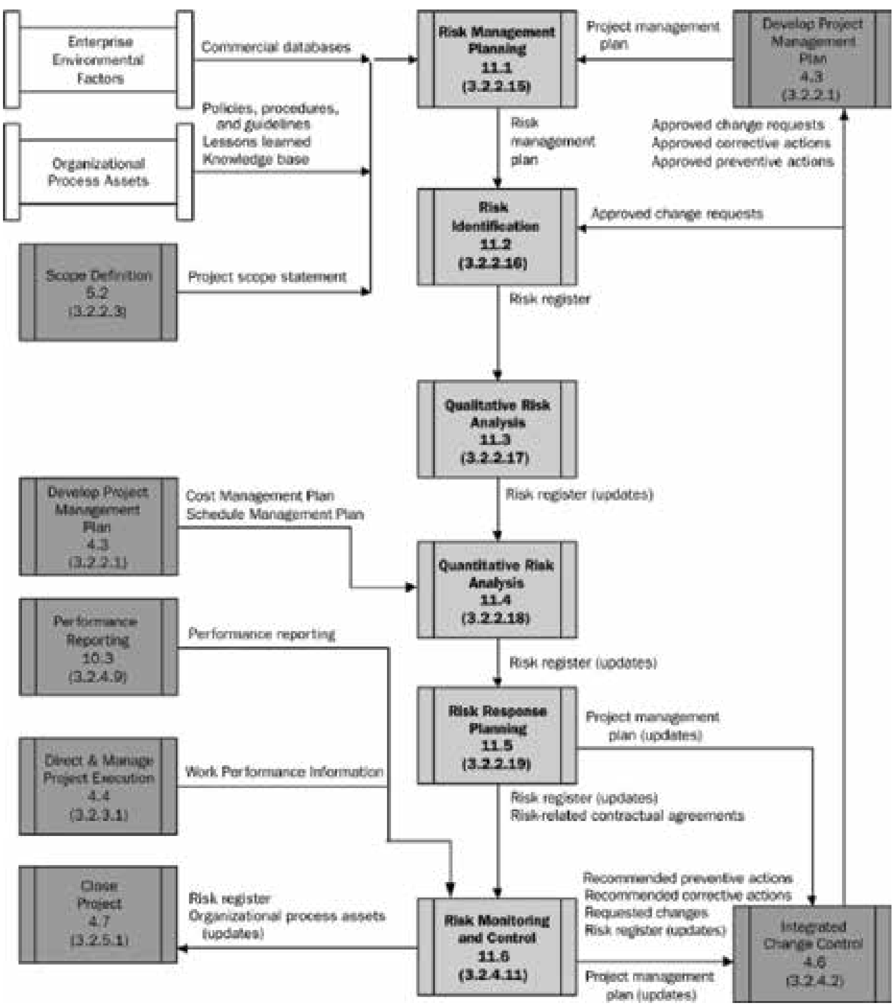

Figure 2. Step of risk management. Source: PMBOK 5th edition, 2013.

two: quantitative analysis and qualitative analysis, risk management action planning, and supervision and control.

Another simple, common and systematic approach to risk management is suggested by Berkely and others [11]. Risk management has four distinct stages: (a) risk classification, (b) risk identification, (c) risk assessment, and (d) risk response. In the first stage, risks should be classified into different groups with certain criteria in order to clarify the relationships between them. The second stage entails the identification of the risks pertaining to risk management. The third stage is to assess and evaluate the effects of these risks. In the final stage, appropriate risk response policies should be developed to reduce and control the risks.

3. Research method

The object of this research is Semarang-Solo toll road Section I in Indonesia. In this case, the risk perceptions of the stakeholders are from contractors, owners, design consultant, supervisory consultants, and community surrounding the project. Differences in stakeholders' perspective on the project and the different interests in the project lead to differing views on project risks.

Primary data were collected by interviews and questionnaire surveys. Primary data were the identification risk and also the impact and probability risk from all stakeholders. The questionnaires were distributed to all five stakeholders. From contractor side, the respondents were the general superintendent, deputy project manager, construction manager, and project engineering manager of the project. From owner side, the respondents were the chairman of the control section 1, the chairman of the control section 2, and the chairman of the control section 3. From design consultant side, the respondents were the team leader project and the expert in the case study project (two person). From the supervisory consultant, the respondents were resident engineer, quantity engineer, soil material engineer, and chief inspector. From the community around the project, the respondents were the urban village heads (two persons) and the proxy of community (two persons). All respondents are decision makers who are directly involved in this case study project and have a lot of work experience.

Secondary data were obtained from the data collection conducted by other study, for example, reference books, magazine articles, and journals related to the topic of study. The secondary data were the toll road technical document, project document, and risk management that will generate output risk and its response to the construction of toll road development.

The method of data processing used risk breakdown structure as described in **Figure 3**.

3.1. Risk management model

A Management Model is simply the set of choices made by executives about how the work of management gets done about how they define objectives, motivate effort, coordinate activities, and allocate resources [7]:

Level 1: planning.

Level 2: risk identification.

Level 3: risk analysis.

Level 4: mitigation.

3.2. Planning

Planning is the first step of any project which includes planning, organizing and controlling, and execution of the project. Project planning is the function in which project and construction managers and their key staff members prepare the master plan. Then this master plan is put into time schedule by scheduling people which is later called project scheduling. Project planning and project scheduling are two separate and distinct functions of the project management. A project planning is mostly responsible for the success or failure of the project, therefore planning of the project should be done very carefully and under expert advice [7].

3.3. Risk identification

The most important step in risk management is to identify the risks involved. The overall risks must be identified to be able to analyze and know the risk response that will be taken. Decision

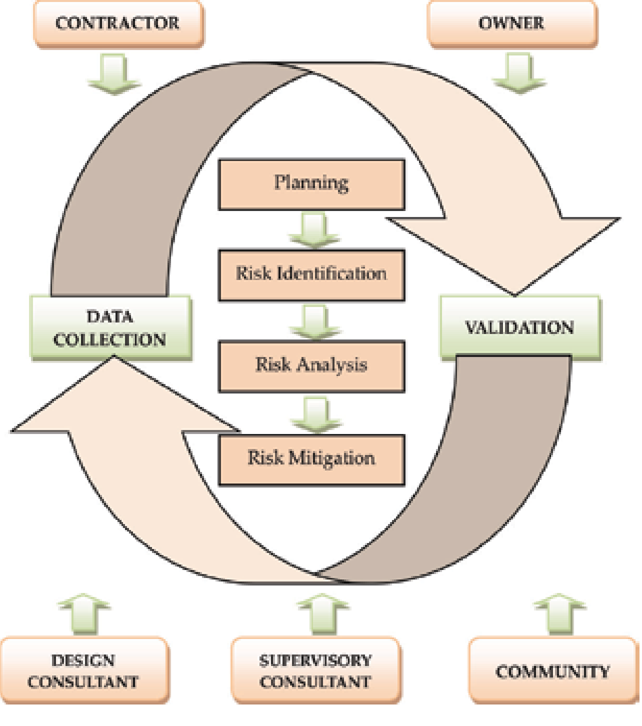

Figure 3. Data processing methods.

makers believe that the most important advantage in risk management is to identify it rather than analyzing it [10]. According to the book, A Guide to the Project Management Body of Knowledge (PMBOK), the steps in the risk identification are document review, information gathering technique, checklist analysis, assumption analysis, and diagram engineering.

3.4. Risk analysis

PMBOK (2013) mentions that in the risk analysis, there are often used methods such as risk probability and risk impact assessment. Estimating possible risk investigates the possibility of occurrence of some specific risk, and estimating the risk impact investigates the potential effects of a project that may affect the project's objectives such as time, quality, price, and scope of work which include both negative and positive impacts. Risk probability and risk impact are used to calculate the risk level of risks. Risk level is calculated using Eq. (1) [11].

$$\text{Risk level} = \text{Risk probability} \times \text{Risk impact} \tag{1}$$

Risks are ordered based on the multiplication of frequency and impact scales, composed from the largest to the smallest. To quantify the values of the risk probability and risk impact, a scale of 1–5 representing low to high probability and impact is used.

3.5. Risk mitigation

Risk response planning is a process of developing options and determining the most effective actions to increase the opportunity and reduce the risk from the negative effect. The types of response to risk can be divided into four, that is, risk avoidance, by altering the project plan to eliminate risks or conditions or to protect the project objectives from the effects/consequences; risk transfer, by seeking the exchange of consequences or risk effects to third parties together with the ownership of the response; risk mitigation, conducting investigations to reduce the probability and/or consequences of adverse risk events to acceptable levels; and risk acceptance, shows that the project team decides not to change the project plan or is unable to identify other appropriate response strategies.

4. Risk identification

The case study in this study is the Semarang-Solo Section I toll road project in Indonesia with the following project details:

- Rigid pavement 4/2 along 3.525 m
- Three main bridges
- Six box culverts
- Four overpass
- Toll facilities and plaza toll

Risk categories	Risk from contractor's perception	Risk from owner's perception	Risk from society's perception	Risk from design consultant's perception	Risk from supervisory consultant's perception
Economic risk	• Loss of costs due to job repairs left by subcontractors • Increase in the price of iron units of concrete		• Payment of land acquisition stagnating • The presence of brokers on land acquisition process • The price of compensation for land acquisition is not suitable • Livelihoods change/disappear • Decrease in value/price of land/house investment due to adjacent to toll road	• Late payment • Changes in interest rates • Monetary policy changes	• Contractor completes the job before the contract expires
Contract and legal risks	• Liquidated damages of 1 per mile per day, no maximum limit • Abandonment of funds due to no date of maintenance guarantee returns, maintenance period of 3 years • Extended Performance Guarantee		• The process of socialization of land acquisition is not according to the regulation • No feasibility study of EIA (Environmental Impact Analysis) • Violation of environmental laws and regulations • Violation of legislation on land acquisition	• Inconsistency of contract documents • Late of completion of planning	
Construction risk	• Work is late • Bored Pile meets the bolder layer and instructs the consultant to proceed • Work path collapsed • Theft may occur at the location of the box culvert and overpass	• Land acquisition is late • Increase in land procurement costs • Late of procurement of review design consultants • Inaccuracy and lack of existing utility data	• Road becomes dirty • Pavement in this area becomes damaged • Some walls of the house become cracked • Accidents due to project vehicles and project activities	• Primary data and secondary data are inadequate • The quality of personnel does not meet the standards • Difficult access to location planning	• Improper design from design consultant • Project delays • Conditions in the project do not support

Risk categories	Risk from contractor's perception	Risk from owner's perception	Risk from society's perception	Risk from design consultant's perception	Risk from supervisory consultant's perception
	• Over material class B2 on ready-mix	• The results of the initial study (engineering, environment) is less accurate • Procurement of supervisory contractors/consultants is late • The quality of the winning supervising contractor/consultant is not as expected • Quality of material does not conform to specifications • Contractor claims for additional fees beyond the contract • Design not in accordance with the conditions and or incomplete • Flooding and environmental disturbance due to lack of handling of temporary drainage and construction methods during construction • Unavailability of construction material • Inaccurate quantity estimates • Increase in construction costs • The flatness and hardness of the pavement surface does not meet the SPM	• Air pollution caused by construction dust (influence on health) • Disruption of activity/accessibility due to project (road closure, route transfer)	• Error of price estimates for bidding • The results of planning are considered less compatible with conditions in the project • The planning completion time is too short	• Construction failure • Contractor works not in correct procedures • Unavailability of PPE (Personal Protective Equipment) • Uncooperative owner
Risk of income		• Not achieving the volume of traffic • Delay of tariff increase			
Risk of operation and maintenance		• Increased operating and maintenance costs are not appropriate to business plan			

Risk categories	Risk from contractor's perception	Risk from owner's perception	Risk from society's perception	Risk from design consultant's perception	Risk from supervisory consultant's perception
Political risk		• Decrease in performance due to changes in government policy		• Changes in wisdom • Changes in government structure • Increase in taxes (related to project cost estimates)	• Changes in policies/regulations • Changes in government structure • Changes in position/organizational structure of owner
Social risk			• Residence changed/moved • Separate/disconnected access road residents due to toll road projects • Noise/disruption of life due to vehicles on toll roads during the operation of toll roads		
Force majeure risk				• Weather conditions during the survey	• Weather conditions during construction

Table 1. Risk identification of Semarang-Solo Section I toll road project.

Particular attention to this project construction is the three major bridges where the land has hilly contours, while the bridge structure has a high pillar (up to 54 m), which in its execution requires special resources (formwork pillar with jump form system and slip form, support system for pier head formwork, and girder launching unit for erection girder job). The geographic and hydrological conditions of Semarang city with high rainfall and unfinished land acquisition conditions are challenges that must be addressed with careful planning and implementation, so that projects can be completed on time, meeting quality requirements, and within the budget.

Risk identification on toll road projects is divided into categories according to stakeholder interests in the project. Risk in the toll road project is divided into four, that is, planning phase, land acquisition phase, operation and maintenance phase, and redelivery phase. The most significant risk is in the phase of land acquisition [12].

Risk perceptions of each stakeholder will differ due to the different interests within the project. **Table 1** presents the results of interviews in the identification of risks from different stakeholders in this project. The identification of risk from the perception of contractor, owner, community surrounding the project, design consultant, and supervisory consultant are divided into eight risk categories. The risk categories are economic risk, contract and legal risks, construction risk, risk of income, risk of operation and maintenance, political risk, social risk, and force majeure risk. Risk identification was carried out for each risk category. Each stakeholder carries different categories of risk, depending on the interests of stakeholders in the project.

Risks as viewed from contractor's perception were risk at economic risk, contract and legal risks, and construction risk. Risks from owner's perception include risk at construction risk, risk of income, risk of operation and maintenance, and political risk. Risks from local community's perception were economic risk, contract and legal risks, construction risk, and social risk. Risks from design consultant's perception were economic risk, contract and legal risks, construction risk, political risk, and force majeure risk. Risks from supervisory consultant's perception were economic risk, construction risk, political risk, and force majeure risk. From this risk identification of each stakeholder, it can be seen that stakeholders have their own risk characteristics, for example, risk of income is only relevant for the owner, and social risk only exist in the community surrounding the project.

5. Risk analysis

Risk analysis was done using risk breakdown structure method. Risk level was obtained by multiplication between the risk probability and risk impacts. The results of the risk analysis suggest that the rank of risks from each stakeholder varies, as shown in **Table 2**.

