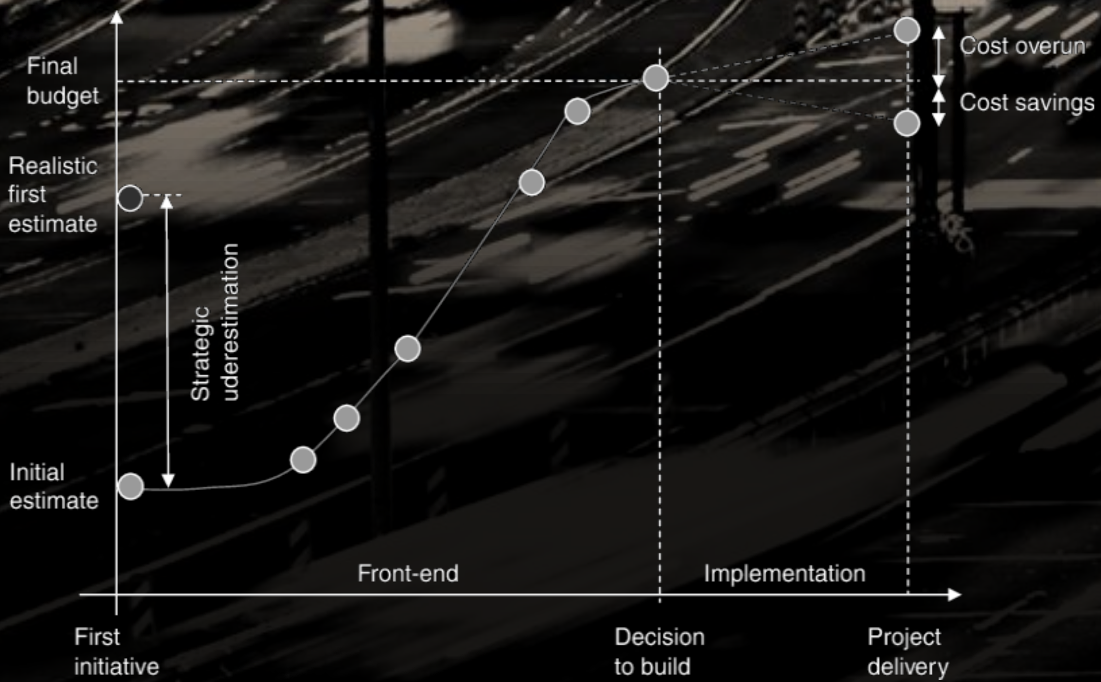
Cost - conscious designing of Dutch transportation infrastructure projects

A first explorative research into the 'control' based factors for reducing the front-end cost escalations



Source : Terry Williams, Knut Samset,, 2010 by the Project Management Institute

Atul Pathak

MSc. Construction Management & Engineering

TU Delft
ARCADIS

Master's Graduation Thesis

A Master's graduation thesis

on

Cost-conscious designing of Dutch transportation infrastructure projects

A first explorative research into the 'control' based factors for reducing the front-end cost escalations

by

Atul Pathak

in partial fulfilment of the requirements for the degree of
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Thesis Committee :	Prof. G.P. van Wee	TU Delft, Committee Chair
	Ing. Peter de Jong	TU Delft, Supervisor II
	Yan Liu	TU Delft, Supervisor I
	Ing. Robert Jan Roos	Arcadis, Company Supervisor

TU Delft

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Schiphol Group

Provincie Noord-Brabant

ARCADIS Design & Consultancy for natural and built assets

Image courtesy: Arcadis,
Project A12/A20 for safe traffic flow to Gouda with the construction of N451 and N457. These new roads are called as Parallel structure A12. Connecting The Hague to Gouda, this project by Arcadis has resolved the traffic congestion around the Gouweaquaduct. Both of these two lane roads were executed with the technical assistance of Arcadis in order to deal with the existing Amali bridge, which was a hurdle to the development. (Province of South Holland)

Piet Mondriaanlaan 26, 3812 GV Amersfoort, The Nederland, Postbus 220 3800 AE, Amersfoort
Tel 026 911 3778; Fax 026 2353515 www.arcadis.nl

Colophon

AUTHOR

Name	**Atul Pathak**
Student number	4739728
E-mail	A.Pathak-1@student.tudelft.nl ; ar.atulpathak@gmail.com
Telephone number	+31 6 490 90964
University	**Delft University of Technology**
Faculty	Faculty of Civil Engineering and Geosciences, Stevinweg 1, 2628 CN, Delft
Master	Construction Management and Engineering (CME)

THESIS COMMITTEE

Committee Chair	**Prof. Bert van Wee**, *PhD* Professor Transport & Logistics Group | Engineering Systems & Services Faculty of Technology, Policy & Management Delft University of Technology Delft, The Netherlands Email : G.P.vanWee@tudelft.nl
University Supervisor II	**Peter de Jong**, *Ing.* Lecturer Design & Construction Management | Management of Built Environment Faculty of Architecture & Built Environment Delft University of Technology Delft, The Netherlands Email : p.dejong@tudelft.nl
University Supervisor I	**Yan Liu,** *M.Eng.* PhD Candidate Section Integral Design & Management | 3Md Faculty of Civil Engineering & Geosciences Delft University of Technology Delft, The Netherlands Email : Y.Liu-9@tudelft.nl
Company Supervisor	**Robert Jan Roos**,*MSc*., Senior Advisor, Cost Leader Project Cost Management | Traffic & Public Transport, Infrastructure Division Arcadis Nederland BV Amersfoort, The Netherlands Email : robertjan.roos@arcadis.com

COMMISSIONED BY

Company	**Arcadis Nederland BV** Piet Mondriaanlaan 26, 3812 GV Amersfoort, The Nederlands, Postbus 220 3800 AE, Amersfoort
Division	Infrastructure Division
Department	P&CM (Project & Cost Management)

This thesis is dedicated to

My father

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Preface

This report is the final deliverable of the Graduation project assignment for the MSc. CME program, with which I would be concluding my journey as a master's student in Delft university of Technology. The thesis was a collaboration between the infrastructure division (Transport & road infrastructure group) of the engineering consultancy Arcadis and Delft University of Technology. The research was an initiation from Arcadis, who were willing to implement their definition of 'cost-conscious designing' within their teams. They defined cost-conscious designing as the practice of accurately estimating a project & controlling its cost with the designing process so as to deliver an accurately estimated & well optimized design'. Being aware with the problem of consistent front-end escalation well documented in literature, Arcadis was interested in how the front-end escalations can be reduced. In their terms, they were interested on how their envisaged practice of 'cost-conscious designing' could be implemented within project teams. With very less past research available for the starting points, I laid the foundation of this research by holding some preliminary discussions with the cost management team of the division. The discussion gave an industrial scenario on what factors have been affecting the front-end cost performance, and how do they interplay to generate front-end escalations. I am very thankful to the Arcadis cost experts who showed up to lay the starting points of this thesis due to the lack of past researches on reducing front-end escalations. Amongst the Arcadis cost experts, I sincerely thank Christian, Wil, Paul, Else, Edwin, Mark & my company supervisor Robert Jan himself. Robert's passion on the front-end performance of infrastructure projects really helped in my growth as a professional in the construction industry. This research is the first systematic attempt ever to conduct an ex-post evaluation of the front-end phases for infrastructure projects. It gave first indications on how the front-end escalations can be reduced in future projects by taking learnings from the ex-post analyses.

After spending almost 7 months in this research, I realized how the feedbacks from academic experts intricately shapes a thesis and strengthens its argumentation. A heartfelt thanks to my first supervisor Yan, who was always available to help me out despite of his own PhD research. Sincere thanks to my second supervisor Peter, who taught me the art of reasoning in the research process. His additions to the research methodology made the thesis more genuine, appealing & with widespread implications. His expertise with the designing process & cost considerations gave meaningful insights to analyze both the case studies. I have learnt a lot from my supervisors and I envy them for their line of reasoning. A great note of thanks also goes to my Chair Prof. Bert van Wee, who was always as pro-active with my research as my daily supervisors. His advises on scientific writing helped me to grow as an academically matured student. Thank you mentors!

Finally, thanks to my family in India & in Delft: Yash, Akshay, Abhishek, Khyathi, Nikhil, Harsh, Ragav, Asmeeta, Pratul, Jyotshni and others, who made my thesis journey like a fun loaded caravan!

Atul Pathak
Delft, September 24th, 2019

Executive Summary

'Cost-conscious designing', as defined by Arcadis cost experts, is the process of accurately estimating a design/cost baseline for a project & adhering to it throughout the front-end phases to finally deliver an accurate & optimized budget with least escalation. This research intended to see the possibilities on achieving such a practice.

Part I - Research Context & Design

Infrastructure projects have been suffering with high cost overruns, and the magnitude of overruns hasn't decreased for the past 70 years (Flyvbjerg, et al., 2004). Average overruns have been found to be 20% for roads, 45% for rail transits, & 34% for fixed links projects like tunnels & bridges (Flyvbjerg, B., Holm, M. S., & Buhl, S. ,2002). In the Netherlands, Cost-Benefit Assessment is widely used to perform comparative assessment between the projects, in order to choose the ones which deserve the national funds for getting implemented. Due to cost overruns in a project, governments are not able to achieve the benefits-cost ratio on the basis of which they favoured a project over others. A lot of projects which were in high overruns in the recent past shouldn't have been approved/funded/preferred by the decision makers over others (For example: The Channel Tunnel in the UK, cost overruns = 100%, Denver intl. airport in the USA, cost overruns =200%). Consistent overruns also indicate that even with consecutive projects, the experts are not learning to improve on it as well. So, cost overruns in infrastructure projects have been a subject of discussion for more than 2 decades now. It has been realized that not only the estimates presented to the decision makers should be accurate, but also the total project costs post approval (at the decision to build point) should adhere to the approved estimate. Either of the two situations/or both would lead to cost escalations/overruns.

Cost escalations/overruns can be experienced by the projects in both the phases: front-end designing & execution. Unlike execution phases, more research has been demanded on front-end phase as most of the researchers have found the first circumstance as the most prevailing reason for overruns (Welde, M., & Odeck, J. ,2017 ; Flyvbjerg, B. et al., 2004 ; T Williams & K Samset, 2010 etc.). It has been realized that the front-end phases allow for the maximum control over the costs & ironically, the industry experiences maximum escalations in the front-end only (Cantarelli C. et al, 2012, Torp O., Thodesen C., 2016). Ex-post studies have been said to bring revelations on how projects suffer front-end escalations. Limited research exists on the front-end phases with almost all of them based on Nordic governance setting and only one on the Dutch governance setting by Nijkamp & Ubbels (1998).

More researches exist on the 'problem chain' of front-end escalations than on the 'solution chain'. This limited research mostly includes the studies that have produced *'characteristic escalation figures'* & the *'factors/causes'* leading to front-end escalations: Flyvbjerg, B. et al., (2004) classified the factors into political, cognitive & technical; Moschouli et. al (2018) & Memon et. al (2011) gathered factors like site conditions, payment methods, way of project financing, contractual disputes etc. All these factors except 'technical & cognitive' are quite external to the project teams and are difficult to research on through ex-post studies. Citing 'political factors' as the prime cause, most researches on the 'solutions' counterpart have been discussing over political misrepresentation. Very less researches have been done on the 'technical & cognitive' factors, which are internal to the project teams and can be easily studied through the ex-post researches on the front-end phases. These factors basically influence the 'estimation' & 'controls' of the costs. Research developments like Reference class forecasting (RCF), Target Value Designing, Activity - based costing, PMBoK Cost control cycle, Earned value management etc. are some existing methods/tools to steer the technical/cognitive factors. But most of these tools are estimation based, i.e. they can estimate a situation accurately but don't give any leads to control the different scenarios in an uncertain front-end environment. Recent researches by Love, P. E. et al. (2011); (2015), have emphasized that researches on strategic misrepresentation & RCF is not enough and more focus needs to be given to the technical & cognitive factors as they can explain 'why' & 'how' events lead to a net front-end escalation despite of the consultant's monitoring. The emphasis could be on 'technical/cognitive' factors for smaller projects which are more in number and may not involve much politics/governance misconducts. Quite significant amount of money can be saved and better project value can be achieved for these many projects. This was the main research interest of this thesis.

From the past, there have been no recommendations on which types of 'factors' and through which research method should studies be done for resolving the problem of front-end escalations. Due to less past researches on the need to steer 'control' based technical factors, this thesis was designed as the first explorative research. Due to lack of past research, it was apprehended that 'control' based technical factors may not prove to be influential enough in the front-end phase. It was also a possibility that they are found to be influential enough, but can't be steered. Either of the result was expected to be considered as an important 'research outcome'. These apprehensions were also due to the existence of the bottom-up based - 'PMBoK 'cost-control' approach and the industry's acceptance for it in the execution phases. The PMBoK cost control cycle is the only existing 'method' that is most closely based on the Deming's circle (Plan, Do, Check & Act) and can steer the 'control' based technical factors. But it is devised for controlling such 'factors' in the execution phases and demands consistency in project documents. Contrastingly, the front-end project documents are not consistent due to frequent variations in the uncertain surroundings. So, an a-priori choice was made to decide a research direction for the problem of front-end escalations:

'The PMBoK based cost control approach for the execution phases also has some relevance/ applications to the front-end phases and it can reduce the problem of front-end cost escalations'

The 'control' based factors were stated as the 'Subjects of learnings (SoLs) in this thesis as not much is known over these factors for the front-end phase, and lots of information/learnings is required on them. Based upon the current know-how on the role of 'control' based factors in front-end cost escalations, following research gaps were identified:

Gap 1: The extent of influence of the 'control' based technical factors/SoLs aren't yet known to the researchers. So, it is not known which of them should be primarily 'steered' for reducing the overall front-end escalations.
Gap 2: Some basic information required for steering the factors are not yet known: Approach to gather data [cross-project data (CL)/open data farming (OA)], approach to process the data [top-down (TD)/bottom up BU)], phase specificity of the factors, cost types influenced by the factors etc.

