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Uncertainty management in the design phase of road projects

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Abstract

Uncertainty management in the project's design phase is perceived to be one of the important stages before the project execution. Studies on uncertainty management could influence projects' objectives such as cost, time, and quality. With the importance of the design phase, there is less research in the project's design phase which tries to know important uncertainties and measures for managing them. Multiple case study approaches were adopted for doing this research. Data was collected through a narrative search, a document study, and interviews. Data analysis of cases showed that there are different uncertainties with various origins in each case and strategies for tackling them were different. In both cases, owners mainly focused on the strategic and contextual uncertainties mostly and contractors focused on operational uncertainties and they transfer strategic or contextual uncertainties to the owner. In both cases, mitigation strategy has been applied mostly for tackling uncertainties, and acceptance strategy has not been observed in cases. The project's complexity, the contract's collaboration form, and the actors' role are factors that influence the uncertainty management strategies in projects. This study revealed the differences and similarities in the two cases from uncertainty factors and uncertainty management strategy based on qualitative evaluation.

Keywords: Uncertainty factors, design phase, uncertainty origins, uncertainty management strategies;

1. Introduction

A study of different authors [1, 2] shows that design changes are one of the main reasons for projects' cost overruns. Kazaz et al. [1], after recognising design changes and their impact on project performance, said that it needs to be managed in projects' early phases. Therefore many changes are related to poor performance or lack of planning during the pre-project or design phase of the construction projects. Aslam et al. [2] categorized design changes into internal (client, designer, and contractor-related factors) and external factors. They evaluated the impact and causes of design changes and mitigation strategies for them. These changes could happen deliberately, unconsciously, or mistakenly by each actor, or they can be outside of their performance territory. The poor performance in identifying uncertainties prior to execution is one of the reasons for such changes.

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There is much research about identified uncertainties in construction projects. However, evaluating these uncertainties in road projects' design phase is investigated less in comparison with the implementation and pre-project phases [3, 4], which highlights a research gap. There is a need for such a study due to the importance of the design phase in fulfilling project objectives and its influence on uncertainty management in later phases [5]. Identified uncertainties in the design phase contribute to practitioners adopting suitable strategies against them, improving project planning, and communicating effectively before the project's execution. Another reason for the lack of focus in the design phase is that companies might mostly be engaged in operations and construction more than planning or pre-evaluation of the projects. As project managers and actors gain knowledge of uncertainties during the design phase, their confidence increases. Although projects are unique, and projects might not have the same results, the study of the historical data or case evaluations of previous projects could provide helpful information for new projects. According to the paper's purpose, which is to improve awareness about uncertainties in the design phase of road projects following questions were presented:

Q1: What are the important uncertainties in the project's design phase?
Q2: How are uncertainties treated in the design phase?

2. From theory to a theoretical framework

2.1. Design phase according to different collaboration forms

Uncertainty level in the design phase of road projects varies according to different collaboration forms of actors. For example, in design-build contracts, the contractor has the responsibility for the design and in traditional design-bid-build the project's owner hand in the project's design to the consultant and then to the contractor to build it. Therefore, the level of risks and uncertainties in each contract form for the project's actor could be different. In this paper, we evaluate common uncertainties in the project design phase, in two projects with different contract strategies.

Osipova [5] evaluated the participation of different actors in projects, their role in the risk management process and their influence on the risk management process. Findings of that study show that contractors have the highest impact on risk management in comparison with other actors. The people's participation in the research majorly depends on their role in the project. For example, consultants participated more in the design and development phase [5].

The research by Osipova and Apleberger [6] shows that clients seek design-build contracts because of a single point of responsibility for the client. Performance-based contracts give more flexibility based on the project's design phase, and the collaboration level for contracts is successful when trust exists between different actors. Collaboration among partners is one of the reasons for projects' success [7]. Projects' complexity also impacts the overall project performance from different aspects such as time, cost, quality, and safety. Complexity is defined by Ward and Chapman [8] based on the influencing factors and their interdependencies. Another definition could be that is defined by the number of different elements (complicacy) and interrelation of different elements in a system (complexity) [8, 9, 10].