Table 2 shows the risk priority of each stakeholder. It can be seen that for all stakeholders, the highest rank of risks is within the construction risk. For the contractor, the most significant risk is the job delay. For owner, the most risk is the delay of land acquisition. For local community surrounding the project, the most significant risk is the risk of having pavement in that area

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Rank of risk	Risk from contractor's perception		Risk from owner's perception		Risk from society's perception		Risk from design consultant's perception		Risk from supervisory consultant's perception	
	Risk	**Risk level**	**Risk**	**Risk level**	**Risk**	**Risk level**	**Risk**	**Risk level**	**Risk**	**Risk level**
1	Work is late	15	Land acquisition is late	20	Pavement in this area becomes damaged	15	Error of price estimates for bidding	8	Improper design from design consultant	18
2	Liquidated damages of 1 per mile per day, no maximum limit	15	Increase in land procurement costs	20	Air pollution caused by construction dust (influence on health)	14	Changes in interest rates	8	Project delays	15
3	Increase in the price of iron units of concrete	15	Increase in construction costs	16	Road becomes dirty	12	Late of completion of planning	5	Weather conditions during construction	11
4	Bored Pile meets the bolder layer and instructs the consultant to proceed	9	Contractor claims for additional fees beyond the contract	12	Noise/disruption of life due to vehicles on toll roads during the operation of toll roads	11.25	Late payment	5	Conditions in the project do not support	8
5	Work path collapsed	6	Not achieving the volume of traffic	12	No feasibility study of EIA (Environmental Impact Analysis)	11.25	Weather conditions during the survey	5	Contractor works not in correct procedures	6
6	Loss of costs due to job repairs left by subcontractors	6	The results of the initial study (engineering, environment) is less accurate	12	Residence changed/ moved	9	Changes in wisdom	4	Construction failure	5
7	Theft may occur at the location of the box culvert and overpass	5	Delay of tariff increase	9	Disruption of activity/ accessibility due to project (road closure, route transfer)	7.5	Changes in government structure	4	Changes in policies/ regulations	4

Rank of risk	Risk from contractor's perception		Risk from owner's perception		Risk from society's perception		Risk from design consultant's perception		Risk from supervisory consultant's perception	
	Risk	**Risk level**	**Risk**	**Risk level**	**Risk**	**Risk level**	**Risk**	**Risk level**	**Risk**	**Risk level**
8	Over material class B2 on ready-mix concrete	2	The quality of the winning supervising contractor/ consultant is not as expected	9	Some walls of the house become cracked	7.5	Monetary policy changes	4	Changes in position/ organizational structure of owner	3
9	Abandonment of funds due to no date of maintenance guarantee returns, maintenance period of 3 years	1	Design not in accordance with the conditions and or incomplete	9	Livelihoods change/ disappear	7.5	The planning completion time is too short	3	Contractor completes the job before the contract expires	3
10	Extended Performance Guarantee	1	The flatness and hardness of the pavement surface does not meet the SPM	9	Separate/disconnected access road residents due to toll road projects	6.9	Increase in taxes (related to project cost estimates)	3	Uncooperative owner	2.5
11			Increased operating and maintenance costs are not appropriate to business plan	9	Violation of environmental laws and regulations	6.9	Primary data and secondary data are inadequate	2	Unavailability of PPE (Personal Protective Equipment)	2
12			Inaccurate quantity estimates	9	The process of socialization of land acquisition is not according to the regulation	5	Inconsistency of contract documents	2	Changes in government structure	1.5
13			Decrease in performance due to changes in government policy	8	The price of compensation for land acquisition is not suitable	4.4	The quality of personnel does not meet the standards	1		
14			Inaccuracy and lack of existing utility and data	6	Accidents due to project vehicles and project activities	4	Difficult access to location planning	1		

Rank of risk	Risk from contractor's perception		Risk from owner's perception		Risk from society's perception		Risk from design consultant's perception		Risk from supervisory consultant's perception	
	Risk	**Risk level**	**Risk**	**Risk level**	**Risk**	**Risk level**	**Risk**	**Risk level**	**Risk**	**Risk level**
15			Procurement of supervisory contractors/consultants is late	6	Payment of land acquisition stagnating	4	The results of planning are considered less compatible with conditions in the project	1		
16			Quality of material does not conform to specifications	6	The presence of brokers on land acquisition process	4				
17			Late of procurement of review design consultants	4	Violation of legislation on land acquisition	4				
18			Flooding and environmental disturbance due to lack of handling of temporary drainage and construction methods during construction	4	Decrease in value/price of land/house investment due to adjacent to toll road	4				
19			Unavailability of construction material	4						

Table 2. Risk analysis of Semarang-Solo Section I toll road project.

damaged by construction activities. For design consultant, the highest risk is the error of price estimates for bidding. For supervisory consultant, the top risk is the improper design from design consultant.

6. Risk mitigation

Risk responses are divided into three according to the level of risks, as follows:

- Low risk ➔ risk acceptance
- Moderate risk ➔ risk mitigation
- High risk ➔ risk avoidance

Based on the results of analysis and interviews with stakeholders, the risk response obtained is shown in **Table 3**.

Risk response	Risk percentage (%)				
	Contractor	Owner	Society	Design consultant	Supervisory consultant
Risk acceptance	30	15.79	5.55	62.5	38.46
Risk mitigation	40	57.89	77.78	37.5	30.77
Risk avoidance	30	26.32	16.67	—	30.77

Table 3. Risk responses of Semarang-Solo Section I toll road project.

7. Discussion

For Semarang-Solo toll road project Section I, risks as perceived by stakeholders are categorized as: construction risk, economic and political risks, legal and contractual risks. These three risk categories are presented in each stakeholder risk analysis with several assumptions and conditions. For the owner, the economic risk is the risk of income. The economic risks refer to macroeconomic risks, related to economic policies such as inflation and devaluation, as well as the micro-economic risks associated with financial stakeholders. The categories of political, legal, and contractual risks are made into one category, because these three risks are considered to be related.

Table 4 shows the top risk levels for these three risk categories. It can be seen that based on the risk analysis, the biggest construction risks are on the owner side, while the biggest economic risks are on the contractor side. For political, legal, and contractual risks, the biggest risk level is also on the contractor side. Compared to previous studies, where the highest risks are in the categories of construction risk, legal and contractual risk, income risk, and financial risk [7, 8], this study found that the top risks are in the categories of construction risk, economic risk, and political, legal, and contractual risk, and the degree of importance differs between stakeholders.

No	Risk category	The top risk level				
		Contractor	Owner	Society	Design consultant	Supervisory consultant
1	Construction risks	15	20	15	8	18
2	Economic risks	15	12	7.5	8	3
3	Political, legal, and contractual risks	15	8	11.25	4	4

Table 4. The top risk level of each stakeholders with risk breakdown structure method.

8. Conclusion

From the application of risk management at Semarang-Solo Section I toll road project, it can be seen that each stakeholder has different perceptions of risks. It is mainly because each stakeholder has different interests in project. The risk categories in this project are economic risk, contract and legal risks, construction risk, risk of income, risk of operation and maintenance, political risk, social risk, and force majeure risk. Each stakeholder carries different categories of risks. The top risks as perceived by all stakeholders are construction risks.

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Chapter 7

Risk Management to Enhance Performance in the Construction SME Sector; Theory and Case Study

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68798

Abstract

Dynamic changes and increasing competition in global markets have caused changes in the management of small and medium enterprises (SMEs). Due to this fact, many SME companies try to implement different methods for strategy and operation management, quality and improvement management, risk management, etc. But the problem is the efficiency and implementation of these methods in the SME company. One way to achieve higher efficiency is the integration of management methods, meaning the combination of performance management with quality, process and risk management. This approach is also recommended in the ISO standards for quality. It was reflected in a new revision of the ISO 9001 standards in the year 2015. Performance can be described by the financial and non-financial key performance indicators (KPI), covering the cost, quality and time indicators that have been implemented in the balanced scorecard framework (BSC). The aim of this chapter is to present a methodological framework, which leads to the integration of the key performance indicators (KPI) in relation to the key risk indicators (KRI), which may affect the KPIs and overall SME performance. This framework combines a process analysis and modelling with risk and qualitative or quantitative risk assessment techniques. The case study describes its practical implementation and the verification of the designed framework. The results of this research will help to build an effective management system for performance and risk management and quality management for the business processes of SMEs.

Keywords: risk management, performance management, risk analysis, risk modelling

1. Introduction and overview of the motivation

Risk and performance management is a very broad and important issue in the business management field. Many companies try to apply and integrate risk management techniques and tools as part of their management processes. Many SME companies try to implement different methods for strategy and operation management, quality and improvement management, risk management, etc. But the efficiency and integration of these methods have a negative or positive impact on the SME company. One way to achieve higher efficiency is through the integration of management methods, meaning the combination of performance management with quality, process and risk management. This approach is also recommended in the ISO standards for quality. It is reflected in a new revision of the ISO 9001 standard (2015). **Figure 1** presents the management framework in the SME industry according to the revised ISO standards. The top level presents the goals of companies described by performance indicators. The companies can be used for performance measurement, financial and non-financial key performance indicators (KPI), including cost, quality and time indicators. On the other hand, SMEs should understand the meaning of performance management and measurement.

Consequently, this chapter describes a system of how to integrate the key process indicators (KPI) and key risk indicators (KRI), which are then integrated into a management system for SMEs.

2. Performance and risk management

The integration of management systems is focused on performance and risk, and quality should be based on an effective management system applicable for SMEs. We can adopt common principles for the integration of the above-mentioned management methods.

Risk management means applying a systematic approach to assess and act on risks in order to ensure that the company objectives are achieved. Many papers have dealt with risk management issues in the areas of strategy, operations, finance and information security [1].

For practical reasons, this term can be defined as the systematic implementation of policies, various methodologies and tools, which help to identify, analyse and manage risks. A systematic review of the implementation of risk management in SMEs was accomplished in the chapter [2]. This chapter demonstrated the importance of a risk management process in SMEs and emphasised the significant impact on their business strategy.

The possible impact of risk management on company performance was mentioned and described in the chapter [3]. The author of this chapter introduced and confirmed that "an effective and integrated risk management system must improve the performance of the

Figure 1. Management framework.

company". It is necessary to describe the role of performance management at present based on a literature review of the previous studies and findings.

Performance management is an important part of management tasks today. The present trends in performance management include these common attributes:

- Implementation of a long-term strategic plan and its translation via the key performance indicators
- Measurement and execution of the key performance indicators
- Forecast of performance
- Support of information technology applications for performance management
- Integration indicators focusing on cost, quality and time measurement in all organisational levels
- Support of data mining and reporting

The core of performance management in SMEs is based on the adoption of the balanced scorecard methodology. This methodology was developed by Kaplan and Norton [4] to help SME managers to implement a relatively understandable system using four types of measures [5]:

1. Financial measures.
2. Internal business measures.
3. Innovation and learning measures.
4. Customer measures.

Finally, if we compare the present principles of risk and performance management, the common attributes are as follows:

- Implementation of process management and the plan-do-check-act (PDCA) cycle
- Use of measurable indicators

2.1. Implementation of process management and the PDCA cycle

Process management or business process management (BPM) is a contemporary term used in many companies. Many successful companies have applied this management approach based on Hammer's *Business Process Reengineering Concept*. Authors have developed Hammer's and Champy's ideas in related works today. Managers use the term BPM in many different ways. Some of them use BPM to refer to *"Business Process Management"* [6].

Business process management implementation is presented in the book, *Business Process Management* written by Jeston and Nelis [7]. Weske, in the publication *Business Process Management—Concepts, Languages, Architecture*, describes the techniques for process modelling and the application of information technologies for BPM and workflow [8]. Schmelzer and Sesselmann [9] discussed a practical view on process mapping and the organisation of processes in a company. Process mapping helps to identify key process parameters and set up key process indicators and risks. It will be used for the setup of the key risk indicators and the key performance indicators.

If an organisation implements the integrated system based on process management, the management should be included for all processes in the enterprise and should improve and measure all the processes. This idea was described by the Deming cycle (PDCA methodology)—see **Table 1**. The plan-do-check-act (PDCA) methodology could be a useful tool to define, implement and control corrective actions and improvements.

"Plan"	Establish policy, objectives, targets, processes and procedures relevant to managing risk and improving information security to deliver results in accordance with an organisation's overall policies and objectives
"Do"	Implement and operate the policy, controls, process and procedures
"Check"	Assess and, where applicable, measure process performance against security policy, objectives and practical experience and report the results to management for review
"Act"	Take corrective and preventive actions, based on results of the management review, to achieve continual improvement of the management system

Table 1. PDCA description of risk and performance management system.

2.2. Use of measurable indicators

Measurable indicators should be determined and implemented for the execution and measurement of results. These indicators should be defined according to the S.M.A.R.T approach (Specific—Measurable—Attainable—Relevant—Timely). The companies should try to define key risk and performance indicators (KRI—key risk indicators, KPI—key performance indicators) regarding the implementation of the risk and performance management system.

2.2.1. Key risk indicators

Many papers have dealt with KRIs and how they help to detect and reduce risk at an enterprise level. Researchers have elaborated many definitions addressing this issue. A risk indicator provides a forward direction and information about risk, which may or may not exist and is used as a warning system for future actions. With KRI indicators, a specific risk can be monitored. There are numerous definitions of KRIs: "*An indicator is a key indicator if it serves a very important statement and does it very well*" or "*Key risk indicators are statistics or measurements that can provide a perspective into a company's risk position, tend to be revised periodically (monthly or quarterly) to alert the company about the changes that may indicate risks*" [10]. Basically, the KRIs should be part of the metrics used by management to show how risky an activity is. Risk factors are commonly known as KRIs, and they can be classified as descriptive, performative or control indicators [11]. The classification of the KRIs is shown in **Table 2**.

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Class	Description
Descriptive	Variables related to the expected impact of a risk event; they exhibit a low ability to predict its occurrence
Performance	Variables related to the probability of a risk event happening; they exhibit a low ability to address the impact of a risk event
Control	Variables related to managerial actions or decisions. Management can predict their evolution and can use them as indicators of how the control environment will be in the immediate future.

Table 2. KRI classification.

2.2.2. Key performance indicators

Performance measurement is a fundamental principle of management. The measurement of performance is important because it identifies the gaps between current and desired performance and provides an indication of the progress towards closing the gaps. Carefully selected key performance indicators identify precisely where action should be taken to improve performance [12]. The KPIs focus especially on the historical performance of the enterprise or its key operations and are important for successful management.

The main difference between KRIs and KPIs is that KPIs tell us if we will achieve our goals and KRIs help us with understanding changes in the risk profile, impact and likelihood of achieving our goals [10]. Management reviews key performance indicators such as trends in direction and the magnitude of risks, the status of strategic and tactical initiatives, the trends or variances in actual results for the budget or for prior periods, and event triggers [13].

2.3. Summary of this subchapter

A review of the state of the art and an introduction of the methods for risk and performance management were the aims of the previous part. The next important step is to develop a methodology, which helps companies to implement an integrated system for risk and performance management. The development of a suitable and simple methodological framework is the aim of our research work. We focused on small and medium enterprises because they comprise an important economic sector and whether there are any applicable solutions for this kind of company. On the other hand, it is possible to find solutions in the market, but these solutions are applicable for large companies. This chapter presents our research results from the construction sector.

3. Design of the methodological framework

3.1. Description of the research methodology

The research has been conducted based on the following research question:

> *"Can the implementation of the selected process management tools help provide an understanding of the risks in SMEs in relation to business performance?"*

The literature review, the development of the methodological framework and its verification in the case study were used to confirm or reject the research question. The methodological framework was developed based on the literature review and the analysis of the relevant papers and presented case study. The proposed framework was verified in the case study. We used various techniques to collect the data and to perform the subsequent analysis. The techniques used were as follows:

- Personal interviews—this technique was used for the process analysis and the process description.
- Brainstorming—this method was used to find problems with the company's management.
- Document analysis—an analysis of the company's internal documents (financial reports, documentation of quality management system, etc.) was performed.
- Interview—this method enabled the collection of information about the management strategy, vision and requirements.

These techniques were able to provide input for the modification of the proposed methodological framework.

3.2. Design of the methodological framework

The results of the literature review and the study of relevant case studies were used for the design of the methodological framework. The integration of the KPIs and KRIs via a process and risk management system is the aim of this methodological framework. This framework combines process analysis and process modelling with risk, as well as qualitative or quantitative risk assessment techniques. The process management and process modelling techniques were chosen because this approach is at the core of performance management. Process analysis helps to identify the key risks in business processes and to link the KRIs with the KPIs. The proposed framework is presented in **Table 3**; for its application in the case study, see the next section.