The thesis eventually targeted to give first indications on whether steering 'control' based factors can reduce front-end escalations or not. Like every explorative research, the intention was not to solve the entire problem of front-end escalations but to finally give indications on whether research on 'control' based factors would be of some relevance or not. Following set of research questions were framed:

Main R.Q.: How can the front-end cost escalations in transportation infrastructure projects be reduced by conducting their ex-post evaluation?

Sub R.Q I: What are the crucial 'control' based technical SoL's/factors leading to the front-end cost escalations?

Sub R.Q. II : What suitable data collection & processing approach can be recommended to steer these crucial SoLs in order to reduce the front-end cost escalations?

Given the time constraints and limited data access, the considered infrastructure type for this research was 'roads' due to their simplicity in design components as compared to rail transits/ fixed-link projects. A triangulation method (Yin, 1984) was adopted for this research due to lack of past researches. The three research methods in triangulation were: Questionnaire survey, Longitudinal Studies & Interviews (See figure 1 below). The research was conducted within the strategies of Survey & Case studies:

- 'Survey' helped in identifying the latest influence/knowledge attainability trends with the most important project control factors gathered from the literature :
  a) Questionnaire survey collected general characteristic figures on front-end escalations and the rankings for the gathered 'factors' from literature (influence rankings & cross-learning attainability rankings). The most crucial 'factors' were considered for the case studies.
- 'Case studies' helped in identifying how the 'factors' influence in a project and what possible actions can be taken to control the SoL/factor :
  a) The longitudinal studies were conducted to identify how the costs of the same project performed with time. Through IDA, The 'factors' that acted in the project were identified. Also, the possibility to extract necessary data for cross-learning was identified. The project specific characteristic escalation numbers were produced as a project specific results.
  b) The interviews with 12 participants helped thereafter in exploring what approach (TD/BU ; CL/OA) was taken in order to control the 'factors'.
- An expert judgement panel of 7 experts was formed to validate the findings form the surveys & the case studies.

The 'survey' strategy was utilized to answer the first sub-question, while the 'case studies' strategy was utilized for answering the second & third sub-question.

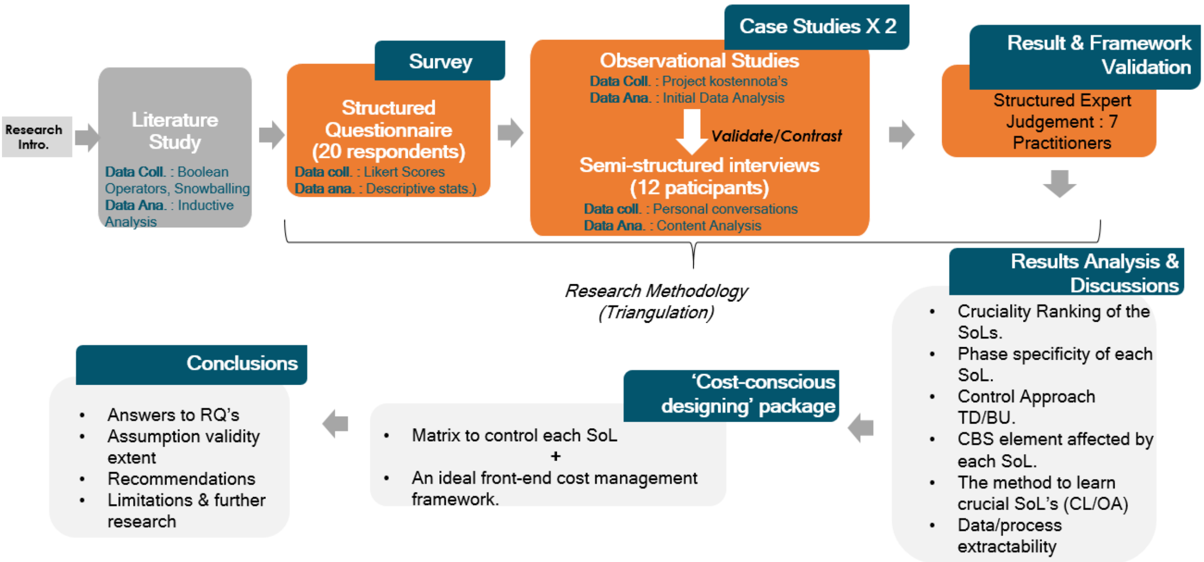

Figure 1 : Research methodology

Part II – Literature Review

To start with the research, firstly the most important ‘cost-control’ based SoLs/factors were identified from the scarce research literature existing on front-end cost-escalation (See table 1 below). Some of these factors were identified as a result of preliminary discussions within the Arcadis cost management team (See table 1 below). These factors were categorized into the three knowledge areas (KA’s) of cost control. The three KA’s of cost control instructs to measure, compare & take actions against an escalation:

i) Knowledge area I : factors which mostly influence the estimation of the escalation.

ii) Knowledge area II : factors which mostly influence the as-design comparison with the cost plan.

iii) Knowledge Area III : factors which mostly influence the ‘actions’ taken to compensate the escalations.

From the expert discussion sessions, the positive & negative behaviour of each of these factors was identified. It was concluded that by positively ‘steering’ all these 19 factors, the front-end escalations can be reduced to some extent. Secondly, the two basic necessities for ‘steering’ a factor was also theorized: A suitable approach for ‘data collection’ for the factor and a suitable approach to process these data. For data collection, the theory of cross-project data retrieval (CL) /project specific data generation (OA) was discussed. Cross-project data retrieval refers to the utilization of past project experiences to gather information, while project specific data retrieval farms unique design/cost data for the very specific project. For processing the data, the existing theory on top-down (TD) and bottom up approaches (BU) was discussed. A top-down approach involves considering a holistic system and breaking it down to get the accurate design/cost. While a bottom up approach utilizes the disintegrated known parts of the design/cost, which are added to produce an accurate estimate/design. No existing literature was found on the top-down and bottom up strategies of approaching any design/estimate for infrastructure projects.

Table 1: Summary of the list of 'control' based factors gathered from the literature & discussion with Arcadis experts.

	Knowledge Area 1 : Estimating the ‘escalation’	
01.	Estimation method for a particular phase	Technical
02.	Cost control thresholds	Technical/Cognitive
03.	Time available for each phase (SO-DO)	Cognitive
04.	Performance measurement regulations (e.g. : The frequency of cost monitoring)	Technical
05.	Completeness of the design/Engineering miscalculations	Technical
06.	Knowledge of cost benchmarks for direct costs	Technical/Cognitive
07.	Risks/contingency calculation	Technical/Cognitive
08.	Underestimation due to strategic political misrepresentation	Political
09.	Price Inflation	Technical
10.	PvA (plan van aanpak)/Requirement lists by client	Technical/Cognitive
11.	Constructability Analysis	Technical
12.	Design Variants Appraisal	Technical
13.	Optimizing time through construction schedule planning	Technical
14.	Scope additions by the client	Technical/Cognitive
	Knowledge Area 2 : Comparing with the baseline	
15.	Method of as-designed comparison with cost plan	Technical
16.	Comparing the current performance reporting with the previous reporting	Technical
	Knowledge Area 3 : Taking actions to reduce the ‘escalation’	
17.	Integrated design - change control process	Technical
18.	Knowledge of design-based cost-drivers	Technical
19.	Aligning designs with the revealed information in each phase.	Technical

Part III - Empirical Research

With the above identified factors from the literature, a structured questionnaire survey was conducted with an objective to receive Likert Scores for these ‘factors’ on two different response categories: Category I – Influence power on the front-end cost escalation; Category II – Cross-project learnability. Responses from 20 cost experts were obtained from different consultancies, who had experienced front-end cost escalations in Dutch road projects. The Likert scores were utilized to generate rankings for the respective categories using the RII (Relative Influence Index) method (See figure 2 below). The purpose of the ranking process was to filter the factors which were more important for the research. The ties in the rankings were resolved through descriptive statistics for the 20 responses received for each SoL in each ranking category. A new parameter called ‘Crucially’ was defined for the SoLs which are not only quite influential, but also difficult to cross-learn from past projects. An important result was that the most influential SoLs were also most difficult to cross-learn, except for three outliers: *‘Risk contingency planning’*, *‘time availability for each phase’* and *‘knowledge of cost benchmarks’*.

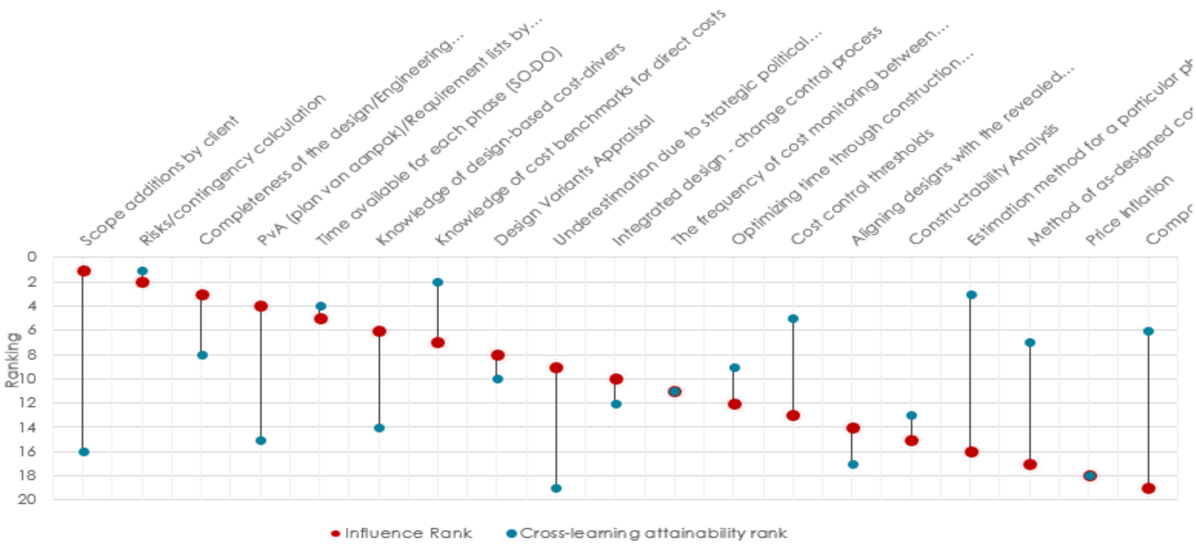

Figure 2 : Results summary from the questionnaire survey

Out of these 10, 7 of the SoLs were from KA- I & three of them were from KA-3, while no SoL appeared from KA-2. The rankings obtained were realized to be the first indications as it is the very first of its kind and represented the voice of only 20 experts. But more reliable was the mutual differences in the influence and attainability rankings for each SoL. The relative differences in ranks amongst the ‘factors’ was more reliable result than the ranks of the ‘factors’ itself, as the survey received less responses. Possibilities of rank changes was concluded, in case more participants would have been surveyed. Apart from providing indicative results on the SoLs, it was also validated that ‘cost-control’ based factors do influence the front-end phases, and the scarce literature demanding a research on them should be appreciated. The survey gave the answer to the first sub-question. The top 10 influential SoLs were taken for the further research as their interplay was to be studied through real life case projects.

The case studies were conducted on two road projects which were recently finished with their front-end phases: Project Schiphol landside works, which is under construction phase & Project N270 Helmond-Deurne, which is currently in its tendering phase. These cases were chosen as they were most recent, had experienced the two different possible behaviours in their front-end cost escalations and also were in different governance settings (pvt. & govt. respectively). While Schiphol landside works experienced a consistent avg. escalation of €2 mln in each phase (net escalation = €4.1 mln), project N270 experienced both escalations & relaxations (net escalation = €4.32 mln. So, longitudinal studies were conducted to study the front-end cost performance of these projects. The studies were done for both controlled and uncontrolled cost components in the respective projects, and the data was analysed using initial data analysis to gather project specific escalation findings. The findings were then validated with interviews. Six (2 cost engineers, 2 design engineers, 2 clients) one on one unstructured interviews for each case study (total = 12 interviews) were conducted.12 participants were found to be enough for data saturation. For each factor, information was obtained through interviews under certain headings : 'Event' , Cause' , 'Effect on the CBS elements and its depthness' , 'Phase specificity' , 'Demanded phase specificity for corrective actions' , 'Actions taken' & 'Generic actions recommended (TD/BU ; CL/OA)'. For each factor, the participants were asked to elaborate these headings by using incidents from the case.

It was found that most of the factors were steered in a BU+OA approach for Project Schiphol, while the same set of factors were mostly steered in a TD+CL approach for project N270. This indicated that project Schiphol experienced unique escalation events due to which the experts utilized the project specific data and processed it in a bottom-up approach for steering the factors. It was also found not every escalation was unforeseen in both the projects, and some of them could have been avoided by steering the 'factors' through better preventive/corrective approaches.

The heading 'Generic actions recommended' were answered by the participants on the basis of their overall experience and not case specific experience. Some differences were observed between the 'Actions taken' in the case projects, and the 'Generic actions recommended', which means that the case projects were slightly different than what the participants had generally experienced in overalls. The table 2 below summarizes the generic 'steering' approaches for each factor and the brackets show the number of participants who advocated it. Out of the 10 most influential factors, 7 of them were suggested to be approach in a top-down manner. The data collection method for these seven factors through varied. A framework was prepared to efficiently plan the front-end phases on the basis of the information gained over the 'factors'. A short expert validation session was held with 7 experts to discuss the results of the survey & the case studies. They approved the top standings in the rankings of both the categories, but advised to generalize the rankings only for the type of projects that were done by the survey participants. For the 'steering' approaches, the panel members agreed that majority of the factors can be 'steered' through a top-down approach but they were hesitant to generalize it again as the recommendations came from a certain expert population with definite project profiles.