2.2. Uncertainty and risk factors' necessity for uncertainty management

Uncertainty "factors" as we chose for this study are the most known uncertainties or important uncertainties which affect the project performance and objectives. Different uncertainty factors exist in literature which has been known by many scholars [2, 3, 4, 11, 12]. The traditional objectives of projects are cost, time, and quality as Atkinson et al. [12] called performance measures which originated from the variation of these factors. The impact of factors is not limited to these three objectives and encompasses short-term and long-term projects' objectives.

"Uncertainty management includes the identification and analysis of uncertainties and developing strategies to exploit or mitigate them". Risk management includes all the process for uncertainty management plus the impact of events [4]. Uncertainty factors make uncertainty analysis easier during the project life cycle. Without having variables or factors and following them up, understanding or analyzing the risk level or uncertainty level will be hard because they change during different project phases. For instance, in the research by Chapman [13] market-related factors are changes in end value, market competition, demand change, raw material cost, a shift in the market, innovative competitors, and new suppliers. All these sub-factors aside under the factor of market condition. These factors help to identify uncertainty origins, which are explained in the next section.

2.3. Uncertainty origins and strategies for managing uncertainties

Uncertainty origins could be categorised into operational, strategic, and contextual. Operational uncertainties are related to the project and are managed by the project team and contractors. Technical issues, use of resources, and efficiency are some examples of uncertainties with operational origins. Strategic uncertainties have origins at the business level and are beyond the control of the project manager and might be controlled by the project owner. For example, starting or ending projects, scope approval, and scope changes are some examples of strategic uncertainties. Contextual uncertainties belong to conditions outside

the project and could affect the project process and result. Law, market conditions, and national culture are some instances of contextual uncertainties [4,14].

After recognising uncertainty factors and their origins, we need to tackle these uncertainties. Based on the types of uncertainties, the strategies for tackling them could be different. According to PMBOK [15] there exist four strategies for dealing with negative risks and threats, which are :

Avoid: It is an effort from the project team to eliminate the threat and minimize the impact of the threat.

Transfer: This strategy involves transferring the impact and responsibility of a threat to a third party.

Mitigate: In this strategy, project team attempt to reduce risk by reducing the probability and impact of an event occurring with undesirable consequences for the acceptable limit.

Accept: Acceptance is a strategy when the project team acknowledges a risk and takes no action until the risk occurs.

In this paper, we consider uncertainty includes risk and opportunity, and we recognized four above-mentioned strategies for uncertainty management in studied cases. Based on uncertainty origins and different strategies for uncertainty management, theoretical framework of this paper has been shaped.

2.4. Theoretical framework

Figure 1 shows the theoretical framework of this paper. Uncertainty factors are categorized into operational, strategic, and contextual as explained in 2.3. According to different uncertainty types and origins which determine the contract collaboration form and projects' complexity, different actors would adopt different strategies for uncertainty management. One of the four strategies or a combination of them could be used.

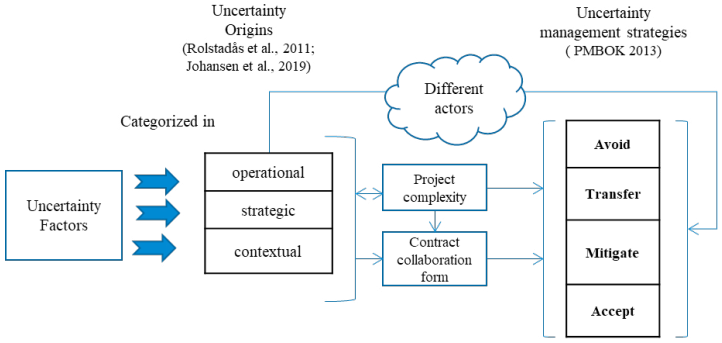

Fig. 1. Theoretical framework of this paper

This framework shows that project complexity and contract collaboration form are factors that influence the adopted strategies, and they perform as mediator variables between origins of uncertainty and uncertainty management strategies. Besides, project complexity also influences the collaboration form. For example, when projects have high technical complexities, the contract strategy differs from projects with a lower level of complexity. Different actors according to their roles and responsibilities and types of uncertainties could choose various strategies (one of four) against uncertainties.

3. Research design

This study includes multiple case studies using interviews and document studies to exploit the theory and develop it [16]. Interview as a qualitative strategy shows which uncertainties are identified and how they are treated in projects. In this section first, the cases were introduced. Second, the document study and narrative search process were elaborated. Third, the semi-structured interviews and limitations of the paper were explained.

