APPLICATION OF A RISK VISUALIZATION FRAMEWORK USING SEMANTIC RISK DATA TO EMPOWER RISK COMMUNICATION

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ABSTRACT

APPLICATION OF A RISK VISUALIZATION FRAMEWORK USING SEMANTIC RISK DATA TO EMPOWER RISK COMMUNICATION

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Risk communication is one of the major factors that effects the success of a project. Conventional risk management focuses on risk checklists and matrices, and considerable amount of risk information is discarded and not communicated. Without communicating the necessary risk information, risk management strategies cannot be applied effectively. The purpose of this study is to develop a systematic and practical risk visualization framework that shall improve the risk communication strategies. The proposed framework is the demonstration of practical applications in construction sector as the communicated information depends on many different factors that can vary between companies. The demonstration of application of such framework starting with determination of nine commonly used types of risk- related semantic data from the literature. After determination of those types, the risk visualization methods that exists in the literature are identified and the selected types of data are integrated to those methods by considering visualization design guidelines. In order to demonstrate the iterative manner of development of risk visualizations that enhances risk communication, a workshop is prepared, and six sector practitioners are invited. The workshop consists two stages, pre- and post-presentation of visualizations. Participants are asked to rate the necessity of selected types of risk-related semantic data and the prepared risk visualizations in terms of four different aspects through a survey. In the end, the importance and value of risk visualization has been verified via the workshop and according to participant comments, visualizations are revisited, and necessary revisions are made.

Keywords: Risk Management, Risk Communication, Risk Visualization, Risk Visualization Framework

ÖZ

RİSK İLETİŞİMİNİ KUVVETLENDİRMEK İÇİN ANLAMSAL RİSK VERİSİNİN KULLANILMASI AMAÇLI OLUŞTURULAN RİSK GÖRSELLEŞTİRME ÇERÇEVESİ VE UYGULAMASI

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Risk iletişimi bir projenin başarısındaki başlıca önemli faktörlerden biridir. Geleneksel risk yönetimi risk kontrol listelerine ve matrislerine odaklanmakta olup, kayda değer miktarda risk bilgisi aktarmamaktadır. Gerekli risk verilerini ilgili paydaşlara aktarmadan risk yönetim stratejileri etkili bir şekilde uygulanamamaktadır. Bu çalışmanın amacı, risk iletişimini geliştirmek amacıyla sistematik ve pratik bir risk görselleştirme çerçevesi oluşturmaktır. Önerilen çerçeve inşaat sektöründe risk görsellerinin geliştirilmesini amaçlayan bir uygulama olup şirketler farklı yapılar gösterebileceğinden dolayı çerçevenin düzeni ve sırası değişebilir. Geliştirilen çerçevenin uygulaması literatürde ortak olarak kullanılan dokuz farklı anlamsal risk veri tipinin belirlenmesiyle başlamaktadır. Bu tiplerin belirlenmesinden sonra, literatürde risk görselleştirmesi için kullanılan yöntemler belirlenmiş ve seçilen anlamsal risk veri tipleri bu görselleştirme yöntemlerine, görselleştirme tasarım kılavuzları çerçevesinde entegre edilmiştir. Böyle bir süreçte görsellerin geliştirilip uygun hale getirilmesi için paydaşların geri dönüşüne ihtiyaç duyulmaktadır. Uzmanların geri dönüşü için bir risk görselleştirme çalıştayı yapılmış ve sektörde aktif olarak çalışan altı uzmanın katılımı sağlanmıştır. Çalıştay iki aşama olarak yapılmış olup görselleştirmelerin sunumundan önce ve sonra olarak ikiye bölünmüştür.

Katılımcılardan seçilen anlamsal risk veri tiplerinin gerekliliğini ve hazırlanan görsellerin dört farklı açıdan değerlendirilmesi istenmiştir. Bu değerlendirmeler bir anket üzerinden yapılmış olup görsellere verdikleri ek yorumlar not edilmiştir. En sonunda, risk görselleştirmesinin önemi ve kattığı değer çalıştayla birlikte doğrulanmış ve katılımcıların yorumlarına göre görselleştirmeler tekrar ele alınarak, önerilen değişiklikler yapılmıştır.

Anahtar Kelimeler: Risk Yönetimi, Risk İletişimi, Risk Görselleştirmesi, Risk Görselleştirme Çerçevesi

Dedicated to my beloved family

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CHAPTER 1

INTRODUCTION

1.1. Motivation of the Study

Traditionally, risk management is a well-known area where expert information and previous experiences are the two of the key factors to address the problems that are faced during the lifetime of a project. Risk management is an area of teamwork and communication and in the case of a decision-maker to analyze the risks, the importance of communication of risk information becomes prominent. Being one of the most critical branches in a project, risks shall be dealt with as a team where all parties that are involved should act together and communicate to transfer the risk information.

Risk communication is an important step for successful risk management. Although the importance is well-known, most of the practices and studies do not focus on an effective methodology to improve risk communication. The traditional risk management methodology focuses on the subjective risk ratings of decision-makers which in the end becomes a qualitative process. While determining the ratings, the experts uses past experiences to rate the risks and to come up with a risk context. In the end, the probabilities and impacts of risks are determined according to the person who prepares the ratings and the risk information such as assumptions are not communicated with decision-maker. During traditional risk assessment processes, some raw data and expertise information have been counted as redundant and have not been reported. When it comes for a decision-maker to act and handle a situation, the lack of such data might lead to uninformed decision making. Traditionally, risks in a project are communicated through risk matrices. In these matrices, the risk scores are identified through judgements of risk experts and represented as qualitative data.

The visualization improves understanding and helps decision-makers (Gershon and Eick 1998). While the information visualization and cognitive science domains focus on improving visualizations (Kelleher & Wagener, 2011) various studies are performed to apply the visualizations in their field and evaluate their effectiveness (Chung et al., 2020; Lam et al., 2012). Risk management area needs that too (Eppler & Aeschimann, 2009).

When the concern is risk visualization, many methods are introduced in sector and literature. Starting from the probability-impact matrices (El-Sayegh, 2008; Elsawah, Bakry, & Moselhi, 2016), Bayesian Belief Networks (BBN) (Luu, Kim, Tuan, & Ogunlana, 2009), risk maps , fault trees (Abdelgawad & Fayek, 2011) and many other techniques have been used which mostly focus on the visualization of the results. On the other hand, some of the existing techniques focus on cause-effect relationships like bow-ties (Mokhtari, Ren, Roberts, & Wang, 2011). A more recent point of approach in civil engineering has been the new location-based visualization assessment methodologies led by Building Information Modelling (BIM).

Despite the many advantages of traditional risk management methodologies, most of these techniques cause loss of raw data. In other words, these applications of construction risk management mostly focus on results, cause-effect relationships and spatial analysis. They do not include different types of risk-related semantic data such as owners of the risks, related contract clauses, relations of the risks and so on. While reporting such data, the communication of relevant data for the decision-making process is important. The beneficial data should be communicated to responsible party so that it can be supportive to decision-maker. Hence, contextual risk data should be represented and transferred through effective visualization methodologies.

In risk management, different methodologies such as risk checklists and matrices are used to analyze the data and come up with an appropriate choice of action. As the area of risk management involves many different stakeholders, the prepared risk management plans should address multiple parties. Thus, the visualization of the data is very important to interpret and come up with efficient decisions considering the integrity of these parties. In addition, due the number of stakeholders and their varying needs, the usability of the visualizations depends on many different factors. Therefore, in the end, the effectiveness of the visualization depends on the visual technique methodology and cognitive style of decision-makers (Engin & Vetschera, 2017). The same study also states that including different visualization techniques such as graphs and tables instead of using only one, will prevent the misinterpretation of information. Thus, the adoption of a variety of visualization methodologies can enhance the decision-making process.

For this purpose, a risk visualization framework that can be applied for practical applications in the sector is aimed to be designed. Risk management processes include many different stakeholders and types of data. A framework that aims to address practical demands should include different steps to identify the needs and produce an output that is effective for decision-makers. Such a framework shall be an iterative flow to gather feedbacks from target parties. Such a framework should guide the risk practitioners towards to most effective ways of visualizing risk-related data.

1.2. Research Questions

RQ1-) How a risk information communication framework can be applied to risk communication processes?

This study initially tries to answer the question of what the components of a risk visualization framework should be. Then, it asks how to use the framework within the existing risk management and communication processes.

RQ2-) How the project risk information should be visualized to increase the effectiveness of risk communication?

The risk communication framework developed as a result of RQ1 is used to develop a scenario to assess the preferences of risk experts for the visualization of risk data. This question has, in fact, two subquestions.

RQ 2.1. What types of risk-related semantic can be included in risk assessment methodology to improve the effectiveness of the risk communication between project parties?

This question is designed to understand the additional needs of decision-makers in terms of type of risk information transferred for effective decision-making.

RQ 2.2. What are the preferences of risk experts for representing semantic risk data via visualizations that are not included in traditional risk assessment methodology?

This question is designed to understand whether a set of visualizations can improve the risk communication of risk experts.

1.3. Objectives

The objectives of this study are as follows:

1. The first objective is to prepare a risk visualization framework that can be used for practical applications in the construction sector. The framework is designed to represent the requirements for the preparation of risk visualizations for decision-makers. The application of such a framework shall include iterative steps to improve the effectiveness of prepared visualizations.
2. The second objective is to evaluate the effect of visualization on risk communication. With the goal of addressing this objective, the developed framework is used to design a workshop session. The purpose is to obtain feedback from a number of risk experts on the need for visualizing semantic risk information. To prepare the risk visualizations for the workshop, a literature survey is performed and prominent types of risk-related semantic data are identified. After the determination of types of risk-related semantic data and visualization methodologies, the risk visualizations are prepared by applying the steps of the framework. Six participants are invited to the workshop, who are risk and management professionals in the sector with different backgrounds. A survey is conducted in addition to acquiring oral

feedbacks to gather the thoughts of participants. In the end, revisions are done on the prepared visualizations to demonstrate the iterative step of the framework.

1.4. The Scope and Outline of the Thesis

This study presents a demonstration of a practical risk communication framework. The prepared framework is designed to form the basis of representing risk visualization requirements as a template. Chapter 2 of the study presents the literature review on risk communication, risk visualization framework, project risk and construction risk visualization, and the types of risk-related semantic data, Chapter 3 explains the research methodology. In this chapter, flow of the study is given in addition to explanation of the preparation of risk visualization framework, risk information communication workshop and the components of the workshop. Chapter 4 presents the findings of the study. The development of the risk visualization framework is given as well as the examples for the framework. The selected types of risk-related semantic data are integrated to selected risk visualization methods and presented to sector practitioners. The participants. The feedbacks of participants are used to reiterate the presented risk visualization methods and given at the end of the chapter. Chapter 5 is the conclusion where the findings are summarized, practical implications limitations and future work are given.

CHAPTER 2

LITERATURE REVIEW

Throughout the years, the area of management has been using historical data, previous information and documents, and expert opinion to overcome and solve crucial problems. Risk management is a well-defined process in project management body of knowledge (PMBOK 2008; ISO 31000:2009). The successful identification of risks is an important step that affects the performance (Eybpoosh et al. 2011; Jung and Han 2017; Liu et al. 2016; Qazi and Dikmen 2019) of risk management. For this reason, researchers and experts have been in search of ways to deliver information in a fast and accurate manner. Even though there are many studies on the identification of risks in construction projects, the way the risk information is communicated is a less focused topic. As the area depends on different parties and expertise information, the search for new ways directed the professionals and researchers to come up with various types of data representation methodologies. Visualization is one of the significant means of data representation and many different methods have been suggested and used among management professionals. While keeping every project participant informed from the situations by communicating through information, visualizations are applied for effective decision-making and problem-solving. Thus, risk communication is a major part of risk management for actors to analyze the situation together and act accordingly.

The traditional methodology of risk management focuses on qualitative data that is prepared by expert knowledge using the probabilities and impacts of the risks. Risks are classified from the gathered data and reported through a probability-impact matrix. Although this methodology is used for many years effectively, the approach lacks a lot of risk-related semantic data. The information that risk experts use to come up with such scoring of risks is not presented in those matrices, where a decision-maker can make use of such information. Hence, the context within which the risks are identified is not communicated to decision-makers.

Visualization is the exhibition of raw or processed data by texts, numbers, symbols, tables, or graphs while keeping the cohesion of the data. It can be considered under three stages; (a) representation, (b) presentation, and (c) interaction (Spence 2014). In other words, the data to be represented is molded through a methodology and presented to the intended audience. Information visualization fosters many benefits including learning, new insights, perception and decision-making (Eppler and Aeschimann 2009; Gershon and Eick 1998). One of the most important subsets of information visualization is expertise information visualization. Within the scope of expertise information visualization, knowledge of the experts is delivered to decision-makers, where they can understand, interpret, and use the information when necessary. Expertise information visualization is a necessity in the areas where expert information is the key factor to succeed. In other words, the area of management requires robust and accurate decisions using historical data, knowledge, documentation and expert opinions. When it comes to risk management, risks are interpreted and acted upon the way they are perceived. Hence, representation, visualization, and communication of risks become an integral part of risk management.

If the necessary information is available, it is expected for decision-makers to be able to make informed and better decisions. Of course, decision making is limited by the cognitive capacity of decision-makers. The presented information should match the capability of decision-makers (Vessey 1991) for the problem-solving process to be facilitated. If a decision-maker has too much information to process, the cognitive capacity may limit the decision-making capabilities, and information might be misleading (Zhu and Chen 2008). Thus, the decision-making process depends on the decision-maker, what type of information is delivered and how it is presented. Such effects of using different risk-related semantic data represented via visualizations to empower risk communication shall be studied and investigated.

Chapters 2.1, 2.2, 2.3 and 2.4 include the literature review on risk communication, project management risk visualization, risk visualization framework, and risk-related semantic data.

2.1. Risk Communication

Risk communication has been stated as an important factor in risk management processes for many years. Vrouwenvelder et al. (2001) stated that to come up with a decision, parties that are involved in a project should communicate. Even if the risk assessment processes are perfect in terms of technical features, without risk communication, it is not enough for parties to come up with an agreement. Perrenoud et al. (2017) indicated many contractors fail to apply risk communication. Even though a foreseen risk occurs, without risk communication, decision-makers can think of it as an unexpected one and try implementing different management strategies.

In order to solve issues with risk communication, numerous methodologies have been suggested in the literature, and some others are applied in the sector. Hall et al. (2001) proposed a software-based risk management system. The study focused on a risk register based software tool that can enhance risk communication through the supply chain of the construction sector. Zhao et al. (2014) worked with three firms in order to learn their risk management styles. These firms have been communicating risks through monthly meetings, e-mails, quarter and annual risk reports and risk information databases. Risk communication has been considered very important, and different methods can be applied to enhance it. Goh et al. (2012) ran a risk workshop in order to collect data while communicating risks and helping the actors for team building. The workshop aimed to implement the risk management processes on a project. The study stated that at some point, risk communication has failed and the workshop reports were not delivered to all participants, failing to achieve expected contributions to the risk management processes. To solve the problem of communication, the necessary documents which include required data should be delivered to responsible parties. Burkhard (2004) stated that visualization is effective to transfer the knowledge to coordinate and communicate. As risk communication is a problem of expertise information transfer, visuals that are prepared for risk data can be effective in enhancing communication. The traditional methodology where the risk probabilities and their impacts are focused and reported is not sufficient when different types of data should be delivered.

2.2. Visualization in Construction Management and Risk Management

Teets et al. (2010) stated that small-scaled problems could be solved with simpler information, while more complex situations require more types of data for robust interferences. The management area includes a variety of stakeholders and work packages, which are mostly related and highly dependent on each other. For that reason, cognitive and causal maps, network analysis, and other map structures are mostly preferred in order for parties to communicate and transfer information. Edkins et al. (2007) prepared a cognitive map with a complicated and repetitive process, to classify the degrees of complexity in projects. In the end, the study discovered that most projects are similar, and the introduction of such a map structure actually aided the managers in focusing on key subjects. For the preparation of these visualizations, the richness of the data to be used is also important. Scavarda et al. (2006) stated that the causal maps that are created with the data from workshops with crowded audiences could be more efficient. While preparing the visualizations with similar types of data, it must be noted that the complexity of visualizations should not decrease the effectiveness. In contrast, the visualizations that are prepared with an uncrowded audience can result in less complex visuals but with less data, the effectiveness can decrease. In the end, the uncrowded audience consisting of experts in the area can result in less complex and highly effective visuals. Although expertise information is very effective, due to the nature of project structure, many different types of unforeseen events can occur. When necessary, expertise information is combined with scenario-based analysis, visualized and delivered to parties. Glykas (2013) introduced fuzziness to strategic cognitive maps on two different case study projects. The study stated that not only can these maps be used for decision-making processes but also for upcoming strategical planning phases.

Experience and knowledge of experts are the pillars of risk management. Decision-makers blend these two in order to come up with efficient management strategies. In the end, expertise information should be expanded between parties and should become the dominant source of success. Traditional methods of risk assessment, which consist of determination of probabilities and impacts of risk factors after identification of risks, have been applied in the sector for many years. This drives the actors to a risk communication gap by causing parties to focus on qualitative data and ignoring the experience-based raw data behind the construction of that qualitative data. Parties should communicate to deliver the risk expertise information effectively. For analyzing the risks, delivery of data, and visualization of risks, many different methodologies have been used. Some focused on probabilistic methodologies like Monte Carlo simulation (Sadeghi et al. 2010, Patterson and Neailey 2002) or Bayesian Networks (Špačková and Straub 2013, Sousa and Einstein 2012, Jensen et al. 2009) to analyze the risks. Some studies introduced fuzziness to probabilistic concepts (Elbarkouky et al. 2016, Dikmen et al. 2007) and to apply fuzzy risk assessment methodologies. Cai et al. (2013) measured the performance of a risk assessment method performance with a bar chart that is formed with historical data which shows the probabilities of risk occurrences. In addition to that, risk factors are delivered with Bayesian-Belief Networks. Badr and Banerjee (2013) integrated fuzziness to traditional risk methodology and prepared a concept map in order to determine the risks. Kremljak and Kafol (2014) used the data gathered from expert knowledge to ease the process of the decision-making process and formed tornado graphs to report risk sensitivity and scatter graphs to report the probabilities of incomes. Soebandrija and Hendryvan (2015) visualized the risks that might come up during risk management processes. In order to project the additional costs of such occurrences, expertise information was used to identify such risks. The study offered a color-coded risk matrix and risk map to visualize and deliver the data. Wu et al. (2015) collected expertise data from interviews in order to visualize the risk dependencies on a matrix and formed a hierarchical tree to come up with a risk map. Vianello et al. (2016) analyzed the risks with different methods by using the data from different databases and visualized the results in different matrices. The study stated that such quantitative approach is complex and can be time consuming but might be useful and necessary. Bucovetchi et al. (2017) visualized the risk scores that are gathered from expert interviews with radar graphs showing the risk profiles, aiming to achieve a sustained decision-making process. Sembiring et al. (2018) categorized the risks and introduced a Bayesian Network Model to show the interrelationships of risks. The method also includes the risk measures in the proposed network model and stated that it eases the risk management at managerial level.

In general, visualization methodologies are selected depending on the type of data to be used. The main aim is to deliver the data for related parties when necessary. The civil engineering sector has been actively using Building Information Modeling (BIM) for communication and collaboration. Even though BIM can represent the information spatially, the lack of nonspatial data may be very important at decision-making stages for risk management. Zhang et al. (2013) combined expert risk data with a BIM model and formed a spatial model for risk assessment. Kang et al. (2013) visualized schedule activity risk scores on a BIM model and prepared a spatial model. Although these models have been actively used and proven to be effective when the focus is expertise information visualization in construction risk management area, the scope cannot be limited with a spatial model, and different aspects (e.g., managerial, organizational, economic risks) are required to be included for appropriate risk communication. Kimiagari and Keivanpour (2018) used bar charts to represent risk weights, risk matrices to represent the interdependencies of the risks and integrated them into a network structure to show the interdependency distances. Li et al. (2016) prepared a risk network, focusing on schedule risks and formed an interactive risk framework for information delivery. Turner et al. (2017) prepared bow-tie diagrams to report the cause-effect relationships of risks to be used as a communication tool. Xia et al. (2017)

used Bayesian Networks to visualize the risks for cost risk assessment and represented risk sensitivities with tornado graphs. As can be seen from the literature, various studies introduced different types of visualization methodologies for different stages of projects. Table 2.1 shows the visualization methodologies that are used in the management and risk management literature.