Table 2 : Generic 'steering' approaches recommended for each factor/SoL

Top 10 most influential SoL / 'control' based factors	Generic 'steering' recommendations		Majority Consensus
	By Project Schiphol participants	By Project N270 participants	
Scope additions by client	TD+CL (6) ; BU+OA (6)	TD+CL (6) ; BU+OA (6)	TD+CL/ BU+OA
Risks/contingency calculation	TD+CL (6) ; BU+OA (6)	TD+CL (6) ; BU+OA (6)	TD+CL/ BU+OA
Completeness of the design/Engineering miscalculations	BU + OA (6)	BU+OA (5)	BU+OA
PvA (plan van aanpak)/Requirement lists by client	TD+CL (2) ; BU+OA (4)	BU+OA (4)	BU+OA
Time available for each phase (SO-DO)	TD (4) /BU (2)	BU+CL/OA (4)	TD + CL/OA
Knowledge over design-based cost-drivers	TD+CL (5) ;BU+OA (1)	TD+CL (5)	TD+CL
Knowledge of cost benchmarks for direct costs	TD+CL (6)	TD+CL (6)	TD+CL
Design Variants Appraisal	TD+OA (6)	TD+OA (2) ; TD+CL (3)	TD+OA
Underestimation due to strategic political misrepresentation	TD+CL (5) ; TD+OA (1)	TD +CL (2)	TD+CL
Integrated design - change control process	BU+OA (6)	BU+OA (6)	BU+OA

Part IV – Research results, Discussions (Reflections) & Recommendations

Due to the striking differences in the responses for 'actions taken' and the 'generic actions recommended', it was concluded that a particular approach to steer a 'factor' can't be generalized for every project. It was also concluded that a top-down approach may not necessarily be coupled with past project data. This can be witnessed in the table above. Instead the selection of an approach is determined by the influence of the factor and the expert dealing with it:

a) If the influence of the factor is very specific & affects the vicinity design components, a bottom-up approach should be adopted. In most of the situations, project specific data should be used for this processing.
b) If the estimator/designer can relate the influence of the factor form his/her past project experiences, then a top-down approach should be adopted. In most of the situations, past project data should be used for this processing.
The escalations caused due to KA-I factors can be measured using the above criteria and then by using the positive behaviour of KA-III, the escalations can be tried to be compensated in a bottom-up approach. In case any escalation is left out uncompensated, average of such escalations can be calculated and future estimates can be uplifted by this average value by the decision makers.

From this research, it was observed that researching over the 'control' based technical factors could be relevant in reducing the front-end escalations. Further research could be carried out in this direction as it could deliver more results on how 'control' based factors could be approached for steering them. It was concluded that the bottom-up based PMBoK cost control method may not have any relevance for the front-end phases, but the principle of 'control' still has relevance for the front-end phases. For the front-end phases, consultancies should develop methods & tools on the 'control' principle, by using the information gained over the 'factors' from this research.
But this doesn't undermines other ways of research approaches to the problem: i.e other types of factors should also be considered in future research. Larger public should be reached out to know over more type of such factors. The 38 industry experts who contributed to this thesis, indicated on the need to adopt a 'control' perspective for the front-end phases as well. It was realized that 'control' based technical factors have not only relevance in the execution phase, but also in the front-end phases. Future studies over more such 'factors' would certainly equip the project teams in dealing with specific situations in the front-end.

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List of Abbreviations

TD : Top down approach
BU : Bottom up Approach
CL : Cross-project data retrieval
OA : Unique project data retrieval
KA : Knowledge Areas
Dtb : Decision to build
CBS : Cost Breakdown structure
PMBoK : Project Management body of Knowledge
K.D.C : Known Direct costs
YtbD D.C. : Yet to be detailed direct costs
I. C : Indirect costs
D.C : Direct costs.

1
Introduction

The issue of cost overruns in transportation infrastructure projects has been widely recognized as a prevalent problem, which deteriorates the project's overall value. Cost overruns are more prevalent than underruns for transportation infrastructure projects, with the average overrun being 34%, regardless of the project type (Odeck, 2019). Due to the complexity of infrastructure projects in addition to the restrained funds allocated for each project, there is immense pressure over the engineers and contractors to execute them within budget and with quality. Generally, cost overruns leads to two different adverse impacts. Firstly, overruns in a particular project also certainly means budget curtailment for other infrastructure projects as the overall fund allocated by the ministry/province is limited for a set of projects. This henceforth results in the realization of less number of infrastructure projects than targeted (Cantarelli, Molin, van Wee, & Flyvbjerg, 2012). Secondly, it leads to huge economic loss as the financial viability of project (project value) is not achieved. More money gets spent on the project than expected, yet the delivered benefits remains the same once the projects are into operation. Major infrastructure projects have been consistently in overruns for the past 70 years and thus the issue of cost overruns demands intensive research into its possible causes and treatment (Flyvbjerg, Skamris Holm, & Buhl, 2003).

Researches have determined the possible causes leading to the issue of cost overruns. The 'technical' factors of estimation & forecasting expertise hasn't been identified as the major cause. Instead, 'optimism-bias' & 'strategic political misrepresentation' in the project's front-end have found to be resulting in the underestimation of costs when the client proposes the project for its approval (at the decision to build stage) (Flyvberg, Holm, & Buhl, 2002). Due to these two causes, the as-built costs exceed the proposed costs. Authors like Cantarelli, Molin, van Wee, & Flyvbjerg (2012) have addressed the optimism bias of estimators/project promoters as the major cause of cost overruns, and not their forecasting expertise. They insisted that 'technical' incapability of forecasting can't be held as a responsible factor as it can be developed and skilled with time. On the other hand, many other researchers hold the technical incapability of realistic estimation and also the contractor's inefficiency as the possible causes. It hasn't been yet scientifically established that to what extent the 'technical' causes are responsible for cost overruns. This research was conducted as an attempt to give first indications over the relevance of 'technical' factors (like cost estimation & controls) in determining cost overruns of a project,

1.1 The research context: A background of the *'interest'*

In the past researches, not much attention have been given to the overruns in the front-end phase. One reason is that many people hold the budget prepared by the contractor during tendering as the reference point of calculation, and the as-built costs as the final costs. But inherently, the real figure of overruns in a project should be determined by considering the budget reference as the time of decision to build in the front-end phases (Flyvbjerg 2005b). This thesis considers this definition for comprehending the concept of cost overrun. The cost escalation from the time of decision to build till the time of budgeting during tendering is described as the front-end cost escalation. Many researchers in the recent past have advocated the front-end cost escalations (and not the escalations in the construction phase) as the major cause of cost overruns (Welde, & Odeck, 2017; Flyvbjerg, Skamris Holm, & Buhl, 2004). With this logic, poor 'cost management' in the front-end has been widely subjected as the core reason for overall project cost overruns in the past. Unlike the many researches which concluded this finding, there are almost no research on how can these escalations be reduced. To start with an explorative research, it can be realized that even smaller infrastructure projects can be studied for their front-end escalations. They are more in number and their data are easily accessible. Being concerned with the limited overall budget for national infrastructure, the first ultimate concern should be to reduce the net cost escalations in smaller projects, than reducing the percentage 'cost overrun' in some big megaprojects. This thesis was designed in this context as the research background.

Apart from the fact that front-end escalations have been proven to be the major contributor to cost overruns, there are other reasons that encouraged this research background for the thesis. Three such motivations for the need to dive into the front-end phases of the past projects are:

a) ***Firstly, diving into the subject of front-end cost escalations would reveal the 'true figure' of possible cost savings (optimizations) in a project***. The front-end phases allow for most control over the project costs. The generally accepted definition of cost overrun factually hinders the economists to research upon the fact: "what could have been the most optimized and realistic expense for an infrastructure project?''. This can be understood with an example. For instance, a medium size project's final budget is forecasted as 15 million euros and it gets executed with its as-built expense as the same 15 million euros. Though one can say the budget was not underestimated, but it is quite a possibility that the budget was overestimated or not optimized to its fullest. However, as per the industry accepted definition of cost overrun, the project was within budget with no overruns. By looking deep into the cost dynamics before the final budget was made in the front-end phase, one can see that there was a possibility of reducing the overall project costs through design drivers (Torp & Thodesen, 2016). It can be explored that whether the escalations were due to underestimations, or due to overdesigning/non-optimizations and not sticking to the prepared estimates. It has been already accepted that front-end phases allow for maximum design freedom and cost control (See figure 3). It is an irony that front-end phases have been the reasons for most project overruns. Does the generally accepted definition for 'cost overruns' needs to be revised as it could also take place before construction starts? (Flyvbjerg, 2005). This should be researched as there is always a baseline to control against, and so it is for the design phases.

b) ***Secondly, research on front-end of infrastructure projects would reveal how different actors interplayed in the designing process***. Apart from the fault of the consultant designer and contractor, the influence of external parties like the government agencies (provinces, municipalities, infrastructure ministry etc.) stakeholders, local inhabitants etc. could also be a reason to project cost overruns as they often influence project scope, EIA (environmental impact assessment) and project duration. In totality, anyone (or everyone) out of the three major involved parties (designing consultancy, contractors or external parties) can be the malefactor responsible for project cost overruns. The escalations caused during the construction phase are the risks of the contractor, but this risk share between the client and contractor depends on different payment methods. In overalls, the extent of influence of these three parties in causing cost overruns may vary in a certain project, though these three major parties are involved throughout the project in all the phases.

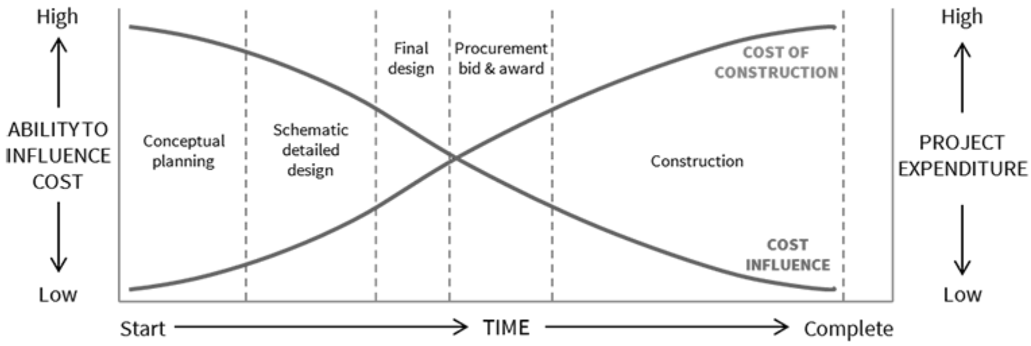

Figure 3 : Cost influence curve for infrastructure projects (Source : www.2hoffshore.com)

c) ***Thirdly, a study into the front-end phases of projects would explain the policy/decision makers the reasons behind front-end escalations and ways to control them***. It is also necessary for the government to know what fluctuations in project costs lead to a final baseline budget and how do the design decisions influence it (Jari, & Bhangale, 2013). Such ex-ante analysis of past projects can help them to make their own judgement over the financial viability of the budget and can prevent them from getting mislead from strategic misrepresentation in future. These learnings will prevent them from getting mislead from false project promoters in future. Through such researches on past completed projects, a zoomed in picture of the early stage cost trajectory can be achieved which can acquaint the policy makers with the nuances of front-end escalations. Although the generally identified cause is strategic political misrepresentation (Samset & Volden, 2016; Welde & Odeck, 2017), but it is highly likely that 'technical' and 'optimism bias' are also the leading reasons as this wasn't scientifically explained in these researches and in the works of Cantarelli, Flyvbjerg, van, & Molin, (2008). Some better estimation/'control' approaches can be developed in case the major causes also tend to be the 'technical' and 'optimism bias' factors.

1.2 Core research 'interest'

Considering the previously mentioned storyline as the starting point, it is clear what is yet known and what is not yet known to the industry. The not yet known facts were explained in the points a, b, c in the previous section. The industry knows about the problem of front-end escalations, but there are no indications on how to control them.

Very less researches have been done on the 'technical & cognitive' factors, which are internal to the project and directly influence the CBS in the front-end phases. These factors basically include 'estimation' & 'control' influencing factors to the costs. Developments like Reference Class Forecasting (RCF), Target Value Designing (TVD), Activity - based costing, PMBoK/APM Cost control cycle, Earned value management etc. are some existing solutions to steer the technical/cognitive factors. But most of these tools are estimation based, i.e. they can estimate a situation accurately but can't guide to control different scenarios in a changing project environment). Recent researches by Love, P. E. et al. (2011); (2015), have emphasized that insisting on strategic misrepresentation & RCF is not enough and more focus needs to be given to the technical & cognitive factors as they can explain 'why' & 'how' events lead to a net front-end escalation despite of the consultant's monitoring. The emphasis could be on 'technical/cognitive' factors for smaller projects which are more in number and may not involve much politics/governance misconducts. Quite significant amount of money can be saved and better project value can be achieved for these many projects. Methods are needed not only steer the 'estimation' based technical factors, but also the 'control' based technical factors. The core interest of this thesis was thus to research **on the approaches for reducing the front-end cost**

escalations of Dutch infrastructure projects, by researching over the 'control' based technical factors through ex-post studies. By such studies of recent projects, suitable preventive & corrective approaches for steering these factors were targeted. Eventually, a framework was developed on how steering of such factors can ultimately reduce the front - end net escalations.