Yin [17] claims you can assess a phenomenon in different scenarios when there are several case studies. With two cases, researchers can compare differences and similarities between cases, and data become more reliable [18]. This paper combines theory with empirical evidence to analyse and verify theoretical propositions. Triangulation is a research strategy that uses different data sources. This strategy was applied for data collection in this research to improve the reliability of the findings [16].

3.1. Cases

Case studies helped to perceive the complexity of the cases such as changes over time, the work process, the interaction of different parties, and so on. The case study also facilitated grabbing the projects' contextual condition [17]. There are strategies for selecting cases according to differences or similarities [16]. Our selection criteria were focused on the similarities of cases. In the construction industry finding symmetric cases is difficult due to each project's uniqueness and choosing cases based on

having similarities was easier. Both cases were state-funded projects and were in the execution phase. Both were large and complex projects in terms of size and operation in Norway. They are located in the same region in Norway. They have differences, such as one of them is located in an urban area and the other in a suburban area. For data collection, two road projects were used with the following characteristics, as illustrated in Table 1.

Table 1. Characteristics of cases for investigation

Road case 1 (bridge and road close to the city- urban area	Road case 2 (Long national road – with road, tunnels, bridges and crossing- rural area
1.2 km new road	19 km road
1.7 km cycling road	Four tunnels with double tunnels
154 million dollars	621 million dollars
Interviews and document study	Interviews and document study

The description for studied cases are as follow:

Case 1 –Cable bridge and belonging infrastructure: An old bridge in the area will be replaced by a new cable bridge, and that new bridge will be connected to a new tunnel. The new 183-meter-long bridge with a tower will be presented as a local landmark in the city, which makes this project more important. This project includes a 1.2 km road, 2.1 km ramps, 570 meters of secondary roads, 1.7 km bicycle road, 14 constructions, and a 160-meter tunnel. It includes the construction of a new road, two new bridges, and an old bridge that will be updated to accommodate pedestrians and bicycles. It is estimated that the project will cost around $154M.

Case 2 –Four-lane highway construction: The old road was introduced as a corridor road and a part of the national transport network. The old road has many problems related to safety and traffic and had a high risk of accidents which needed to be improved. The new four-lane road will replace the previous two-lane road. Higher speed limits and a shorter length together with higher quality will reduce the travel time and increase safety on the highway. This project has four double tunnels. The project has at least seven consultants involved in the project. The road length is approximately 19 km. The estimated cost of the project is around $621M.

3.2. Narrative search and document study

The first step of this process started with choosing important keywords related to research questions. After searching for keywords, related studies were selected for each paper's part. Primary keywords for a narrative search were uncertainty factors, risk factors, uncertainty management, design phase, construction projects, and road project. In the second step of the narrative search, some studies based on suggestions of experienced co-authors are selected for writing definitions, theory section, making theoretical framework, and paper's methodology part.

A document study was conducted to know project characteristics, important uncertainties related to each studied case in the paper, and uncertainty analysis processes in the projects. Document study was a complementary study before doing the interviews to get knowledge about projects and related uncertainties in these projects. During the research process, this information was completed with new documents in contact with project parties.

3.3. Semi-structured interviews and Limitations

The cases were different but for each case, we did interviews with different parties. For example, in case 1, we interviewed with the project owner and contractor. In case 2 we interviewed the project owner and general contractor. The general contractor was responsible for project design and execution. The interviews resulted in preliminary knowledge about the different uncertainties and uncertainty management of these uncertainties during the project's design phase. The questions have been asked during the interview were as follows:

i. What are the five important uncertainties during the design phase?
ii. Why do you think these uncertainties are the most important?
iii. How did you manage them during the design phase?
iv. How do you collaborate during uncertainty management with other actors?

The main questions were asked with the guidance of experienced co-authors with over 20 years' experience in uncertainty analysis of different construction projects. The schedule of interviews varied depending on the interviewees' time limitations from 60 to 90 minutes. The interviewees' roles were project manager, project planner, and project controller.

This study does not show the perspectives of all team members in projects and only shows the perspective of part of the team in the project. The findings of the study are not applicable to all road projects, and in this study, we only focused on two state-funded road projects in Norway. Multiple case studies need much time and effort compared to a single case study. In addition, multiple case studies reduce the observation time which could be improved if we study one case [16].