Table 2.1. Visualizations in the Construction and Risk Management Domains

Visualizations	*Risk Data*	*Authors*
Cognitive Maps	Causal Relations	Scavarda et al. (2006)
	Causal Relations	Edkins et al. (2007)
	Causal Relations	Glykas (2013)
Bayesian Networks	Causal Relations	Jensen et al. (2009)
	Causal Relations	Sousa and Einstein (2012)
	Causal Relations	Sembiring et al. (2018)
	Causal Relations	Cai et al. (2013)
	Causal Relations	Špačková and Straub (2013)
Conceptual Maps	Interdependencies of Activities	Badr and Banerjee (2013)
Building Information Modeling (BIM)	Spatial Information of Risk Factors	Zhang et al. (2013)
	Spatial Information of Risk Factors	Kang et al. (2013)
Tornado Graphs Scatter Plots	Probabilities and Sensitivities	Kremljak and Kafol (2014)

Table 2.1. (Cont'd) Visualizations in the Construction and Risk Management Domains

Visualizations	*Risk Data*	*Authors*
Color-coded Risk Matrix Risk Maps	Classification of Risks and Relationships	Soebandrija and Hendryvan (2015)
Risk Dependency Matrix Risk Maps	Risk Factors, Relationships and Causal Relations	Wu et al. (2015)
Risk Matrix	Classification of Risks	Vianello et al. (2016)
Radar Graphs	Classification of Risks	Bucovetchi et al. (2017)
Risk Network	Relations of Risks with Major Activities	Li et al. (2016)
Bow-tie Diagrams	Causal Relations	Turner et al. (2017)
Bayesian Networks Tornado Graphs	Causal Relations and Sensitivities	Xia et al. (2017)
Bar Charts Risk Matrix	Risk Weights and Risk Correlations	Kimiagari and Keivanpour (2018)

The changes in the representation of risk data do not show a specific trend over the years. While the most commonly preferred methods are Bayesian Networks and Cognitive Maps, the many different risk-related semantic data that is produced during the preparation of risk management plan such as risk scores, assumptions or related contract clauses are not shown. For the construction management domain, even though the latest trend is the use BIM, the traditional risk management methodology has not changed. In addition to those, risk scores are represented with a variety of visualizations where the effectiveness have not been evaluated. In addition, the risk-related data that is focused on the literature is not visualized through these methods. Moreover, no systematic procedure or framework has been followed in these studies for the development of such visualizations. In order to introduce a new point of view, a risk visualization framework that focuses on practical applications is needed. The needs of the decision-maker should be considered while preparing such a framework. Using a risk visualization framework that considers the possible needs, the problem of risk communication can be overcome.

For parties to communicate at every stage of the project, the data should be delivered appropriately. Information and expertise information visualizations have been widely used for many different research areas for many years. Researchers have been in the search for appropriate methods of data representation, presentation, and interaction. Vessey (1991) compared the performance of tables and graphs in different situations. The study discovered that the two are not prior to each other, but the effect of visualizations actually depends on the perception of the audience. Dragicevic and Jansen (2018), compared bar charts with plain texts while delivering information in a replication study. Although the same methodology has been used with the replicated study, same results could not be obtained. This shows that the importance of perception of the audience can change the effectiveness of a visual. In addition to the importance of audience perception, the way of presentation of visuals is also important for effectiveness. Borkin et al. (2013) stated that even though the increase in the intensity of data can cause a decrease in digestion and understandability of visualizations if the visualizations are prepared in a more “natural” manner, the opposite can be observed. The same study discovered that the complex visualization methods (matrices, networks, tree structures, etc.) are more memorable than common (bar, scatter, line, etc) ones. If the visuals are prepared according to the audience, the intensity of data does not negatively affect the effectiveness of the visualizations.

Expertise information visualization relies on the experience of the audience, who can understand, analyze, and interpret the data with existing knowledge when necessary. Eppler and Burkhard (2004) stated that such delivery of information helps to communicate and solve problems by coordinating, gathering attention, and motivating parties. Expertise information data is gathered (Huang et al. 2006) from past experiences of experts, historical documentation or expert opinions. For instance, Khakzad et al. (2017) used the data from older documents, Kang et al. (2013) gathered the expert opinions through surveys and Ackermann et al. (2014) obtained experience-based data with workshop group suggestions. Visualization of expertise information aims to reach out to the intended parties by representing the experience-based data and interact with the audience to deliver the information. In the end, by delivering expertise information to parties with visual techniques, communication between parties should become stronger.

As can be seen from different studies, many different visualization methodologies are used for the representation of risk data. In addition to that, different approaches are used to gather the data which also changes the method used for visualization. The effectiveness of visualization methodologies against each other depends on the needs and cognitive capability of decision-makers. Hence, there is a need to systematically represent the range of risk visualization approaches and the circumstances that affect their selection.

2.3. Risk-Related Semantic Data

When the concern is what to visualize, the data should be selected according to the audience and aim of the visual techniques to be formed. Throughout the years, many different data representations are included in the scope of risk management. As aforementioned, traditional methodology focuses on the delivery of *"Risk Probabilities, Impacts, and Scores."* The involvement of many different parties drives the scope of risk management to be wide enough to satisfy the needs of decision-makers. While determining the data to be represented, one of the major concerns should be the *"Success Criteria"* (Kang et al. 2013; Soebandrija and Hendryvan 2015; Turner et al. 2017) so that a field can be focused and unnecessary data can be eliminated. In addition to that, many examples which included *"Risk Interdependencies"* (Kimiagari and Keivanpour 2018; Eybpoosh et al. 2011, Qazi and Dikmen 2019) can be found in the literature, showing that such data should also be included in order to calculate the scores of risks by considering the effects on each other.

The importance of raw data, which is mostly neglected to be presented during risk assessment processes, is actually stated in the literature but not visualized. Therefore, risk communication can be intensified with the introduction of such data. *"Controllability of risks"* (Cagno et al., 2007; Fan et al., 2008), *"Risk Management Strategies and Effects"* (Han, et al., 2008; Khaled and Aziz, 2015), *"Owner of the Risks"* (Zhao et al., 2015), *"Assumptions That are Made During Risk Assessment"* (Hastak and For 2000; Shortridge et al. 2017, Dikmen et al. 2018), *"Related Contract Clauses"* (Charoenngam and Yeh, 1999; Hanna et al., 2013) and *"Time Periods of Risk Validities"*(Muriana and Vizzini 2017) are some of the data types that are referred in the literature. Several studies concentrated on the selected risk-related semantic data. The most prominent types of risk-related semantic data with related studies can are presented in Figure 2.1.

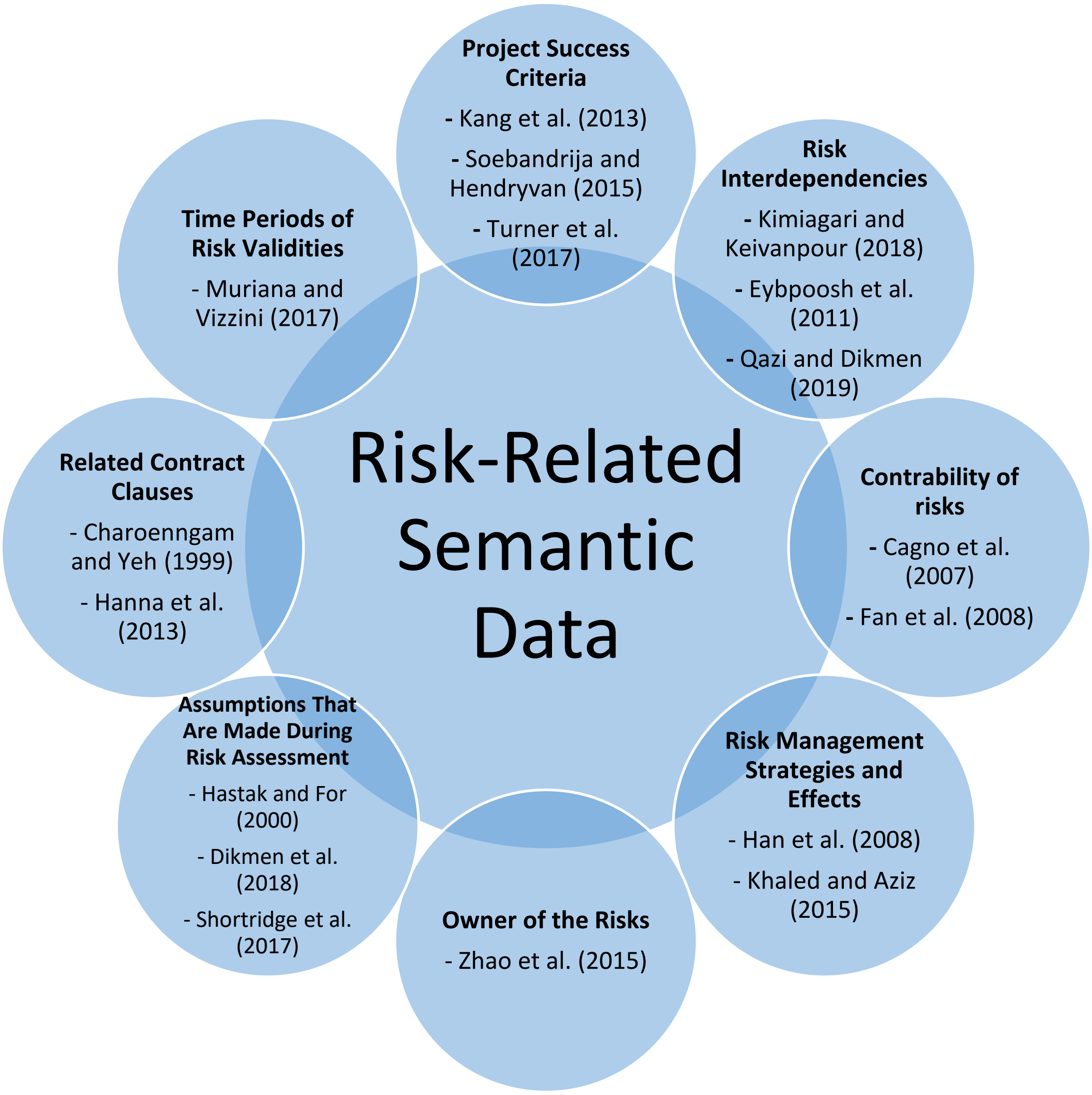

Figure 2.1. Selected Risk-Related Semantic Data and Related Studies

While executing risk management plans, companies have been gathering and using these data types to identify, assess and manage risks. Although the existence of such data is known, some of them are not communicated. When the needs of decision-makers are determined, the data should be communicated. The communication shall be executed through visualizations but the data to be delivered shall be determined while identifying the needs.

2.4. Defining Risk Communication and Visualization Framework

In order to solve the problem of communication of risk information, practitioners shall be applying frameworks for a systematic approach to the situation. Eppler and Aeschimann (2009) offered a risk visualization framework for this purpose. The framework in Figure 2.2 was prepared as a flow that shall repeat during risk communication. The study presents examples for the application of the framework, however, the fitting of the framework into existing management process needs to be examined. It is a conceptualized framework where the components are processed through questions.

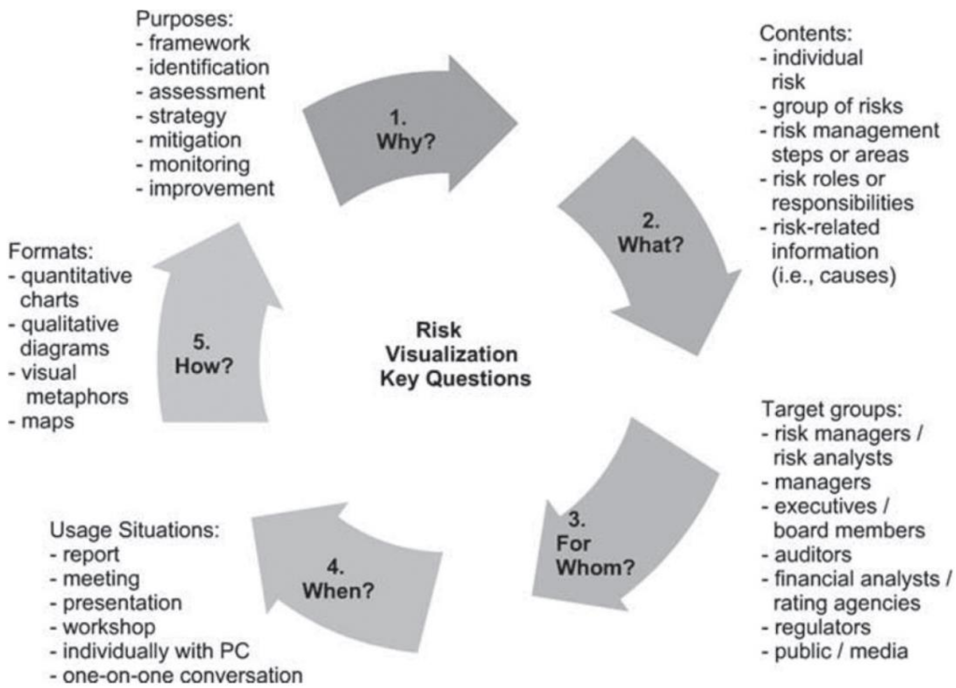

Figure 2.2. The Framework of Eppler and Aeschimann (2009)

To be applied in practical applications by risk experts, this study offers a risk communication framework as a modeled system. A formalized approach is need to acquire a process-based framework. Risk management includes many different aspects, and a simple flowchart that is too general for such topic shall be more detailed.

A conceptual framework is challenging to adapt to practical applications. In order to come up with a process-based framework, Integrated Definitions Methods (IDEF) can be used where IDEFØ can be used to model a process-based system to enhance risk communication. IDEFØ is a simple methodology that is used to represent the systems. Every node represents a component of the system where the left side of the node is the input parameter, the top is the control parameter, the bottom is the mechanism or resource and the right side is the output of the node. A simple representation node is presented in Figure 2.3.

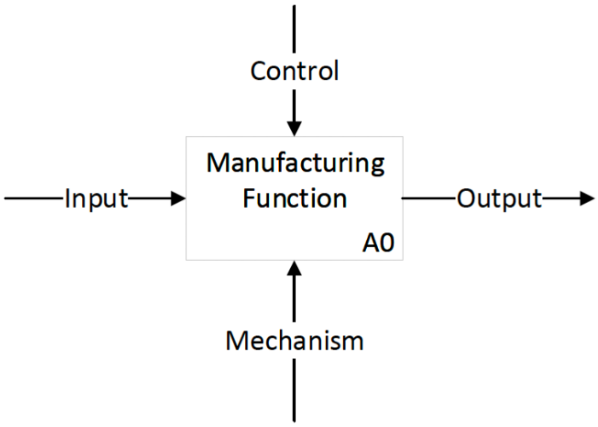

Figure 2.3. A Sample Node Representation in IDEFØ

A risk information communication framework should include the steps to identify the components and requirements of the output, which is a risk visualization for this study. The determination of the needs affects the type of visualizations. Without the necessary risk data, the visualization process cannot be valid and applied.

There are key factors that should be included in such a framework. The current completion condition of the project is one of the crucial factors. One cannot use the data that is related to the mobilization phase in the construction stage. Thus, such information should be one of the determinants of the output, and this process should be included in the framework. One of the other factors that affect the prepared visualizations is the audience that the visualization will be delivered (Chung et al.

2020). This may change in a company structure as many different parties are included in projects. In addition to that, the reason behind the visualization to be prepared can be a meeting, a risk workshop, a presentation, and so on. The visualization to be prepared also depends on the reason and should be included in the framework (Eppler and Aeschimann, 2009). Finally, the availability of information should be considered with these factors to determine the necessary information to be communicated (Omar Sharifuddin Syed-Ikhsan and Rowland 2004). By defining the given factors and available type of risk-related semantic data that is available for the company, the possible uses of visualizations can be selected. By getting directed by the use of visualizations, which is determined through available data and the represented factors, a final visualization can be selected and delivered to the necessary party. While it is clear that these factors should be components of a risk communication framework, further components need to be identified.

There are several guidelines that exist in the literature which focus on the development of effective visualizations. These guidelines do not focus on specific topics; instead the studies are in search of representation of data in the most effective ways. While preparing visualizations, the guidelines shall be followed to increase effectiveness. Ware (2004) states that important data should be visualized more distinctively from the less important data. In other words, the important data shall be foregrounded. In addition to that, Tufte (2007) stated that the simplest visualizations shall be prepared for the information that is aimed to be delivered. By considering these, base visualization methods can be determined, aiming the visualization of required data. The less important information can be represented around the more important ones by using the base visualizations to represent the more important data. Although this brings up the question of which data is the important one, it shall be determined through processes like reviewing literature.

2.5. Point of Departure and Existing Literature Gap

The visualization methodologies have been studied in multiple domains. Management, construction management, and construction risk management domains have been focusing on different approaches to visualize the data but a systematic approach for practical applications has not been studied. In order to enhance risk communication, different aspects for every company, such as past experiences, company structure, cognitive capabilities of parties and availability of types of risk-related semantic data, should be considered. Hence, there is a need to develop a risk visualization framework. While keeping these in mind, the development of framework and identification of an effective process is mostly iterative. The iterative process is forced by the nature of the construction projects, which include many different stakeholders and introduces multiple needs and success criteria for each one. The literature does not include an example of the effectiveness of such methodology.

In the end, whether there is a necessity for the visualization of risk-related semantic data to empower risk communication among project parties is not known. The preferences of risk experts on various risk-related data visualizations are not known. There is a need to conduct user studies (e.g., survey, workshop) to explore and verify new ways of application for selected risk-related semantic data, appropriate visualization methodology and demonstrate the iterative process of discussion with parties to identify the needs of decision-makers.

The literature survey shows that different methodologies to represent and communicate the risk data are used. On the one hand, the studies mostly focus on the processes that are used to procure the data but not the ways of communicating them. As can be seen from the literature review, the problem of construction project risk communication still stays as an unsolved issue, which should be elaborated depending on the decision-maker that will make use of the data. The method to deliver the data depends on the availability and type of information and cognitive capability of decision-makers. On the other hand, the traditional methodology of risk assessment processes does not focus on the importance of semantic risk data, which is used to prepare the risk data. Hence, there is a need to understand whether communication of different risk-related data is valuable for risk experts.

CHAPTER 3

RESEARCH METHODOLOGY

In this study, a risk visualization framework is introduced to come up with a process that examines several factors related to projects. The proposed framework is aimed to enable generating appropriate visualizations. Such a methodology should be an iterative process where parties should be working together in order to find the best way by considering the existing structure of the company. Although the steps of the framework can be applied differently for different parties, the parties that are involved should be included in the iterative process (e.g., workshops) of developing the appropriate methodology for information delivery. An abstract framework that can support such needs is developed in the study.

The traditional methodology of risk assessment includes many different types of data to come up with effective risk management strategies. While many of these data come from previous practices, historical data, and expert experiences, the traditional methodology may not include such data. Commonly, the risk-related data that is used by risk experts to identify the scores are not delivered to other project participants (e.g., decision-makers), only the PI matrices are communicated. Depending on the availability of data and decision-makers who should make use of the data, such risk-related data can enhance the decision-making process. The iterative process of determining the proper visualizations can also help to interpret such data. In this study, through a literature survey, mostly used types of risk-related semantic data are identified, and a workshop is performed to verify the necessity of these types through a survey among participants.

Risk communication is a significant problem where ideal risk assessment strategies can fail if risk information is not communicated appropriately. Traditional reporting methodology of risk assessment processes should be improved through the implementation of non-traditional visualizations. The non-traditional visualizations can be useful if determined according to the audience and organizational structure. The effectiveness depends on both the properties of visualizations such as clarity and usability and the decision-maker who is evaluating the situation. In this study, by following the steps of the prepared framework, risk visualizations are developed and presented to risk experts in a workshop setting, and depending on their oral and survey feedbacks, necessary revisions are made.

In light of the above statements, this chapter explains the ideas that are used to develop an iterative framework that shall be used to determine the risk-related semantic data to be communicated with appropriate visualizations. The flow of the study can be found in Figure 3.1. The iterative process to review the prepared visualizations, and the necessities for the workshop are explained in this chapter.