It was realized that the devised 'approach' should not only 'estimate' a situation, but also 'control' the changing scenario with suitable actions. 'Controlling' the approved costs not only accurates the final estimate, but also optimizes it (Flores & Chase, 2005; Liu & Zhu, 2007). By not focusing separately over 'political', 'cognitive' and 'technical' causes unlike other researches, this thesis proposed to study this problem with a 'cost control' ideology, which would consider all the factors in terms of their influence into the 'cost breakdown structure'. The thesis classified all the factors in a cost control perspective or the Deming's circle (Plan, Do, Check & Act) i.e., the factors influencing the 'as-designed' estimation (costing a design); the factors influencing the 'as-designed comparison with the baseline'; and the factors influencing the 'necessary actions to bring the designs back to the baseline' (designing a cost) (Obara, 2014; Adjei et al., 2018). These three activities have been classified as the key knowledge areas by several authors in the past and the PMBoK as well. In regards to this devised 'approach' for controlling the front-end escalations, a new term was coined by the research commissioning consultancy Arcadis. The term was called as **'Cost-conscious designing'. It was perceived as a practice/approach, that not only provides a realistic cost/design baseline to the decision makers, but also controls the project costs in reference to it. Cost-consciousness doesn't necessarily aims to make the design cheap. Instead, it aims to give the team members the dynamic skill to increase/decrease the constituting costs in a particular element in order to deliver what the clients & stakeholders desire.**

However, **there were some reservations in studying the factors only from a 'control' perspective.** It was difficult to assure that researching in this direction would result in the desired 'approach/practice' and solve the entire problem of early escalations. Following were the three main reservations/doubtfulness in this direction of problem solving:

a) Moschouli, E. (2018) & Memon, A. H. et. al (2011) gathered factors like site conditions, payment methods, contractual arrangements, way of project financing etc. These factors also influence the front-end of the projects. By limiting the research study only in terms of 'control' based technical factors, the cohesion between the different types of factors is lost. So, the final devised 'practice' may not be a complete solution to the problem. It was realized that through an ex-post study, only 'control' based factors can be easily studied as their influence can be immediately observed/captured through the design/estimate files. Other factors like 'contractual disputes'. 'financial arrangements', 'site conditions' etc. can't be captured in an ex-post study of a project's front-end cost performance.

b) The 'control' principle has been defined for the execution phases in the construction industry. The PMBOK and other sources of cost control have devised the cost control principle for the execution phases. The execution phases are generally dealt in a bottom-up approach and the principle of 'cost control' has been formulated in that context. In this regard, the implementation of the 'control' principle in the front-end phases could be not of much use because of the following facts:

- The front-end phases have been mostly encouraged with the top-down approach (Torp, & Klakegg, 2016; Black, 2002; Gardner, 2015). Recent developments like RCF (Reference Class forecasting) advocate a top-down approach with very few cost indicators to deal with the design/estimation situations of the front-end phases. But they talk solely on estimating a 'situation' and not controlling a 'scenario'. Other latest methods like Artificial Neural Networks have also been used in the top-down approach to estimate road projects in the front-end phases (Gardner, 2015). But the PMBoK control cycle is mostly bottom-up based. This fact led to some reservations whether researching over ‘control’ based factors would be beneficial or not.

- The PMBOK based cost-control process requires project specific open farmed data as it is meant for the execution phase, where the project definition is highest and the number of work packages are also clear. Implementing it to the front-end phases would require lots of cross-project data learning. So, it was another assumption that the PMBOK based cost control cycle would deliver in a data scarce front-end environment. Similarly, font-end phases utilize a lot of past project data due to lack of project information (Chou, 2011; Kiziltas, & Akinci, 2009), than the later phases which utilize a much open - approach by calculating the data from the specific project itself.

c) This system of ‘cost-control’ is generally deployed for the construction phase and no researcher in the past has theoretically recommended it for the front-end phases. But the ‘cost-control’ system could possibly work for the front-end phases as well, which has not yet been explored in the past, though some cost control models like TVD (Target value design) by authors like Do et al. (2014) and others have been developed.

So, exploring the applicability of the bottom-up based ‘cost control’ principle in front-end phase was considered to be an assumption. There was almost no literature support, which encouraged to research on the escalation causing factors from a control perspective.

The contrasting differences between the design and construction phases with respect to the ‘extent of uncertainties’ and ‘available project information’, makes the proven concept of cost-control cycle an assumption/hypothesis for the design phases. It was not necessary that this idea of PMBOK based cost-control methodology with cross-learning could be the *‘appropriate practice’* which the thesis wanted to explore for the front-end phases. It was difficult to pre-determine the success of this research approach. **Due to the less available literature on reducing the front-end escalations and the reservations associated with the problem solving through a ‘control’ ideology, this thesis was designated as the first explorative study. The assumption made for carrying out this research was finally framed as:**

‘The PMBoK based cost control approach for the execution phases also has some relevance/ applications to the front-end phases and it can reduce the problem of front-end cost escalations’

With the study being a first explorative one, it was also realized that whatever (the ‘assumption’ or its inverse) emerges out as a ‘suitable practice’ would only be the first indications, and not a theorized formula/mathematical expression. Based upon these indications future research would have to be done to give a mathematical importance to the devised practice called as the ‘cost-conscious designing’.

1.3 Relevance of the ‘interest’ to academia and industry

This research exhibited the very first attempts on the ex-post evaluation of the front-end phases in infrastructure projects. Front-end escalations can cause two scenarios. Either there are escalations from the point of decision to build till the tendering phase, but the final estimates by the engineering consultancy is accurate (Williams & Samset, 2010). In this case the estimate at the point of decision to build would be considered as underestimated. This is generally when the consultant’s internal processes are efficient in terms of cost control, but due to extra scope additions/inflations (justified external additions or political additions) there are front-end escalations. Another scenario could be that along with the front-end escalations, the final estimate delivered by the consultancy is not accurate, which would mean that there would be more escalations once the project enters construction phase. In this case, it could be that both internal mismanagement in ‘control’ and ‘external influences’ played a role in the escalations.

Relating to the second scenario, the industry has realized that being dependent upon the contractors for cost control was never a solution as most of the project costs are already manifested before the execution commences. Relying on the tendering phase for getting a cheap contractor was never a solution. If most of the bids from the contractors exceed what the consultancy had prepared (called as ‘contractraming’ in Dutch), this means that the consultant’s design was underestimated. This also means that the consultant designed the project on underestimated decisions, which means that there was no real cost optimization in it. A contractor can then only stick to the baseline costs, and can’t optimize it as there is no room left for cost reduction through design variants by that time.

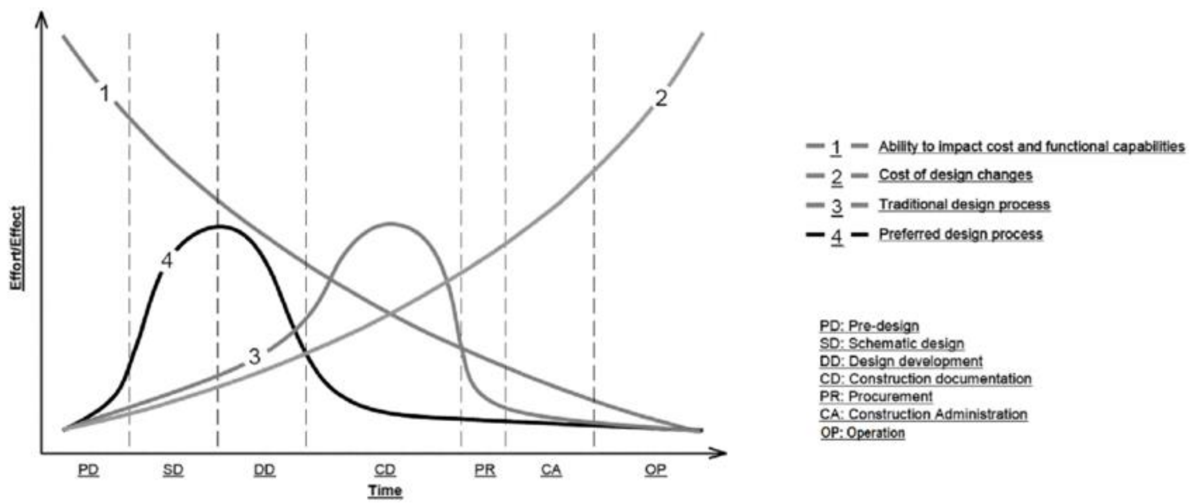

Figure 4 : The desired curve is denoted by curve (4). [Source: BIM Assisted Design Process Automation for Pre-Engineered Buildings (Delavar, 2017)]

Within the academic fraternity, the problems due to the absence of cost-consciousness in early stages have been identified (See figure 4). Firstly, the issue is with unrealistic forecasting due to unconsciousness in estimation. Shane, Molenaar, Anderson, & Schexnayder, (2009) have debated for a serious concern towards this issue of underestimation which occurs due to erroneous cost forecasting (especially indirect costs of risks and contingencies). Secondly, researchers have also witnessed some projects that are within the budget according to their as-built total expense records, but due to cost-unconsciousness they are associated with high life cycle costs due to non-conformance to quality and cost optimizations. This issue also occurs due to non-involvement of cost engineers in the initial phases. They adjust the costs non-proportionally, few days before the decision to build is made in order to keep the overall estimate within the available budget. Through constructability analysis, proper change management and design conflict recognition, the failure costs (sunk costs) for a particular type of design can be reduced. By generating design variants and doing MCA (multi-criteria analysis), the most optimized design in terms of cost and quality can be achieved. Thirdly, researchers have argued over biasing and deceptive project promotion. This can be overcomed by advocating cost-conscious designing within the government policy/decision makers. Through cross-project learning and with the information gathered for the three knowledge areas, decision makers will no more be dependent on forecasters’ information and can genuinely make self-introspection without getting mislead. Hence, some policy recommendations can also be achieved out of this thesis for the government. The project specific data produced from this research couldn’t be generalized to the academia as the research would conduct an in-depth study of very less past projects. But, the methodology of learning from past projects would give the academicians a framework to study other types of infrastructure projects through a systematic process. The govt. clients can then conduct ex-post evaluations for past projects and get the real savings that could have been achieved for those projects. They can thus learn from their mistakes.

Therefore, this thesis has both academic and industry relevance as even brief indications to reduce the front-end cost escalations would be of huge importance to both of them.

1.3.1 The knowledge Gap

From the initial chapters, the research context and the main 'interest' of the thesis have been made clear. It can be summarized that research by the industry, government and the academia is already being done on the issue of cost overruns, its causes and its affects. Both broader and in-depth analysis are being done. In broader terms, researchers and consultancies are studying the cost overruns for past projects in order to analyze the statistics for the amount spent on infrastructures against the forecasted budget. In-depth analysis is also being conducted by various researchers who hold two causes as the most accountable: cost misinterpretation due to underestimation and optimism bias. But the role of 'control' based technical factors in determining cost escalations isn't researched yet, and has the potential to reduce the front-end escalations. Also from the previous para in this subchapter, it is clear that the research 'interest' holds both academic and industry relevance.

The difference between the current industry's/academia perception (subchapter 1.1) & the relevance of the research interest (subchapter 1.3) is the research gap:

Gap 1: The extent of influence of the different 'control' based technical factors/SoLs isn't yet known to the researchers. So, it is not known which key factors should be focussed upon in order to reduce the front-end escalations with minimum efforts.

Gap 2: Some basic information required for steering the factors are not yet known: Approach to gather data (cross-project data/open data farming), approach to process the data (top-down/bottom up), phase specificity of the factors, CBS elements/cost types influenced by the factors etc.

1.3.2 Problem Statement (step wise refinement to a statement)

After a review over the current scenario, the situation with front-end phases can be clearly seen with huge escalations. There are not much research on the solution counterpart (envisioned by Arcadis as the practice of cost-conscious designing) to this problem due to its dilemmatic nature: 'The front-end phases offer the most freedom to control the costs of infrastructure projects, but it is difficult to control the costs due to limited project information in this initial stage'. It terms of solution, the widely accepted PMBoK based 'cost-control principles' and cross-project learning can help in being more conscious about the cost development curve in initial phases. But this is still an assumption because the 'cost-control' system is based on a bottom up approach, unlike the front-end situations which require a top-down approach. Also such a system is better for project specific open farmed data but the front-end requires mostly cross-project data. The synthesis of the problem statement therefore is:

'An effective practice (termed as the 'cost-conscious designing' practice) for reducing the front-end cost escalations in infrastructure projects is not yet known to the industry & academia'

1.4 Research Agenda

The research objective, specific research questions & the research scope was finalized to formulate the research agenda.

1.4.1 Research Objective

The sole objective was to explore a practice which can reduce the front-end cost escalations. The main objective of this research was thus framed as:

'To explore a suitable practice for reducing the front-end cost escalations by conducting ex-post evaluations of recent infrastructure projects'

1.4.2 Research Questions

With the above recognized problem statement & research objective, the set of research questions requiring immediate attention were figured out. The research queries demanding investigation were arranged as in the Figure 5 below. It was found that a complete research for the implementation of the so-hypothesized 'cost-conscious designing' practice would demand research queries in the following three areas: a) what specifically (data/resource/knowledge) is acquired for implementing the process of 'cost-conscious designing'? b) Why these knowledge/data should be found? ; and c) How it can be achieved? More specific queries (blue boxes in the figure) were also obtained upon breaking these three queries.