Step	Activities	Output
No. 1: process analysis and mapping	Process mapping Process classification Process attributes description	Processes are analysed and mapped
No. 2: process modelling	Implementation of process modelling methodology Process model-making	Processes are described and modelled
No. 3: identification of key risk indicators (KRIs) and key performance indicators (KPIs) from the perspectives of BSC and risk modelling	Identification of KPI and KRI based on process analysis Risk modelling	KRI and KPI are defined Risks models
No. 4: implementation of management performance system	Setup of KPI and testing of relationship between KRI and KPI Design of system for planning, measurement and execution, auditing of KPI and KRI	Performance management system is implemented

Table 3. Proposed methodological framework.

On the other hand, this methodological framework was used for the verification of our research question, because the methodology combines the principles of process management with performance and risk management. This framework was developed for implementation in small and medium enterprises (SMEs).

These companies play a key role in the global economy. They represent 99% of all businesses in the EU. In the past 5 years, they have created approximately 85% of the new jobs and provided two-thirds of the total private sector employment in the EU. The European Commission considers SMEs and entrepreneurship as the key to ensuring economic growth, innovation, job creation and social integration in the EU [14].

The management of SMEs needs to implement a management system, which is compatible with international standards for risk and quality management based on "best practices" and without special requirements on human, finance and infrastructure resources. The proposed framework attempts to achieve the requirements discussed above.

4. Case study

The designed framework has been applied in a construction SME company. The case study describes the practical implementation and verification of the designed concept according to the steps presented in **Table 3**.

The construction company is a traditional Italian small company providing building services in the local construction sector. The company has implemented a quality management system according to ISO 9000 standards, has 43 employees and has total assets of 3 mil EUR. The company invests money in innovation activities for new materials and technologies in the construction sector.

4.1. Step 1: process analysis and mapping

Process analysis helps to identify the risks in business processes. Based on this analysis, it is possible to develop a process model and to link the risk with the activities in a process. The designed concept tries to integrate a process of objective modelling with risk and qualitative and quantitative risk assessment techniques. Two approaches based on different process modelling methods (EPC and BPMN) can be used effectively for process modelling. Process models help to link the risk with the activities in a process. The risk is a process attribute in this concept (see **Figure 2**), and the model can be used for risk factor calculation.

The process mapping collected all the process attributes and the relationships between them. The aim is to identify and describe all the process attributes and activities in the SME company. This means that the process analysis and mapping should include these particular processes:

Study of the internal documents and organisational structure of the company

- Identification and description of all the processes in the company
- Determination of controllable and measurable parameters
- Definition of all the attributes

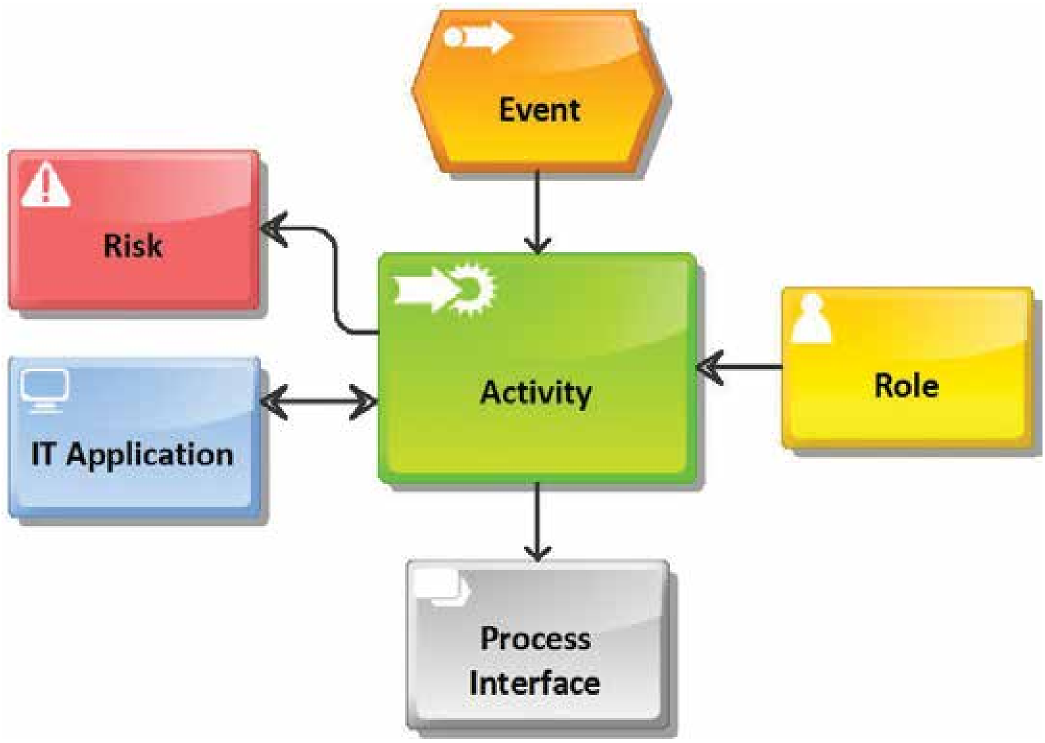

Figure 2. Model of process attributes.

The results of this step can be summarised in a table. In this case study, **Table 4** presents an example of how to describe the processes, sub-processes, process type, input, output, key process-measured parameters and key process risks.

4.2. Process modelling

The ARIS (Architecture of Integrated Information Systems) methodology was used for the process modelling. The ARIS methodology allows the description of reality from another point of view. It offers methods for process analysis and takes a holistic view of the process design, management, workflow, and application processing. The ARIS approach provides not only a generic methodological framework but also a business process modelling tool. The other tools, such as the QPR Process Designer, provide a powerful solution, which enables us to describe, analyse, communicate and improve enterprise processes. The processes were modelled by two kinds of modelling software. The EPC methodology was chosen for ARIS, and BMPN notation version 2.0 was chosen for the QPR. Examples of the process mapping are shown in **Figures 3** and **4**.

The EPC diagram allows us to display and connect risk to an activity. The same process can be used with a documentation or IT interface. The disadvantage of the EPC diagram is that it is impossible to clearly separate the process through an organisation chart. A possible

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Processes	Subprocesses	Process type				Input	Output	Key process measured parameters	Key process risks
		Main	Supportive	Management	Key				
Offer/tender		x			x	Client requirements or tender call	Offer or tender documentation	Process time	Quality of project and relevant documentation
	Preparing of offer or tender								
	Negotiation with client								
	Review of offer								
Contract acceptance	Preparation of agreement	x			x	Accepted contract	Started construction works	Process time	No complete information, technical risks
	Preparing of folder								
	Distribution of information								
	Takeover building site								

Table 4. Proposed concept.

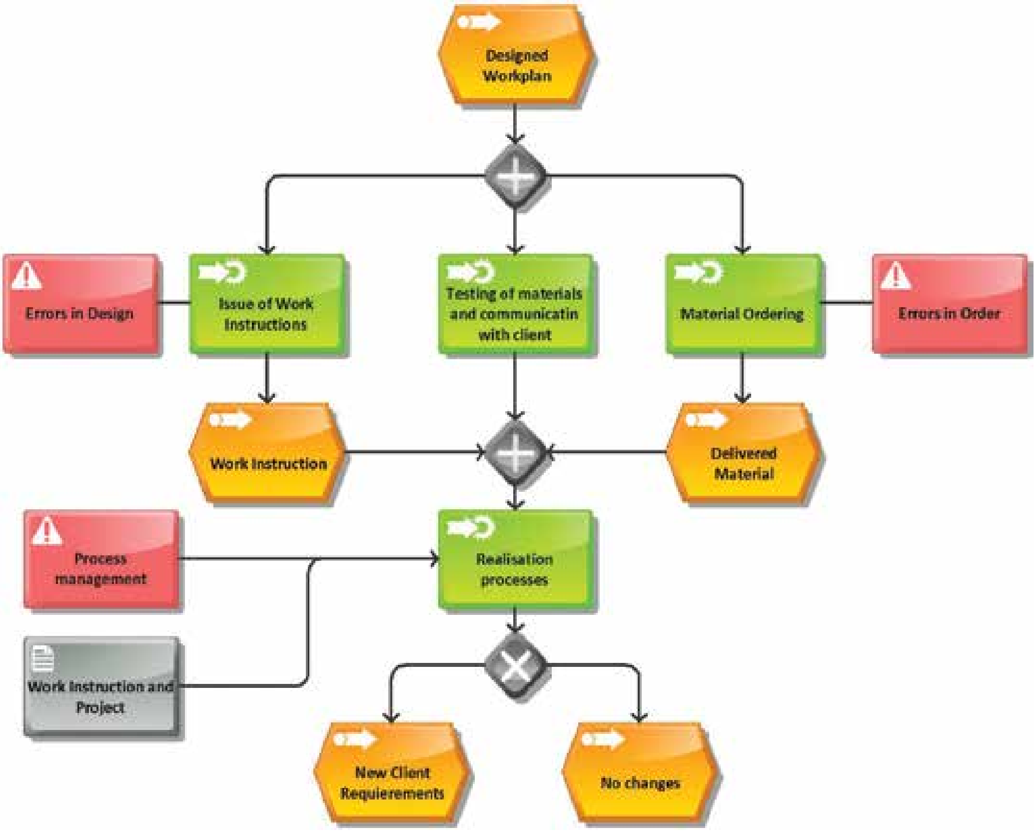

Figure 3. Example of an EPC diagram with the process attributes (ARIS software).

solution is to connect a "role" or organisational unit to each activity. However, this solution means that the EPC diagram is difficult for potential users from the evaluated company to read. The BPMN diagram allows organisational units to be split into separate blocks (in **Figure 5**—"Enterprise"), and each organisational unit into separated lines (swim lines), which are addressed to the roles in the organisation (in **Figure 5**—"Role 1" and "Role 2") based on an organisational diagram of the company.

The main advantage is that the process is clearly separated into the organisation's units, roles, risk distribution and responsibility. It is possible to see which role can be responsible for some risk because this risk is placed in a specific line. The second advantage is that the risk is connected to a specific activity. Thus, it can provide distinct help in conducting a quantitative risk assessment, because in that case, the owner of the process knows all the process attributes (see **Figure 2**).

4.3. Step 2: identification of the key risk indicators (KRIs) and key performance indicators (KPIs) from the perspectives of BSC and risk modelling

The company first had to determine the measurable strategic goals. The method used was the balanced scorecard. This method supports linking the goals between all the perspectives;

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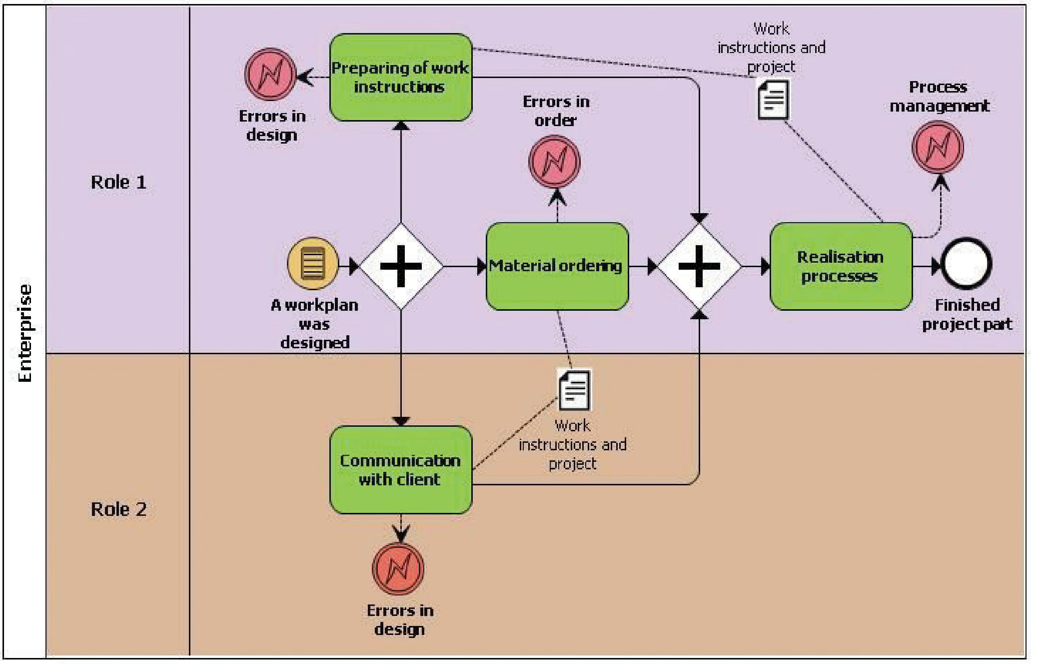

Figure 4. Example of an BPMN diagram with the process attributes (QPR software).

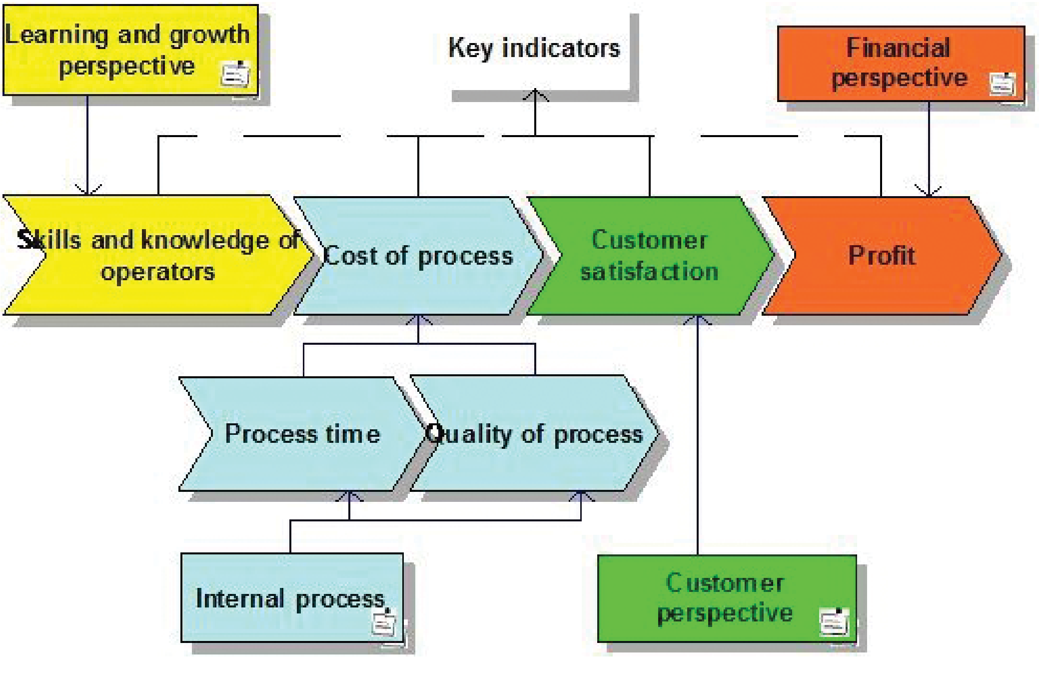

Figure 5. Example of the application of the BSC method.

Figure 5 shows examples of the goals and metrics (indicators). The important aspect of the BSC, as a process measurement method, is the definition of the number of metrics/indicators and the period of measurement in relation to total production costs.

The company must define strategic goals from four perspectives. The most important global indicators in the balanced scorecard in the construction sector are focused on:

- Profit
- Customer satisfaction
- Cost of the process
- Skills and knowledge operators

These global indicators were identified based on personal interviews with the owners and managers of construction companies. The relationship of the aforementioned indicators with the BSC perspective is presented in **Figure 5**.