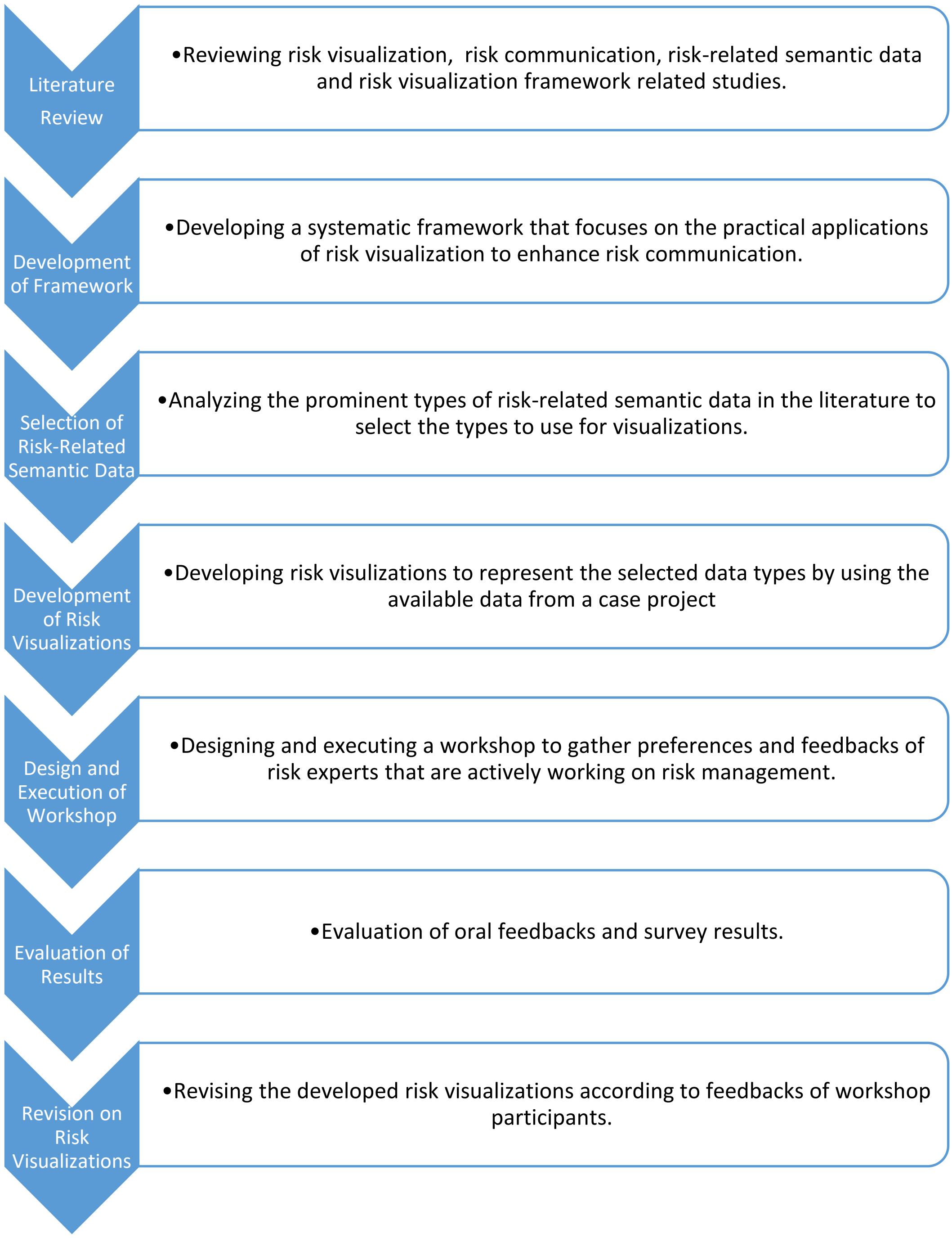

Figure 3.1. The Flow of the Study

3.1. Risk Information Communication Framework

Risk communication is still stated as a problem through risk assessment processes. While reporting and communicating risks, prepared documents shall be suitable for decision-makers. Even though the risk analysis process ran perfectly, if decision-makers cannot make use of the existing information, risk mitigation can fail. The determination of necessary data, which is communicated through a suitable methodology is crucial for a well-executed mitigation phase. Parties should work together in order to determine the appropriate strategy for risk communication. Most situations require different types of risk-related data, which decision-makers should make use of. For this purpose, an iterative risk information communication framework can be useful. A framework that is prepared by the parties that are responsible for risk assessment processes shall be effective and robust for companies.

3.2. Preparation of Risk Information Communication Workshop

In order to simulate an iterative process of the development of visualizations for risk communication, a workshop is performed in the scope of the study. Firstly, to determine the necessary data, literature is scanned, and types of risk-related semantic data that is not included in traditional risk assessment processes are identified. Secondly, participants are invited. In order to widen the scope, a variety of project roles are targetted so that feedbacks can be gathered from different points of view. Depending on the availability of selected types of risk-related semantic data and participants' role in the projects, the visualization formats can differ. After the communication session (i.e., the workshop), feedbacks are gathered. In the end, prepared visualizations are revised according to the experts' feedbacks until the most desired and appropriate visualization is prepared.

3.2.1. Risk-Related Semantic Data

To prepare appropriate risk visualizations to empower risk communication between parties, firstly, the types of risk-related semantic data that is available should be determined. For this study, prominent types of risk-related semantic data from the literature are selected. The implementation of such data to the methodology can be useful for sound decision-making. By doing so, different features of risks can be assessed other than traditional methodology, which focuses on impact-probability data. Such a process should be effective in improving risk communication between various project parties by taking advantage of prepared risk management documents from different aspects. The types of risk-related semantic data are commonly known, but they are not represented and reported. For decision-makers to act rapidly, redundant and corrupted data should be eliminated. Therefore, the need for visualization strategies becomes compulsory for such applications. The communication between every party should be enhanced with the visual delivery of such data and should be used when necessary.

3.2.2. Identification of Participants

While communicating risks, parties that are responsible should be well-defined so that unnecessary and irrelevant communication can be avoided. Project participants should be informed about the relevant party to avert such a problem. In addition to that, parties that are responsible should be well-defined during the preparation of the risk information and communication processes. For this study, different types of stakeholders with different responsibilities are aimed in order to demonstrate the delivery and revision steps of the risk information communication framework.

3.2.3. Identification of Types of Visualization and Design

In order to come up with appropriate formats to deliver information, as aforementioned, a literature survey was conducted. Although many different methodologies to represent risk information exist in the literature, the effectiveness and practicality of those visualizations are not mostly focused. While communicating the risk information through visualizations, one of the most common data that is visualized is the risk interdependencies. By using risk networks and maps, studies represented and visualized the dependencies of risks. In addition to that, risks are transient in terms of their validity throughout the project. One of the most common formats to visualize the time-dependent variables is the Gantt Chart. Risk networks and Gantt charts are used as starting points, and further visualizations are developed around these two base representations. In other words, selected risk-related semantic data are integrated into these representations. In the end, according to expert feedback from the workshop, the visualization formats are reviewed and revised. The iterative process of risk information communication framework is demonstrated through the feedback from the workshop. While generating visuals, there are several guidelines that increase the effectiveness of visualizations. In order to produce effective visuals and eliminate some of the iterations at the start of the process, these guidelines should be taken into consideration.

The following chapter starts with the introduction of the prepared information visualization communication framework. The steps of the framework are explained in detail. The developed visualizations, the workshop, and the feedbacks of the participants are presented.

CHAPTER 4

RESEARCH FINDINGS

This chapter presents the preliminary risk information communication framework, generated risk visualizations, the outputs regarding the preparation and execution of the workshop, and the revised visualizations based on the feedback acquired from the workshops.

In order to propose and demonstrate an exemplary workflow for practical applications, this research study starts with the preparation of a risk information communication framework. After the determination of necessary steps to iteratively find out the appropriate visualizations to communicate risk information, the steps in the framework are applied one by one. In the end, depending on the needs that the framework demonstrates and available risk data, several visualization formats are prepared. A workshop is performed to gather feedback from the sector professionals, which led to the revision of prepared risk visualizations.

4.1. Risk Information Communication Framework

The main idea of the framework is that it exemplifies an enhanced risk communication flow using visualization. The framework is designed considering the project risk management process, stakeholders, tasks, data types, purpose and visualization method, which in the end, suggests an output that shall enhance risk communication between project participants. By considering these six factors, the needs of decision-makers are planned to be met and communication of data is aimed to be more effective.

Construction projects include many different stakeholders. Every stakeholder has different responsibilities where the definition of every step of risk information communication framework can differ. As the framework includes multiple components, it presents decision-makers options to consider. While preparing the risk visualization framework, and determining the risk visualization methodology, selecting different options in the components offers different outputs that can satisfy the needs of decision-makers. The proposed framework is aimed to be as generic as possible, while the steps also depend on the company and the company's role in the project. There is no single visualization or process that fits all decision-makers' needs; hence the framework is planned as a guiding source to develop visualizations to communicate risk information.

The steps of the risk information framework can change depending on company structure, but mostly, these steps should be included so that different parties can communicate not only at the end of the visualization preparation process but also between the steps. By communicating between these steps, the processes of information representation can be more effective while keeping every party updated through every step. If only the end-product is delivered to decision-maker and iteration is eliminated for a framework like this, the appropriate visualization format may never be achieved. The parties that prepare the end-product should be able to improve the end-product for decision-makers; thus, iterations between these steps is very important. The visualization formats should be reviewed when necessary so that the end-product can be idealized.

For this purpose, instead of a generalized approach, a demonstration for different needs covering different aspects shall be done for practical applications. Depending on different aspects such as company structure and experiences of parties that are responsible for decision-making processes, the applications shall differ. According to those aspects, methodologies shall be identified systematically for every company to find the appropriate process which aims to enhance risk communication.

As aforementioned, Eppler and Aeschimann (2009) offered a conceptual framework with five steps that are formed by simple questions that should lead to risk visualization. Although that framework includes a cyclic flow that can be applied for the preparation of visualizations, it is conceptualized. For practical applications, the proposed framework in this study has a task-oriented approach, and it is prepared using Integrated Definition Methods (IDEF) where IDEFØ format is used to model the system (See Figure 4.1).

The framework is composed of iterative steps to identify the particulars of the components to develop visualizations. Such an iterative manner shows that a risk visualization framework to enhance risk communication depends on the data availability, the current stage of the project, and the target audience of risk visualizations. The proposed framework (Fig. 1) is explained and demonstrated through several examples. It should be noted that the particulars (options/enumerations) of the components are not presented as a fixed list; based on the users, these particulars should be modified or enhanced.

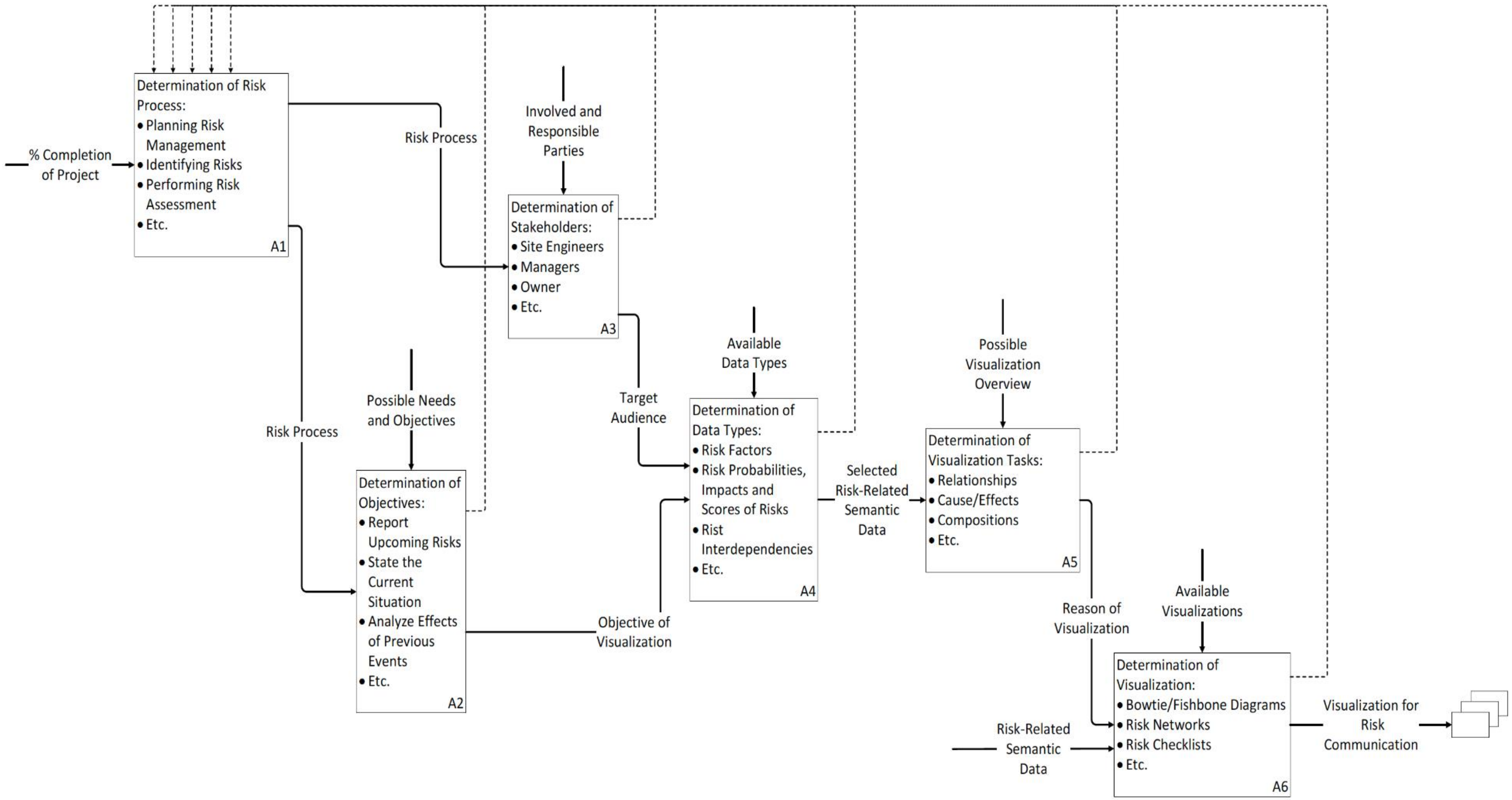

Figure 4.1. Proposed Risk Visualization Framework (in IDEFØ Format)

As can be seen from Figure 4.1, the framework starts with component A1 “Determination of the Risk Process”; by considering the current state of the project and the expected risk processes to be performed. Before gathering data and developing necessary visualizations, expected risk processes must be considered, where “Risk Process” is the output. This component also represents the current state (e.g., % completion) and phase of the project. This way, the scope of the visualizations can be narrowed down for the decision-makers. Component A2 “Determination of Objectives” helps identify the target audience and component A3 “Determination of Stakeholders” helps identify the project risk management process for the visualization. The objectives of the target audience should be determined by considering the expected risk process. These outputs aid the users in identifying component A4 “Determination of Data Types” so that the target audience can make use of the data for the necessary decisions. At the end of this step, depending on the available risk-related semantic data, data types to be visualized is identified as the output. After this step, depending on the data, component A5 “Determination of Visualization Tasks” is determined. This component helps identify the data analytics methods that indicate how the user intends to interact with the visualizations. The intended uses of visualization is identified as the output. In the end, the necessary data along with the reasons for visualization is used to identify component A6 “Determination of Visualizations” that offers a suitable visualization for risk communication.

While the flow of the framework is simple, each step shall be executed with the integration and communication of all responsible parties and possible audiences, when necessary. The feedbacks of these parties are very important as the cognitive capabilities and experiences of each party differ. Not only this but also the responsibilities of these parties’ change, thus the necessity and use cases of visualizations shall differ depending on the end-user. In addition to stated inputs and outputs of each component of the framework, these components actually include another input, which is the feedbacks of parties through the communication process. The feedbacks shall be gathered when it is available, but not necessarily in every step as it may not be possible to accomplish every time. The risk information communication is crucial to identify and standardize the process of risk visualization development, which is also the key to enhance risk communication. Although this is the flow that the framework is used through this study, the steps of such a framework may change depending on the existing structure and processes of the companies.

4.1.1. Framework Usage: Hypothetical Cases

As stated, the framework is designed for practical applications. In the case where reporting information regarding risks is needed, the framework can be used to identify the needs. In the end, an appropriate visualization can be prepared as the final output. The following three examples demonstrate some hypothetical practical applications.

Figure 4.2 shows the first exemplary use of the framework. To start using the proposed framework, “Determination of the Risk Process”, is identified as reporting risks. The risks shall be reported at the requested phase of the project (e.g., planning) where the target stakeholder is the risk experts and their main task is assessing possible risks at that the planning stage. The risk scores, assumptions related with them and foreseen mitigation plans are delivered as the necessary data types. Such data shows the composition of risks where risk checklists can be an appropriate method to deliver the information.

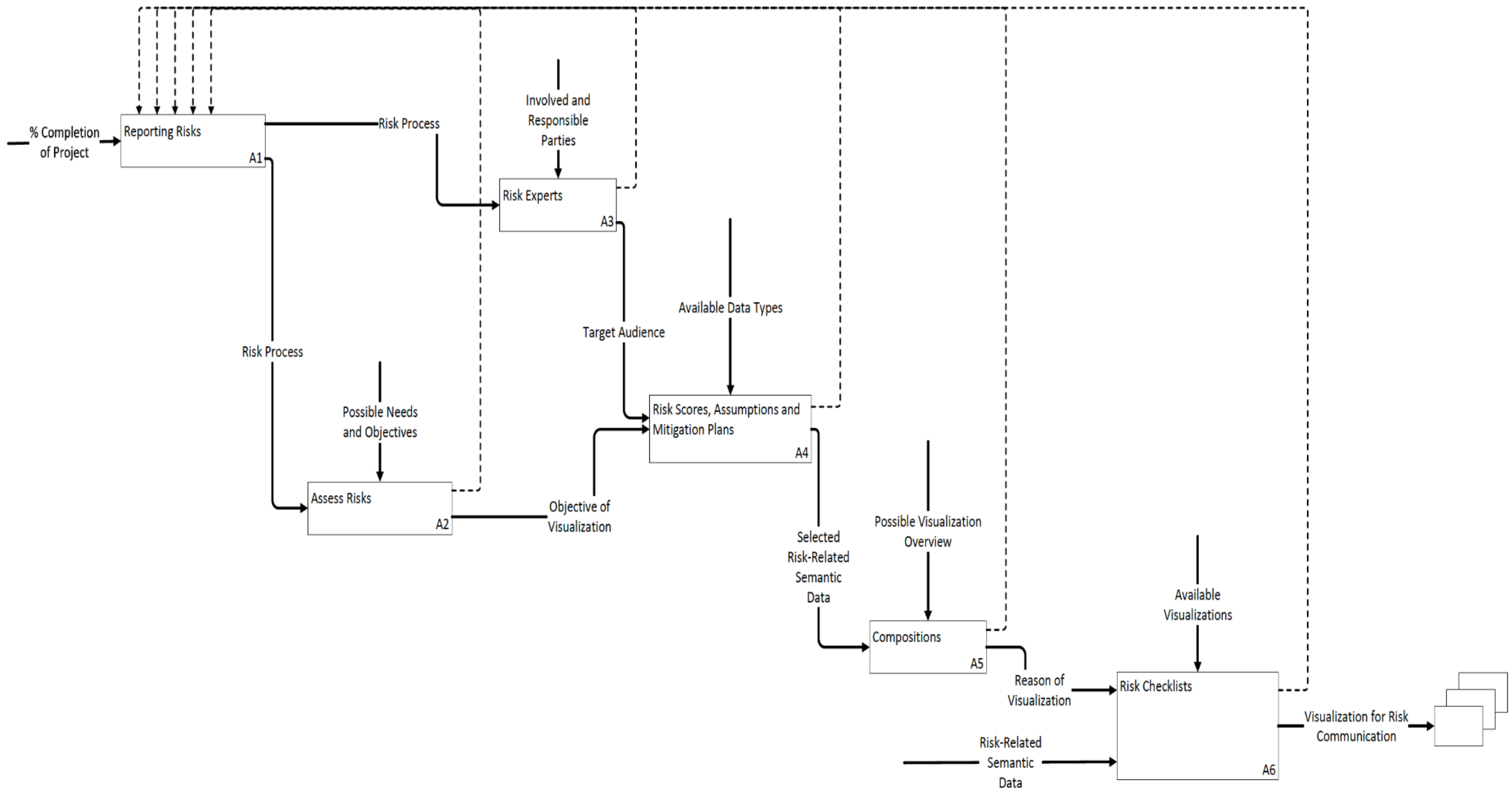

Figure 4.2. Framework for Visualization via Risk Checklist

For the second example given in Figure 4.3, the process is Plan Risk Responses, where the existing risks are assessed and upcoming risks are analyzed. The planner needs the risk visualization to plan and to develop an appropriate mitigation strategy. Project manager might need to visualize possible mitigation scenarios, causes of risks and expected outcomes. For this purpose, the cause/effect relations of the risks shall be reported. Bowtie diagrams are effective visualizations to report such cause/effect relationship to communicate information, which is the end-product of this example.