4. Findings

In Table 2, according to interviews, the main uncertainty factors and measures for tackling them are summarized. Uncertainties in a project could be divided into operational, strategic and contextual as it is shown in Table 2. For instance, closeness to rivers is categorized as contextual uncertainty as it is not under the control of the owner or contractor. Although, actors could adopt some measures to reduce related uncertainties and risks of it. Another interview finding was that designers and consultants were not involved in the uncertainty management process.

Table 2. Uncertainty factors and measures for tackling them for two cases

	Roles	Five main uncertainties	Measures for tackling uncertainties
case 1	owner	Closeness to river (contextual)	Having rules and considering distance with river during construction (mitigation)
		Technical complexity in execution (strategic)	Using competent people and relying on competency of contractor (transfer)
		Quick clays (contextual)	Using lime and cement pile of soils in order to ensure stability / applying detail geotechnical investigations before start of the project (mitigation)
		Tender competition for Choosing best contractor (strategic)	By choosing the competent contractor in competition and giving much weight to quality and competence of contractors (avoidance)
		HSE related uncertainties in execution (operational)	Setting up measures for HSE and external environmental analysis for related risk early in design phase by owner and consultants (mitigation)
	contractor	Traffic management during execution (operational)	Scheduling closure of traffic / giving suggestion to people use public transport / planning for making temporary roads and roundabouts to facilitate transport around construction area (mitigation)
		Safety in execution (operational)	Using 3D models (mitigation)
		Vicinity to agricultural land (contextual)	Planning and spending much time in order to know which plan is good for placing of internal flow of material (avoidance)
		Tunnels in mountains and securing them (operational)	Trying to consider rules and standards by authorities (mitigation)
		Access to construction site (operational)	Using experience-based capacities of team members and 3D models (mitigation)
case 2	owner	Unstable ground condition (contextual)	Detail design and consulting with expert in geotechnical and evaluation of differed alternative considering HMS, cost, competency of contractor (mitigation)
		Environmental risk (contextual)	Having meeting with authorities and following rules and safety standards (mitigation)
		Vicinity to agricultural land (contextual)	Changing the other alternative or choosing expensive solutions (avoidance)
		Tunnels in mountains and securing them (operational)	Having more investigation and detail planning and evaluations during design phase (mitigation)
		Access to construction site (operational)	Preplanning and improving logistic would help to solve this uncertainty (mitigation)
	contractor	Ground condition (contextual)	Choosing optimal alternative (avoidance)
		Technical uncertainties (operational)	Considering buffers for price increase by the owner (transfer)
		Increase in prices (contextual)	Contract strategy and choosing suitable execution strategy (mitigation)
		Sharing risk with owner and Execution model (strategic)	As mentioned, it will transfer to owner and based on requirement of client, contract type, and complexity of project the execution model will change (transfer)
		Changes in scope (strategic)	Preplanning and more investigation during design phase (mitigation)

Interview with the owner in case 1 (Table 2) showed that uncertainties were as follows: limited construction area, the closeness of the construction site to the river, selection of the best design in the design competition, ground condition near the railway, and choosing the best contractor(s) were the main uncertainties in this project. In case1, the main uncertainties based on the project's document study were as follows: The contractor has responsibility for maintenance during construction. There are three main uncertainties before the project starts, such as closing the road because of traffic, closeness to the railway, and closeness to the river. Each of these uncertainties has its related risks and opportunities. For instance, closing traffic can lead to an increase in costs and finally the risk of cost overrun for the project. Being close to the train track could increase the risk of accidents and injury to people and property. Quick clays are another problem that relates to ground conditions. Tender competition is another uncertainty that needs to be evaluated well in order to give the work to a trusted contractor. Choosing the best alternative by the owner is another uncertainty. Mass handling should ponder the environment and CO2 production. Closing the main road and setting up rigs for construction there. Uncertainty about the satisfaction of cycling road for users. There is

much uncertainty related to Health, Safety, and Environment (HSE) in the execution phase of the first case in the future which needs to be considered.

Uncertainty factors from the contractor perspective in case 1 were as follows, having traffic flow during projects' execution and safe execution, which is hard to manage both. Space shortage for project execution while letting traffic flow. Nearness to rivers which is important to keep it safe and not to pollute the river with the aid of a suitable logistic system and making concrete inside the river and trying to not pollute the river. Different uncertainties are found in case 2 through the document study. One of them is to make a culvert in the path of the train line which is replaced by the old one. Vicinity to the river in this area makes the work challenging because of environmental considerations such as avoiding water pollution or considering fish. Rockfall and landslides are another uncertainty. Besides, a major landslide over the roadway can lead to death and injury. The unstable ground has the risk of slipping off the road, especially when heavy vehicles and soft ground are used. Quick clay landslide is another uncertainty.