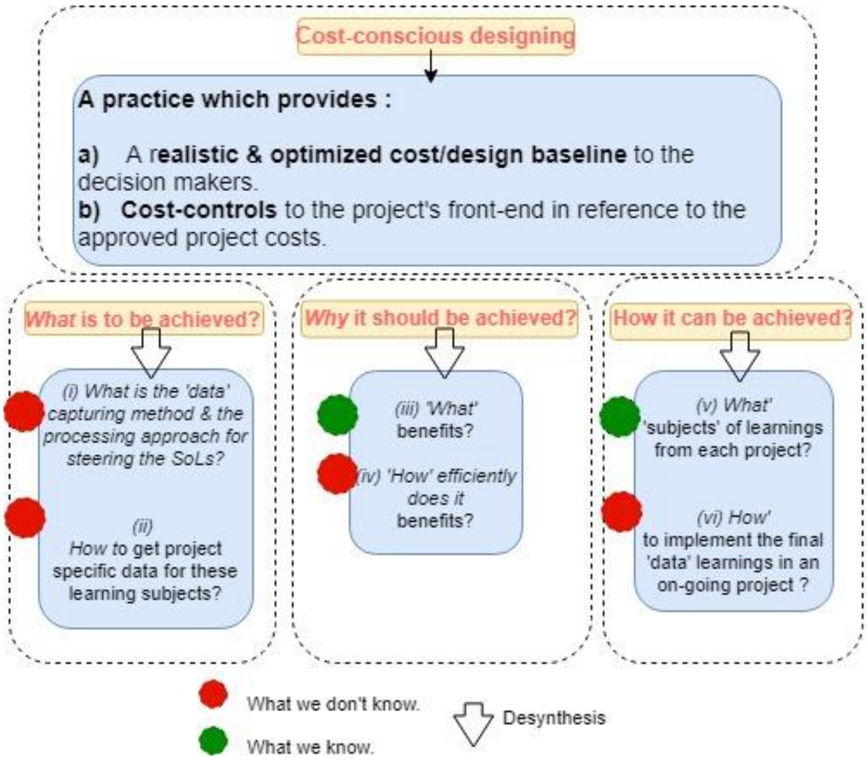

Figure 5 : Key queries related to the 'cost-conscious designing' practice which demand exploration (self-illustration)

The breakdown gave a set of possible research questions. It was found that out of the six possible research questions, the existing literature has some answers to two of them:

Query no. (iii) : *'What benefits can cost-conscious designing provide ?'* Some Arcadis cost experts were found to have some idea on how such a practice can benefit the consultancies (illustrated in chapter 3.3.2).
Query no. (v) : *'What SoLs from each past project can be studied ?'* As stated before, some researchers have gathered and classified the list of factors that affect the front-end cost performance.

Considering the limited available time and prospective hurdles in an explorative research, it was thus practically impossible to cover all the research queries as shown in the figure 1.4. In an attempt to make a justified and intelligent move, it was considered necessary to prioritize the research queries/objectives that should be explored in order of their importance. Some of these queries were dependent upon the results of the other ones. This priority order was arranged as under:

(iii) > (v) > (i) > (iv) > (ii) > (vi)

However, it was realized that a scope demarcation is required for studying the 'factors'. The most important factors which have the most impact on the front-end cost performance were ought to be studied. In that regard, query (v) was considered as the first most research question demanding immediate attention. The second query demanding immediate attention was found to be query (i). It would explore the approach towards data/information collection & its processing for the different 'control' based factors under study. Along with the data handling, it would also explore the project team's accountability, i.e. who is responsible for what in the process of data flow. The next query demanding attention was found to be query (iv). It aims to test the efficiency of the 'action framework/practice' developed after researching on query (v) & (i). It is meant to test the practical usefulness of the developed 'action framework'. In this thesis, this query was researched through an expert validation process during the final months of the research. After getting convinced with the positive potential of the 'action framework', it was then considered necessary to research upon how project specific data can be acquired for the 'SoLs/factors', whose data can be collected from cross-learning (query ii). This query aims to produce the required 'data' from past projects by establishing a method to extract data. A collection of all such data from past projects would make it statistically significant, and ready for use in future projects. Query (vi) was kept in the last priority as it aimed on the practical implementation of the developed practice of 'cost-conscious designing'. This query would require an in-depth research into the organizational strategy of a company for its implementation, and henceforth was kept in the last priority.

Since query (ii) and (vi) demanded more time and more projects for ex-post study, they were not considered as the research questions/sub-questions. In line with the obtained priority order of the key research queries, query (v), (i) and (iv) were considered for the research questions. It was realized that exploring these three queries as the research sub-questions would provide a significant and systematic beginning into the exploration of the broad 'assumption'' under probe.
While query (v) would give the important 'control' based factors leading to front-end escalations, query (i) would provide the first indications on what data collection & processing approaches should be taken to steer these SoLs/factors. Together, these two sub-questions can give the basic work order framework on the desired 'practice' to reduce the front-end escalations. The findings can be validated & criticized by the Arcadis experts in order to fulfil query (iv).

The main research question was thus framed in line with the thesis research objective:

How can the front-end cost escalations in transportation infrastructure projects be reduced by *conducting their ex-post evaluation?*

The research sub-questions were:

a) *What are the crucial 'control' based technical SoL's/factors leading to the front-end cost escalations?*

b) *What suitable data collection & processing approach can be recommended to steer these crucial SoLs in order to reduce the front-end cost escalations?*

1.4.3 Research Scope

The project type chosen for conducting this research was 'provincial/municipal/privately funded' road projects due to their simplicity in program management and infrastructure layout. Unlike, rail terminals, bridges etc., 'road' projects generally don't have too many sub-assets (like stations, plazas etc.). So, it is easier and quicker to evaluate road projects. Following points demarcate the scope boundaries which were considered for this research :

a) By the term 'designing' in 'cost-conscious designing', the thesis has limited to only engineering design actions. Needless to say that the term 'designing' can advocate a lot of actions i.e., engineering design actions, contractual actions, stakeholder management actions etc. But this thesis focuses only on the 'engineering design' actions as it is tangible and can be easily researched upon from the past project files.

b) Only project phases from SO (sketch estimation phase) till DO (Detailed estimation phase) were considered for the ex-post study. The contractor's as-built costs weren't included in the cost development study as it could have included extra costs, which could have occurred due to the contractor's fault (costs due to reworks, costs due to procurement delays). Including contractor's as built costs in cost development study won't give an honest and true picture of front-end cost development curves. It would rather mislead and distort the observations.

c) The study was conducted by using only the consultant's project files. The accuracy of the consultant's estimate files utilized in this research could be less. Comparing the contractor's bids with the consultant's final estimate is the industry practice for measuring the underestimation in the consultancy's estimate. It was difficult check the accuracy of the files used in this thesis as the contractor's bid were not accessible. So, the cost figures utilized to prepare the cost-development curves could be underestimated figures.
But since the research is concerned with the cost control efforts, relative fluctuations of the graph were studied to analyse which all 'factors/SoLs' influenced the project's front end. However many times, there are chances that even the contractor's bid contains some underestimations and eventually the as-built is even higher. It can be said that by looking up at a project's overrun, it is very difficult to remark over the fact whether it was designer's underestimation or contractor's underestimation or both.

d) The life cycle costs were not considered for the ex-post studies. The SSK provides the instructions to calculate the LCC for the asset as well, as that determines the true investment costs in a project. There have been road projects in the past that were in huge overruns initially,

2

Research Design

A research design refers to the overall framework in which different components of the research are integrated. The process of research designing is initiated by choosing a research strategy. Based upon the strategy, the research methods are chosen. Finally, peculiar data collection & analysis steps are formulated for the research method, which eventually finds the answers to the research questions. After understanding the problem and research questions in the previous chapter, this chapter explains over the research design utilized for this thesis. It discusses the two major constituents of the research design (See figure 6 below):

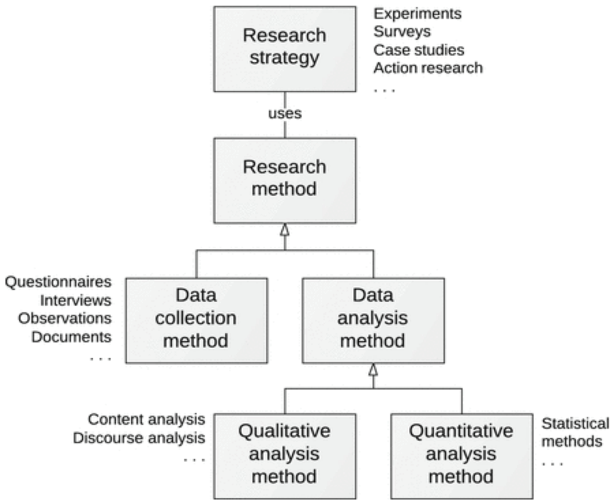

Figure 6 : Elements in a research design (Johannesson P., Perjons E., 2014)

a) The research strategy: A research ‘strategy’ is a plan of action, with a justification for conducting a research in a certain way. Based upon the research problem, a particular strategy is used. It is not a specific ‘method/path’ but provides a theoretical underpinning for identifying the nature of the research question, which eventually helps to choose a suitable ‘research method’. It determines the research type and subtype on the basis of various criteria such as: availability of past studies, need of repeated observations, need of research cycles etc.

b) The research method: A research method is imbibed in the research strategy and sharply describes the data collection and their analysis processes. Basically, a research method is composed of suitable tools that should be utilized in order to perform rational data gathering and their analysis.

Considering these elements of research design, the next sub-chapter discusses over the these three elements

2.1 Research Strategy

The research questions in this research were explored for the first time, or were at its very preliminary stage of exploration. Since, there were very less previous studies to refer, this research was designed as a 'first explorative study'. An explorative study targets not to present universal findings, but rather to produce a more focussed direction for future research on the topic. This meant that the results obtained from the chosen research methods were designated to be the first findings.

The research was conducted with two prime research strategies: Survey & Case studies. These strategies had the competency to unravel the latest trends over an unexplored research topic.

2.1.1 Survey strategy: Motivation

A 'survey' strategy was considered essential to know over the latest trends with the problem under consideration from the experts. The industry scenario over an explorative topic is rarely found in the research repositories, which made the 'survey' strategy suitable for this research. Using the strategy of survey, two research methods were deployed: Questionnaire & Expert validation. Questionnaire was utilized in the very beginning to know the existing industrial know-how over the 'factors'. Expert judgement was utilized in the last to survey some Arcadis's experts on what they felt over the thesis's findings (see section 2.2.1). The findings from the questionnaire survey were explained with the terms and conditions associated with them. They were generalized, but with the fact that only a smaller expert population represented them.

2.1.2 Case Study strategy: Motivation & Project selection

The research objective was to give first indications on how front-end cost escalations could be reduced in future through the ex-post analysis of the front-end stages of road projects Considering this, a 'case-study' approach was considered to be a suitable research strategy. It would consider past projects as cases and investigate what factors (SoL's) were crucial to them, how they interplayed in the front-end, what was their effect in the CBS, and how was the data retrieved & processed by the project team to steer them. A case-study strategy was considered useful for a research like this where one has to test whether a specific 'assumption/hypothesis' applies to the real world. Precisely, *'Case - Study'* was a suitable strategy due to following reasons:

a) As explained in the introduction chapter, researchers have demanded ex-post analysis of the front-end cost performance for infrastructure projects. Through cases studies, a research can show first attempts on a systematic ex-post analysis on live projects.

b) Case studies can verify, whether such analyses can really help in determining the causes/SoLs leading to front-end escalations.

c) Also, a systematic ex-post analysis can be laid out after the completion of the case studies, (in case it produced informative results on the 'factors').

d) Just like the survey targeted to explore more over the front-end escalation in terms of 'causes/factors/SoLs', the case studies were necessary to explore more on the 'solutions'/'approaches' to steer these SoLs. With recent projects under the study, the case studies helped in delivering the 'actions' that are being taken in the front-end to steer the SoLs.
In order to retrieve maximum information with considerable accuracy, recent projects were considered to be suitable for the case studies as the cost teams had fresh memories with the

project incidents. Upon numerous consultation meetings, two projects were finally selected: Project Schiphol landside works, which is under construction phase & Project N270 Helmond-Deurne, which is currently in its tendering phase. The reasons for selecting them was justified because they offered many desired features (apart from being recent projects). Such features were not offered by the other projects in the repositories:

a) they were found to be well enriched with project/cost/contractual data (from SO till DO) and were also recently finished up with their front-end phases.

b) they both exhibited two different possible behaviors in their front-end cost escalations. While Schiphol landside works experienced a consistent avg. escalation of €2 mln. in each phase (net escalation = €4.1 mln.), project N270 experienced both escalations & relaxations (net escalation = €4.32 mln.).

c) They also provided perspectives on the two different governance settings (pvt. & govt. respectively) and the SoL's influence on costs on these two governance setting was also contrasted.

d) A thorough analysis through multiple interviews in a single case was made as the priority, than the consideration of any more number of cases. These two projects offered the most available project members than other projects, who were still in Arcadis and were willing to participate in the case studies.

e) The projects to be considered for the ex-post studies should be under similar project delivery background, i.e., under similar contractual arrangements. It was necessary to ensure that the 'engineering design' and cost knowledge maturity was same with the design teams of both projects in their front-end phases. These two projects were under the same delivery method of design-bid-build. The comparison made between both the projects got more justified due to this fact. Generally, projects under integrated contracts have more designing and costing maturity due to the early contractor involvement.

2.2 Research Method: Data collection & Analysis

Researchers in the past have utilized statistical analysis, interviews and literature studies as their research method to assess the cost influencing factors/indicators (Jong, Annema, & Van Wee, 2013). In their paper, the authors concluded that different research methods produce different project performance influencing factors. For instance, they advocated that desk-based research methodology produced *'Accountability of a team individual'* as one of the major performance influencing factor, which wouldn't have been produced from another research method. After deciding over the research strategies, three key decisions were made regarding the research method in order to choose the apt research methods for this thesis. These three decisions were made on the basis of the time and data availability for this research:

a) Regarding the principal sources of study (Desk based/Empirical based): The research was decided to be mostly *empirical* as the objective was to study the industry. Desk research through literatures & project reports of the case study was be rather limited.

b) Regarding the nature of information to be dealt (qualitative/quantitative): The research was decided to be a mixture of both *qualitative & quantitative* data gathering/processing. Quantitative processes were required as the project costs were to be studied for their front-end development. Qualitative studies were also considered a pre-requisite because the description over the 'factors' were also required from the case-project's record files.

c) Regarding the detail extents (in-depth/breadth oriented): Within this short duration, a research would produce convincing results for the chosen scope, if researched *in-breadth* for a particular asset type: Road infrastructure. An in-depth approach would have covered the analysis of a particular dominating 'factor/SoL' in detail. Since, this is the one of the few first attempts to study the front-end cost performance of the projects, a broader initiation was required. An in-depth research would have required more number of case studies in order to generalize a finding for a particular SoL being researched. In order to fill the research gap within the limited duration of 5 months, it was considered suitable to follow the 'broader' approach for less number of projects and more number of factors. The ultimate idea was to give first indications on how to steer the factors to reduce the overall net project's front-end cost escalation.