The specification of the KPIs was done through interviews with the owner and the project manager from the case study company based on the previous step, and the important KPIs and risk indicators were identified based on process analysis and mapping. The determined KPIs from the BSC perspective are shown in **Table 5**.

BSC perspective	KPI 1	KPI 2	KPI 3	KPI 4
Financial	Cash flow	Net profit	Stock turnover	Turnover claim
Customers	Client satisfaction	New clients	Client loyalty	x
Business processes	Service quality	Number of errors	Percentage of projects delivered on time	Average of labour hourly cost
Learning and growth	Resource consumption for training	Workers satisfaction	Number of prestigious projects	Resource consumption for research

Table 5. Identification of KPIs from the BSC perspective.

An evaluation of the list of risk factors, which were established as important factors in the construction project during the case study, was conducted after the identification of the KPIs. This means that each risk factor from the list was evaluated for all the KPIs (if a KPI is influenced by that factor).

Table 6 presents how many risk factors could have an impact on a KPI (there is a number for each KPI; it is also expressed by a percentage). An evaluation of the relationship between the risk groups and the KPIs was also performed. This allows us to find the most significant risk groups for a company's performance. It was found that the most significant risk groups are Financial (31 connections) and Contractors (32 connections). These two were followed by Subcontractors (26), Clients (24), Equipment (20), Legal (20), Political (19), Consultants (19), etc. We analysed all the risk factor groups for each perspective to find the significance of each risk group. We performed that analysis by conducting interviews, and part of the output table sheet is shown in **Table 7**.

BSC perspective	KPI 1		KPI 2		KPI 3		KPI 4	
Financial	Cash flow	26/33%	Net profit	60/77%	Stock turnover	24/31%	Turnover claim	15/19%
Customers	Client satisfaction	27/35%	New clients	13/17%	Client loyalty	8/10%	x	
Business processes	Service quality	31/40%	Number of errors	18/23%	Percentage of projects delivered on time	32/41%	Average of labour hourly cost	7/9%
Learning and growth	Resource consumption for training	6/8%	Workers satisfaction	2/3%	Number of prestigious projects	4/5%	Resource consumption for research	3/4%

Table 6. Identification of the most significant KPIs.

	Financial perspective		
	KRI => CREDIT RISK		
	KPI		
Risk factor	**Profit**	**Stock turnover**	**Turnover claim**
Financial			
1. Inflation and sudden changes in prices	1		
2. Exchange rate fluctuation	1	1	
3. Incomplete and inaccurate cost estimates	1		
4. High competition in bids	1	1	
5. Unmanaged cash flow	1		1
6. Delayed payment in contracts	1		1

Table 7. Part of the group significance table sheet.

The identified risks were recorded in a risk model. This model shows the important groups of identified risks and helps to classify the risks into categories. The different colours used in **Figure 6** (for a better illustration of the process) divide the risks into operational (red) and strategic (yellow) risks. Each risk group may also have a different colour (see **Figure 6**), for example, for categorisation, priority or responsibility. As shown in **Figure 6**, each risk group can be broken down into individual risks.

As mentioned above, each risk can be monitored by the KRI(s), which influenced the KPI(s) in connection with enterprise performance. This idea is presented in **Figure 7**. We also demonstrate an idea for systematic measurement, assessment and evaluation through the risk management system (RMS) for SMEs, which is one of the research results. There is also an assumption that each risk is connected with a responsible person (persons), and the RMS provides an online report about the condition of the project risks and the enterprise KPIs.

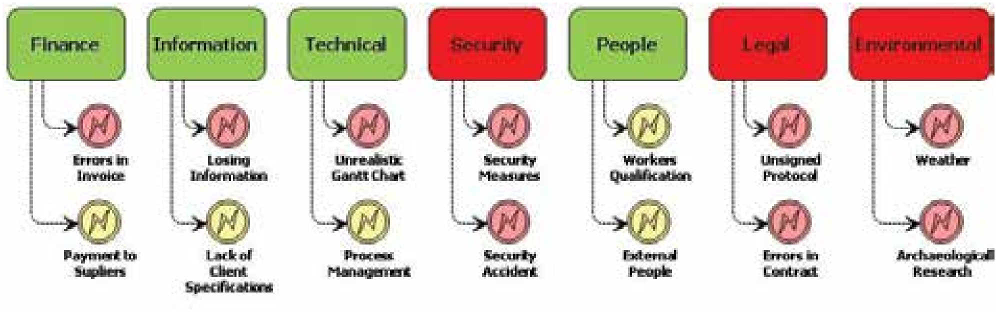

Figure 6. Model of risk groups.

The development of a methodology for risk assessment and a simulation based on a sustainable enterprise risk management (SERM) approach for SMEs was the next aim of this research. A diagram developed for the concept is shown in **Figure 8**.

4.4. Step 3: implementation of the management performance system

The implementation model was developed based on the previous research for the development and the application of the framework. This model describes the interaction and procedures between the risk and performance management and can be used for the design of software—**Figure 8**.

For the software model application, there is an expectation that users will be divided by knowledge level. The model anticipates different levels of knowledge in the users. This is the reason that the inputs are strictly dependent on the users' experiences, and there is a logical recommendation for some evaluation of the skills of new users. There is an assumption that

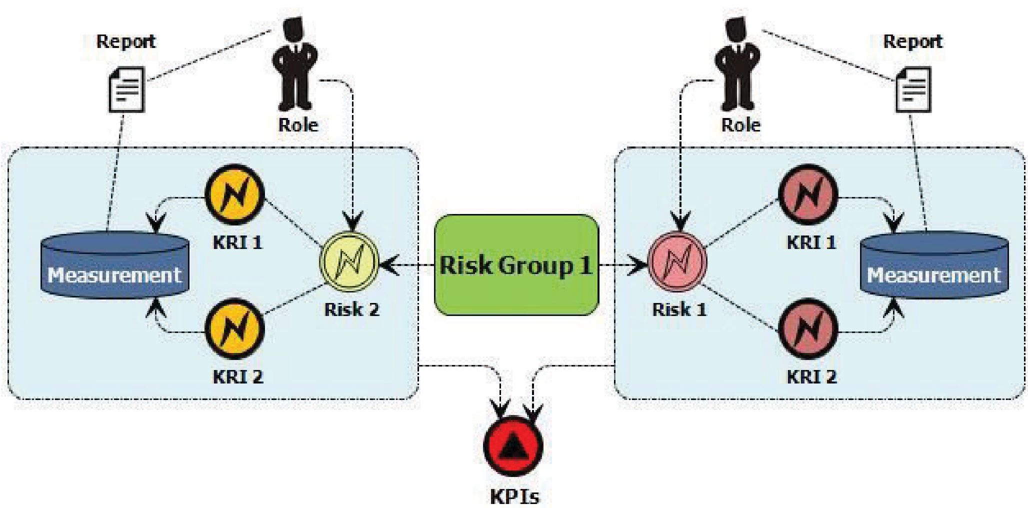

Figure 7. Relationships between risks—KRIs—KPIs.

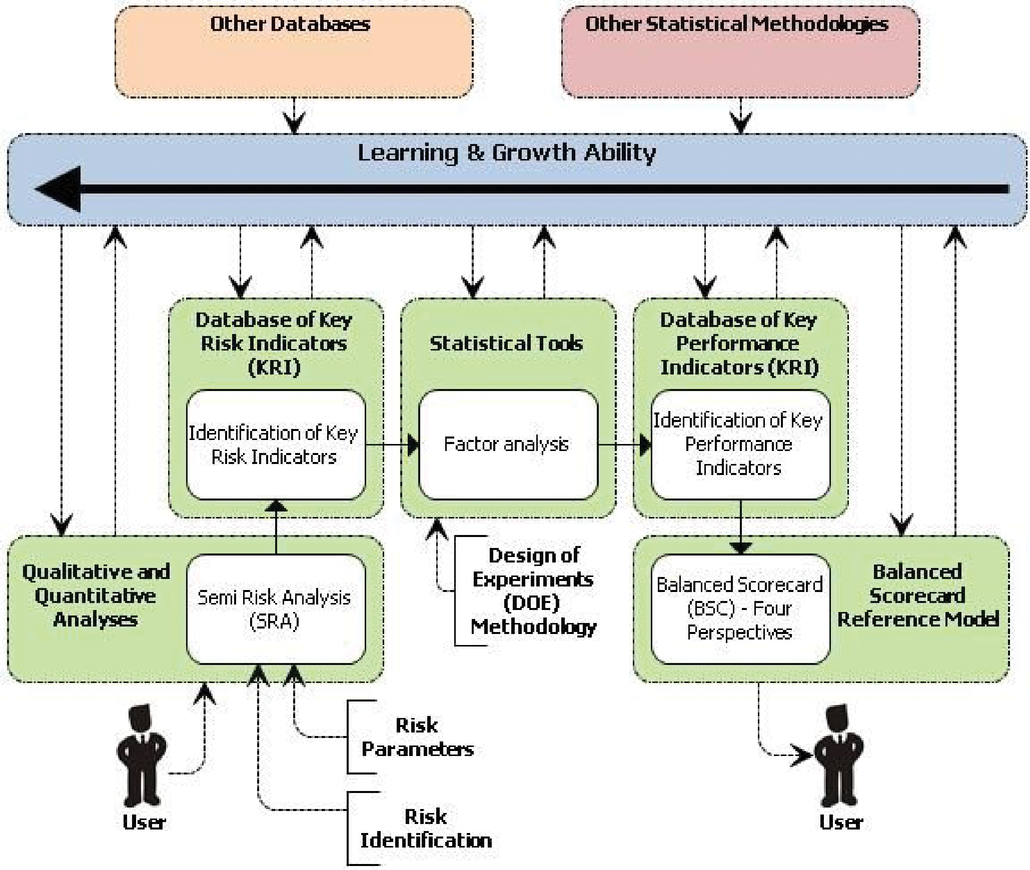

Figure 8. Generic model for the implementation of the framework.

the software should have a Learning and Growth Ability for the users' support and improvements in the risk simulations.

There is a strong need to determine and understand the dependencies between the KPIs and the KRIs for the implementation of risk management to function properly. An understanding of the paths and the dependencies of the linkages between risk and performance can distinctly enhance, among other things, the profitability, quality and competitiveness of a company.

The setup of the KPIs and the testing of the relationship between the KRIs and KPIs are important goals to address that issue. The most important KPIs were identified for the SME construction company—see the previous chapters.

The next important step is to identify the areas of dependence between the KRIs and the KPIs. The design of experiment (DOE) methodology was applied in this research. A factor analysis was also applied to provide an evaluation of the results and better understanding and support for decision-making [15]. This analysis can help in identifying the influence of input factors on the values of output. This method is often used to detect more and less significant factors. Therefore, it should answer the questions in the defined hypothesis. This means that it is able to provide a clear view of the dependencies between the different KRIs which affected a KPI.

Based on this graphical output, it is possible to determine which KRIs from specific KRI groups have the main influence on specific KPIs. An example of a DOE application is shown in **Figure 9**. The case of the KPI "on time delivery" from the database is demonstrated there. Many potential risks influence this KPI.

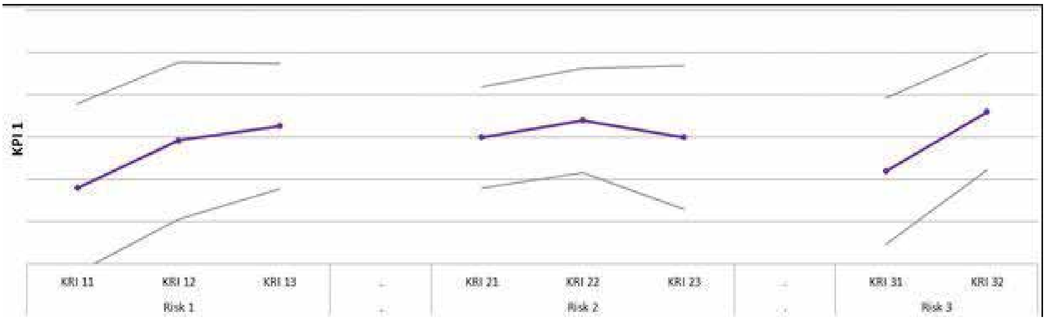

Figure 9. Example of the application of the DOE (influence of factors on the KPI1 from the DOE methodology).

The number of subcontractors, the materials used and changes in the project database was used for this experiment. For these risks, the possible KRIs, which have a dominant character, were chosen. Next, the experiment with all the possible combinations of the individual KRIs was processed, and the results of the analysis show how these combinations affect the output. The results were obtained via MS Excel based on the SMEs owners' experiences and from the project databases.

The final step was to design the experiment based on the DOE methodology and to present the results through the arranged charts (see **Figure 9**). As shown in **Figure 9**, the DOE allows the dependencies between the KRIs and the KPI to be clearly displayed, in order of each KRI within the possible risk (Risks 1, 2 and 3). This statistical tool allows us to identify the important KRIs, which influence the KPI, and to focus on them effectively for the KPI.

5. Conclusion

This chapter deals with the relationship between risk and performance management. The idea was to create a general methodological framework for the implementation of risk and performance management in SMEs according to any requirements defined by the revised ISO quality management system or by the owners. The designed framework tries to combine objective process modelling with risk management and qualitative or quantitative risk assessment techniques. The designed framework was evaluated based on the results of the process analysis and interviews with the managers of the case study company.

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The proposed solution integrates process management and performance and risk management according to one methodological framework. The definition of how to integrate the key performance indicators (KPIs) in relation to the key risk indicators (KRIs) was an important step in the implementation.

The next task was to describe the relationships between the risks, the key risk indicators and the key performance indicators in connection with the risk management software for SMEs. Part of the designed model and the results is shown in the case study. It was verified that the KRIs influence the organisations and the KPIs based on different dependencies between them. It is possible to break the dependencies down into a transparent graphical model, for example, with an implementation of the statistical tool (in this case study, the DOE).

The case study describes an example of the implementation of the proposed framework in a real SME construction company from an EU country (Italy). Our first experience with the proposed concept in this case study shows the benefits of this solution—the relationship between the KPIs and the KRIs. Finally, we conclude that the research hypothesis formulated in the introduction was confirmed by the results of the case study. The implementation of the selected process management tools helped provide an understanding of the risks in the SME in relation to its business performance.

The application of mathematical methods for risk simulation, such as the Monte Carlo simulation, for more complex analysis and its verification, may be one possible direction for further research work. However, a barrier for robust mathematical methods is the quantity and quality of storage data for SMEs.

Acknowledgements

This research has been supported by the Ministry of Education, Youth and Sports of the Czech Republic under the RICE—New Technologies and Concepts for Smart Industrial Systems, project No. LO1607, by the European Commission under Marie Curie action FP7, project Risk Management Software System for SMEs in the Construction Industry (RiMaCon), project No. FP7-2012-IAPP-324387 and by the Student Grant Agency of the University of West Bohemia in Pilsen, Grant No. SGS-2015-020 "Technology and Materials Systems in Electrical Engineering".

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Leadership Initiatives for Health and Safety Risk Management Systems in a Small Construction Company: A Case Study

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.80697

Abstract

The need for leadership in the construction industry has been greater due to the fact that health and safety has become an important business tool to reduce accidents to save lives and minimise injuries. This chapter demonstrates the importance and role of leadership for manging risks associated with health and safety aspects in small construction companies. A case study of an Italian family run small construction company is investigated and reported. A diagnostic tool Leadership and Worker Involvement toolkit was administrated in the company. The toolkit had assessment levels (walking, running and sprinting). Analysis showed the company was at walking and running stages in various aspects. But the leadership aspiration of the company was to reach the 'sprinting' stage as a long-term target and sustain it to minimise health and safety risk. A holistic approach was developed to achieve the leadership aspirations of the company. In conclusion, the role of leadership in small companies is to understand the importance of H&S aspects and develop strategies which are then embedded in the processes of the companies to minimise H&S risks for their sustainability and competitiveness. This chapter is beneficial for professional at site, project and programme level and for leadership team.