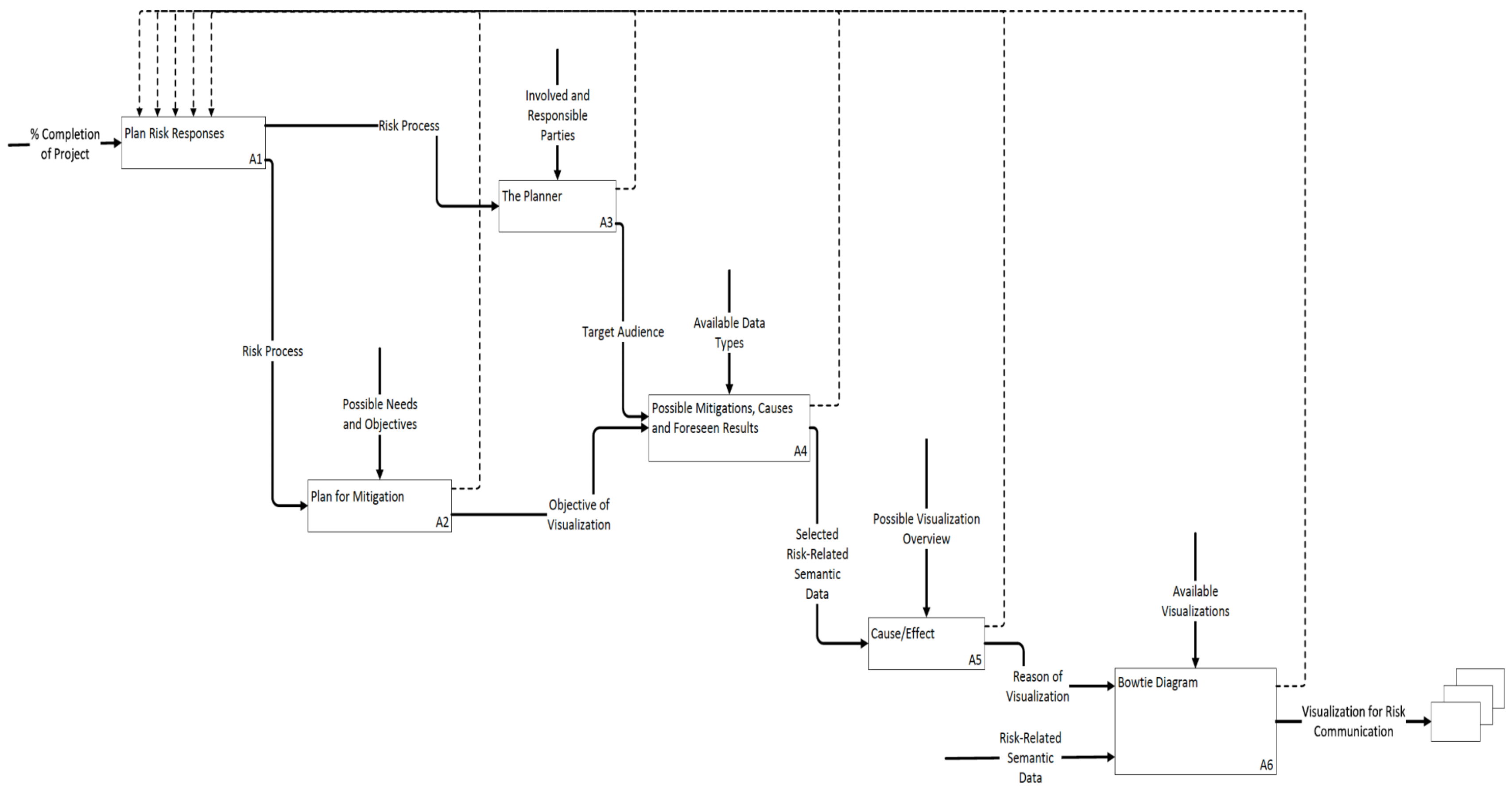

Figure 4.3. Framework for Visualization via Bowtie Diagram

Finally, Figure 4.4 demonstrates that the project is in “Control Risks” process and the current situation of the risks should be analyzed. The project manager needs to evaluate previous and upcoming risks. At this stage, the project manager is interested in the interrelationship of these risks to observe the effects of existing and upcoming risks on each other. Hence, a risk network is suggested for the project manager.

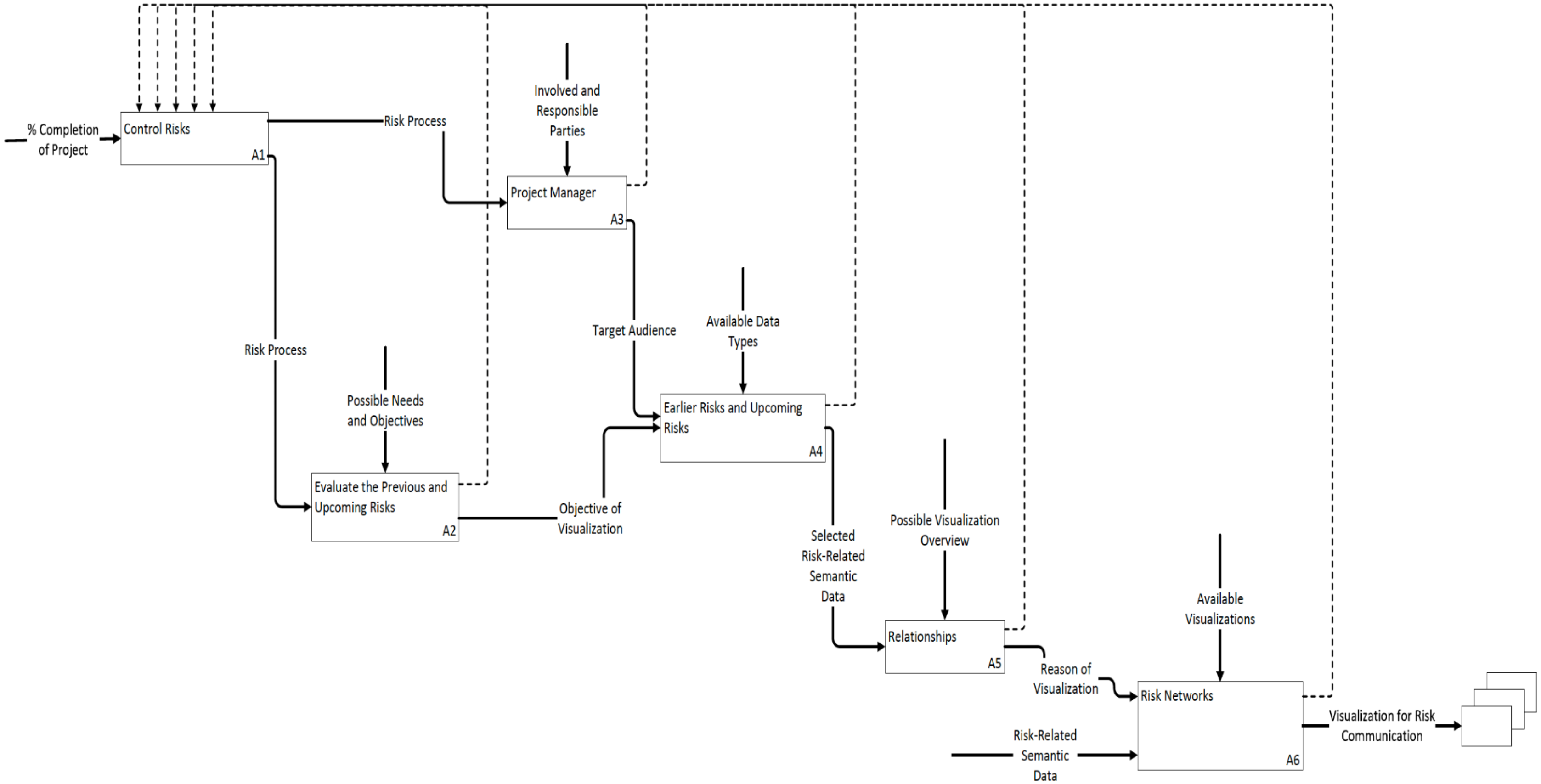

Figure 4.4. Framework for Visualization via Risk Network

4.1.2. Framework Usage: Risk Workshop

The data that is used to prepare the visualizations are obtained from a real-life project where the data is used as a small-scaled example as the information about the project is classified. Thus, some assumptions are made through the process, which is stated below, and the applied framework of the study is also given below, in Figure 4.5.

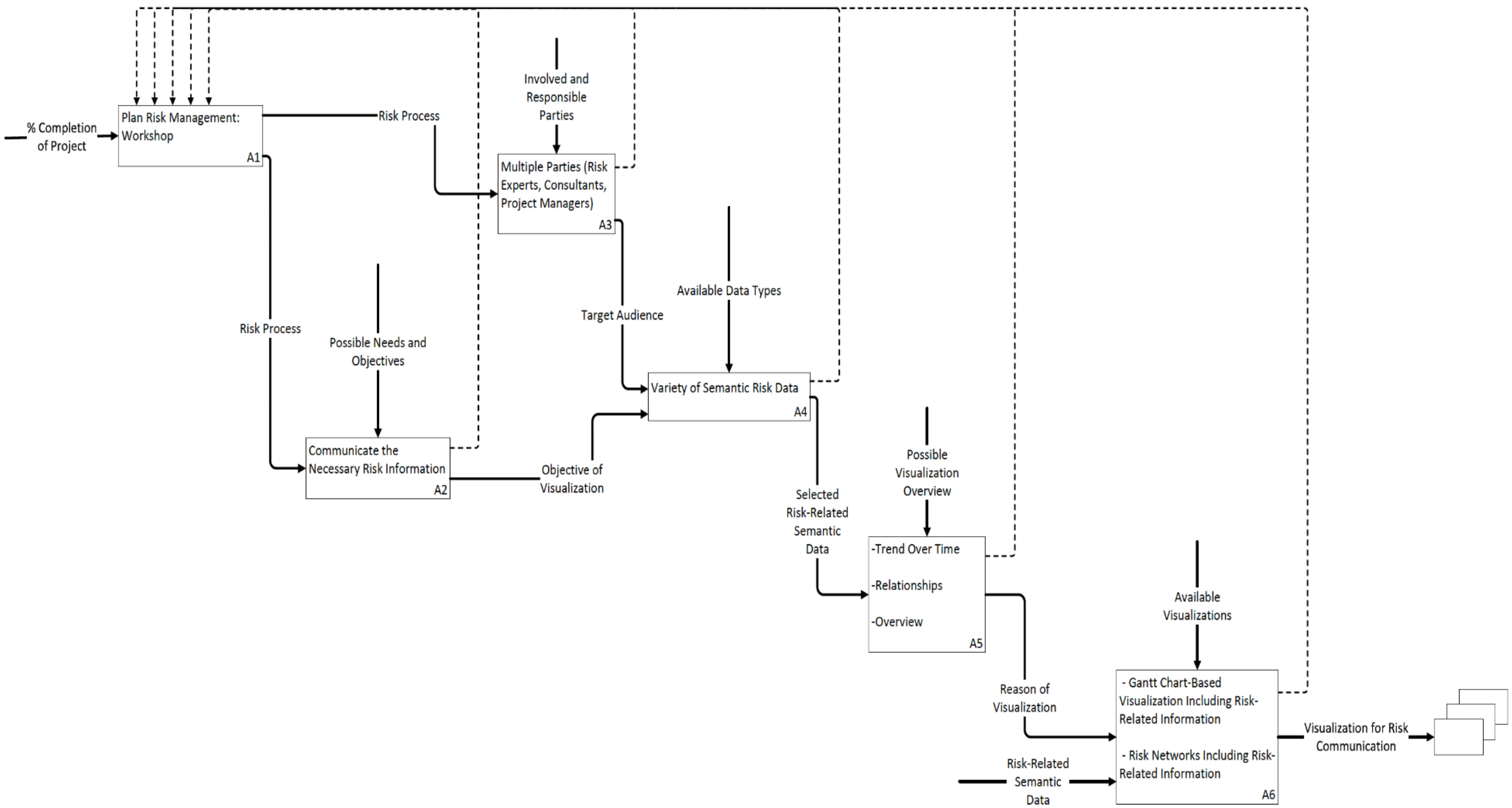

Figure 4.5. Application of Framework to Flow of the Study

For the demonstration of the proposed risk visualization framework, firstly, the project is assumed to be at the beginning phase, where the construction works have not started, and the initial risk plan is going to be prepared through a risk communication workshop. The target audience of visualizations is identified as multiple parties (risk experts, risk consultants, project managers) who have different responsibilities. The objective is to communicate necessary risk information to the target audience. At this point in the framework, the available types of data should be identified. This is important to eliminate the redundant effort of looking for irrelevant data. Also, required data should be available in the predefined formats. Since the purpose of the workshop is to evaluate the value of visualizing various risk related data, a variety of semantic risk data (e.g., relations, assumptions, owners) are selected. Identification of such data lead to determining the reasons for visualization such as understanding the risks, their relationships and characteristics at a certain point or over time. Based on the cognitive capability and experience of the expert, appropriate visualizations that can eliminate misinterpretation can be identified through an iterative process. For this study, all identified semantic data are used and integrated in different ways to develop visualizations, which are presented in Section 4.2.2. To demonstrate the effectiveness of visualizing such data, a workshop is planned. Using a de facto methodology such as a workshop, different parties can give feedback from different perspectives, and hence, prepared risk visualizations can be revised accordingly.

4.2. Preparation and Execution of Risk Information Communication Workshop

To go through the steps of risk visualization framework, firstly, types of risk-related semantic data that is going to be visualized were selected. Not only types but also the availability of data should be considered during the data selection process. Thus, in light of the information from the literature review, available data types are selected. After that, visualizations are developed. The selected types of risk-related data are presented through visualizations to the target audience, who are working as risk experts. The workshop is designed as two sessions, where the participants evaluate the effectiveness of selected types of risk-related semantic data on risk communication in the first session. In the second session, the visualizations are introduced and evaluated. Oral feedbacks of the participants are noted, and two surveys are used to gather numerical data for the effects of presented information on risk communication. This section of the thesis presents the selected risk-related semantic data, preparation of risk visualizations, execution of the workshop, acquired feedbacks and surveys, and the revision of risk visualizations according to the feedbacks of the participants.

4.2.1. Case Project

A case project is created by taking data from a small part of a real-life project. The original data consists of 89 risks registered for the Integrated Risk Management Plan of a railway project conducted in Turkey, which is prepared according to ISO 10006-2003. Complete raw data is obtained from the experts, where the details are confidential. For demonstrative purposes, five risk factors, with pre-defined relations and known raw data is selected to be used in this study. The descriptions, probabilities, impacts, and scores of these risks are given in Table 4.1.

Table 4.1. Risk Probabilities, Impacts, and Scores

Risk Factor	*Probability*	*Schedule Impact*	*Cost Impact*	*Risk Ranking*
R1 - High inflation due to local or global economic crisis	4	4	5	36 - Critical
R2 - Payment Delays	4	4	4	32 - Serious
R3 - Performance Failure of Subcontractors	2	3	3	12 - Acceptable
R4 - Contamination of the Site	3	3	2	15 - Acceptable
R5 - Problems with the Concrete Supplier	6	6	5	66 - Intolerable

4.2.2. Selection of Risk-Related Semantic Data

The first column of Table 4.2 presents the risk-related semantic data that is gathered through the literature review. To begin with, the focus of traditional methodology on "Probabilities, Impacts, and Scores of Risks" has to be included at the very beginning of the selection process. In addition, raw data that is used to prepare the risk management plan should be supportive of decision-makers at when neccessary. It must also be noted that omitting the de facto data types can cause misjudgments. Moreover, "Risk Interdependencies" has major importance on the evaluation of effects of risk on each other. These relations also define the parties that should communicate through the processes of risk assessment. "Effects of Risks on Different Success Criteria" such as cost, schedule, and safety might be within the scope of different parties; hence, such compositions should not be missed out.

Other than the evaluation processes of the result, the risk management processes include many different types of raw data that assist decision-makers. To start with, for an expert to evaluate the risk ratings, "Controllability of Risks" should be communicated, which is a factor that can affect the ratings. "Risk Management Strategies" should be defined to notify the decision-maker about the variety of solutions that can be applied in certain cases. By introducing such types of data, decision-makers can have a chance to reach out to other experts. The data should not limit the decision-makers but should encourage them to apply pre-determined strategies as well as new solutions to recently developed events. When it comes to seeing the effects of those strategies, probabilities, impacts, and scores of the risks should be updated throughout the project, thus "Effects of Risk Management Strategies" should be communicated between parties. Although the delivery of the data can be useful for every party, the parties that are responsible for managing the risks should also be disclosed. To do so, "Owner of the Risks" should be communicated so that in case a risk factor affects others, parties will have the chance to communicate according to ownership data. In addition, through the risk identification and assessment processes, many different assumptions are made to obtain qualitative data. Parties managing and mitigating the risks cannot know every one of these assumptions, and this data should be delivered to reflect the perspective of the risk assessors. In other words, "Assumptions That are Made During Risk Assessment" should be communicated so that communication between these parties can be empowered. Not only assumptions but also the "Related Contract Clauses" should also be included for more informed decision-making. Finally, it must be emphasized that not every risk has to be managed or mitigated all the time; every risk factor has a different valid time period to occur. For decision-makers to know the time to be aware of risk factors, "Time Periods of Risk Validities" should be communicated and delivered in an appropriate form. Subsection 4.2.3 explains how the selected types of risk-related semantic data are visualized.

Table 4.2. Risk-Related Semantic Data

Risk Related Data	*Usage*
Probabilities, impacts, scores	The size/magnitude of risk factors are determined using this characteristic in all visualizations
Interdependencies	The relationship of risks is revealed in network-based visualizations, using this characteristic
Effects of Risks on Different Success Criteria	Different interdependencies are developed using this characteristic
Controllability of Risks	A scale of this characteristic is presented in some visualizations as a visual cue
Risk Management Strategies	The foreseen management strategies are integrated to related risks as a visual cue
Effects of Risk Management Strategies	The change in size/magnitude of risk factors are shown if a strategy is applied.
Owner of Risks	This characteristic is used as a semantic data on some of the visualizations

Table 4.2. (Cont'd) Risk-Related Semantic Data

Risk Related Data	*Usage*
Related Contract Clauses of Risks	The related contract clause of the risk is shown as semantic data
The Assumptions that are Made During Risk Assessment Process	The assumptions that are made by the person who prepares the risk management plan are shown as semantic data
Time Periods/Durations of Risks	The valid duration of the risks is shown in a Gantt Chart-based visualization

4.2.3. Preparation of Risk Visualizations

Ineffective communication of parties is a significant problem for the delivery of risk information in construction projects. In order to make use of expert information, communication should be reinforced. While enhancing risk communication, one of the major concerns is the delivery of essential data for decision-makers. Generally, the presentation of raw data is challenging and mostly not focused according to the need. For example, some risk visualization methods like Risk Matrices focus on importance of risk as well as BBN's, and Fault Trees mostly focus on the representation of causal relations. Although such an approach is effective, many of the information is lost due to the elimination of raw data. In addition to that, rarely, construction risk management uses spatial visualization methodologies, which help location-based risk assessment using the activities or physical components of projects. But in the case of location-based visualization, the semantic information is excluded and replaced with mostly spatial information.

Existing methods ensure the appropriate calculation of risk results while including the joint effects with network structures. In this study, the development of risk information visualizations is conducted by considering this strength of such visualization methods. Most of the visualizations have a base of network models, and selected risk-related semantic data is associated with that structure. On the other hand, the time periods when the risks are active or expected are shown with a different approach. A Gannt Chart alike method is used to indicate the valid periods of risks and risk-related data integrated.