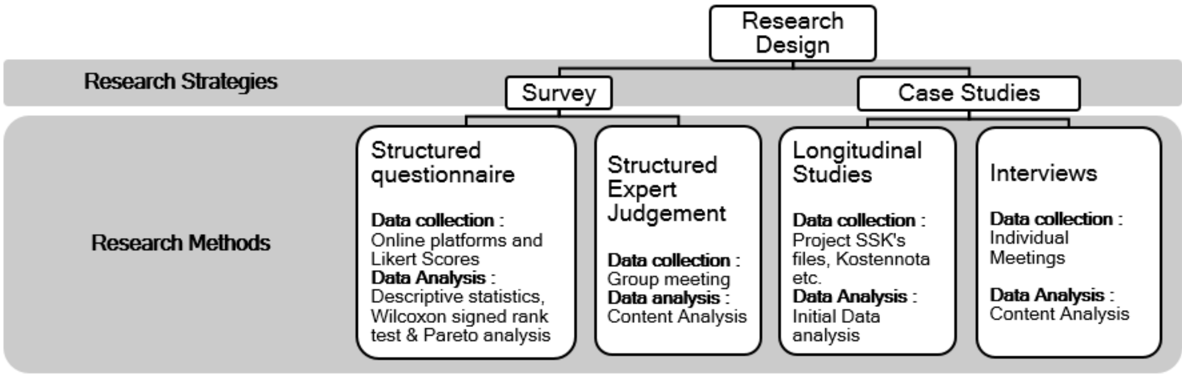

Figure 7 : Chosen research methods under the research strategies (self-illustration)

Unlike common research topics in areas of cost management, no recommended method was found for achieving reliable results on this explorative topic. Outcomes from a research method applied to an exploratory topic are considered to be only first indications. Due to this fact, these outcomes require multiple validation through different research methods until some saturation is reached with the 'outcomes'. Considering these reasons, a *'triangulation'* (Yin, 1984) was considered to be suitable for this research topic. Firstly, a list of 'control' based technical factors was obtained from the literature study. Considering the list of factors and the scarce known information over them, the empirical research was carried on thereafter. Following a triangulation procedure, a successive research method was deployed to validate some/all of the outcome of a research method. Considering the three decisions taken (previous para.) and the need for a triangulation in research methods, four research methods were chosen to constitute the *'triangulation' empirical research:* Structured survey, Longitudinal Observational studies, Semi-structured interviews & Expert validation (See figure 7 above). The motivation for their selection and ordering in the triangulation process is motivated in the following sub-chapters.

2.2.1 Structured Questionnaire

Firstly, a *'Structured questionnaire'* was used to conduct a survey for gathering the current know-how over the 'factors' identified from literature. The total time duration was around 15 minutes for each participant. A semi-structured/structured questionnaire way of conducting a survey has been widely utilized for researches in the construction industry to collect the responses (Keung & Shen, 2017; Shen et al. 2017; Liu et al. 2018). The survey consisted of three sets of questions. The first set was meant to know over the participant's professional background & expertise with Dutch road projects. The second set was meant to know the current extents of front-end cost escalations with Dutch road projects. The third set of questions helped to filter the most important factors from the list of factors gathered from the literature. These factors were then considered forward for conducting the case studies.

Data Collection: The survey was created in Google forms, due to people's awareness to its interface. The survey was only intended for cost engineers/project leaders/project managers of road infrastructure projects, who work either in a designing consultancy, or in a govt. organization (RWS, provinces etc.). The third set of questions targeted to gather the perception of the experts over the different 'factors' gathered from the literature. The most common methods that have been deployed to collect people's perception over a 'factor' is *Likert Scoring* (Hwang, B. G, et al., 2018 & 2013; Love, P. E. et al., 2017). For this research, Likert Scoring was adopted for collecting the responses from the participants as well. The response scores were taken in two different categories: Relative influence extents (Category I) & Cross-project learnability (Category II) for the 'factors' gathered from the literature study.

The survey was floated within consultancies like Arcadis, Royal Haskoning DHV, AT Osborne and Rijkswaterstaat through various platforms: Through colleague connections within Arcadis, Techno-social websites like Yammer, LinkedIN, Arcadis' Intranet etc. Many personal emails were also sent to the secretaries of Road infrastructure department of the above mentioned consultancies regarding the survey filling. Excluding the floating through techno-social platforms, the survey was sent to 45 people. By cross-verifying the names of the responders with the list of survey receivers, there were some additional names (5 names) which were not in the list of survey receiver. These responders responded therefore due to the survey promotion in the social media. It can be stated that in total, the survey was sent to an overall population of 50 plus cost experts/project controllers who are involved in the front-end phases of road infrastructure projects.

Data Analysis: The major data analysis part was for the third set of questions. The surveyed Likert scores were analysed in two phases :

a) In the first phase, the relative ranking of the factors was produced for the scores obtained on both the response categories. The low range of Likert Scoring helped in producing the rankings through methods like RII (*Relative importance index*) even for 20-25 responses. The scores obtained for both response category were also analysed statistically. *Descriptive statistics* was utilized within MS Excel to resolve the ties in the rankings. SPSS is generally widely utilized in the research for construction industry (Yu et al. ,2015, Le et al. ,2014) but has certain limitations as well (Foster et al., 2005). So every analysis was done manually in MS Excel, so that the reasoning can also be motivated simultaneously. Finally for analysing the possible differences in the influence extent & cross-project learnability extents for a 'factor', the *Wilcoxon signed rank test* was used. The difference test revealed the mutual cruciality ranking for the 'factors' under study: Factors that influence the most, and are least learnable/tameable from past project learnings. The Wilcoxon test had relevance to a limited extent due to the less number of responses on each 'factor'.

b) In the second phase, the data sets of both the response category were analysed to rank them on the basis of their extreme behaviour using *Pareto Chart*. The 'factors' were analysed for the number of '5's received by them. For category I responses, the factors that received most '5's were considered to be occasionally highly influential. For category II responses, the factors that received the most '5's were considered to be occasionally highly learnable.

2.2.2 Longitudinal Studies

Next, a *'longitudinal observational study'* was performed. Longitudinal study is the process of collecting & analyzing data over different time durations on the same variable (Shadish et al., 2002). It is often used to study fluctuations and pattern behavior of a variable with time. After the data were collected, initial data analysis (IDA) was conducted to minimize the risk of misleading & confusion (Huebner, 2016). Due to the numerous case files/estimate sheets that were available for the data collection in longitudinal studies, it was necessary to condense them by analyzing through IDA.

'Longitudinal observational studies' were necessary:

- To get a summary of the project cost behaviour by summarizing the escalations in each phase at different CBS levels (Project Specific observations).

- To understand in terms of cost figures, how different costs performed from SO till DO in the project, and what responsible SoLs/factors can be speculated behind the ups & downs in the respective curves. Only primary SoLs (directly visible reasons) can be identified through the IDA and the secondary SoLs (reasons that can't be seen in the estimate sheets) can be only speculated. These speculations were then clarified through the interview participants who explained what really happened in the case project.

- This method of conducting IDA can be also reproducible in future research for other researchers. It would explain the readers how to analyse a case project and scrutinize it to find the key causes/SoLs/factors responsible for the escalation (Generic observation).

- To identify the effect depthness of the SoL. This depthness would indicate whether one should have a Top-down approach or a bottom-up approach in order to steer the SoL (Project Specific observation)

- In case a SoL's data was recommended to be cross-learnable from the past projects by the interview participants, the exact data retrieval process was understood using the cost data from the case project's estimates (Generic observation).

Data collection: The Arcadis' project repository from the department of 'Project and cost management, 'roads' section'; was the primary data source. In case of some missing data, the corresponding project client/commissioning authority was approached. Project data was collected from the SSK summary, 'Kostennota' and other project documents. Cost development curves were eventually plotted.

The data for longitudinal studies was collected from the final project SSK files for different phases (SO, VO & DO). These were the final versions of the estimate that were sent to the client for the respective design phases. The experiences with the data collection for both the projects were different. These have been explained within the respective case studies in chapter 5.
The SSK of both the case projects summarized the total costs in following cost types:
a) Total Direct costs = known direct costs + yet to be detailed direct costs (YtbD). The YtbD direct costs are a part of total direct costs, which are kept separate as they are not known in the moment, but certainly emerge in the next phase.
b) Indirect costs
c) Estimated costs = Total direct costs + indirect costs
d) Total investment costs excl. VAT = Estimated costs + Risk reserves
e) Total project costs = Sum of all investment costs + objects transcending risk + VAT (if applicable).

Before diving into the IDA of the cost estimates for each phase, the typical estimation methodology was also understood as a part of the data collection process. The SSK cost breakdown structure had generally 2 main levels:

a) The top level: Each of the constituent in this level has been termed in this thesis *'cost* *element'*. These were namely: Construction works, Engineering works, Land Acquisition works and other additional costs. Its conjunction with direct/indirect/risks costs has been termed as *'cost component'.* For instance: 'construction works – YtbD D.C' has been called as a cost component.

b) The bottom most level being the detailed works: The elements within it have been termed as the 'work packages'. The 'work package' level is the smallest entity after which the CBS can't be broken down. For instance: *'removing asphalt pavement'* is a work package under the cost element of 'construction works'.

The aggregate total at all the three levels were calculated from the bottom most work package. For each work package, different *'cost types'* were calculated : Direct costs [Known direct costs, Yet to be detailed direct costs, total direct costs, indirect costs, estimated costs (direct + indirect), risks reserves]. These were calculated in the structure mentioned in the SSK standard.

Data analysis: Initial Data Analysis (IDA) is generally used to summarize the key data for starting the main research. It's a quick method to summarize the actual happenings of a case. The analyses were done for both controlled and uncontrolled cost components in the respective projects, and the data was analysed using IDA to gather the project specific escalations & the SoLs which acted in them. In the IDA process, the attempt was not to directly search the (ii) & (iii) research sub – questions, but the data was normalized to carry out the main analysis. The IDA aimed only to condense the major data as some conclusive numbers were needed to query the interview participants. The known direct costs for construction works' was the main focus of interest in both the case studies, as they generally hold the maximum share in the overall project's costs. All other cost elements are calculated as a percentage of the 'Known direct costs – construction works'. So, only the known direct costs were broken to the further CBS levels and were studied.

2.2.3 Interviews

After the longitudinal studies, the research method of *'interviews'* was utilized. Through interviews from the case, the associated cost engineers, designers and clients gave insights on how the 'factors' interplayed in the case projects, and how they were steered. The responses were analysed using *'deductive analysis/content analyses*. Interviews have been usually considered as an appropriate research method for an exploratory study (Creswell, 2014; Sekaran, & Bougie, 2013). Interviews have the potential to dig out critical incidents from the participant's hidden experience, and they allow the researcher to ask follow up questions till the clarity in reasoning is reached (Collis & Hussey, 2014). Such knowledge is not generally probably found in the project files/literature studies (Goffin, K., & Koners, U. , 2011).

For this research, 'interviews' were necessary to validate the findings from the longitudinal studies. A rise in costs from 'x' mln euros to 'y' mln. euros could be due many SoLs, which can't be predicted, but only speculated through IDA. Interviews helped in identifying exactly the 'factors'/SoL that was responsible for the escalation. Also, the interviews helped in revealing the incidents on how the SoLs influenced to the front-end cost performance. The steering approach for both data retrieval & processing was also a matter of investigation through interviews.

'Interviews' were considered a necessity under the strategy of 'case studies' as they had the potential:

- To validate the cost escalation figures obtained for each phase durations (Project Specific Observation).

- To identify the secondary SoLs that acted in the project (Project Specific observation).

- To identify the generic effect of the SoL in terms of its depth in the CBS by contrasting the actions taken vis-à-vis the actions that should have been taken Topics from the case were used to understand the effects. (Generic Observation).

- To identify the uniqueness of the SoL in terms of the participant's past experience with it. If the effect is unique in every project, then that would indicate that the SoL's data should be open farmed for each new project based upon the design problem. If the affect is not unique to the participant, then the data over the SoL can be retrieved form past projects with the desired corrections. Topics from the case were used to understand the effects. (Generic Observation).

- To identify the SoL's phase specificity in the front-end of infrastructure projects (Generic Observation).

Data collection: Six one on one unstructured interviews [2 cost engineers (E1,E2), 2 design engineers (D1,D2), 2 clients (C1,C2)] were conducted for each case study (total = 12 interviews). Selecting participants with these three different profiles helped in determining the accountability of the actors for steering a SoL. It also clarified the working relationship between the participants. Six participants from each case project were found to be enough for data saturation, which has been also experienced by past researches in the field of construction management (Razek, M. E et al, 2008). A systematic interview protocol was prepared that laid the basis for framing suitable questions for the interview (See Appendix B1). One principal participant from each project was selected as a mentor for resolving any queries over the case study. The principal participant introduced this research to the other targeted professionals who were in the project team of the respective cases. Interviews dates were then arranged in advance with all the 12 participants. Prior to these interviews, all the IDA tasks were completed and summarized in order to be presented before the interviewer while interviewing him/her. This summarization helped the participant to recall over the incidents of the project while the questions were being asked to him/her. A consent form was also used to take undertakings from the participants since the case studies involved lot of data sharing, both cognitive & physical (See Appendix B2).