According to the owner, in case 2 they had large areas with unstable ground conditions. Environmental risk is another risk that is extra relevant in this project due to its closeness to a river. Vicinity to agricultural land can put a project at risk. For example, in parts of the project to avoid damaging agricultural land, they should go toward building on quick clay and the roads will be much more expensive. Tunnels toward mountains and securing them is another uncertainty. Access to construction sites was one of the challenges. A contractor said the main uncertainties were: "ground conditions, technical uncertainties, changing prices, sharing risks with the owner in each issue which results in price increase and expected scope".

5. Discussion

5.1. Important uncertainties in the design phase of the projects

Uncertainties could be perceived differently for each stakeholder involved in the uncertainty management process. There were some differences in pre-project analysis from design analysis. Besides, comparing of cases showed us that different owners and contractors could have faced different uncertainties. Uncertainty types could influence on responsibilities and response of stakeholders. Interviews in both projects showed that owners mainly focus on contextual and strategic uncertainty and risks, and contractors mostly focus on operational risks. Although they have some common concerns in all operational, strategic and contextual uncertainties. Consultants help owners with strategic uncertainties such as design changes which affect the projects' scope and changing solutions with significant influences. Therefore, project managers and their role in operational uncertainties follow the same line with the literature [4]. In case 1 it seems that the owner has a managing role in uncertainty management, and they are less involved in technicalities, but in case 2, the owner has the main and active role, and they are active in technicalities, and they have the system for uncertainty management. Case 1 has three main contracts, and the bridge contract was a separate contract from other parts of the project. Because they assumed that small contracts create better competition in the market. Open tender competition helps to save time in removing preparing documents and also helps contractors to become acquainted with the project.

In case 1, the designers respond to the client about changes and in case 2 the designers respond to the contractor. Case 1 follows a traditional design-bid-build contract, and case 2 seems to be a collaborative design-build contract. The study by Kristensen et al. [19] shows that designers have a challenge not only in choosing the contract model, but the real difficulty also relates to who they respond to in the project – the contractor or the client, In the first case, the owner control design work and they follow a unit price contract. Therefore, based on unit price contracts the owner has a lower risk of changes in the design of the work. In the second case, there was a cooperation contract between owner and contractor and the contractor-controlled design work. In ground condition, risk and uncertainty belong to the owner. In the first project, a contract with the designer was the main contract in which the designers were responsible for whole the design work.

As depicted in Figure 2, in case 1 contractor has more focus on operational uncertainties and owner has more focus on strategic and contextual. In both cases, owner has more focus on contextual uncertainties with 5 items, which is in accordance with Johansen et al's. [4] research. The difference between the two case studies might be related to contract collaboration form, and project characteristics.

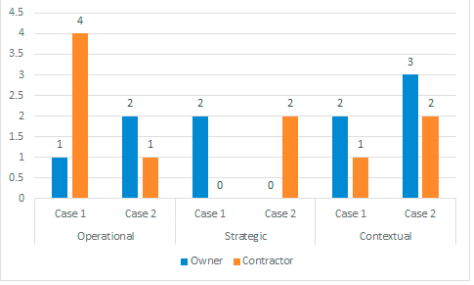

Fig. 2. Origins of uncertainties according to roles

5.2. Uncertainty treatment in the design phase

It is noteworthy that the difference between uncertainty management and risk management was that the impact of events was not considered in uncertainty management. All the steps of risk management were evaluated in this paper such as identifying uncertainties, evaluating them and mitigating them except defining the impact of events which was not covered [6].