Keywords: enterprise risk management, leadership, health and safety, risk management, small companies

1. Introduction

Every day, people die as a result of occupational accidents or work-related diseases—more than 2.78 million deaths per year, according to [1]. Additionally, there are about 374 million non-fatal work-related injuries and illnesses each year, many of these resulting in extended absences from work. Construction is a major industry providing jobs to millions of people and contributing to individual countries and the world economy. With the construction industry being notorious for safety, this condition has compelled companies to improve their safety performance. There are at least five reasons which demonstrate the importance of safety for construction companies [2]: lack of safety; increase probability of accidents; increase human suffering through injuries; accidents leading to disabilities; and fatalities. Governments around the world have laws that require construction organisations to provide safe work conditions and adequate supervision. Lack of safety, therefore, may lead to prosecution or claims, which will become the source of extra costs and adverse publicity. When an accident happens, the morale of workers is weakened. On the contrary, accident prevention programs strengthen morale and improve on-site productivity. A good safety record and proven safety management system is a valuable marketing tool to attract new clients and support business expansion. A safe operation of workplace is considered as a moral obligation imposed by the current society, thus good safety practices are essential to improve and maintain reputation; and safety management program contributes to the financial health of construction companies by helping them avoid costs associated with accidents. An accident incurs both direct and indirect costs as well as insured and uninsured costs. Sun and Zou [3] found that an accident can cost up to a $1.6 million. The hidden costs could be 36 times greater than the direct costs of the accident [4].

In most countries, the rates of accident and injury prevailing in the construction industry are higher than what prevails in other industries. For developed countries, Idoro [5] found that the United States construction industry currently accounts for over 22% of all occupational fatalities in the entire United States even though it employs less than 7% of the country's workforce. However, according to the UK Health and Safety Executive Warren [6], each year in the construction sector alone, 4% of workers suffer from an illness they believe to be work-related and 3% of people suffer from a work-related injury. That is 79,000 people have musculoskeletal disorders.

The situation in developing countries is worst because research studies discovered that accident and injury rates in many of the developing countries such as Kingdom of Saudi Arabia [7]; Nigeria [8, 9], Thailand [10], and Tanzania are considerably higher than in European countries [5]. Mbuya and Lema [11] are of the opinion that in most developing countries, safety consideration in construction projects delivery is not given a priority and the employment of safety measures during construction is considered a burden Enshassi et al. [12]. Also discover that in many developing countries, the legislation governing Health and Safety is significantly limited when compared with UK. They report further that there are rarely any special provisions for construction on workers' safety and the general conditions for workers are often not addressed.

Health and safety globally is enacted by varying regulations, standards, model and acts. The International Labour Organisation (ILO) publish a database of current occupational health and safety legislation globally, described in **Table 1** are countries who apply occupational health

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and safety law, who is responsible for ensuring regulation, standards are being enacted and the occupational health and safety laws they are compliant with regards to training and development of their given work forces. In spite of this every 15 seconds, a worker dies from a work-related accident or disease. 317 million accidents occur on the job annually; many of these resulting in extended absences from work. The human cost of this daily adversity is vast and the economic burden of poor occupational safety and health practices is estimated at 4% of global Gross Domestic Product each year [13]. Therefore, investment in health and safety initiatives is critical to a company's sustainability and future competitiveness.

Lee and Halpin [14] discovered that in many of the countries where safety legislation exists, the regulatory authority is weak and non-existent and employers 'pay lip service 'to regulations. Koehn and Datta [15] further discover that in developing countries, injuries are often not reported and the employer only provides some form of cash compensation for an injury to the employee. Suresh et al. [7] study concluded that it is possible to improve construction industry Health and Safety through effective enforcement of existing Health and Safety laws. In addition

Country	H&S regulation	H&S compliance
United Kingdom	Health and Safety Executive	Health and Safety at Work Act 1974
United States of America	Occupational Safety and Health Administration (OSHA)	Occupational and Safety Health Act 1970
Canada	Canadian Centre for Occupational Safety and Health (CCOHS)	Canada Labour Code (Labour Code), Part II and the Canada Occupational Health and Safety Regulations (OSH Regulations)
Australia	Safe work Australia	Work Health and Safety Act 2011
Russia	Russian National Centre of Occupational Health	The Labour Code 2001
Portugal	National Council for Health and Safety at Work	Occupational Safety and Health Law (L102/2009, amended and consolidated by L3/2014)
China	State Administration of Work Safety (SAWS)	Major OSH laws are Law on Work Safety, Law on Prevention and Control of Occupational Diseases, Laz on Safety in Mines
Sweden	Work Environment Authority	Work Environment Act (1977:1160)
Switzerland	Secretariat for Economic Affairs (SECO)	Labour Law, the Order No. 3 on Hygiene and the Order on the Prevention of Accidents
Peru	National Council on Occupational Health and Safety	Safety and Health at work 2012
Oman	Ministry of Manpower, Occupational Health and Safety Department	Omani Labour Code 2003
New Zealand	Ministry of Business, Innovation and Employment	Health and Safety and Employment Act 1992

Table 1. Health and safety in 12 different countries.

to the company leadership team recognising the importance of health and safety especially for small companies which constitute to more than 90% in the construction industry.

Health and Safety is always considered as a management issue in which the top management team, who has the authority to allocate resources and enforce organisation's policies, plays a key role in successful health and safety management [16]. The top management team must be willing to accept responsibility for the safety of their employees and must consider safety as an integral part in conducting business. They need to announce and demonstrate their safety commitment as well as stimulate safety awareness from the rest of their employees. Therefore, a safety program or any other implementation of a safety management system must start from or be supported by top management.

2. The role of leadership for health and safety

Without management support, safety is degraded into behavioural issues, such as asking workers to work with care and to wear protective equipment. Proper behaviours are, of course, necessary, but it is important to remember that humans are prone to error. Changing people's mindset and implementing a safety management system are more important and effective to counter safety issues [17]. On the other hand, safety should not only be the responsibility of top management. Due to the complexity of the nature of safety, concerted efforts by all stakeholders, directed at all levels in the influence hierarchy are required to achieve a sustained safety improvement [18]. Everyone in the organisation must be involved and accountable. Sunindijo and Zou [19] stated that misalignment of management commitment and subordinates' actions lead to continuous unsafe conditions of work. More so the concepts of safety by the managers are not fully disseminated to their subordinated to take measures on the construction site. These attribute to lack of safety leadership [20].

Tyssen et al. [21] noted that effective leadership plays an important role in ensuring the success of construction project facing a high degree of uncertainty. A project team will either succeed or fail largely by the quality of the leadership skills of project managers. Therefore, strong safety leadership should be the key for improvement.

The roles of leadership are distinct from those of managers. Health and safety managers hold employees accountable to health and safety and typically held accountable for outcome numbers. Thus, they use outcome numbers to direct the behaviour of those who report to them. While health and safety leaders motivate others to be self-motivated and self-accountable for health and safety go beyond the call of duty on behalf of their co-workers' safety, health and well-being [22]. Health and safety leaders also hold people accountable for accomplishing proactive process activities that can prevent harm and lower injury rates.

Most of the leadership research has focused on outcomes such as productivity, profit, and worker satisfaction as their criteria, and very few research studies have looked at health and safety as a criterion for measuring leadership effectiveness. This is surprising, given that creating a safe workplace and promoting effective leadership are key goals of most modern organisations. Yet it cannot be assumed that similar leadership behaviours will be associated with effectiveness in health and safety as with other outcomes because safety, unlike other organisational outcomes is intangible. Good safety performance culminates in non-events which are not self-reinforcing. Thus, in order to develop and sustain employee motivation for safety it is likely that leadership in construction projects will require certain communication and motivational skills, which may differ from those required to fulfil task orientated goals.

Cattell et al. [23] noted that productivity is about getting the best value from all inputs across the whole value chain and for this, there needs to be sustained improvement in leadership, culture and processes. Furthermore, Ribiere and Sitar [24] referred leadership behaviour as 'leading through a knowledge lens'. Leading through a knowledge lens gives some special characteristics since it is dealing with knowledge workers having specialised expertise, leading them can be done only by intellectual power, conviction, persuasion and interactive dialogue, it requires skills that build confidence and engagement. Therefore, leaders should establish trust and commitment that will help the knowledge organisation to achieve its business goal. Leadership initiatives for health and safety risk management systems in a small construction company is paramount as construction workers are already at a higher risk of accidents in construction than in any other industry.

3. Does size matter for health and safety?

The employees of small companies have less experience, less education and are younger than employees of large companies. Moreover, they are not conscious of the risk they confront because of their lack of knowledge and information about H&S. Lin and Mills [25] research in Australia showed that small companies did not consider they have to pay attention to H&S administratively. On the other hand, large companies consider that the H&S needs to be included in the administrative system and in all the projects developed by the company. H&S is not a priority in small companies for several reasons. First, they are economically vulnerable, which make them consider that investing in H&S is not profitable as the benefits are perceived in long term. Furthermore, owners and managers tend to take responsibility of all managerial aspects of the company, without having any management knowledge and training. Also, as the frequency of accidents is in these types of companies is low, owners tend to misinterpret these facts [26]. In order to have a more specific analysis of the size of the companies these workers belong to, the range of the number of employees followed the definition of SME from the European Union, which is used also by the UK government. In terms of quantity of employees, a SME is described as follows:

- Micro business: compound of less than 10 employees.
- Small business: compound of less than 50 employees.
- Medium business: compound of less than 250 employees [27].

Small businesses in the UK account for 99.3% of all private sector businesses at the start of 2016 and 99.9% were small or medium-sized (SMEs). The combined annual turnover of SMEs was £1.8 trillion. Just under a fifth of all SMEs operate in the construction industry [28]. These numbers show that there is a significant presence of SMEs in the industry, thus it is important for the construction sector that these types of companies implement H&S practices in the workplace in order to diminish accidents and any other risks that affect their workforce and people around the construction site. Small and medium enterprises are being increasingly recognised as "the life blood of modern economies" [29]. Even though this was stated more than a decade ago it still stands true reflecting on the statistics. Therefore the role of leadership for H&S in a construction small company was investigated using the leadership toolkit.

4. Leadership toolkit for health and safety

The Leadership and Worker Involvement toolkit was developed by the construction industry's Leadership and Worker Engagement Forum in UK to help contractors and managers learn how to make health and safety improvements in their businesses. This contains of assessment sheet and then knowing the status and way forward (**Figures 1** and **2**). The assessment is in the

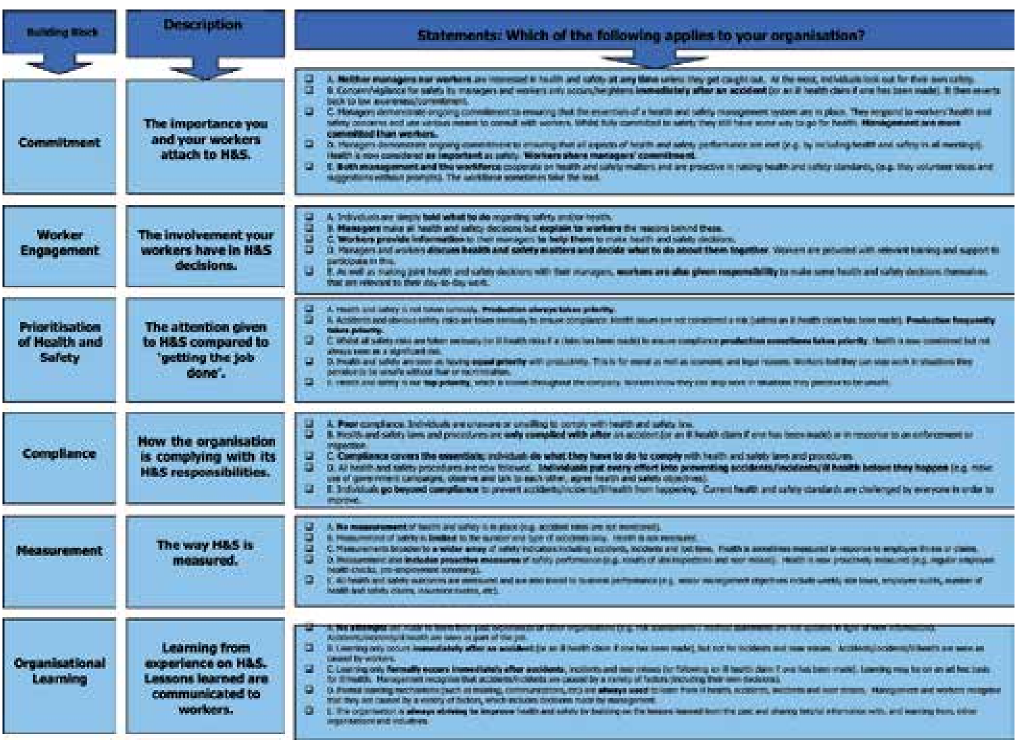

Figure 1. Leadership toolkit.

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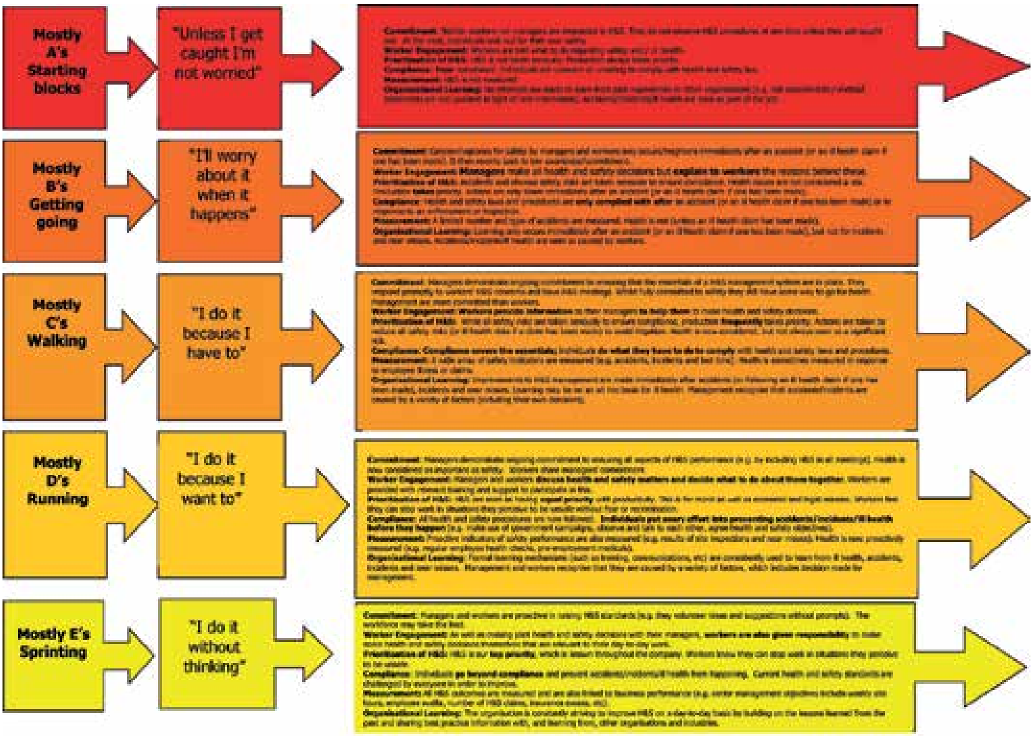

Building Blocks	Starting blocks (A)	Getting going (B)	Walking (C)	Running (D)	Sprinting (E)
Commitment	1	2	3	4	Continue to ensure that managers and workers are proactive in raising H&S standards by volunteering their ideas.
Worker Engagement	5	6	7	8	Continue to ensure that workers take the lead on H&S matters and are involved in making H&S decisions
Prioritisation of health and safety	9	10	11	12	Continue to emphasise H&S as a core company value.
Compliance	13	14	15	16	Continue to seek out proactive and innovative ways of preventing accidents and ill health.
Measurement	17	18	19	20	Continue to measure H&S outcomes and link these to business performance.
Organisational learning	21	22	23	24	Continue to make efforts to improve H&S on a day-to-day basis. Share and seek ideas from industry peers and colleagues.