Data Analysis: Content analysis is generally utilized to decipher the common pattern in the response given by every interview participant (Alan & Bryman, 2011). Patton (1990) described it as the process of observing, coding and classifying the patterns gathered from the interviews. It has been generally recommended for explorative studies (Huang, Quaddus, Rowe, & Lai, 2011). Information sorting was done for the responses from each interviewer by grouping similar phrases together in certain 'themes/headings' (Merriam & Tisdell, 2016). These headings aimed to sort the different information gained over the SoL/factor through the case projects: such as its 'causes', 'effect' and 'remedies' to steer the SoL. Both preventive & corrective remedies were queried to the participants.

Each interview analysis was initiated first with a repetitive transcript reading and audio listening. Both intra-analysis (amongst the responses of the same participant) and cross-analysis (amongst the responses of different participants) were conducted.

2.2.4 Structured Expert Judgement

An expert panel session was finally conducted in order to validate and verify the findings obtained from the above three research methods. A validation from the team of Arcadis experts was considered necessary because:
a) The research findings from different empirical methods required validation from the industry

experts. The obtained framework for reducing front-end escalations required practical validity.
b) It was necessary to obtain issues which were still not resolved by the research findings and were prospective future research.
c) It was necessary to know whether the research methodology had a role in determining the completeness & accuracy of the results. In other words, it was speculated that an expert can criticise over the research methodology.

An expert panel was made within Arcadis, which consisted of 7 cost experts. These seven experts were selected on the basis of following criteria:
a) They were senior experts and were involved in the decision making of the front-end of projects. They were considered suitable for validating the ‘practice’ developed to reduce the front-end escalations.
b) They were not involved in the interviews. Their viewpoints on the research results obtained through the case studies were considered to be unbiased. They provided their opinions on the basis of their experiences with other projects.
c) These were the only experts who were available for the validation session. Some amongst these were also involved in the very first discussion sessions which was conducted along with the literature studies. These experts were specially included because they already had some lead over the research type.

Firstly, a short presentation was given to the panel members over the research methodology. After the presentation, a brief was given over the ‘control’ based factors identified form the literature and how can they influence positively/negatively to the front-end cost escalations. The whole session of 2 hours was organized in three phases:
a) First phase: To validate the survey results.
b) Second phase: To validate the ‘steering’ approaches derived for the SoLs.
c) Third phase: To validate the practical feasibility of the proposed framework.

Data collection: The first phase was conducted through open interaction. For the second and third phases, there were distinct data collection and data analysis processes.
For the second phase, the list of ‘factors’ was handed over to the experts and they expressed their opinions on the suitable data collection & data processing approaches. Individual sheets were given to the experts for all the factors, so that the experts don’t get biased by the opinions of the other experts. After the filling of the sheets, the experts were asked one by one for the reasoning behind their responses. This was then recorded.
For the third phase, a validation framework was prepared on the guidelines of a research validation rubric by White, & Simon (2014). These were distributed to all the experts for filling their feedbacks over the research on different criteria: correctness, reproducibility, validity, practicality & implementation ease. Questions were prepared for each of these criteria which were in-filled by the experts (See Appendix C).

Data analysis: No special analysis method was deployed for the second phase. The data gathering and processing approaches for the SoLs as said by the experts were contrasted with the results obtained from the interviews. The differences were motivated by citing the reasoning given by the experts. The final thesis findings were also modified by implementing these opinions of the experts.
For the validation session of third phase, the collected data from the rubric was analysed using ‘content analyses’. The responses were already sorted into five different criteria/headings. The feedbacks by different experts on these headings were contrasted. The proposed practice framework was then criticised for its validity.

3
Literature Review

In the Part I of this thesis, an instinctive and introductory idea was given about the thesis to brief the readers over the research topic and the research design. It explained how the curiosity to research on the *‘control ’- based technical factors* emerged from a broader research context of cost overruns. The further parts of this report would now capture the main research, with the stepping stone being the chapter of ‘Literature review’. A literature review was conducted to firmly understand the current scenario on the front-end cost performance of infrastructure projects. It was necessary to lay the starting points of the research, before the empirical research was carried out. Through a systematic literature review, it was understood that what is known and what is not yet known to the industry. Firstly, highly cited past researches which have already discussed the ‘research context’ of this thesis were reviewed. The focus then moved to review few scarce past researches that have already attempted to explore the specific research ‘interest’ of this thesis.

While reviewing the literature, the prime objective was to understand the industry’s current knowledge on the ‘research interest’ i.e., the existing knowledge on ‘control’-based technical factors which influence the front-end cost performance. Some fundamental definitions/standards pertaining to the Dutch road industry were understood, for example: the front-end project phasing process and the CROW estimating standards. The known SoLs/factors were identified, which laid the basis for the empirical research of this thesis. The definitions of these SoLs were also established as they had to be kept consistent for all the research participants who were involved in this thesis. With the concepts defined and stated in this chapter, the communication of this thesis to its research participants became easier and much clearer.

Moving from the much outer ‘research context’ to the main ‘research interest’, this chapter discusses the existing literature in four sub chapters (See figure 8 below)
The sub-chapter 3.1 discusses the existing literature on the ‘research context’ of this thesis: the front-end cost performance of infrastructure projects. Sub-chapter 3.2 to 3.4 outlays the existing literature which had discussions over the ‘research interest’ of this thesis. Discussions over ‘control’ based technical factors causing front-end escalations and the different ways to approach/steer these factors.

Sub-chapter 3.1 discusses the issue of front-end cost escalation:

- The desired objective by the infrastructure industry and national government.
- The mechanism through which a realistic and optimized budget reduces net cost overruns.
- The need to reduce front-end escalations to achieve such a budget.
- ‘Factors’ leading to front-end escalations.

The sub-chapter 3.2 discusses the phenomenon of cost control:

- The principle of cost control: The Deming's circle
- The PMBoK based 'cost-control' process for construction phases: The 3 Knowledge Areas
- Existing tools/methods for improving front-end cost performance (like TVD,RCF)
- The need to explore the 'subjects of learnings (SoLs)' within the 3 KA's for establishing a 'control' cycle in the front-end phases.

Sub-chapter 3.3 discusses the 'control' based technical factors which are known to the industry and can be classified within the 3 KA's. It explains :

- The already identified 'control' based technical factors.
- Why each of them is a 'subject of learning'.
- The need to resolve the major approach dilemmas to steer these 'factors/SoLs'.

The sub-chapter 3.4 discusses the major approach dilemmas to steer a 'factor's' influence on a design/estimate :

- Top-down (TD) versus bottom-up (BU) approach.
- Cross-project data farming (CL) versus project specific data generation (OA).

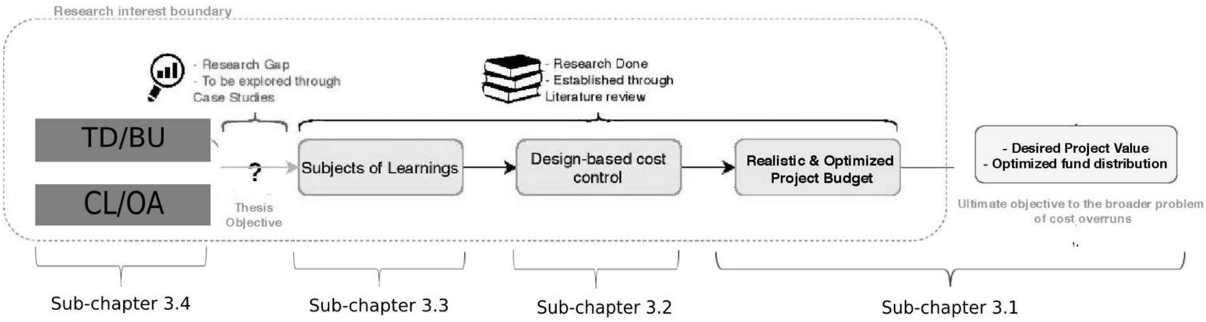

Figure 8: The research boundary showing the causal chain/relationship between the key concepts in this thesis (self-illustration)

The approach to a systematic literature review was laid out through database searches and backward snowballing. Database searches was done by searching literatures through 'key words' in some major research databases. The main keywords used were: 'front-end', 'transportation infrastructure projects', 'cost escalation', 'top-down/bottom-up and 'cross-project data', and were fed with Boolean operators like 'and' & 'or'. The major research databases were Scopus, T&F online, Researchgate, Science direct & JSTOR. In the searched results, Journal articles were given the first preference along with published books. The major journals that eventually delivered most important papers were: The journal of Transport geography, the European journal of transport and infrastructure research and the international journal of project management. In case no literature was found within these literature types, then the preferred types were past academic theses, conference papers, company white papers & other types of articles. The number of citations was also a criteria to consider a literature. With backward snowballing, the cited 'works' in the literature searched from the databases were openly explored in google scholar. With backward snowballing, almost all highly cited researches which are core to this thesis were reviewed. The key fraternity of the authors was also known in this process, and so some more literatures were collected by searching the works of those authors.

3.1 Cost performance over project phases

Several past researches have made concluding remarks over the topic of cost performance of infrastructure projects, which is the research 'context' of this thesis. These outcomes of these researches highlight the need to research more on the cost performance of infrastructure projects. Cantarelli et al., (2011) identified the core cause of overruns as the misinformation about costs, which leads to cost overruns and eventually affects project's value viability along with the country's GDP. The research also stated that the extent of inaccuracy in the cost estimate indicates the size of the overruns as projects suffer more overruns in the front-end phases than in the execution phases. They also emphasized that it is not just any estimate that matters. What matters is the estimate that reaches finally to the decision makers. Odeck, (2019) emphasized over the measurement methods followed by the researchers to measure overruns. It discussed that different projects have different phases during final decision making process, thereby making it difficult to identify the exact baseline for determining overruns. This situation has been termed as a 'lock-in' at the decision making level because budget approved gets further increased in the later estimates (Cantarelli, Molin, van Wee, & Flyvbjerg, 2012). Wachs, (1987) also concluded that in most cases, forecasts are inaccurate with underestimated costs and overestimated traffic demand. His research also criticised imperfect techniques and deliberate false assumptions. By stating the transportation forecasting as politically gripped, he stated that forecasts are modulated until they produce politically attractive outcomes. The major causes identified by him were: scope changes, assumed rate of inflation and delay. Nijkamp, & Ubbels, (1999) highlighted the importance of estimates in the decision making of infrastructure projects. They insisted the negligence towards the 'before' and 'after' studies of costs in such large projects. This is the only research in the history of Dutch infrastructure which conducted an ex-post analysis of the completed projects. They traced the project costs escalations in the front-end phases of five Dutch road projects: A2 – Den bosch to Eindhoven motorway, A73: Boxmeer to Venlo, A22: Wijkertunnel, the Hemspoortunnel and the Van brienenoord bridge in Rotterdam. This paper by Nijkamp & Ubbels, (1999) is the only literature which had the same research 'interest' as that of this thesis.

From the research literature in the past, few research works were also reviewed which explicitly focussed on the front-end cost escalations as the prime reason for net project overruns.

a) Torp, Belay, Thodesen, & Klakegg (2016) studied 110 Norwegian transportation infrastructure projects for their cost deviation over time through both qualitative (expert ratings) and quantitative methods. They identified the critical factors influencing the project cost development in the planning phase with the major factors being 'project complexity' and 'scope changes'. Their results showed that the planning phase had large deviations with the maximum being 50% (when the projects moved from the National transportation Plan (govt. decision) to the 'Action Plan' (parliament's decision). This confirmed the issue of 'lock-in' as cited by Cantarelli, Molin, van Wee & Flyvbjerg (2012). For future research, they demanded a closer case study on few critical projects with additional research attributes. Such missed attributes could be that they didn't classified the identified 'critical factors' as 'external' or 'design team' driven. Also, they didn't proposed possible solutions to manage these factors. Also, no speculation was made by them on how these factors should be approached for steering them. This thesis carried forward the same type of research with the demanded additional attribute. The thesis determines the 'control' based factors which are central to the design team, and explores them as a 'subject of learning'. Also it considers the issue of cost savings through design optimizations in the control process, which these authors didn't consider.

b) Welde & Odeck (2017) also addressed the need to study the front-end cost development of transportation infrastructure projects, stating that early underestimation can result in the wrong project selection. They found that the cost estimates assessed at the time of decision to build are accurate and not biased. However in the phases before the decision to build is made, they found the estimates to be largely underestimated, biased and with more overruns than the execution phases. This means that, they support the research outcomes of van Wee & Rietveld, (2013): *'the extent of cost overruns as found by researchers in the past is underestimated to a large extent in the sense that there have been huge cost escalations even before the decision to build was taken'*. They held the phenomenon of 'anchoring' (relying heavily on first piece of project information) as the key cause for such escalations. Highlighting the work of Westney (2012), they emphasized that the traditional practice of fixing ranges to the deterministic cost estimates misleads the design team from strategic risks. Due to the consideration of such ranges, the design teams are devoid of extensive early risk assessments for external strategic risks which is beyond their control. Furthermore, the involvement of project promoters in such early phases doesn't allows the team to doubt on their estimates. Another major finding was that the projects suffer more overruns in the front-end phases than in the execution phases. However, the authors didn't take a clear stand on whether such escalations are 'design team' driven or 'external (clients/stakeholder)' driven. The solution to this issue of front-end cost escalation wasn't researched upon by them. Their demand of a research on a different country setting was fulfilled by this thesis. Unlike this thesis, they didn't speculated on possible cost savings through design optimization as well, which could be a facet of '*cost-conscious designing'*.

c) Williams, Samset, & Sunnevåg (2009) pointed out the lack of research on front-end decision making in projects and discussed few difficulties: organizational strategy of decision makers and political biases in cost-benefit assessments. However, more focus was given on the 'external' influences to costs (such as governance framework and politics). The extent to which the 'design' team could have influenced through 'control' based technical factors was overlooked by this research as well.

d) In order to achieve maximum feasibility, the project costs should be optimized for the given benefits, but should not be underestimated in this process of optimization. It has been found that the feasibility of most projects are intentionally advocated by the client (municipality/province) in front of the national govt./fund granter. In other words, the project promoters try to represent their projects as more feasible than others by lowering the investment costs and weighing up the benefits coming out of it (Flyvbjerg, 2011). Unlike social infrastructure projects which involve investments from an individual company/person, transportation infrastructure projects involve the money of the entire country/province. Due to this, the decision making process is long and had to start very early. Since the project surroundings are not unfolded, the clients easily beautify the feasibility studies by false representations of their project and it gets equally difficult for the decision maker to judge it.