The second column of Table 4.2 presents how the risk-related data is presented in visualizations. During the literature survey, it was seen that the significance of checking *"Risk Interdependencies"* and *"Risk Scores"* have been emphasized, and this study uses risk networks as a base visualization format. Figure 4.6 shows the visualization of *"Risk Interdependencies"* and *"Risk Scores"* in a network structure. In this figure, the network connection arrows indicate the interdependencies of risk factors, and risk scores are indicated with the size of risk nodes. Figure 4.7 shows the *"Effects of Risk Factors on Different Types of Success Criteria"* in which light blue circles indicate the cost impact, yellow circles indicate the schedule impact and green circles indicate the equality of effects of that risk factor on cost and schedule. Figure 4.8 indicates the *"Controllability of Risks"* which shall give an idea for mitigation strategies such as proactive and reactive ones to decision-makers. The visualization is made through using the transparency of network nodes. Figure 4.9 shows the *"Risk Management Strategies"* with a triangle icon showing the number of as-planned mitigation strategies for the related risk factor and strategies is explained furtherly. Figure 4.10 presents the *"Effects of Risk Management Strategies"* in order to communicate the information of existing conditions of risks after implementation of proactive strategies to decision-makers. If a strategy is planned to be applied during the assessment process, it is shown with a big triangle including the mitigation strategy placed on the related risk factor. Figure 4.11 visualizes the *"Owner of the Risks"* by indicating the party who is responsible for that risk factor. Figure 4.12 shows the visualization of *"Related Contract Clauses of Risk Factors."* Information on related contractual clauses and issues is indicated with a small contract icon on top of each related risk factor and explained furtherly. Figure 4.13 shows the *"The Assumptions that are Made During Risk Assessment Process."* Mostly, several assumptions are made while assessing risks of projects to evaluate probability and impacts. The main idea of communicating such information is to highlight and deliver the idea behind risk evaluation. Figure 4.14 shows the *"Time Periods/Durations of Risks"* where instead of network visualization, a Gantt Chart like visualization is used. In this risk visualization, although the interdependencies of risks cannot be seen, the valid time period of risks can be identified, and decision-makers can focus on valid and upcoming risk factors. The length of the bars show the valid time periods of risks and the height of the bars show the risk score of risks. All types of data may be integrated to both base visualizations. During the workshop, because of time limitations, the other types are not implemented to time period visualization one by one. Instead, for both base risk visualizations, all selected types of risk-related information are integrated to both bases and shown to participants. Figure 4.15 shows the *"Integration of Most Features on Time Periods/Durations of Risks"* and Figure 4.16 shows the *"Integration of Most Features on Network Structure"*.

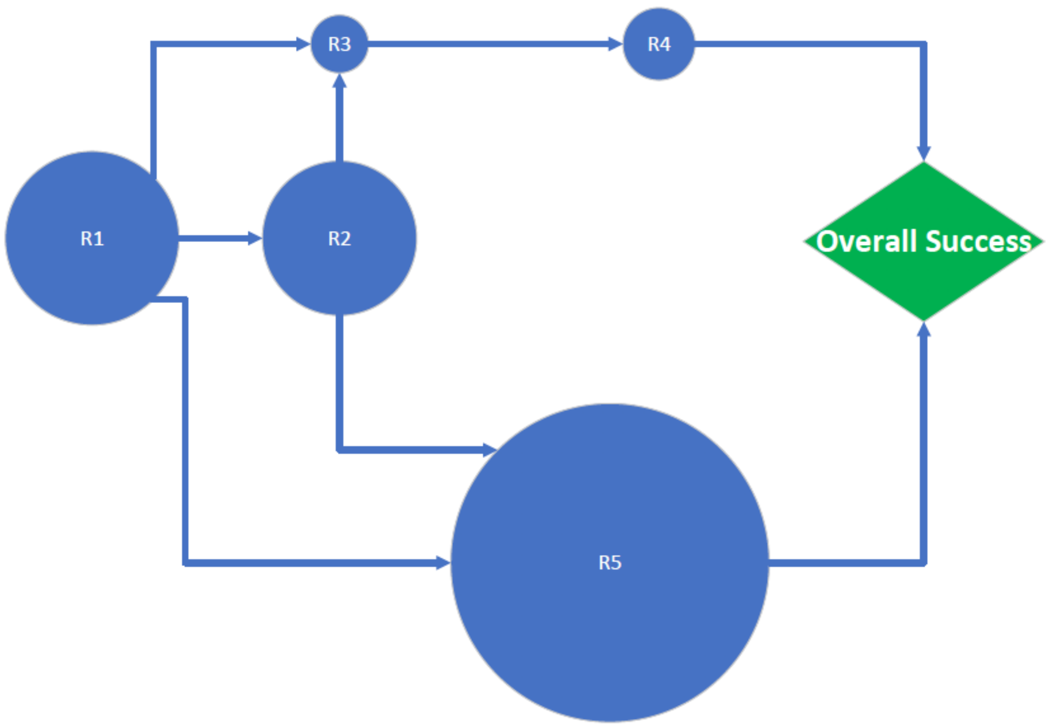

Figure 4.6. Risk Scores and Interdependencies

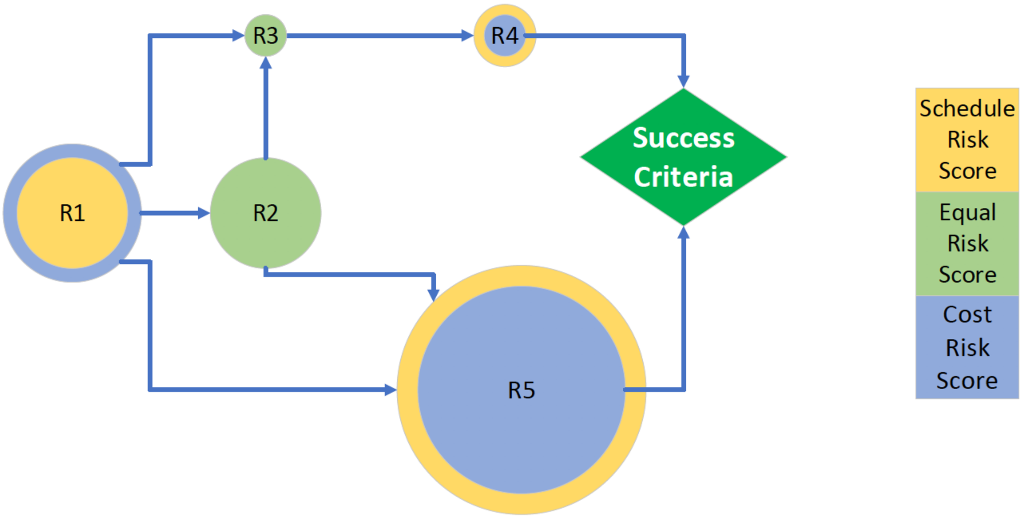

Figure 4.7. Effects of Risks on Different Success Criteria

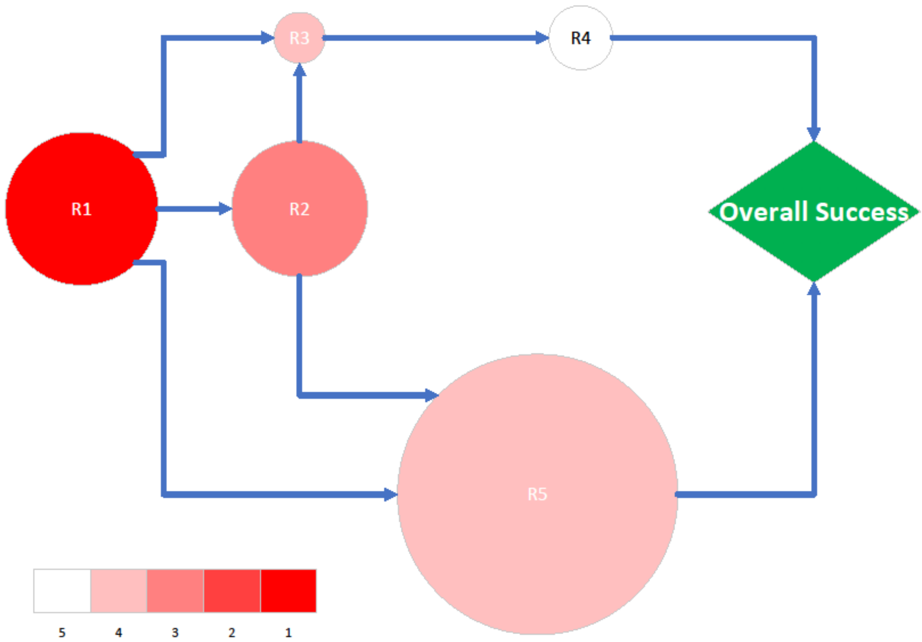

Figure 4.8. Controllability of Risks

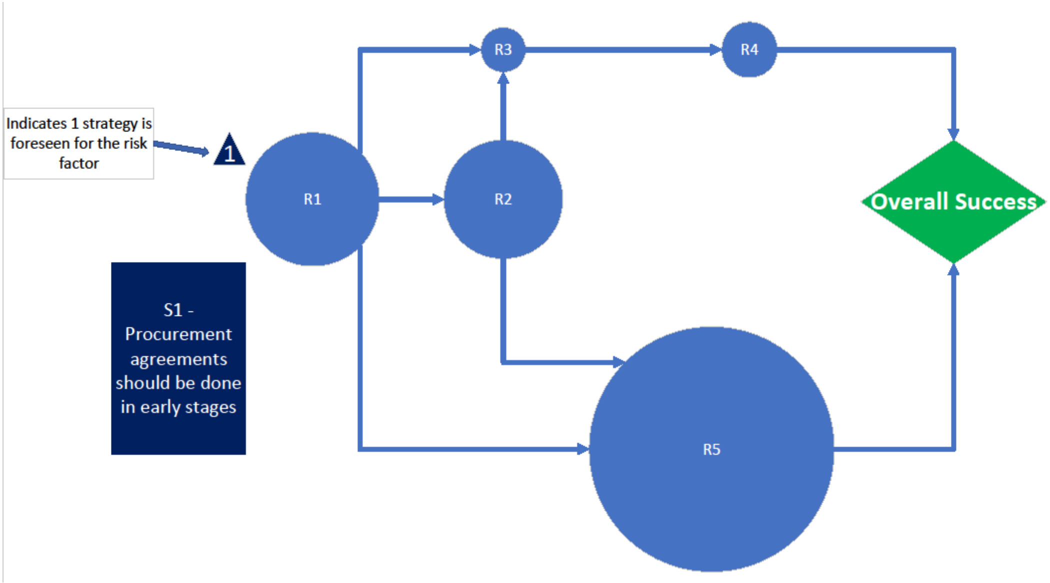

Figure 4.9. Risk Management Strategies

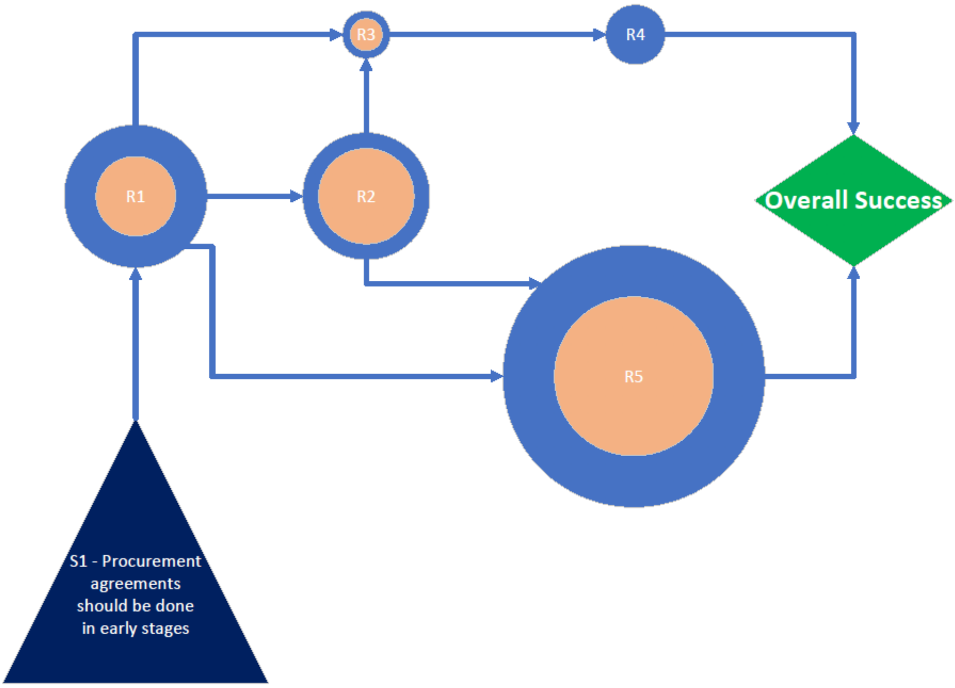

Figure 4.10. Effects of Risk Management Strategies

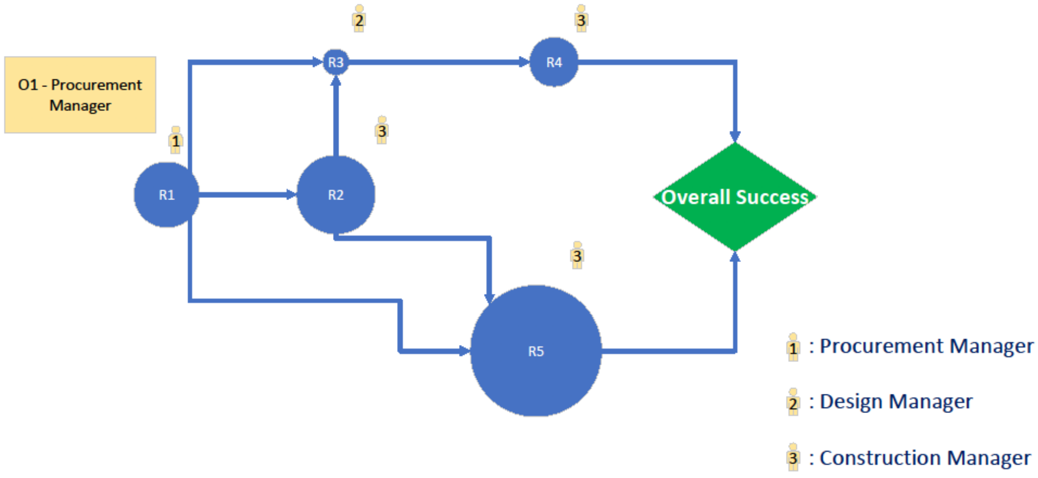

Figure 4.11. Owner of the Risks

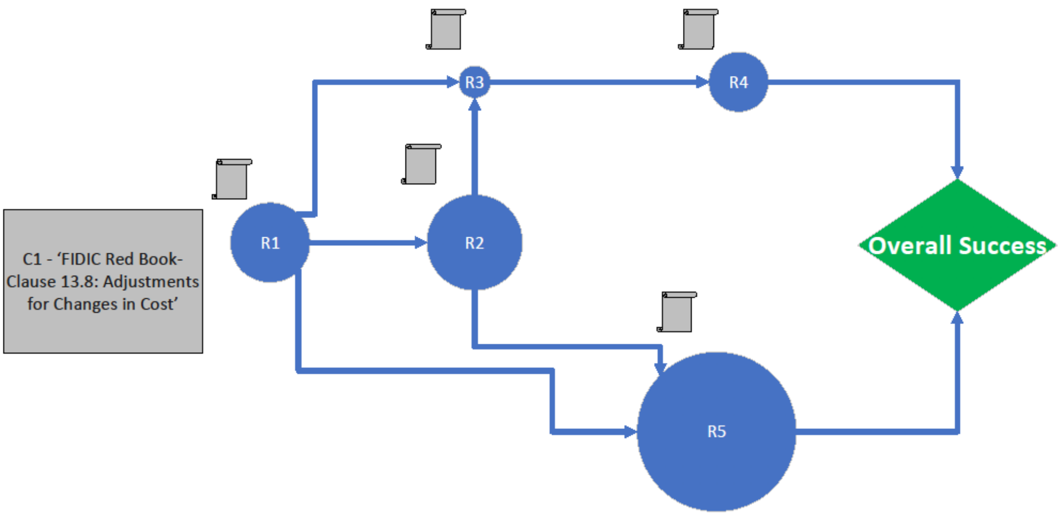

Figure 4.12. Related Contract Clauses of Risks Factors

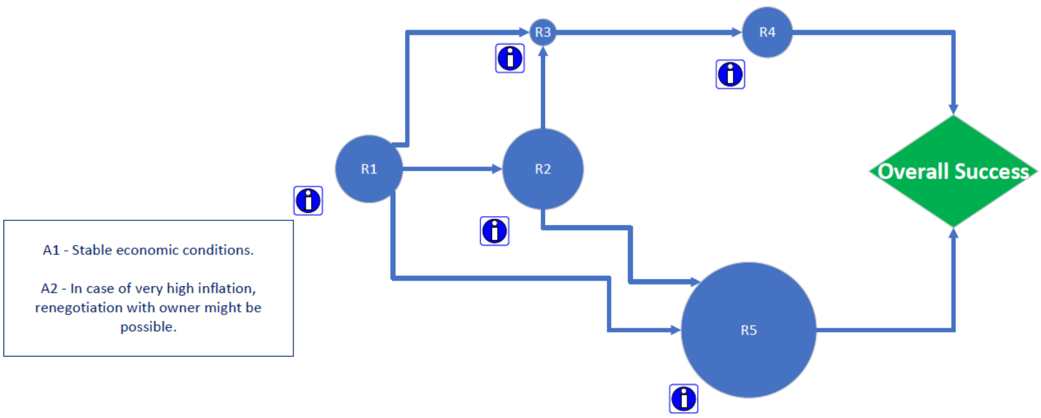

Figure 4.13. The Assumptions that are Made During Risk Assessment

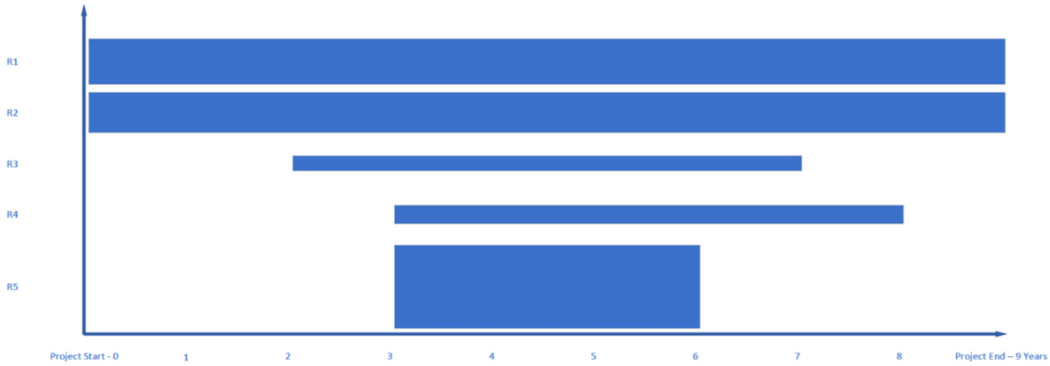

Figure 4.14. Time Periods/Durations of Risks

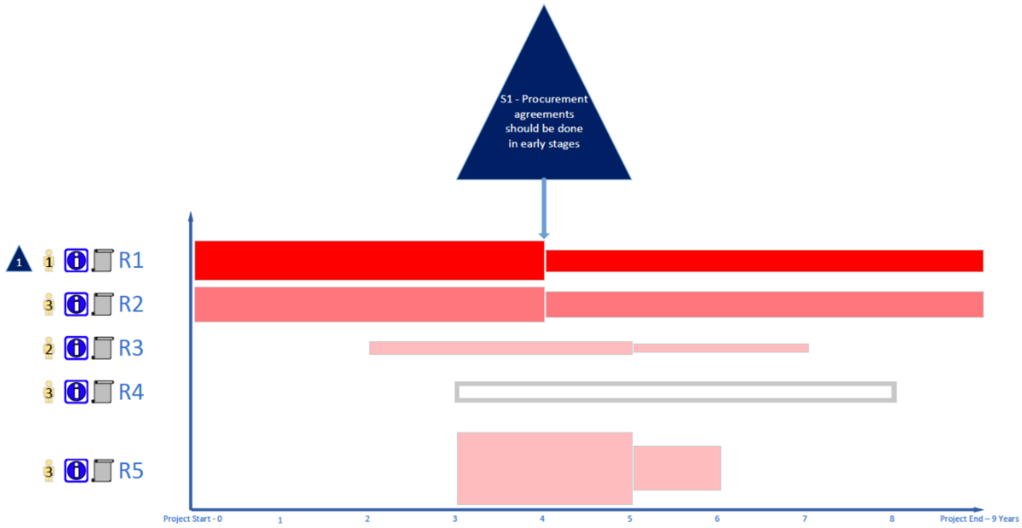

Figure 4.15. Integration of Most Features on Time Periods/Durations of Risks

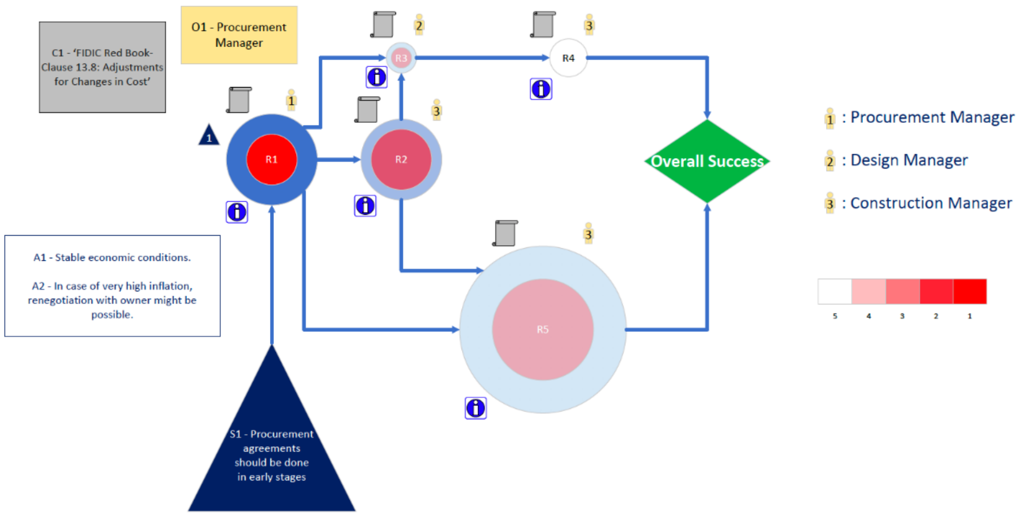

Figure 4.16. Integration of Most Features on Network Structure

With the methods proposed, every risk owner can communicate and manage risk factors, knowing the corresponding risk score, related contract clause, assumptions made for foreseen events with planned risk strategy, having knowledge on the controllability as well. In addition to that, if a strategy is applied at an earlier stage, the responsible party can also be aware of the current state of the risk factor and can have a chance to act accordingly. In addition, every party has an opportunity to reach out to the owner of another risk factor when necessary. Finally, the delivery of raw data should encourage the included responsible parties to communicate and act together instead of dealing with the situation by themselves.