According to the document study and interviews, the strategies and measures for tackling uncertainties were presented in Table 2. There are different strategies for tackling uncertainties, and when the uncertainty is uncontrollable for owners or contractors, they choose the acceptance strategy. For example, market and price changes are instances of these uncertainty types. When the uncertainty is controllable by actors, they choose a mitigation strategy. Contractors in cases which do not have enough control over risks such as market conditions use a transfer strategy and move it to the owner. In projects, this depends significantly on the type of contracts. As it was explained, mitigation and avoidance were the most common strategies for actors. Transfer strategy from the owner to contractor works in the context of contextual and strategic uncertainties. For example, ground conditions and an increase in market prices could be transferred to the owner. Strategic uncertainties are mostly handled by choosing different solutions which need to be in accordance with the client's requirements. For example, changes in contract strategy or scope changes are types of strategic uncertainties. Operational uncertainties are mostly done through mitigation and trying to reduce the consequences for early planning in the project's design phase.

As depicted in Figure 3, in both cases 1 and 2 mitigation strategies were used, which shows both contractor and owner try to reduce the uncertainties which might lead to expected risks. The acceptance strategy shows zero, which might be due to the fact that both contractor and owner normally consider contingency for uncertainties which are not under their control.

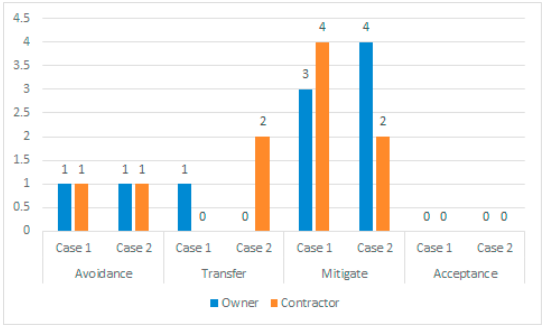

Fig. 3. Origins of uncertainties according to roles

Figure 4 illustrates the relation between the origins of uncertainties and strategies for tackling them. Contextual and operational uncertainties were handled mainly by mitigation strategy. Transfer strategy applied mostly to strategic uncertainties. Acceptance strategy would not apply in these two cases, which however does not mean that it is not adopted by actors. Because these types of uncertainties are not under the focus of actors nor not reflected as the most important uncertainties, we could not see the measures against them.

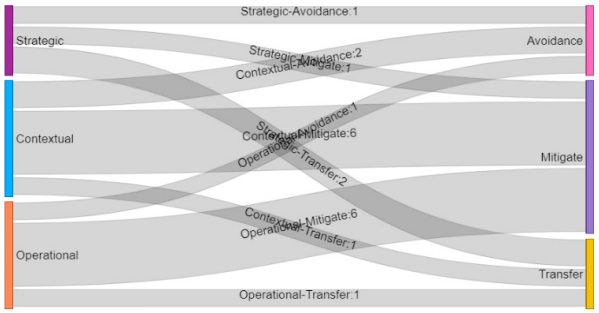

Fig. 4. Relation of origins of uncertainty with strategies

This paper provided an overview of actors involved in a project about important uncertainties, although project-specific findings are not generalisable to other projects, it would give insight to readers and researchers about uncertainties and their origins for large road projects in Norway. This study also showed researchers and different project actors how collaboration form of contract in the design phase influences uncertainty management strategies, which is one of the main contributions of this paper. In this paper, uncertainty management was studied.

6. Conclusion

This paper sheds light on important uncertainties in the design phase of the projects and the strategies for tackling them. A theoretical framework was introduced which shows the choices of strategies for uncertainty management according to different uncertainty types. The case study approach contributed to answering the research questions.

This study looks into the design phase from identifying uncertainties to tackling them. In this paper, the first question was answered by finding important uncertainties for different actors and the origins of important uncertainties. The second question was answered by finding important measures which actors adopt for tackling uncertainties. According to the type and origins of uncertainties, contract collaboration form, projects' complexity and different roles these strategies could be different. Based on this research, we concluded that owners mostly focused on uncertainties with strategic and contextual origins and contractors mostly focused on uncertainties with operational origins. Complex project in an urban area as in case 1 have different contract strategy which tries to reduce the risk of design and transfer it to a third party. In case 2 contract strategy is more like a collaborative strategy, and they share risk with the contractor in the design phase. This study is valuable in seeing the quality of uncertainty management in adopting suitable strategies. Although this research might suffer from subjective evaluation of authors in defining uncertainty origins.

This research focuses on two road projects in Norway. The findings of this study cannot be generalized to other road projects and other project types. However, the findings of this study and theoretical framework are helpful and give insight to other projects in the road construction industry. The future study could focus more on quantitative analysis to uncover important factors in the project's design phase as one of the important phases in the life cycle. Besides, more cases could be considered for future studies.

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