Figure 2. Current H&S system.

areas of: commitment, workers engagement, prioritisation of H&S, compliance, measurement and organisational learning. There are five options for each of the areas and the participant should choose one statement which applies to their company/organisation.

Once the options are chosen in **Figure 1** the next step is to analyse the data to identify which state the company is i.e. starting block, getting going, walking, running and sprinting (**Figure 2**). Thereafter suggestions are provided how to proceed to the next level.

As part of a European Commission (EC) project this tool was administered in an Italian company which is reported in the following section.

5. Case study of a small Italian construction company

This is a company that started 60 years ago which is a family lead small construction company. There are 15 employees working and specialise in commercial, residential, school and refurbishment projects. The project cost varies from 30,000 to 2 million Euros. They undertake three types of work i.e. Skeleton 15% (foundation, column, beams and brickwork); skeleton with plaster and screed (75%) and complete building (10%).

Health and Safety legislation within the UK is established by statute law, the Health and Safety at Work Act 1974 although not a detailed act, it enables further legislation (regulations) to be passed without going back through parliament and under guidance from the European Union guidance in the form of directives. There are similarities of UK and Italian regulations. For example: PPE is called DPI. The Health and Safety Executive (HSE) implemented the Construction Design and Management Regulations (CDM 2015) with the intention to encourage the integration of health and safety into project management. A principal designer/principal contractor is appointed by the client to control the pre-construction/construction phase on projects with more than one contractor. The main duty is to plan, manage, monitor and coordinate health and safety during this phase which they are involved in.

Similarly Italians have Coordinalove per IA Sicurezza. D. Lgs nr. 81/08, "a model of organisation and management" satisfies the requirement on health and safety, if it is constructed in accordance with OHSAS 18001 or with the UNI-INAIl guidelines. The regulations include

Building Blocks	Walking (C)	Running (D)
Commitment	✓	
Worker Engagement	✓	
Prioritisation of health and safety	✓	
Compliance	✓	
Measurement		✓
Organisational learning		✓

Figure 3. H&S system.

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construction activities in Italy are defined by state law. A company after a firm enrolled in an institution dedicated to work should follow the provisions of the Law D. lga. nr. 81/2008. This law identifies the liable subject around the activity of work and then gives each of the roles. It also lists the minimum requirements necessary to be able to exercise (technical and professional qualification). Therefore in this study it was explored how leadership in small company implements the regulations. As a starting point, the Chief Executive Officer (CEO) and the project manager filled the leadership and workers involvement questions of the toolkit. The mean scores were calculated for the options selected which resulted in 4C's and 2D's (**Figure 3**). This indicated that the company was in "walking mode" and in some instances in the "running mode".

Building Block	Walking ▸ Running	Running ▸ Sprinting
Commitment	You should now be focused on gaining the commitment of your workers to H&S. Get your workers to think how their behaviour not only affects them, but also their work mates/colleagues and their family if they were to fall ill or become injured as a result of working unsafely. To encourage workforce commitment, continue to make H&S top of the agenda in all meetings, giving it due thought and attention.	Consistently demonstrate an 'open door' approach to any H&S suggestions put forward by your workers and involve them in implementing their own solutions (where feasible).
Worker Engagement	Regularly include your workers in your decisions on which solutions you choose for improving H&S. Ensure workers are trained to participate in decision making. Discuss the pros and cons of different options with them. Encourage them to come to you with their ideas. You should now be jointly making H&S decisions with your workers.	Give your workers appropriate responsibility for making decisions on H&S matters that are directly relevant to them (e.g. PPE selection; tool choices; when they have breaks, hygiene etc). Give your workers every opportunity to generate ideas on improving H&S on an ongoing basis.
Prioritisation of Health and Safety	Ensure your workers are familiar procedures. Through appropriate communication and your own actions ensure that they feel able to stop work in situations they perceive to be unsafe. Make sure you include in your communications that health matters are as important as safety matters. H&S together should be regarded as important as productivity. Develop a strong business case (i.e. cost benefits of H&S) to persuade leaders that H&S is a top priority.	As far as possible, make sure that H&S have a visible presence in all your dealings with your workers (e.g. as the first agenda item on any meeting, in all your documentation, and all your decision- making). Continue to ensure that H&S is a top priority for all leaders by progressing your business case, (i.e. cost benefits of H&S taking priority over production). H&S should now be a core company value.
Compliance	In consultation with workers, and considering previous risk assessments, start to think about what might go wrong in the future. Put preventative measures in place (e.g. signage/prompts, training, etc) following task specific risk assessments carried out with workers.	Use worker engagement and your learning from experience on H&S to identify new ways of improving the company's overall H&S. Generic and task specific risk assessments should be used on a regular basis to inform your H&S decision-making.
Measurement	Broaden what you measure to include proactive indicators of both H&S (e.g. amount of training provided, amount of discussions you have with your staff on H&S). What do these additional measures tell you about your overall productivity in relation to H&S? Consult your workers to help you decide what action to take.	Together with your workforce, continue to monitor the link between what you are collectively measuring, your company's productivity and everyone's attitudes and approach to work, (e.g. morale, job satisfaction). Continue to take appropriate action based on your findings. Set yourself and your leaders objectives to improve H&S on site.
Organisational Learning	Formal learning mechanisms should be in place (e.g. training, communication systems). Formal measures should be in place that uses worker engagement to identify and understand why ill health/accidents/ incidents and near misses happen. Modify your safety management system accordingly. Leaders openly admit to workers that their decisions play a part in H&S outcomes.	Look at what other companies of your size and type of work are doing to improve their H&S. Identify what you can learn from them and what they can learn from you.

Figure 4. Way forward H&S system.

Figure 4 shows the way forward for the company for leadership initiatives in: Commitment; Worker Engagement; Prioritisation of health and safety; Compliance; Measurement and Organisational learning. The next stage, the leadership of the company should aim is to reach the 'sprinting' stage as a long-term strategy.

For short term (within 6 months) the company should reach the 'running' stage. To enable achieve this ERM framework was proposed as part of the EC project.

6. Incorporating the enterprise risk management framework to health and safety

Analysis of the documents and focus group discussions with project team revealed that there should be a health and safety strand in the enterprise risk management framework and hence it was developed (**Figure 5**). This aspect was further taken forward and details of strategy, process and performance are looked into greater depth. This chapter discusses only the health and safety strand.

Strategy—organisational visions and objectives: as part of the strategy in any organisations H&S is paramount and must be considered. The starting point is to have a vision and objectives from the leadership team. Discussions reveal that there was no H&S policy document as part

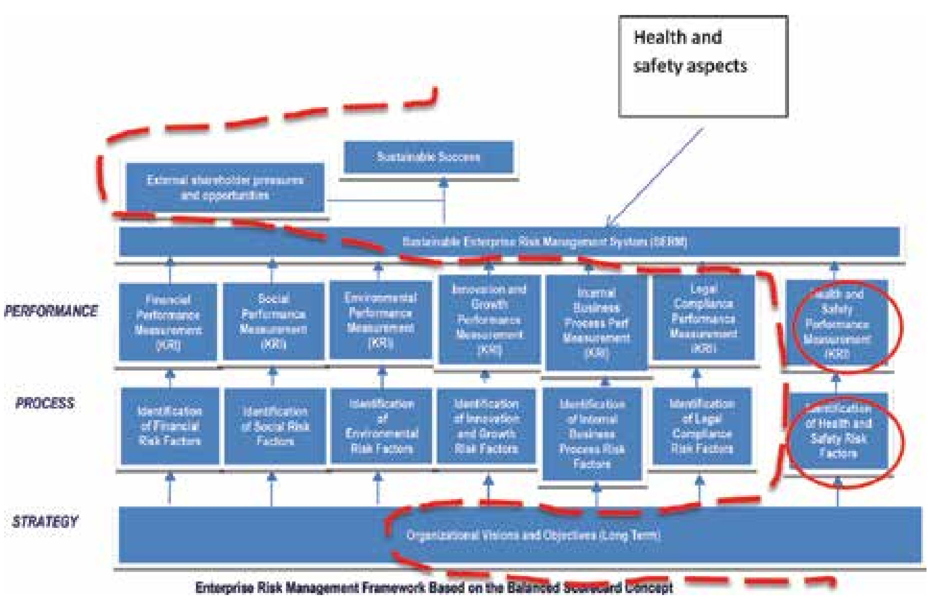

Figure 5. Enterprise risk management with health and Safety.

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of the company strategy but they were following aspects on H&S within the company and in its projects. Henceforth a health and safety policy was developed and provided to the company. The policy had general and specific aspects. The nine general aspects included:

1. to provide adequate control of the health and safety risks arising from our work activities
2. to consult with our employees on matters affecting their health and safety
3. to provide and maintain safe plant and equipment
4. to ensure safe handling and use of substances
5. to provide information, instruction and supervision for employees
6. to ensure all employees are competent to do their tasks, and to give them adequate training
7. to prevent accidents and cases of work-related ill health
8. to maintain safe and healthy working conditions
9. to review and revise this policy as necessary at regular intervals

Specific aspects must relate to who takes the responsibilities (a named person within the organisation); Arrangements for Health and Safety Risks Arising from Work Activities; Consultation with Employees; Safe Plant and Equipment; Safe Handling and Use of Substances; Information, Instruction and Training; Competency for Tasks and Training; Accidents, First Aid and Work Related Ill-Health; Emergency Procedures, Fire and Evacuation; Monitoring (ensure safe working practices are followed). This partially agrees with Warren [6] who states 8 ways in which safety in the construction sector can be improved:

1. Ensure equipment has been correctly assembled and installed
2. Make sure that all equipment is properly maintained and regularly checked
3. Avoid working at height where possible and find ways of decreasing it
4. Keep all walkways, stairs, and work areas clear of debris and obstructions
5. Make sure that all materials are stored away safely
6. Provide staff with protective equipment and make sure they can use it correctly
7. Ensure all employees are appropriately trained
8. Ensure all workplace tasks are risk assessed

The H&S policy provided to the small company is comprehensive as it takes into account Safe Handling and Use of Substances; Information, Accident reporting, First Aid and Work Related Ill-Health; Emergency Procedures, Fire and Evacuation; Monitoring. The next step within the ERM is to look into the process of health and safety which in discussed in the following sections.

7. Process within the ERM system: identification of health and safety risk factors

In Italy it is based on the type of client. If it is a public sector client then Health and Safety is considered separately and the cost of the project for construction is separate. Therefore there is no negotiation on the H&S aspects whereas the cost on the construction activities could be negotiated. For example if the total cost of the project is one million Euros the cost allocated for H&S is 50,000 Euros and 950,000 Euro for the construction phase. 50,000 Euro is fixed and must be used for H&S aspects whereas there is room for negotiations in 950,000 Euro say 10–20%. In the case of private client it is a lump sum contract and the cost of health and safety is included in the total cost of project at the tender stage.

When the contract is awarded and the site is to set up there is a checklist that could be used in the construction phase to make sure aspects of health and safety are considered. This can be a document which is based on knowledge gained from previous projects. In the case study company each project has a risk assessment H&S file which identifies project specific risks and also suggests methods to mitigate risk. The issue lies whether the labours on site are able to read and write to understand the risk assessment document.

The project level has to be linked to the company level. Therefore, based on the literature review and focus group with three members (CEO, Senior project manager, project manager) in the case study company 38 risk factors were identified (**Table 2**).

This list was given to the senior project manager who had experience as developer, planner, contractor and working for a company populated the matrix. Prior to that, they have to understand the risk scale. In a scale of five the risk factors are to be identified where 1—being the least risk and 5—being catastrophic (see **Table 3**). The probability factor is not considered as it depends on the projects they are involved. Also the relationship of the risk factors for project and the company was asked. **Table 4** is a snapshot of 13 factors of the 38 risk factors. Y means it is a risk factor. Prior to discussing the risk factors it is important to look into the role of effective leaders in this context.

Edgeman et al. [30] noted that leaders are the raw material of business excellence as well as organisational failure. Some of the causes of failure are: lack of long-term management commitment; wrong people on the team; teams do not understand their work completely; team take too much; focus on metrics rather than processes; not positioning projects within a larger strategy; misunderstanding the organisation's mission, goals and objectives. Welch and Welch [31] and McEwan [32] listed seven rules for effective leaders (see **Table 5**).

Leaders can be effective in helping those involved to think creatively and discover the possibility of achieving a win-win situation only when they incorporate the interests, pronounced or latent, from the different participating groups [33]. Thus, vision formation should result from mutual influences in the collaboration. In studying leader effectiveness, Denison et al. [34] found that the most effective leaders have styles that reflect greater complexity in their thinking and variety in their behaviours. They are able to recognise paradox, contradiction,

http://dx.doi.org/10.5772/intechopen.80697

1. Cost allocated to H&S aspects in the clients brief (CDM co-ordinator/co-ordinator)	20. Extreme task demands—example: high workloads, boring and repetitive jobs, jobs that require a lot of concentration, too many distractions
2. H&S aspects during tight project schedule	21. Social issues—example: peer pressure, conflicting attitudes to health and safety, conflicting attitudes of workers on how to complete work, too few workers
3. Checklist provided by the co-ordinator for risk assessment thorough out the project life cycle	22. Individual stressors—example: drugs and alcohol, lack of sleep, family problems, ill health
4. Checklist followed by the company for risk assessment	23. Violation of health and safety laws and regulations
5. Lack of method statement	24. Risks associated with project transport
6. Lack of DPE/PPE	25. Premises
7. Measure to prevent falling from heights	26. Defined roadways/one way system
8. Excavation activities	27. Need for reversing eliminated/minimised
9. Rebars/steel rods edge exposed	28. Roadways in good condition
10. Defective scaffolding	29. Speed bumps
11. Welfare aspects	30. Plant
12. Access to utilities (water, electricity)	31. Vehicle selection e.g. good driver access/visibility
13. Equipment condition aspects	32. Vehicles maintained in good condition—tyres/brakes
14. Equipment usage aspects—example: inaccurate or confusing instructions and procedures	33. Seat restraints fitted
15. First aid aspects	34. Reversing aids provided
16. Fire prevention measures	35. Procedures
17. Accident reporting procedures including near misses	36. Speed limits set for vehicles
18. Human error which involves mistakes	37. Vehicles chocked appropriately
19. The work environment—example: too hot, too cold, poor lighting, restricted workspace, noise	38. Reversing controlled

Table 2. Risk factors.