4.2.4. Preparation of Survey for Risk Communication Workshop

As stated, the workshop consisted of two sessions. The first session was the demonstration of a risk checklist/register application and a risk matrix visualization. For this part of the workshop, feedbacks of participants on shortfalls of the methodology are gathered. In addition to that, the opinions of participants on the selected data types of risk-related information that is not included in demonstrated traditional risk methodology is asked through a survey. The survey included the evaluation of the aforementioned risk-related semantic data types which are evaluated on a scale of 1 to 3, being *"Not Necessary", "Neither Necessary nor Compulsory"* and *"Compulsory"* respectively. Survey 1 can be found in APPENDIX A with detailed answers of participants to this survey.

In the second session, the prepared visualization formats that are given in the previous section are presented to participants. In addition to their oral feedbacks on visuals to improve them and obtain a different perspective from different project parties, a second survey is also distributed to participants to evaluate risk visualizations. The survey consisted of four criteria for each visualization format for evaluation, which are *"Clarity; the level of clarity of visualizations.", "Usefulness; the degree of the value added to the risk/project. Management plan by the use of visualizations", "Aesthetics; the degree of the attractiveness of visualizations"* and *Effectiveness; the* *degree of resources (e.g. time, manpower, and cost) that is necessary to produce to visualizations"*. All aspects are evaluated on a scale of 1 to 5, being *"Very Low", "Low", "Intermediate", "High", Very High"* respectively, and Survey 2 can be found in APPENDIX B with detailed answers of the participants to this survey.

4.2.5. Execution, Results, and Interpretation of the Workshop

Traditional methodologies like risk matrices or checklists remain incapable of delivering the expertise information, and communicating risks become harder. Workshops are key methods of gathering data when the concern is gathering risk expertise information. The workshop, whose flow is given in Figure 4.17, was designed to discover the needs of risk experts, for communication of risk-related semantic data.

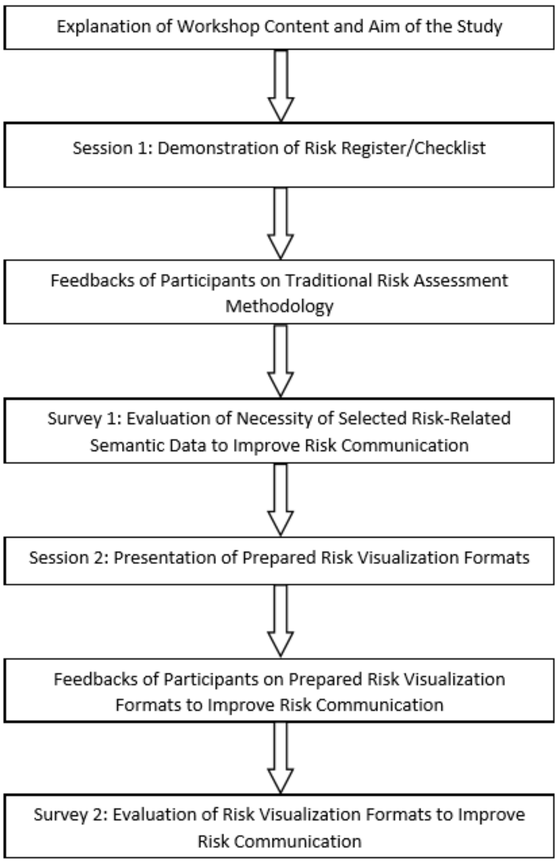

Figure 4.17. Flow of the Workshop

According to (Kerzner et al., 2019), a workshop of 5 to 15 participants is suitable for workshops, where 6 participants are included in the scope of the designed workshop. 2 of the participants have Ph.D., 3 of them have MSc and 1 of them has BSc degrees. All of them are sector practitioners who have been working on risk management. One of the participants has 20 years, 1 of them has 12 years, 3 of them have 10 years and 1 of them have 2 years of project and risk management experience. Detailed information of the participants is given below, in Table 4.3.

Table 4.3. Participant Information

Participant	*Education Level*	*Professional Experience*	*Experience in Project and Risk Management*	*Current Role of the Participants*
Participant 1	PhD.	9	6	Project Manager
Participant 2	MSc.	25	20	Technical Consultant
Participant 3	MSc.	12	12	Contract Manager
Participant 4	PhD.	12	10	Project Management Specialist
Participant 5	Msc.	15	10	Financial Consultant
Participant 6	BSc.	2	2	Risk Consultant

4.2.5.1. First Session of the Workshop

The first session of the workshop started with the introduction of participants, the research team, and the definition of the project. Then, the aim of the study and the workshop content was explained. Subsequently, the risk register/checklist application is demonstrated as a traditional risk management methodology from "Project Management Body of Knowledge" (PMBOK). The objective was to start a debate to comprehend the practical applications of risk assessment and how communication is enabled. This way, participants had knowledge about the risk factors, as they were also used for the developed visualizations.

For the demonstrated checklist methodology, a sample data from a real-life project was used as explained subsection 4.2.1. Five risk factors of that project were selected for simplification purposes. The process consists of the determination of risk probabilities and impacts to come up with risk scores, where the scores correspond to the multiplication of these two factors. For the probability ratings of risks a scale from 1 to 6 is used being; “Extremely Unlikely”, “Very Unlikely”, “Unlikely”, “Somewhat Likely”, “Likely”, “Highly Likely”, respectively. For the impact ratings, a scale from 1 to 6 is used being; “Negligible”, “Marginal”, “Moderate”, “Substantial”, “Severe”, “Disastrous”, respectively. For this risk register, risks were evaluated through two different success criteria, schedule, and cost impacts. After identification of risk factors, probabilities and impacts, risk scores were determined. From the determined information, evaluation of risks was achieved through determining risk scores. Risk scores of the selected risks were determined by multiplying total impact (schedule + cost) with probabilities. In the end, these risks are inserted into a probability/impact matrix for reporting, which can be found in Figure 4.18.

Probability Impact Matrix												
Highly Likely	6										R5	
Likely	5											
Somewhat Likely	4							R2	R1			
Unlikely	3				R4							
Very Unlikely	2					R3						
Extremely Unlikely	1											
		2	3	4	5	6	7	8	9	10	11	12
		Very Low	Low		Medium			High		Very High		

Figure 4.18. Probability Impact Matrix for Case Project

The challenge of risk communication has to be stated to highlight the necessity of data. It must be noted that the proposed semantic data has to be evaluated before and after the visualizations in order to assess both the performance of developed visualizations and the necessity of such data. Thus, at the end of the presentation of the first session, opinions of participants are gathered orally and through the aforementioned survey. The purpose of the first survey was to discover the expectations and considerations of the participants for the risk-related semantic data. The selected risk-related semantic data was evaluated by the participants. The critical oral feedbacks, survey results, and deductions are as given in sections 4.2.5.1.1. and 4.2.5.1.2., below.

4.2.5.1.1. Session 1: Key Oral Feedbacks

After the presentation of the first session and before the first survey, participants discussed the risk assessment and communication methodologies that they have been using for decision-making. All of them stated that they were using risk register and checklist methodology, as well as risk matrices through the risk management planning procedure. They all evaluated the performance of existing methodologies as "Partially Sufficient", which shows that the traditional methodology that focuses on probability and impact has some limitations.

Participants stated the importance and criticality of risk information communication within the company, between related parties, starting from preparation of risk management plan and throughout the project. Even before the survey, some participants stated their problems with the non-existence of some data types during decision-making processes. P2 stated that:

- *"Controllability of the risks should be included in the risk management plan as well as updated states of the risks. While evaluating the risks, this information can help the decision-maker to focus on accepting, avoiding, transferring, and reducing the risks.*

The preparation of a risk management plan from the perspective of the person who prepares it causes a problem for decision-makers. The information that is used to prepare the risk management plan shall be shared through the related parties so that decision-makers can analyze the situation from their perspective. P4 stated that:

- *“The thoughts of the person who prepares the risk management plan and the related reports such as risk matrices can be interpreted differently by reviewers as no information is provided about the risk context. Hence, risks might be prioritized differently. Information delivery methods, such as risk matrices fail to show the bigger picture and assumptions.”*

Furthermore, P5, who faced a similar problem, proposed the following solution:

- *“During the risk assessment process, a standard set of questions can be asked to understand the context and assumptions under which experts evaluate probability and impact values. Decision-makers can prioritize or re-evaluate risks accordingly, and throughout the project, risk management plans can be updated easily.”*

Practical applications cause the experts to search for new risk information communication methods to carry out the risk assessment by different parties. P3, who has multiple responsibilities while managing risks has stated that:

- *“When the focus is on multiple performance criteria, data to use for mitigation strategies might differ. Depending on the situation, qualitative and quantitative performance criteria should be evaluated separately. The prepared risk information should be communicated to related parties to prevent ineffective deductions.”*

Thus, communicated information that is obtained according to the aim of the decision-maker shall be usable to decision-maker's scope. A risk management plan that is prepared for health and safety cannot be used for cost-overrun. Hence, the purpose of the decision-maker should also be evaluated while communicating the information.

For P5, who is managing different financial portfolios has stated:

- *While managing financial portfolios, the relativity of risks can be kept as a degree of measurement while mitigating. A decision-maker may not be able to mitigate all risks at the same time. By knowing the relative effects of the risks,* *their reasonings, and classifications, the focus of that person can be directed effectively*.

This statement shows the importance of the relativity of risks to be communicated through parties. A decision-maker can be responsible for different projects of a company and shall evaluate the relativity between risks when the mitigation is necessary for effective risk management strategies.

4.2.5.1.2. Survey 1: Interpretation of Survey

The first survey was held to identify the importance of what types of risk-related semantic data shall be communicated. Participants were asked to evaluate the types of semantic data that is selected from the literature survey according to practical necessities. Some of the included types are evaluated as redundant. In other words, it has been evaluated that not each and every data can be understood to be useful unless it is used. In addition, the data has to be used together with other types in order to enable new ways of thinking. The evaluation of the necessity of selected semantic data out of 3 is given below in Figure 4.19.

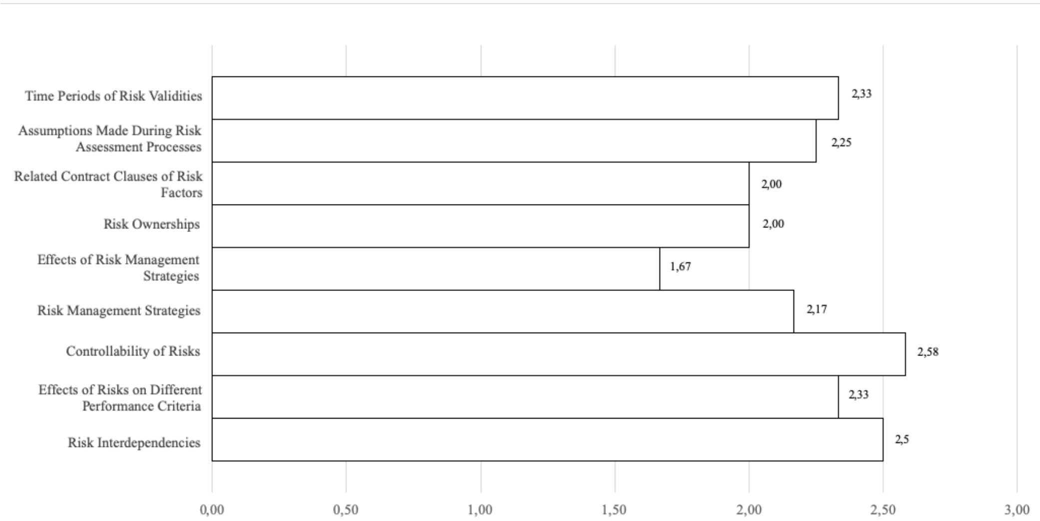

Figure 4.19. The Average Ratings of Participants on Risk-Related Semantic Data

As can be seen from the average participant evaluation, “Risk Interdependencies” and “Controllability of the Risks” are the only risk-related semantic data that exceeds 2.5 (on a scale of 1 to 3). In addition to that, the results of the survey show that “Effects of Risk Management Strategies” is evaluated as redundant. The other risk-related semantic data are rated between 2 and 2.5. This indicates that those types of data are evaluated as “Neither Necessary nor Compulsory” and can actually be omitted during risk management applications, according to participants’ initial comments.

4.2.5.2. The Second Session of the Workshop

Following the first session, the developed risk expertise information visualization techniques were presented. The main purpose of the visualizations is to offer an option of enhancing risk communication while making an example of risk-related information delivery. Visualizations can also inspire the participants to explore new ways of approaching risk communication through data. In the end, the second survey has been conducted to evaluate the visual techniques and proposed risk-related semantic data.

By showing all selected types of risk-related information one by one, participants shall be able to analyze the necessity of communication of data types through visualizations. In addition to that, participants shall also be able to evaluate the intensity of visualization if all of the information is shown at one time. The effectiveness of visualization depends on the audiences’ experience, cognitive capabilities, and visualization itself. By showing an intense visualization, participant feedbacks shall be able to show if such intensiveness makes the information clutter or not for decision-making.

Afterward, a final debate was initiated to gather participant ideas and comments. Participants debated the effectiveness of selected semantic data, opportunities of such visualization techniques applied to raw data, the power of risk communication, and how it can be affected by the incorporation of risk-related semantic data and risk expertise information visualization techniques. The key oral feedbacks, survey results, and deductions are as given in sections 4.2.5.2.1. and 4.2.5.2.2., below.

4.2.5.2.1. Session 2: Key Oral Feedbacks

At the end of the presentation of prepared risk visualizations, a debate and feedback session have started. Participants are asked to state the pros and cons of presented visualizations, and the possible improvement that they would request if given visuals will be used for decision-making. Furthermore, they are asked to state any other visualization techniques that they have been using or think of for risk communication. P1 started the discussion with pros, as follows;

- *"The visualization of risk-related semantic data is way more useful compared to the risk register format. If the visualization formats are kept simple, they lose their effectiveness for decision-making. They should be effective enough for the involved parties to understand the current situation but not too complex."*

And while approving the effectiveness of risk communication, P6 also stated a point which should be kept in mind:

- *"At the point where visual techniques are prepared by the person other than decision-maker, visual techniques might be interpreted differently. Decision-makers can focus on different aspects other than the ones that are focused by the party who prepares the visual techniques. In the end, prepared visual techniques become meaningless and lose their strength, if required information is not included."*

While the effectiveness of visualization is stated, P1 also indicated that the high intensity of visual could cause the decision-maker to misinterpret the information as well as, without communicating the necessary information, it shall not be effective. For companies that will be using such methodology should determine the needs and capabilities of project participants to solve the problems of low and high intensity and delivering the required information of visualization in an iterative manner so that decision-makers shall be able to analyze the ongoing situation correctly.

Another important factor is the target of the prepared risk visualization. P1 stated this as follows:

- *"The data should be analyzed, and visualizations should be prepared according to the party that is being targeted. Every aspect of risk-related semantic data is shaped by the party that is going to evaluate the situation to be mitigated."*

Not only the intensity but also the selection of the target audience of prepared risk visualization is very important. While the parties will need different types of information, different decision-makers that are responsible for similar operations and counted as the same parties may have different cognitive capabilities. The delivery of information should be done according to this consideration, and decision-maker's cognitive capability shall also be determined during the iterative process that will result the development of risk visualizations.

4.2.5.2.2. Survey 2: Interpretation of Survey

For the second survey, the representation of the semantic data on risk communication is evaluated by participants. Four different criteria that are given in section 4.2.3 are used to evaluate the visualization formats being, (a) Clarity, (b) Usefulness, (c) Aesthetics, and (d) Effectiveness. The individual ratings of each participant on the selected data for both Survey 1 and Survey 2 (converted into a scale of 1 to 3) are given in Figure 4.20. From the figure, the results of the pre and post visualization ratings show that the opinions of experts have changed. Some of the selected data types that are rated as to be redundant in the first survey were understood to be more necessary, where participants also stated such feedbacks on the debate session. On the contrary, some of the types that are not rated as redundant in the first survey were understood to be less needed.

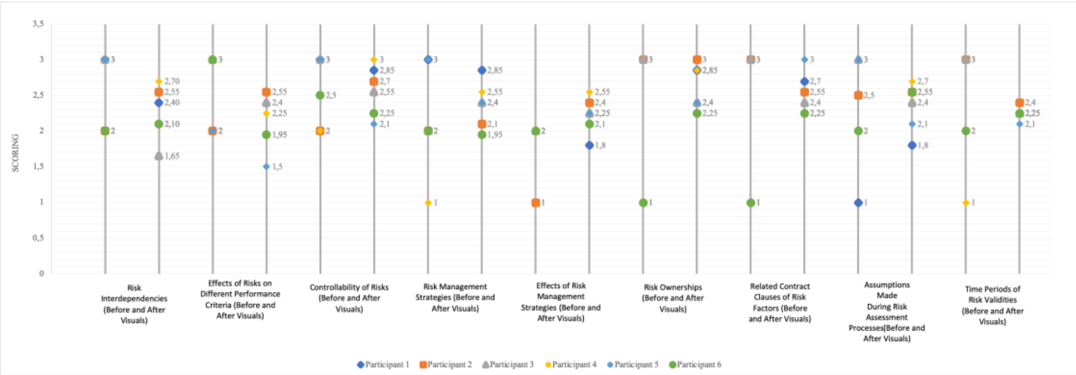

Figure 4.20. Individual Evaluations of Participants on Risk-Related Semantic Data (Pre- and Post-Visualization Formats)

When the selected risk related semantic data is analyzed individually, “Controllability of Risks” was considered to be prominent for all participants in both phases of the workshop. “Risk Ownerships” and “Related Contract Clauses of Risks” are considered to be important post visualizations, even though the participants have been dealt with different levels of risks in their earlier experiences. “Risk Management Strategies”, “Assumptions of Risks,” and “Effects of Risk Management Strategies” increased slightly post visualizations. In contrast, “Risk Interdependencies”, “Effects of Risks on Different Performance Criteria” and “Time Periods of Risks” decreased.

While discussing, participants stated their concerns on the effort and time to gather the data and prepare the risk visualizations for practical applications. For practical purposes, the visuals shall be prepared by also considering the possible value to be added. Some may not add value in the return of the effort required. Participants have stated the complexity of visualizations can also be a challenge for decision-makers during the discussion. “Clarity” of the visuals is important as well as their “Usefulness” when the complexity of visual is being considered. In addition, “Effectiveness” is important when the resources are considered. “Aesthetics” is also an effective factor for decision-maker to make use of prepared visual deliverable, which should be evaluated with “Clarity”. Figure 4.21, Figure 4.22, Figure 4.23,

Figure 4.24 shows the average ratings for each visualization for each evaluation criteria.

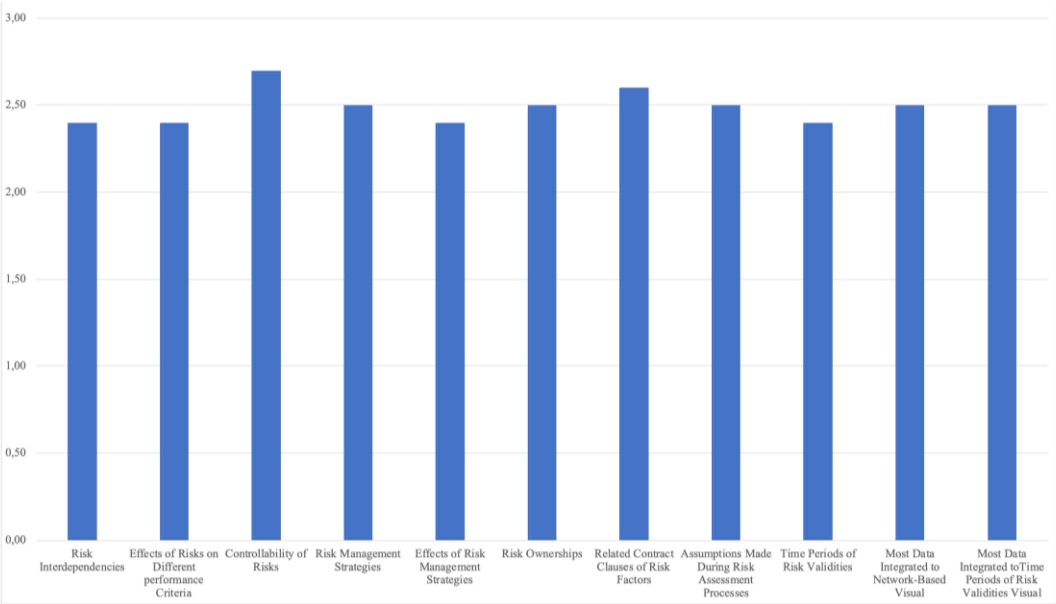

Figure 4.21. Average of Usefulness Ratings

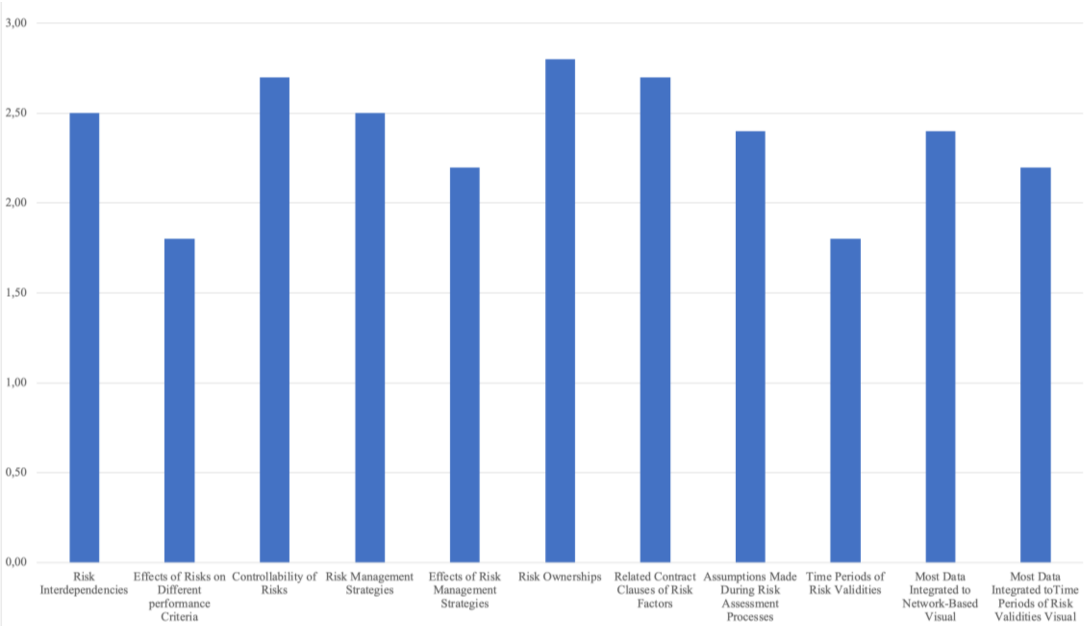

Figure 4.22. Average of Clarity Ratings

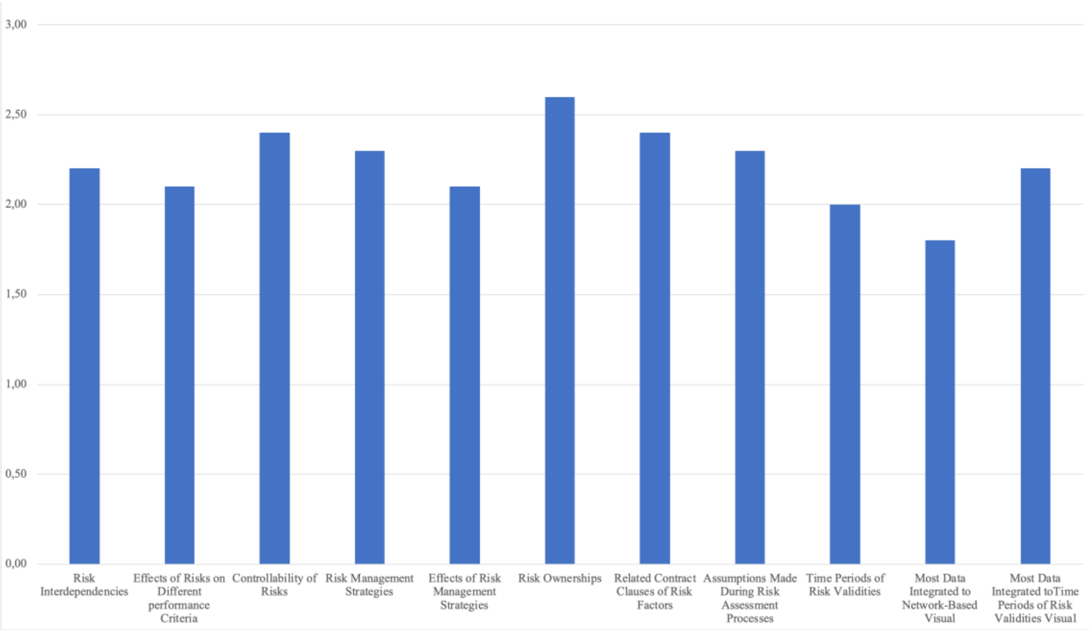

Figure 4.23. Average of Aesthetics Ratings

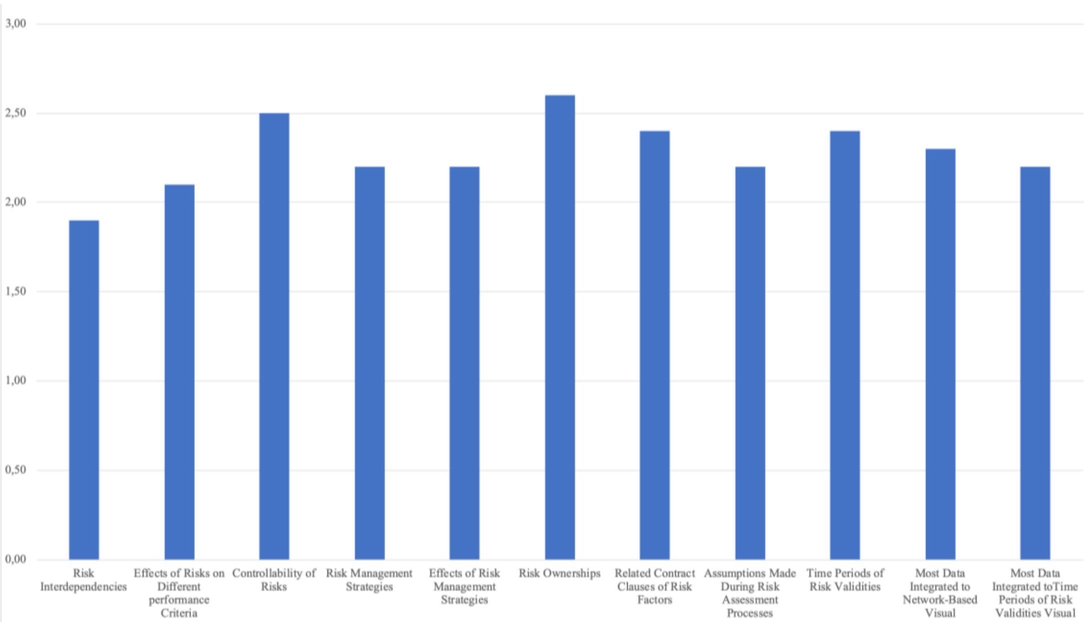

Figure 4.24. Average of Effectiveness Ratings

To avoid misinterpretations, decision-makers should evaluate the current situation effectively using the information that is delivered through visualizations. Because of this, “Clarity” and “Aesthetics” are important factors to consider when delivering risk visualizations. For most cases, “Usefulness” is equal to or higher than “Aesthetics” and “Clarity of the visuals. When the information is delivered through a visual, it recognized to be more useful compared to feedbacks from the first session, which is without visualizations. If the “Aesthetics” and “Clarity” of visualizations is improved, the “Effectiveness” of risk visualization shall be higher on enhancing risk communication. As the visual becomes clearer and aesthetically appealing, it will be easier to interpret the information, thus it will add more value compared to the effort to create the visualization. From Figure 4.21, it can be seen that “Usefulness” of selected types of risk-related semantic data are above 2.4, which shows that, when necessary, decision-makers can make use of visualizations when necessary.

For “Clarity”, “Risk Interdependencies”, “Controllability of Risks” and “Risk Management Strategies”, “Risk Ownerships” and “Related Contract Clauses of Risk Factors” are higher than 2.5, which can be seen from Figure 4.22. Only “Risk Ownerships” is higher than 2.5 for “Aesthetics”, in Figure 4.23, which is an indication that the visuals shall be improved. When “Clarity” is considered with “Aesthetics”, only the “Risk Ownerships” has a score higher than 2.5. In order to improve the effectiveness of visuals, the “Aesthetics” shall be focused. Moreover, if the “Usefulness” is considered, the ratings of “Effects of Risks on different Performance Criteria” and “Time Periods of Risks” also show an increase from the results of the first survey to the second. In addition to that, “Effects of Risks on Different Performance Criteria” and “Time Periods of Risk Validities” has a scoring of 1.8. Same visuals are rated as 2.1 and 2.0, respectively, in terms of “Aesthetics”. Both criteria shall be improved by following necessary design suggestions to increase effectiveness which shall be done through iterative steps. Even though the data delivered is from a small-scaled application, the visual density of some visualization formats can be considered as high by participants. This can be seen from the low ratings of “Aesthetics” and “Clarity”. While communication the risk data through visualization formats, although the information itself is useful, it may not be effective because of visual density and complexity.

In the end, “Effectiveness”, shown in Figure 4.24, and overall ratings of visuals are mostly affected by the “Aesthetics” and “Clarity”. This might be because of visual complexity. As the visualization that are shown are seen by the participants first time, the fit between decision-makers’ way of thinking and the way the visuals are represented may take more iterations. The visualizations shall be improved through the iterative steps as well as the way of decision-makers’ approach to the communicated information.

Overall, the primary concern presented by the experts is the time for the application of such visualization methodology. For practical uses, experts prefer robust and useful outputs, which are visualized in less complex ways. Even though the information is useful, it may not worth the time and energy that is used to form such representation with the existing risk information management processes. The effects of visualization formats generating new ideas on experts can be seen from the change in evaluation of pre- and post-presentation of visualizations. When risk communication is considered, the risk-related semantic data that was thought of as unnecessary is perceived to be useful and effective after the visuals are presented to the participants.

In addition to given oral feedback and results of the survey, there are participant feedbacks directly related to the revision of prepared risk visualizations. Those feedbacks are given in Section 4.3.1. and consecutively, revised visualization is given in Section 4.3.2. with reasons and explanations.

4.3. Revision of Risk Information Visualization Formats

In order to demonstrate the steps of the framework, the feedbacks that are obtained from the participants were used to revise the prepared risk visualizations. The feedbacks that are obtained during the debate session is given in Section 4.3.1. and the revisions that are done in the light of the feedbacks are given in Section 4.3.2.

4.3.1. Feedbacks for Revision of Risk Visualizations

The following quotations are the feedbacks that caused to the revision of the visualizations. One of the feedbacks is directly led to the revision of a visualization . P6 stated that:

- *"Instead of using different circles that coincide with different colors, each node of the network can be represented with pie charts. This way, the intensity of the visuals can be decreased."*

After the statement of P6, P3 added another idea to that feedback:

- *"Pie charts can be more effective for decision-makers to analyze the situation faster. If such visualization is presented, the pie chart can also show the numerical value of risk ratings for different criteria, as well as the numerical value of total risk score that is calculated, can be shown in addition to the size of the pie charts."*

Another feedback to increase the effectiveness of the risk visualizations came from P5:

- *"Even though the controllability of risks is very useful, representing them with transparency may be misleading. Instead of using transparency, a color scale can be determined and used.*

The participant suggested that the use of a color-scale can cause the controllability of risks to be more apparent and not confusing for decision-makers. When the overall ratings are also considered with this feedback, instead of focusing on valid time periods of risks, the interdependencies can be focused, which can be updated depending on the situation when necessary. Finally, P2 stated that:

- *"Using a lot of risk factors may increase the complexity of visuals. In this case, as 5 risks are used, it is easy to understand and analyze the situation. For practical applications, the visualizations can be prepared by using the top 10 risks that exist at that moment. Instead of focusing all risks, top 10 risks can be identified, and insignificant factors can be eliminated to focus on significant* *risk information. The decision-maker will not waste time to interpret the visualizations, and fewer resources can be used, increasing the effectiveness of visualizations."*

As the prepared visualizations are a demonstration, it includes fewer nodes. For practical purposes, this can be an effective approach to use fewer resources in terms of time and manpower.

4.3.2. Revising Visualizations According to Feedbacks

In the end, the visualizations are revised according to the acquired feedbacks. Of course, the information visualization principles and guidelines presented by Ware (2013) are also used at this stage. Indeed, when the design guidelines of Tufte (2007) regarding the data-ink ratio were re-considered, no color was used for the nodes to represent strategies, as given in Figure 4.25. The other indications (contract clauses, assumptions and owners) are kept same as they use matching colors with symbols.

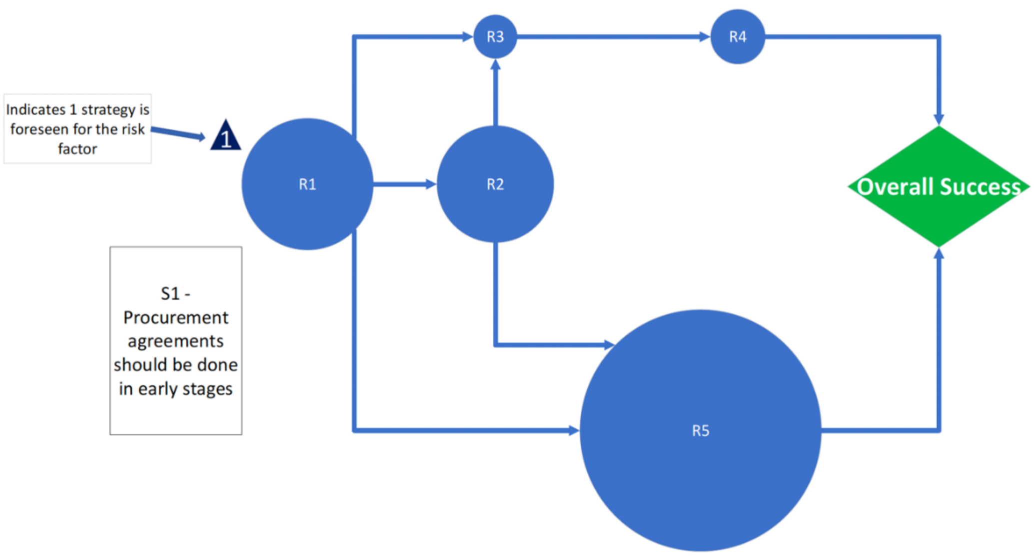

Figure 4.25. Revised Form of Strategy Visual

After revisiting the visualizations, pie charts are used for the revised risk visualizations in order to represent different success criteria, as given in Figure 4.26. This is a good example depicting the iterative process of preparing risk visualizations. Controllability of risks are changed to a color scale instead of transparency to present fewer complex visuals, as given in Figure 4.27.

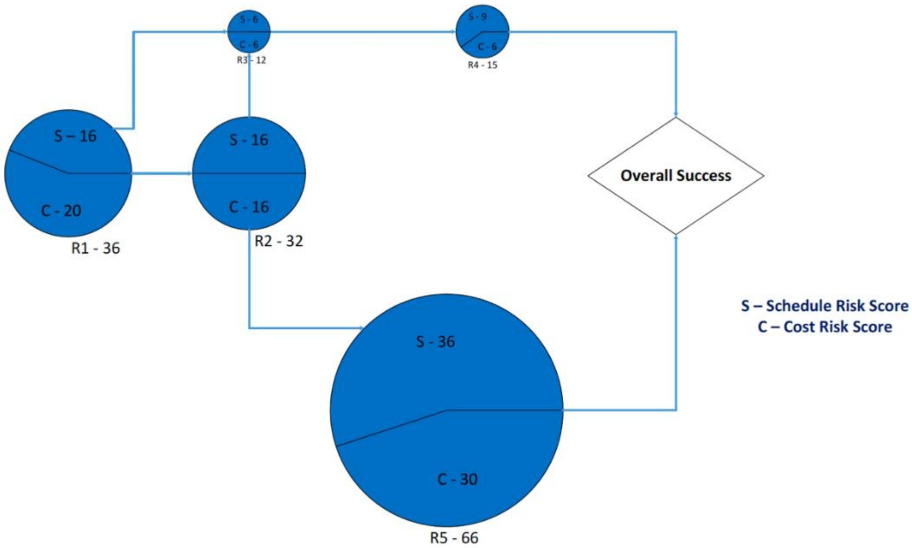

Figure 4.26. Revised Visualization For the Effects of Risks on Different Success Criteria

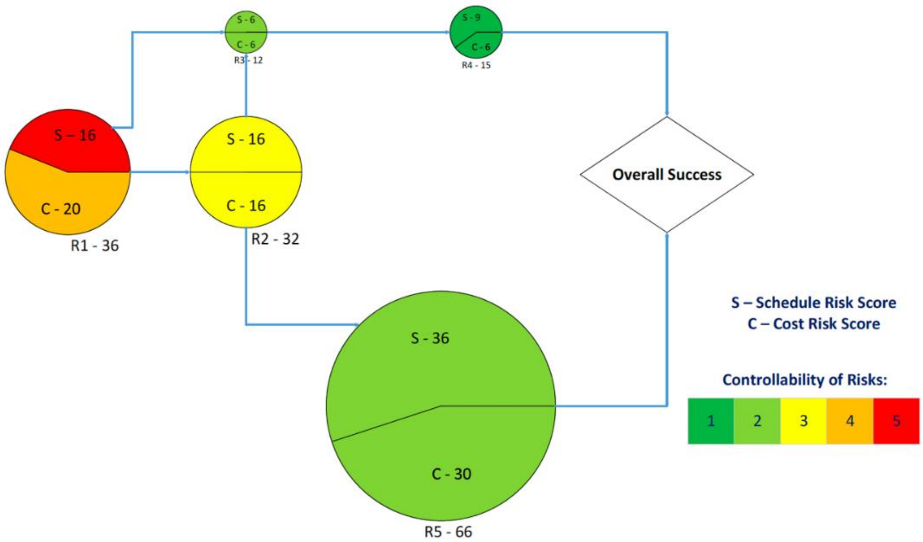

Figure 4.27. Revised Visualization for Controllability

Figure 4.28 is the revision of integration of most features on network structure. Firstly, all nodes are represented as a pie chart that shows the overall risk score of the risks, which is divided into two depending on the percentage of cost and schedule risk scores as percentages. Secondly, the risk score for that criteria is also written inside that charts, and total risk scores are written below the representing node. Thirdly, for controllability, instead of using transparency-based representation, a color scale is determined, which is given as a legend below the prepared visualization. Also, the color of strategy arrow is removed due to previously stated reason.