Scale	Classification	Explanation
1	Insignificant	Insignificant infringement of operating procedure with immediate correction, none loss
2	Minor	Low loss, <10% cost increase, <5% time increase, only very demanding applications are affected
3	Moderate	Substantial loss, 10–20% cost increase, 5–10% time increase, quality reduction requires sponsor approval
4	Major	Major loss, 20–40% cost increase, 10–25% time increase, quality reduction unacceptable to sponsor
5	Catastrophic	Enormous loss, permanent damage, >40% cost increase, >25% time increase, project end item is effectively useless

Table 3. Risk scale.

Sl. no	Welch and Welch [31]	McEwan [32]
1	Leaders relentlessly upgrade their team, using every encounter as an opportunity to evaluate, coach, and build self-confidence	Leaders should establish, implement and achieve great standards
2	Leaders make sure people not only see the vision, they live and breathe it	Leaders should be an instructional resource for your staff
3	Leaders get into everyone's skin, exuding positive energy and optimism	Leaders should create a school culture and climate conducive to learning (for everyone)
4	Leaders establish trust with candour, transparency, and credit	Leaders should communicate the vision and mission of the organisation
5	Leaders have the courage to make unpopular decisions and gut calls	Leaders should set high expectations for staff and themselves
6	Leaders probe and push with a curiosity that borders on scepticism, making sure their questions are answered with action	Leaders should develop leaders
7	Leaders inspire risk taking and learning by setting the example	Leaders should establish and maintain positive relationship with other staff members

Table 4. Seven rules for effective leaders.

and complexity in their environment, and simultaneously attend to seemingly opposing and competing requirements, such as the need for integration and differentiation, and the demand for accountability and creativity at the same time. Alternatively, Pitcher and Smith [35] examined the possibility of sharing strategic decision-making processes in teams of leaders with different leadership strengths. They concluded that top management teams that exhibit strong cognitive diversity—a balanced combination of different types of leaders—are more successful in producing long-term results, because they include diverse ideas stemming from different

Health & Safety risk factors : *There are 20 key risk factors identified for Health and Safety aspects for construction SMEs. Please put "y" in the approporiate places for the table below. KRF mean key risk factor and MRF means minimum risk factor. The risk factors for project and compnay could be marked as "x". Please see three examples provided at the bottom of the sheet. Also for influnce of KRI (key risk indicators) instructions are provided at the bottom of the table.*

	Construction company		Developer		Planner		Contractor			Connection with	
Risk factor	KRF	MRF	KRF	MRF	KRF	MRF	KRF	MRF		Project	Company
Health & Safety risk factors											
1. Cost allocated to H&S aspects in the clients brief (CDM co-ordinator/co-ordinator)		Y	Y			Y		Y		Y	
2. H&S aspects during tight project schedule	Y		Y			Y	Y			Y	
3. Checklist provided by the co-ordinator for risk assessment thorough out the project life cycle		Y		Y		Y		Y		Y	
4. Checklist followed by the company for risk assessment	Y			Y		Y	Y			Y	Y
5. Lack of method statement		Y		Y		Y		Y			Y
6. Lack of DPE/PPE	Y			Y		Y	Y				Y
7. Measure to prevent falling from heights	Y			Y		Y	Y			Y	Y
8. Excavation activities	Y		Y		Y		Y			Y	
9. Rebars/steel rods edge exposed		Y		Y		Y		Y			Y
10. Defective Scaffolding	Y			Y		Y	Y			Y	
11. Welfare aspects		Y		Y		Y		Y			Y
12. Access to utilities (water, electricity)	Y		Y			Y	Y			Y	
13. Equipment condition aspects		Y		Y		Y		Y		Y	Y

Table 5. Health and safety risk factors.

cognitive perspectives and permit a more comprehensive and creative analysis of strategic alternatives. Therefore it is necessary to have H&S measurement performance matrix.

8. Performance—health and safety measurement performance

Thiveos [36] noted that leaders with responsibilities for health and safety concerns in their organisations rely on technology solutions to manage training, certification, incidents, observations, records, documents, risk assessment, corrective actions, inspection, monitoring, auditing, and to provide results-oriented performance metrics to stakeholders. Furthermore, Kelloway et al. [37] identified the 10 different health and safety leadership actions including: expressing satisfaction when jobs are performed safely; rewarding achievement of safety targets; continuous encouragement for safe working; maintaining a safe working environment; suggesting new ways of working more safely; encouraging employees to openly discuss safety at work; talking about personal value and beliefs in the importance of safety; behaving in a way that demonstrates commitment to safety; spending time to demonstrate how to work safely; and, listening to safety concerns.

In the EC project a Balance Score Card (BSC) concept developed by Kaplan suggests that we view the organisation from four perspectives, and to develop metrics, collect data and analyse it relative to each of these perspectives were adapted. Therefore the identified health and safety risk factors were mapped with the four perspectives i.e. financial, clients, business process and learning and growth. These are further classified as: Financial (cash flow, profit, stock turnover, turnover claim); clients (client satisfaction, new client, client loyalty); business process (quality of services, number of errors; percentage of delivered project; average hourly cost of labour); learning and growth (resources spent in training; workers satisfaction; number of prestigious project; resources spent in research).

From the analysis of **Table 6** it clearly indicates that health and safety risks factors fall into learning and growth of the company within which works satisfaction is ranked as high and medium risk (8 major + 6 medium + 1 minor = 15 risk factors) followed by business process related to quality of services (5 major + 3 medium = 8) and clients related to client satisfaction (4 major + 3 medium + 1 minor = 8). Thereafter is the financial aspect (4 major + 1 medium + 1 minor = 6) related to profit followed by business process related to number of errors (2 major + 3 medium + 1 minor = 6).

It is interesting to note that financial aspects comes third whereas the learning and growth comes first therefore it does not surprise why small and medium enterprises pay less attention to health and safety aspects. Especially activities on a project or in a company are going well i.e. no accidents or fatality and/or no inspections on site. However, it is revealing that violation of health and safety law and regulations have an impact on all the four aspects of BSC (financial, clients, business process and learning and growth). This is an important finding from this case study which informs professional at site (operatives/site trainees), project and programme level (site/project/programme managers) and for leadership team (directors/board members) regarding the attention that H&S needs to be given.

		Financial	Clients		Business process			Learning and growth
Risk factor	Influence of KRI	Profit	Client satisfaction	Client loyalty	quality of service	n. of errors	% of delivered project	Workers satisfaction
2. H&S aspects during tight project schedule	4	Y			Y			Y
6. Lack of DPE/PPE	4		Y		Y			Y
7. Measures to prevent falling from heights	4	Y	Y		Y	Y		Y
8. Excavation activities	4	Y						Y
10. Defective Scaffolding	4							Y
16. Fire prevention measures	4				Y			Y
• Individual stressors - example: drugs and alcohol, lack of sleep, family problems, ill health	4		Y			Y		Y
18. Violation of health and safety laws and regulations	4	Y	Y	Y	Y		Y	Y

		Financial	Clients		Business process		Learning and growth
Risk factor	Influence of KRI	Cash flow	Client satisfaction	New client	quality of service	n. of errors	Workers satisfaction
1. Cost allocated to H&S aspects in the clients brief [illegible]	3		Y		Y	Y	Y
4. Checklist followed by the company for risk assessment	3		Y		Y		Y
5. Rebar/steel rods edge exposed	3						
12. Access to utilities (water, electricity)	3						
13. Equipment condition aspects	3	Y	Y		Y	Y	Y
15. First aid aspects	3						
17. Accident reporting procedures including near misses	3			Y			
• The work environment - example: too hot, too cold, poor lighting, restricted work space, noise	3					Y	Y
• Extreme task demands - example: high workloads, boring and repetitive jobs, jobs that require a lot of concentration, too many distractions	3					Y	Y
• Social issues - example: peer pressure, conflicting attitudes to health and safety, conflicting attitudes of workers on how to complete work, too few workers	3					Y	Y

		Financial	Clients	Business process	Learning and growth	
Risk factor	Influence of KRI	Profit	Client satisfaction	n. of errors	Resources spent in training	Workers satisfaction
11. Welfare aspects	2	Y	Y	Y		Y
14. Equipment usage aspects - example: inaccurate or confusing instructions and procedures	2				Y	

Table 6. Balance score card with high, medium and minor risk factors.

9. Conclusion

The construction sector is characterised for having the largest numbers of accidents and health deterioration among all the working sectors. Companies must also have a health and safety system which has the strategy, process and performance aspects. Irrespective of the size of the company there should be a health and safety policy. This leads to providing health and safety manual at the construction site which has the risk assessments. The companies should make sure the employees on the site are able to read and understand the associated risks which will enable them to implement it. In addition, it is important for construction stakeholders to invest in health and safety strategies.

The first step is to assess at what level the company is i.e. starting, get going, walking, running and sprinting from six building blocks. They are: commitment, workers engagement, prioritisation of H&S, compliance, measurement and organisational learning. Thereafter apply the ERM which includes strategy, process and performance to enable to achieve sustainable company success. In the case study company eight risk factors stood out of the 38 identified which had influence on financial, client, business process and learning and growth. All the eight risk factors contributed to workers/professional satisfaction. They are H&S aspects during tight project schedule; Lack of DPE/PPE; measures to prevent fall from heights; measures during excavation; using defective scaffolding; providing fire prevention measures; individual stress and violation of regulations.

http://dx.doi.org/10.5772/intechopen.80697

In small companies leadership must have health and safety policy which clearly publicise and states the values behind health and safety standards and procedures through simple ways such as posters and the repetition of goals such as everyone going home safely at night. Therefore, in conclusion leadership for H&S risk management is paramount for a survival and sustainability of small companies.

Acknowledgements

The authors would like to express their gratitude to the European Commission for granting the project and also to the company which supported us. This enabled us to write the book chapter.

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Landslide Risk Management for Urbanized Territories

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79181

Abstract

The problem of geological and landslide risk management is seen as series of events leading to risk reduction, including risk analysis, risk assessment, risk mapping, vulnerability evaluation, concept of acceptable risk, monitoring organization, engineering-technical methods, insurance, and others. The problem is investigated on the examples of Moscow and Taiwan.

Keywords: landslide, risk, risk management, risk assessment, risk reduction, monitoring

1. Introduction

The problem of landslide risk management is seen as a series of events leading to landslides risk reduction. **Natural risk** is a relatively new and not fully explored concept. There are many definitions of natural risk. Often a scientific study or a scientific approach to the problem begins with a presentation of the author's position and the choice of the definition of natural risk for the problem. This individualistic approach is difficult to avoid. Spores are carried out so far. For example, if there is a risk without material damage to people or not.

If one of the main systematic approaches to hazards research is their classification, so now also the concept of **risk management** can be considered as a new step of science development and a new basement for systematic hazards investigations.

Development of the **risk** concept demands the promotion of the methods for **risk assessment** and calculation. It makes the theory of **risk** the scientific discipline with a good mathematical background. It is necessary to elaborate common approaches to the risk calculation for different types of natural hazards. The methods of seismic risk assessment as the most promoted ones must be spread to landslides, karst, suffusion, flooding, pollution and other types of natural hazards and risks and also to complex and multirisk.

Arising from everyday life, gambling, finance, business and building the **risk** concept became the subject for scientific research and basement for systematic investigations of natural and man-made hazards and disasters.

In common sense, **risk** is the potential possibility to gain or lose something (life, health, property, money, environment, etc.). Risk situation can rise at meeting with uncertainty resulting from action or inaction. Risk is a consequence of unpredictable outcome.

In **risk-analysis** science**, risk** is considered as a measure of the probability of damage to life, health, property, money, or the environment. Risk is defined as the probability of the natural hazard event multiplied by the damage from possible consequences.

According to Corominas et al. [1]:

Risk analysis is the use of available information for hazard identification and vulnerability evaluation.

Vulnerability is the degree of loss of a given element or set of elements exposed to the occurrence of a natural or man-made hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss).

Risk assessment is considered as the process of making decision on whether existing risk is acceptable or nonacceptable and implies the risk analysis and risk evaluation processes.

Sometimes, risk assessment is considered as risk calculation on the basis of selected parameters and establishment of ranking risk criteria.

Acceptable risk is defined by the level of human and property loss that can be tolerated by an individual or community. The probability of acceptable risk is very small. The concept of acceptable risk arises from the understanding that absolute safety is an unachievable purpose.

Risk management is considered as the complete process of risk assessment and risk reduction.

Risk reduction implies some methods and measures, as legislative, organizing, economic, engineering, information and others.

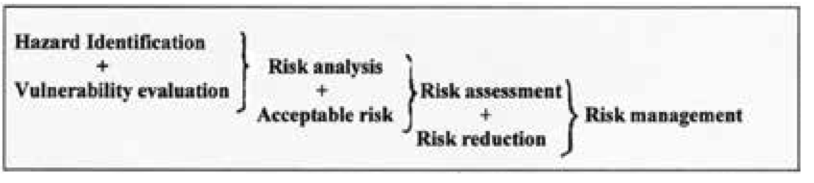
Sometimes in narrow sense, **risk management** is considered as measures for risk reduction.

In this sense, the problem of **landslide risk management** is seen as a series of events leading to landslides risk reduction and avoiding. It includes landslides monitoring, landslide forecast, engineering works, slopes strengthen, insurance and others.

Summarizing systematic approach to natural hazards research on the base of the **risk** concept, it is possible to present the next steps and scheme to establish criteria for ranking risk posed by different types of natural or man-made hazards and disasters, to quantify the impact that hazardous event or process have on population, structures and to enhance strategies for risk reduction and avoiding (**Table 1**).

Risk management
1. Hazard identification
2. Vulnerability evaluation
3. Risk analysis
4. Concept of acceptable risk
5. Risk assessment
6. Risk mapping
7. Measures for risk reduction:
Legislative
Organizational and administrative
Economic, including insurance
Engineering and technical
Modeling
Monitoring
Information

Table 1. Risk management structure.



Relationships between main items of risk concept for systematic approaches to natural hazards and disasters research.

According to the most common definition, the risk is the probability of the natural hazard event multiplied by the possible damage:

$$R = P \times D \tag{1}$$

where R is risk, P is probability, and D is damage.

For multirisk assessment, it is possible to use sum of risks of different hazards:

$$R = \sum R_i \tag{2}$$

For risk maps construction, it is necessary to use the natural hazards maps and maps of possible damage. These maps can be of local, regional, federal (sub-global), and global levels.

Landslide is a major geological hazard, which poses serious threat to human population and various other infrastructures such as highways, rail routes, and civil structures such as dams, buildings, and others.

Landslides occur very often during other major natural disasters such as earthquakes, floods and volcanoes.

The word “landslide” represents only a type of movement that is slide.

However, it is generally used as a term to cover all the types of land movements including falls, creep, spreads, flows and other complex movements.

A correct term to represent all these movements may be “mass movement” or “mass wastage.” However, the term “landslide” has been accepted and is being used commonly around the world as a synonym of “mass wastage.”

Some main aspects of landslides risk management are considered.

2. Landslides risk assessment and mapping

Geological risk mapping is an important step toward solving the problem of natural risk management [1, 2]. Due to the complexity and diversity of the problem, the combination of probabilistic and deterministic approaches and expert estimates arises.

The probability of landslide process depends on the stability of the landslide slope, trigger mechanisms (precipitation, earthquakes), technological factors. The first step is studying the physical and mechanical sliding process at different conditions. Nevertheless, the landslide process mechanics is still not fully understood. Landslide prediction is not always possible. Even statistical frequency of landslides activation for a particular area varies very widely.

An example to be considered is the approach to the construction of the landslide risk map in the territory of Moscow.