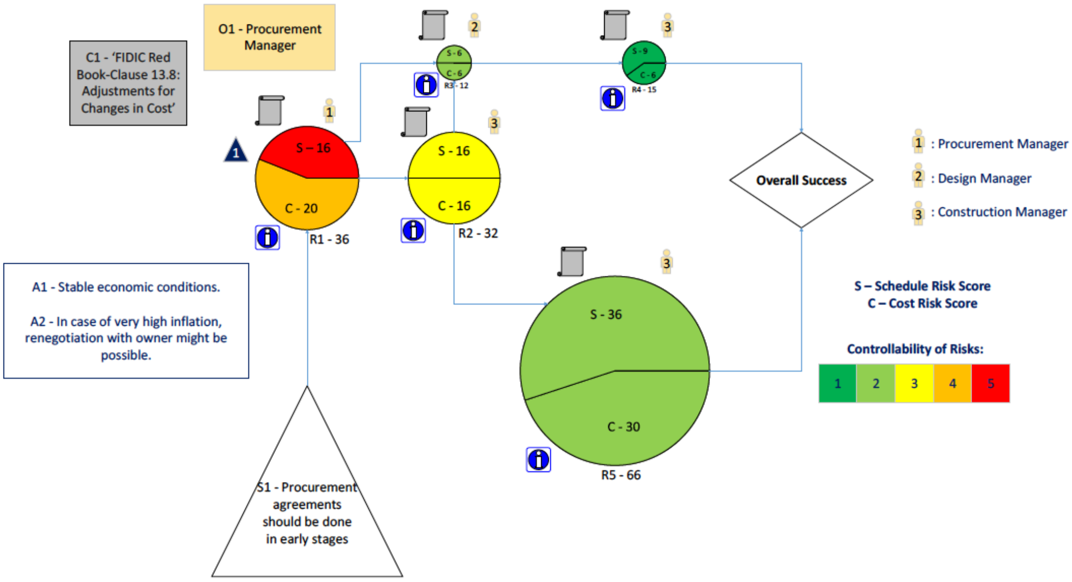

Figure 4.28. Revised Visualization for the Integration of Most Features on Network Structure

In Figure 4.29, the colors of strategy arrow is also removed and controllability is changed to color scale because of design guidelines. Finally, if this process will be applied in a real-life project the number of risks can be higher. Hence, the feedback from P2 regarding the usage of Top 10 risks can be noted while preparing a risk visualization for the projects with many different aspects. As this is a demonstration of the approach, it is not included in the scope of this study. Representation of risks such as top 10 risks or upcoming major risk factors can be effective, enhancing the risk communication between parties.

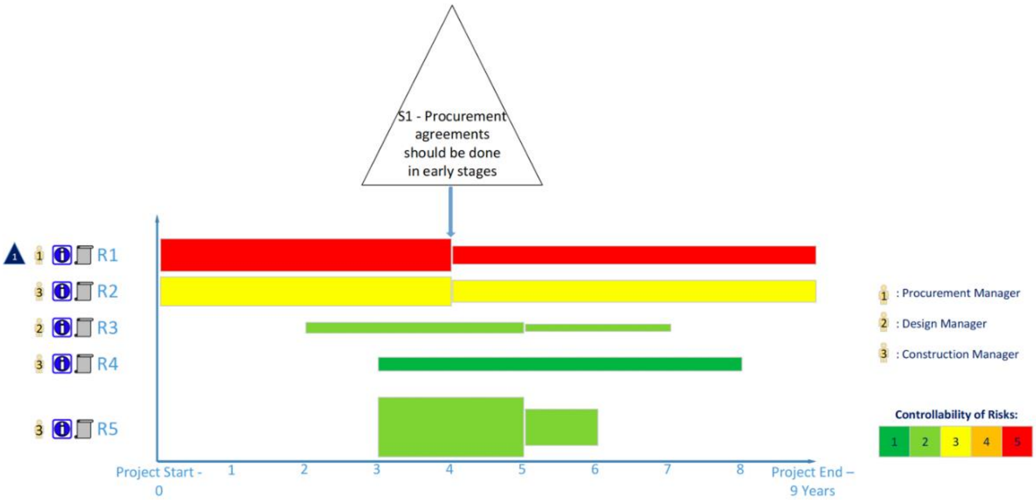

Figure 4.29. Revised Form of Integration of Most Features on Time Periods/Durations of Risks

In the end, the iterative process to develop risk communication visualizations to deliver risk information is demonstrated and visualizations are revisited according to participant feedbacks. The framework and the methodology to apply iterations might differ depending on the company structure, however a demonstration is presented to make an example of risk communication methodology using visualizations. Following design guidelines can improve the methodology to deliver effective visualizations as well as it can decrease the number of iterations. This can result in more robust and accurate visualizations.

CHAPTER 5

CONCLUSION

5.1. Summary of Findings

Various risk modeling and assessment methodologies have been suggested and applied in literature and the sector. These methodologies are mostly qualitative and focus on the processed risk data in the form of probability impact (PI) matrices. Besides, existing risk communication among project participants generally does not concentrate on the context of the risk data (e.g., assumptions, relations) that can be useful for decision-making. In other words, project participants mostly communicate the PI matrices and fail to communicate related risk context, which case can hinder robust decision-making. From another perspective, a vast amount of studies that prove the value of information visualization in different domains (e.g., HCI, Data Analysis, Healthcare) have been performed. In contrast to these numerous studies, project risk visualization has been an understudied area in the construction domain. Hence, this research study is designed to answer the question of whether the systematically prepared visualization of risk-related semantic data can improve the risk communication between project participants.

This study firstly offers a risk visualization framework that aims to be a starting point for practical applications of risk visualization. The framework includes six steps to improve communication between parties while answering the needs of decision-makers. The components of the framework include: 1) Determination of Risk Process, 2) Determination of Objectives, 3) Determination of Stakeholders, 4) Determination of Data Types, 5) Determination of Visualization Tasks and 6) Determination of Visualization. A few exemplary uses of framework have been shown on hypothetical cases.

The second part of this study focuses on the visualization of a set of risk-related semantic data. A total of ten risk related data are identified from literature: (a) Risk Scores, (b) Interdependencies, (c) Effects of Risks on Different Success Criteria, (d) Controllability of Risks, (e) Risk Management Strategies, (f) Effects of Risk Management Strategies, (g) Owner of Risks, (h) Related Contract Clauses of Risks, (i) The Assumptions that are Made During Risk Assessment Process, (j) Time Periods/Durations of Risks. To strengthen communication, network and Gantt Chart based eleven visualizations are developed that contain represent various risk-related semantic data. These visualizations are evaluated by six risk experts through a workshop. It should be emphasized that this study does not focus on the best way to apply a risk visualization framework or the best way to visualize the most useful data. Instead, it is a demonstration for a practical application in the construction sector. In the end, this study offers a start point for a risk visualization framework as well as visualization of risk-related semantic data.

During the workshop, the risk-related semantic data are evaluated for both pre- and post-visualizations. For both stages of the workshop, “Controllability of Risks” is evaluated as prominent. Without the visualizations, “Risk Interdependencies” has also been evaluated as an important risk-related data. Post-visualization results show that the importance of “Risk Interdependencies” decreased, while the “Risk Ownerships” and “Related Contract Clauses of Risks” increased, showing the importance of these factors by different stakeholders.

5.2. Practical Implications

In order to apply the process of this study for practical applications, firstly, the companies shall develop the appropriate risk visualization framework. New visualizations should be identified according to involved stakeholders’ needs. Each company might need to customize the information visualization framework according to their characteristics and needs. Firstly, the roles of the companies differ in projects where ineffective data should be eliminated before processing. After the development of the framework, even though the sequence of the steps can change, there are important tasks that shall be applied. The availability and necessity of risk-related semantic data shall be determined. A similar workshop can be structured within the company or project operatives to identify the cognitive capabilities of decision-makers. In addition, by starting the process with commonly used graphs and data, organizational learning can be improved. By iterating through these meetings, the types of risk visualizations that fits the decision-maker can be identified as well as the risk-related semantic data that is asked to be delivered. Such workshop should help project participants to communicate and share the past experiences through the prepared visualizations.

5.3. Limitations and Future Work

The existing problem of risk communication have been reported many times and the value of risk-related data visualization has been verified in the workshop. However, the observations from the workshop are limited to six invited participants that have been actively working as risk management professionals in the sector and they might not be generalized.

Delivery of information and communication of risks is necessary for every stakeholder in every project step. From the findings of the workshop, (a) there is a need for different types of risk-related semantic which should be identified according to needs and (b) different visual techniques to deliver the risk-related information should be determined depending on the organization to enhance the risk communication.

This study suggests variety of risk visualizations that are developed using five risk factors. In other words, the case study is a simplified version of a real-life project and the scope (number and types of risks) can be widened.

The future studies can include the application of the visualization framework on a real-life case study. Doing so, comparisons with the traditional methodology can be studied in terms of the quality and quantity of the insights acquired and decisions-made using the framework. Moreover, a risk visualization tool that focuses on identifying and processing the needs of decision-makers via the framework can be developed. Such a tool should be flexible to answer the needs of different company structures, including different types of risk-related semantic data, related databases and different risk visualizations and tasks.

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APPENDICES

A. Workshop Surveys

A.1. Participant Information Form

1. Kısım

Ad ve Soyad:

1- Öğrenim durumunuz nedir?

☐ PhD ☐ MSc ☐ BSc ☐ Diğer ☐

2- Sektörde kaç yıllık profesyonel deneyime sahipsiniz?

3- Proje ve risk yönetimi alanında kaç yıllık profesyonel deneyime sahipsiniz?

4- Kendinizi risk yönetimi alanında ne kadar deneyimli görüyorsunuz?

☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek

5- Şu an çalışmakta bulunduğunuz firmanın projelerdeki rolü nedir?

☐ Teknik Müşavir ☐ Danışman ☐ Yüklenici

☐ İşveren ☐ Finansör Kuruluş ☐ Diğer ☐

6- Çalışmakta bulunduğunuz firmanın risk yönetim prosedürü var mı?

☐ Evet ☐ Hayır

7- Risk yönetimi sürecinde kullandığınız standart rapor formatları var mı?

☐ Evet ☐ Hayır

8- 7. soruya cevabınız evetse hangilerini kullanmaktasınız?

☐ Yazı ☐ Tablo ☐ Grafik ☐ Diğer ☐

9- Risk yönetimi için kullandığınız bir yazılım var mı?

☐ Evet ☐ Hayır

10- 9. soruya cevabınız evetse kullandığınız yazılımı belirtiniz.

A.2. Survey for Risk Related Semantic Data

2. Kısım

1- Geleneksel olarak kullanılan risklerin 'Olasılık' ve 'Etkileri' odaklı risk değerlendirmesini yeterli görüyor musunuz?

☐ Yeterli ☐ Kısmen Yeterli ☐ Yeterli Değil

2- Risk 'Olasılıkları' ve 'Etkilerinin' yanısıra, aşağıdaki faktörlerin de risk görsellerinde kullanılmasına ilişkin görüşleriniz nelerdir ?

a. Risk faktörleri arasındaki ilişkiler

☐ Gösterilmese de olur ☐ Gösterilirse iyi olur ☐ Mutlaka gösterilmeli

b. Risklerin farklı performans kriterlerine (süre, maliyet, kalite, iş güvenliği, vb.) olan etkileri

☐ Gösterilmese de olur ☐ Gösterilirse iyi olur ☐ Mutlaka gösterilmeli

c. Risk faktörlerinin kontrol edilebilirlik seviyeleri

☐ Gösterilmese de olur ☐ Gösterilirse iyi olur ☐ Mutlaka gösterilmeli

d. Risk yönetim stratejileri (finansman, kontrol, vb.)

☐ Gösterilmese de olur ☐ Gösterilirse iyi olur ☐ Mutlaka gösterilmeli

e. Risk yönetim stratejilerinin etkileri

☐ Gösterilmese de olur ☐ Gösterilirse iyi olur ☐ Mutlaka gösterilmeli

f. Risk faktörlerinin sahipleri (riski yönetmekle sorumlu kişiler)

☐ Gösterilmese de olur ☐ Gösterilirse iyi olur ☐ Mutlaka gösterilmeli

g. Risk ile ilgili sözleşme koşulları

☐ Gösterilmese de olur ☐ Gösterilirse iyi olur ☐ Mutlaka gösterilmeli

h. Risk değerlendirmesinde yapılan varsayımlar

☐ Gösterilmese de olur ☐ Gösterilirse iyi olur ☐ Mutlaka gösterilmeli

i. Risklerin geçerli olduğu süreler ve proje süresince değişimleri

☐ Gösterilmese de olur ☐ Gösterilirse iyi olur ☐ Mutlaka gösterilmeli

A.3. Survey for Evaluation of Risk Visualizations

3. Kısım

Görselleri, aşağıda bulunan değerlendirme kriterlerine göre lütfen değerlendiriniz.

(Not: Yararlılık derecesine karar verilirken, görselin risk yönetim planına kattığı değer ve proje yönetimi açısından faydası değerlendirilmelidir. Etkinlik değerlendirilirken ise, görselin hazırlanması için gerekli olan zaman (verilerin toplanması, girilmesini vb.) ve gerekli işgücü düşünülmeli, yarar ve maliyet birlikte düşünülmelidir.)

G1 – Riskler arasındaki ilişkiler

• Anlaşılırlık	☐ Çok Düşük	☐ Düşük	☐ Orta	☐ Yüksek	☐ Çok Yüksek
• Yararlılık	☐ Çok Düşük	☐ Düşük	☐ Orta	☐ Yüksek	☐ Çok Yüksek
• Görsellik	☐ Çok Düşük	☐ Düşük	☐ Orta	☐ Yüksek	☐ Çok Yüksek
• Etkinlik	☐ Çok Düşük	☐ Düşük	☐ Orta	☐ Yüksek	☐ Çok Yüksek

G2 – Riskler arasındaki ilişkiler ve farklı performans kriterlerine etkileri

• Anlaşılırlık	☐ Çok Düşük	☐ Düşük	☐ Orta	☐ Yüksek	☐ Çok Yüksek
• Yararlılık	☐ Çok Düşük	☐ Düşük	☐ Orta	☐ Yüksek	☐ Çok Yüksek
• Görsellik	☐ Çok Düşük	☐ Düşük	☐ Orta	☐ Yüksek	☐ Çok Yüksek
• Etkinlik	☐ Çok Düşük	☐ Düşük	☐ Orta	☐ Yüksek	☐ Çok Yüksek

G3 – Risklerin kontrol edilebilirlik seviyeleri

• Anlaşılırlık	☐ Çok Düşük	☐ Düşük	☐ Orta	☐ Yüksek	☐ Çok Yüksek
• Yararlılık	☐ Çok Düşük	☐ Düşük	☐ Orta	☐ Yüksek	☐ Çok Yüksek
• Görsellik	☐ Çok Düşük	☐ Düşük	☐ Orta	☐ Yüksek	☐ Çok Yüksek
• Etkinlik	☐ Çok Düşük	☐ Düşük	☐ Orta	☐ Yüksek	☐ Çok Yüksek

G4 – Risk yönetim stratejileri

- Anlaşılırlık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Yararlılık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Görsellik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Etkinlik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek

G5 – Risklerin stratejiler sonrasındaki değişimleri

- Anlaşılırlık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Yararlılık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Görsellik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Etkinlik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek

G6 – Risklerin sahipleri (riski yönetmekle sorumlu kişiler)

- Anlaşılırlık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Yararlılık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Görsellik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Etkinlik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek

G7 – Riskler ile ilgili sözleşme koşulları

- Anlaşılırlık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Yararlılık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Görsellik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Etkinlik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek

G8 – Risk değerlendirmesinde yapılan varsayımlar

- Anlaşılırlık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Yararlılık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Görsellik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Etkinlik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek

G9 – Tüm bilgilerin bir arada gösterilmesi

- Anlaşılırlık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Yararlılık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Görsellik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Etkinlik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek

G10 – Risklerin proje süresince değişimi

- Anlaşılırlık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Yararlılık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Görsellik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Etkinlik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek

G11 – Risklerin değişimi ve ilgili diğer bilgilerin birlikte gösterilmesi

- Anlaşılırlık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Yararlılık ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Görsellik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek
- Etkinlik ☐ Çok Düşük ☐ Düşük ☐ Orta ☐ Yüksek ☐ Çok Yüksek

B. Detailed Survey Evaluations

B.1. Evaluation for Risk-Related Semantic Data

Participant	*Q1*	*Q2a*	*Q2b*	*Q2c*	*Q2d*	*Q2e*	*Q2f*	*Q2g*	*Q2h*	*Q2i*
P1	Sufficient	3	2	3	3	1	3	3	1	3
P2	Partially Sufficient	2	2	2	2	1	3	3	2,5	3
P3	Not Sufficient	3	3	3	2	2	3	3	3	3
P4	Sufficient	2	2	2	1	2	1	1	2	1
P5	Partially Sufficient	3	2	3	3	2	1	1	3	2
P6	Partially Sufficient	2	3	2,5	2	2	1	1	2	2

B.2. Evaluation for Risk Visualizations

Visual No	*Criteria*	*P1*	*P2*	*P3*	*P4*	*P5*	*P6*
V1	Clarity	4	4	4	4	4	5
	Usability	4	5	3	5	4	3
	Aesthetics	5	4	2	5	3	3
	Effectiveness	3	4	2	4	3	3
V2	Clarity	3	4	4	3	2	2
	Usability	4	5	4	4	3	4
	Aesthetics	4	4	4	4	2	3
	Effectiveness	2	4	4	4	3	4
V3	Clarity	5	5	5	5	3	4

	Usability	5	5	4	5	4	4
	Aesthetics	5	4	4	5	3	3
	Effectiveness	4	4	4	5	4	4
V4	Clarity	5	4	4	4	4	4
	Usability	5	4	4	5	4	3
	Aesthetics	5	3	4	4	4	3
	Effectiveness	4	3	4	4	4	3
V5	Clarity	3	4	4	4	4	3
	Usability	4	4	4	4	4	4
	Aesthetics	3	4	3	5	3	3
	Effectiveness	2	4	4	4	4	4
V6	Clarity	5	5	4	5	4	5
	Usability	5	5	4	4	4	3
	Aesthetics	4	5	4	5	4	4
	Effectiveness	5	5	4	5	4	3
V7	Clarity	4	5	4	4	5	5
	Usability	5	5	4	4	5	3
	Aesthetics	5	3	4	3	5	4
	Effectiveness	4	4	4	4	5	3
V8	Clarity	3	4	4	5	3	5
	Usability	4	5	4	4	4	4

	Aesthetics	3	4	4	5	4	3
	Effectiveness	2	4	4	4	3	5
V9	Clarity	3	3	4	3	2	3
	Usability	5	3	5	4	3	4
	Aesthetics	4	3	4	3	2	4
	Effectiveness	4	4	5	4	4	3
V10	Clarity	4	4	4	4	4	4
	Usability	4	4	4	4	4	5
	Aesthetics	3	4	3	3	2	3
	Effectiveness	4	4	4	4	4	3
V11	Clarity	4	4	3	3	4	4
	Usability	5	4	4	4	4	4
	Aesthetics	4	4	3	3	4	4
	Effectiveness	4	4	4	3	3	4