2.1. Study area

Landslide processes in Moscow are well investigated [3–21]. Landslides cover approximately 3% of the city, where there are 15 deep and a lot of small landslides, and the landslide hazard is mapped. Last years in Moscow, there is a significant activation of landslide processes. To assess the landslide hazard, the height of the slope, the landslide body volume, mass velocity, rock properties, topography of the surrounding area, the range of possible promotion landslide masses, hydrogeological conditions and trigger mechanisms have to be taken into account. Selection of taxons (special areas) varying degrees of landslide hazard in the city is completely solvable task. Gradation is possible as in the three degrees of danger (high, medium, low) as in five ones (very high, high, medium, low, not dangerous), depending on the detail of the task.

The most expensive land and buildings in Moscow are located in the city center, where there are also the oldest historic buildings, the most vulnerable to natural hazards, and the most expensive new ground and underground construction, subway lines, complex traffic, and technical communications of high density. There is an increased density of population. We can assume that the closer to the center of Moscow, the greater the potential damage from possible landslide process.

Hazardous industrial production brought to Moscow's periphery. But the protected zone of Moscow on the Vorobyovy Hills and in Kolomenskoye also has high cultural value, and the potential damage there is highly evaluated. Therefore, a first approximation map of landslide risk in Moscow may be an overlay of landslide hazard maps and population density, building density, land prices, density of roads and infrastructure maps. Areas with the highest degree of landslide hazard and the highest damage are the areas of the highest landslide risk in the territory of Moscow.

The methodology for risk evaluation and mapping is suggested in the following paragraph.

2.2. Methodology for landslide risk mapping

For the automated analysis of the factual material and the risk maps construction, it is needed to find the intersection of the landslide hazard map and integrated map of possible damage i.e. for each i-th fragment Ri of risk map to find the product of probability Pi of landslide event to the amount of different j-th possible damages from landslides, that could be damage to land, to buildings, to transport, to communications, to people and others:

$$R\,i = P\,i\ \sum j\,D\,ij \tag{3}$$

Maps of landslide hazard are necessary calibrated from 0 to 1, to reflect the probability of landslide events ($0 \le P \le 1$). Thus, gradation, for example, is possible on a scale of (0; 0. 25; 0.5; 0.75; 1), where 0 corresponds to no danger of landslides, 0.25 - low, 0.5 - average 0.75 - high and 1—a very high probability of the landslide process. This assessment is an expert in nature. In principle, it is possible to construct the landslide hazard maps as the intersection of maps of factual material, such as map of relief contrast, rock strength, slope stability, speed of motion of the surface, the density of rainfall, seismicity, and so on. Of course, this will require additional research and evaluation.

For a comprehensive assessment of the damage in each region, it is suggested to calibrate the possible damage of each option on a three-point system (0, 1, 2), where 0 means no damage, 1 is middle, and 2 is high damage. The parameters here are, for example, (1) cost of land, (2) cost of housing, (3) density of buildings, (4) population density, (5) density of roads and communications. The higher the value (the value of land, housing, etc.), the greater is the damage in case of a hazardous event.

Then, the possible damage to five parameters for each element varies from 0 to 10.

The risk also in each element ranges from 0 to 10. This is the risk in relative terms (high-low), on a 10-point scale.

$$D\,i\ = \sum j\,D\,ij,\ \ j = 1-5,\ \ D\,ij\ = (0,1,2),\ \ 0 \le D\,i \le 10, 0 \le R\,i\ \le 10. \tag{4}$$

After defeating the map of the area into squares and calculating the risk for each square, you can get a map of the area at risk on a 10-point scale.

On the basis of preliminary expert estimates, it will be the areas in the vicinity of Moscow River and Yauza River, as well as in the areas of contrasting relief along riverbeds of paleorivers in the city center.

The places of high landslide risk are Andronievskaya embankment (**Figures 1** and **2**), Nikolo-Yamskaya embankment (**Figure 3**), Kotelnicheskaya embankment (**Figure 4**), and Samotechnaya street (**Figure 5**) in the center of Moscow.

The places of the highest landslide risk are Vorobiovy Mountains (Hills) (**Figures 6** and **7**) and Kremlin Hill (**Figures 8** and **9**). They are shown as white circles in the map of geological danger in Moscow (**Figure 10**).

These areas may be considered as "hot spots" on the risk map. Even though in some of these areas, the population density is not so high, the other components (cost of land, the historical

Figure 1. Andronievskaya embankment with Svjato-Andronikov monastery.

Figure 2. Cracks near Svjato-Andronikov monastery.

Figure 3. Nikolo-Yamskaya embankment.

Figure 4. Kotelnicheskaya embankment.

Figure 5. Samotechnaya street.

Figure 6. Vorobyovy Mountains with Moscow State University, ski-jumps and metro-bridge.

Figure 7. Vorobyovy mountains with building of Presidium Russian Academy of Sciences (RAS), Andreevsky monastery and new living houses.

Figure 8. Kremlin embankment.

Figure 9. Center of Moscow with Kremlin Hill and Moscow River.

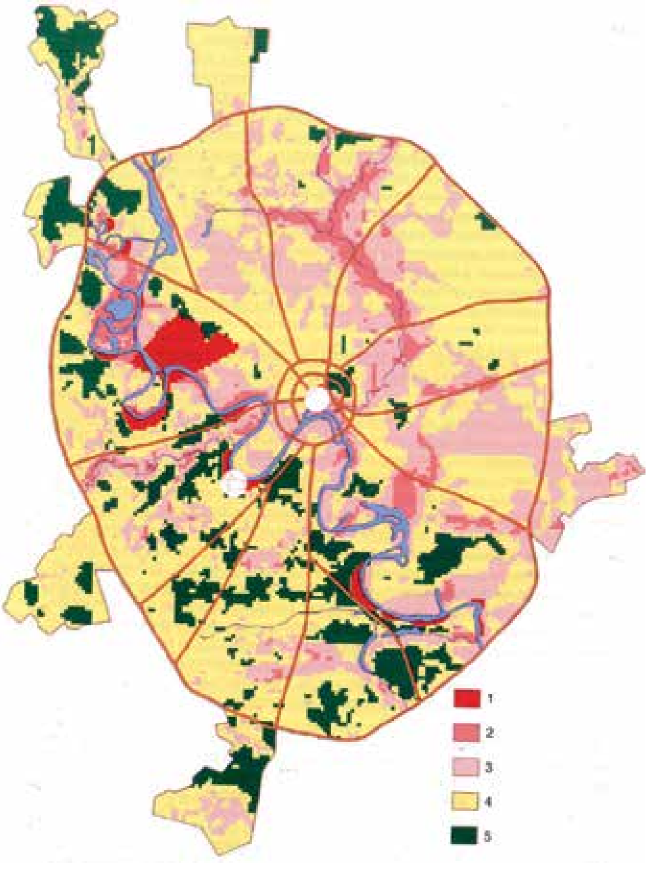


Figure 10. Map of geological danger in Moscow. Landslides, karst, underflooding (Osipov et al. [3]). Landslides are near rivers in semidark (red and pink); 1—very high danger, 2—high, 3—middle, 4—low, 5—no; white circles—risk "hot spots"; Kremlin Hill (center) and Vorobyovy mountains (southwest).

Figure 11. Cosmic photo of Moscow at night.

importance of the object, the density of underground utilities and others) give a great contribution to the high risk assessment.

These areas must be at measures for risk management and reduction at the first line. It means monitoring organization, slope strengthen, ban of extra buildings and activity.

As an additional fact, it is interesting to use night cosmic and aero photos of Moscow that reflect the density of communications and possible damage (**Figure 11**).

3. Monitoring organization for debris flow: a case study of Taiwan

Taiwan is located on the edge of Eurasian Sea Plate and Philippine Sea Plate. The maximum length and the average width of Taiwan is about 395 and 144 km, respectively. The total area is about 36,000 km^2. The mountains in Taiwan are high and steep, and the terrain is highly variable, as well as the elevations. (Taiwan's highest point is Yu Shan, also called Jade Mountain, which is at 3952 m). In Taiwan, the plains are narrow, which is only occupied with one-third of Taiwan. Earthquakes occur frequently in Taiwan. The rainy season in Taiwan is caused by rainfall along a persistent stationary front between spring and summer; and typhoons are influencing Taiwan mostly in the summer and autumn. The annual average rainfall is more than 2500 mm.

There is abundant rainfall in Taiwan. Variable rainfall duration and intensity lead to floods and debris flow disasters [22–30] (**Figure 12**).

Since the 1999 Chi-Chi earthquake (ML = 7.3) occurred (earthquake 921), the frequency of the disasters, which are caused by landslides, complex landslides, debris flows and soil erosion, has increased more than before.

The 921 earthquake (ML = 7.3) took place in central Taiwan on September 21, 1999. A 195-ha slopeland was devastated by a gigantic rock avalanche, called the Chiu-Fen-Erh-Shan (Chiufengershan) landslide, near the Nankang village of Kouhsing in Nantou County during the earthquake; the slid materials blocked the confluence of two streams leading to the formation of two landslide dams (**Figures 13** and **14**).

Figure 12. Landslide after rain in 2010, Taiwan.

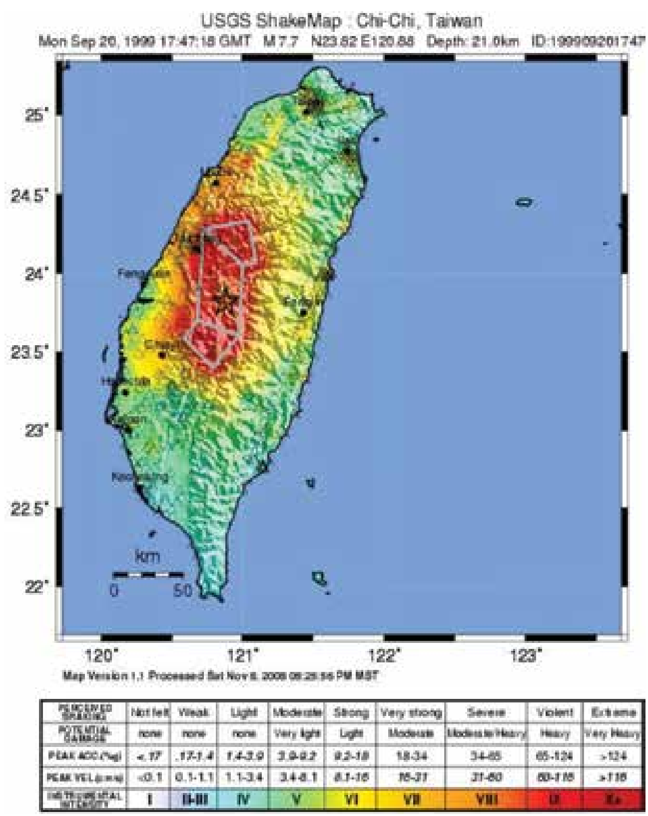


Figure 13. USGS ShakeMap for the 921 earthquake.

Further monitoring and hydrology studies on landslide area became necessary for landslide management. Thus, a project for monitoring the Chiu-Fen-Erh-Shan landslide began in 2003. It includes:

1. landslide dams water-level monitoring;
2. post-failure behavior simulation;

Figure 14. Chiufengershan landslide after 921 earthquake in Taiwan.

Figure 15. The equipment at the Fengqiu Debris Flow Monitoring Station include one rain gauge, two CCD cameras, two geophones, four wire sensors and one water-level meter.

3. morphological fluctuation using light detection and ranging (LiDAR); and
4. long-term monitoring using photogrammetry images.

Figure 16. The equipment at the Shang'an Debris Flow Monitoring Sstation includes one rain gauge, one CCD camera, one geophone, two wire sensors and one water-level meter.

Figure 17. The equipment at the Songhe Debris Flow Monitoring Station includes one rain gauge, two CCD cameras, two geophones and eight wire sensors.

The post-failure behavior and impact area of Chiu-Fen-Erh-Shan slope along the inferred sliding surface were investigated by using the method of discontinuous deformation analysis (DDA).

In order to prevent life and economic losses due to landslide, complex landslide, debris flows and soil erosion, the Soil and Water Conservation Bureau (SWCB) has aimed at debris flow disaster management and early warning operations and begun the construction of debris flow monitoring station and Formosa Emergency Management Action System (FEMA) since 2000. Satellite imagery, geographic information, high-end communications and sophisticated monitoring technologies have been implemented and integrated in the system. (**Figures 15–17**). SWCB is keen on the international exchanges for debris flow disaster prevention.

4. Engineering and technical methods: debris flow management

4.1. Source management

To reduce the amount of sediment material, source management is very important. Different engineering methods are utilized according to the terrain and its recent history.

Large amounts of water is one of the main factors that cause debris flows, so excess water must be eliminated to the fullest extent possible. This can be done using inbuilt drainage pipes in stream beds or in slopes to divert groundwater.

Runoff with a thick deposition layer can easily induce debris flow. Often, rocks are set in stream beds to capture sediment from the water and prevent further sediment from being lifted, reducing the risk of debris flows.

Cleaning unstable depositions in and around streams such as rocks and logs as well as overhanging braches prevents the obstruction of a debris flow, which can cause the debris to build up and then burst, creating a more dangerous situation.

4.2. Transportation stage management

Engineering and re-vegetation can lower the velocity of debris during the transportation stage of debris flow, and thus to reduce the damage caused by debris flow.

The velocity of debris flow is closely related to the slope degree. In order to lower the velocity, check dams or submerged dams are used to increase the roughness of the streambed. This allows accumulation of sediments, making the slope gentler, decreasing the velocity of debris flow.

Debris flows contain a lot of water that allows it to move fluidly. If the water and sediments are separated, the debris flow will slow down. Check dams can reduce the velocity of debris flow while horizontal grates allow sediment and water to be separated, stopping the debris flow (**Figure 18**).

Figure 18. The debris flow dehydration.

In order to prevent the accumulation of debris in valleys, check dam are used to accumulate sediments more efficiently.

4.3. Deposition stage management

When the debris flow comes to flat areas, the accumulation of sediments often causes riverbed siltation, elevating the riverbed. It is necessary to dispose of this sediment effectively.

The velocity of debris flow will slow when it reaches a gentler slope. Check dams are set in broad, flat terrain to form deposition areas, adjusting the slope and stabilizing the streambed.

Using debris or concrete cofferdams to form deposition areas allows safe debris accumulation. They are often located on flat, broad areas such as alluvial fans, usually about 30–40 m wide and located close to valleys.

Setting forest buffer zones in outlets help stop debris flow and contribute to debris accumulation.

If the outlet is not wide enough for debris flow accumulation, diversion dams or artificial channels are used to lead debris flow to a safer place to discharge.

5. Conclusions

Risk management is an important way to risk reduction. The main aspects of landslides risk management could be considered as landslides risk assessment and mapping, landslides monitoring and engineering methods for slope strengthen, water discharge and rational land use.

The problems of risk assessment, monitoring and engineering methods for risk reduction as parts of risk management concept are considered and analyzed.

Methodology for landslide risk assessment and mapping at urban areas is elaborated. The construction of landslide risk map in the territory of Moscow is suggested. Engineering-technical methods for landslide risk reduction are considered for Taiwan landslide areas.

The case studies for Moscow and Taiwan are presented.

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Edited by Chike F Oduoza

This book "Risk Management Treatise for Engineering Practitioners" has been published by academic researchers and experts on risk management concepts mainly in the construction engineering sector. It addresses basic theories and principles of risk management backed up, in most cases, with case studies. The contributions for this book came from authors in Europe, the Far East and Africa, and it is hoped that the contents of this book will be useful to anyone interested in understanding the principles and applications of risk management, especially within the construction engineering sector. Researchers and postgraduate students in science and engineering disciplines, especially those interested in project management, will find this book useful.

Published in London, UK

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ISBN 978-1-83881-237-9