So, from the literature study conducted on the research 'context' of the thesis, the need to focus on front-end phases for reducing net project overruns was found to be more than the need to focus on execution phases. The three major motivations were:

- ***There are characteristic figures proving that the % overruns in front-end is more than in the execution phase.***
- ***The current position of the 'Dtb' milestone in the project timeline further hinders the presented costs (baseline) to be realistic and optimized. Promoters take the advantage of uncertain project surroundings and manipulate the estimates which makes them underestimated.***
- ***The front-end phases allow for maximum optimization of costs as a design can be tried and tested, unlike in the execution phase.***

3.2 'Control' as a *technical* factor

By reviewing these literature works in relation to the research context of this thesis, a clear perception over the current know-how on 'cost overruns' was made. The birth of cost overruns in a project always begins somewhere during the front-end project journey and is a type of risk. Flyvbjerg (2006) classified the front-end escalation factors into 'political', 'technical' and 'cognitive' (Cantarelli, Flyvbjerg, van, & Molin, 2008), and cited the 'political' factors as the major causes. Researchers like Moschouli (2018); Memon et. al (2011) gathered other factors like site conditions, contractual arrangement, way of project financing etc. which also largely influence the front-end cost escalations. Cost overrun doesn't emerge out all of a sudden on the date of project completion, but it grows with the project development due to the interplay of all these factors. Therefore, it is evident that the attitude of the key actors towards these 'factors' determines the escalation extents. Largely, this attitude is also sometimes governed by the type of payment method in the contractual arrangement (Jahren, & Ashe, 1990). Though the principle of cost control is same for all infrastructure projects, but the difference towards the attitude of cost controlling is dependent upon the fact: *'Whose money is at risk (the owner or the contractor)?'* Contracts with payment methods like 'cost plus percentage' and 'cost plus fixed fee' involve more of owner's risk than that of contractor (See figure 9 below). If an infrastructure project under such a contract provisions experiences cost overruns due to underestimation, the extra expenses (apart from what was quoted by the contractor) would be a responsibility of the owner. For such projects, a realistic budget is a must with an accurate contingency reserve in order to secure the project's feasibility. If the contract is 'lump-sum or 'fixed price incentive' based, then such risks are the responsibility of the contractor and the govt. funds are not at risk. In such cases, the contractor pays enough attention to make sure that his bidding amount is a realistic estimate and not underestimated.

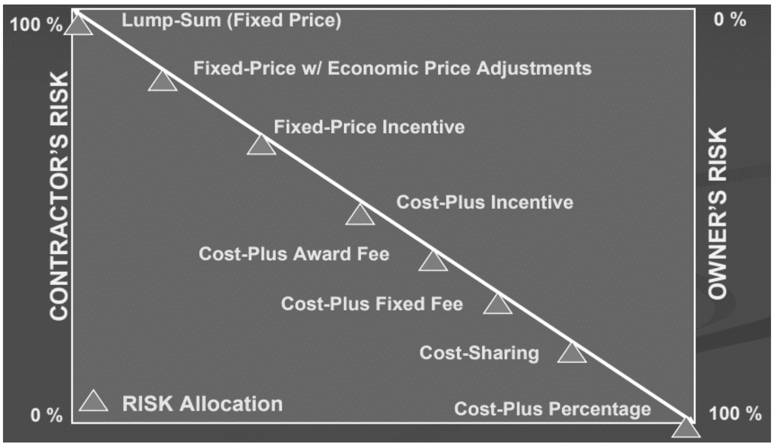

Figure 9 : Risk sharing Meter between the contractor & project client (Kerzner, 2000).

But none of the payment methods involve the risk sharing of non-optimization, which results in the casual attitude of designers towards it. The contractors can be subjugated through suitable contractual modes, but methods still need to be addressed for subjugating a designer's attitude.

For a successful project from the owner/government's/taxpayer's perspective, both designers and contractor should have the correct attitude to deal with cost-underestimation. Recent researches by Love et al. (2011); (2015), have emphasized that insisting on 'political' factors is not enough and more focus needs to be given to the technical and cognitive factors as they can explain 'why' and 'how' events lead to a net front-end escalation. The emphasis should be at least on 'technical/cognitive' factors for smaller projects which are more in number and may not involve much politics/governance misconducts. Quite significant amount of money can be saved in the govt. treasures and better project value can be achieved for these many projects. This emphasized that the attitude of the designers and estimators towards the project costs can also reduce significant escalations. Such an attitude towards costs can be achieved by focusing on the 'control' based technical factors, which directly influences the CBS in the designing process. Unlike other factors, 'control' factors directly influence the costs, and can be traced in the project's cost breakdown structure/estimate files. ***This was the motivation to conduct the research with an explicit focus on 'control' based technical factors.***

3.2.1 The phenomenon of 'control' for front-end : why is it necessary?

As far as the genesis of the 'cost control' concept is concerned, it is based upon the Deming's circle: Plan, Do, Check, & Act (Tague, & Nancy, 2005). For the construction industry, the concept of 'control' was introduced long back in 2013 by the 5th edition of PMBOK (Project Management Body of Knowledge) to the project management fraternity. In its chapter 7.4, it stated 'cost control' as the process of status monitoring, impact forecasting and taking actions for restoring the project as per the baseline. *APM* (2019) defines cost control as the management of actual and forecast costs against the agreed budget. Acebes, Pajares, Galán, & López-Paredes, (2014) explained the principle of 'cost control' as the process of comparing the as-built project status with the as-planned baseline, and introducing required changes in the baseline in order to fulfil the desired project objective (project budget & quality). Ashworth (2013) & Nunnally (2011) also defined cost control as the process of maintaining the total expenses within pre-agreed budget along with delivering the anticipated project value.

Contemporarily, a lot of methods have been developed by the cost engineers for controlling the costs. Some of them include the Earned Value Method (EVM), the TCPI (To-complete cost performance index) etc. But despite of stringent control methods, still many Dutch infrastructure projects suffer cost overruns as exemplified in the previous sections. Target value design (TVD) is one of the most prevalent processes utilized to monitor the costs in the front-end. This process is a systematic approach to collaborative planning and review of designs through target costing. These designs are based on group discussions, detailed estimate of issues/problems and a calculated array of solutions to take the design process forward against the budget and target values of clients (Barberio & Macomber, 2007). However TVD doesn't discusses how to realistically estimate/optimize the target value being targeted.

Love et al. (2011) insisted that these tools can estimate a situation but can't foresee the changes that the project goes through. Tools like RCF can accurately forecast the first estimate of a project, but they can't control a scenario. Every project is different and experiences 'factors' which change the original situation on the basis of which the estimate was prepared. Some researchers like Malkanthi, Premalal, & Mudalige (2017) addressed that the reason behind this is not the un-effectiveness of the control strategies, but ineffective implementation. Other researchers insist that out of the total factors responsible for cost overruns, most of them can be identified and optimized in the design stages by determining the constructability of design, conflicts in designs, possible inflation in prices etc. (Delavar, 2017). Henceforth, in case a project is in cost overruns, the probability of 'control' based technical factors being the root cause is very high.

Apparently, most of these techniques mentioned above for cost control are designed for the execution phase and are meant to utilized by contractors in the execution phase. This is because these techniques are based upon the ideology of controlling the costs against the project baseline, which is prepared on the final days of the project planning phase. The industry needs control techniques for the planning phase as well, so that they can exploit the initial phases for maximum project cost control. Preparing cost control techniques for planning phases is a difficult task, due to lack of project information (even though we have the most freedom of controlling the cost). This is the biggest dilemma with the project managers (Nasir, Nawi, & Tapa, 2016). Unlike execution phase, the designers in the planning phase don't have a fixed baseline cost plan to control against as designs keep changing.

The need to implement cost control system has been widely recognized in order to achieve the project value which was forecasted when the decision to build as taken. Avison, Baskerville, & Myers, (2001) insisted that cost performance can be upgraded by proper cost control measures in the required phases. The cost control process runs throughout all the project phases: from feasibility till project execution. The only variation in the process is that the reference cost plan keeps revising/updating and eventually becomes a project budget for the execution phase. During this course of updating, the accuracy bandwidth associated with it also keeps decreasing due to the gradual divulgence of project uncertainties/information. Also, a major difference between the design phase cost monitoring and the construction phase cost controlling is that, the design phase offers change interventions at a much less expenditure than the construction phase. As discussed earlier in the previous sub-section, the essence of a good cost control practice is the ability to update/change the cost baseline at the minimum corollary surcharges to restore the cost baseline plan. Undoubtedly, design phase would allow for maximum change interventions at a minimum corollary expense. In design phases, such changes lead to virtual design revisions and hence are a subject to only extra consultancy costs (engineering design and planning costs). On the other hand, changes during construction phases lead to the reworks/demolition of the already executed works. Thus, they are a subject to redesign and reconstruction, i.e., both consultancy and contracting costs.

The activity of *'designing'* experiences a cumulative effect of decisions i.e., a design action for an element has secondary effects on other elements. Being 'cumulative' in nature, these secondary effects are least in the early phases and keep increasing with the successive project phases. ***It can be thus realized with some literature support, that the term cost control should be advocated more for the design phases as well. The current tools/methods utilized for monitoring the front-end costs can only estimate a situation but don't give insights on controlling them.***

3.2.2 The PMBoK 'cost control' cycle

One of the tools which is based on the phenomenon of 'control/PDCA cycle' is the PMBoK's cost control cycle for the execution phases (last stage of cost management), i.e., after the stages of 'Plan cost management'; 'Estimating costs' and 'Determining Budget' (Project Management Institute, 2017).

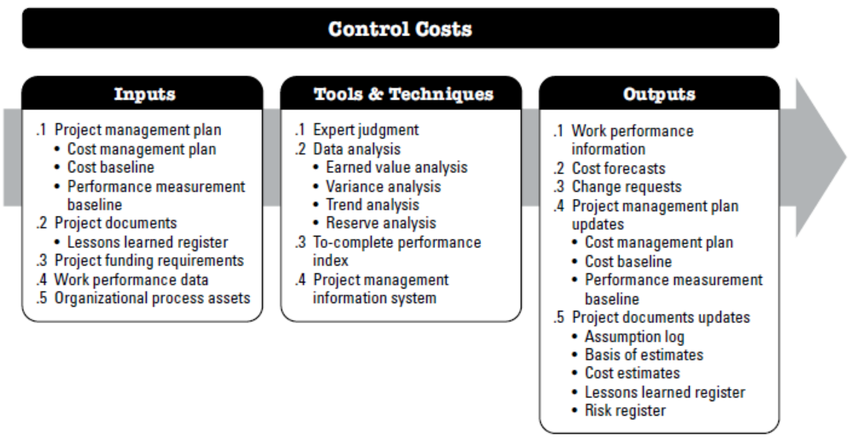

Figure 10 : Inputs, Tools & Techniques & Outputs in a 'Cost control' process (Source : PMBoK)

The PMI defines 'cost control' as: *'monitoring the status of the project by updating the project budget and managing changes to the cost baseline'.* Cost control involves both costing a design and then designing a cost, in order to maintain the pre-determined baseline budget. In terms of data flow, the PMI identifies three stages in the process of cost control: *inputs, tools/techniques and outputs* (See figure 10 above).

The 'inputs' refer to the preliminary knowledge required as a participatory raw material for beginning with cost control. The 'tools and techniques' refer to the mechanisms through which the as-built status is compared with the planned baseline using the inputs from the previous stage. The 'outputs' refer to the cost forecasts and change actions to be taken in the cost baseline in order to restore the pre-agreed budget.

These three stages can also be otherwise referred as the 'knowledge areas' required for efficient cost-control. The 'control' based technical factors can be understood to be embedded within these three KA's. It can be reviewed that without these three knowledge-areas, the phenomenon of cost control/PDCA can't be implemented to construction projects. Hafeez, Aziz, & Elzebak (2015) also identified the same three core knowledge areas for implementing the control phenomenon in the construction industry.

Due to the definite requirements that this process demands in its 'inputs', it becomes difficult to implement this process for the execution phases. Execution phases do have 'change orders' and it utilizes the 'cost control' cycle is to regularly update the baseline documents with those changes. Li (2013) insisted that in the design phases, the change orders are much more because the project expenditure doesn't really starts in the front-end phases. Due to this, the clients often keep a casual attitude in their decisions which keeps fluctuating.
The PMBoK cost control cycle doesn't works for the front-end phases as the WBS keeps changing. No literature support was found which discussed the 'control/PDCA' phenomenon for reducing the front-end escalations. Due to its non- applicability in the front-end phases, it was apprehended that researching on 'control' factors for front-end phase may not produce any significant results. It was considered a possibility that the outcome from the research would not produce any measures to steer the 'control' based factors. This was the point when an assumption (as stated in the introduction chapter) was made before proceeding the empirical research on 'control' based factors.

Before diving into the different subjects within the three KA's, a brief study was conducted over the existing front-end phasing of Dutch transportation infrastructure projects.

3.2.3 The Dutch project planning process

Every project has a unique governance structure, unique phases & milestones. In the Neherlands, the project analysis method as defined by Rijkswaterstaat (The Directorate General for Public Works and water management) is generally followed. Rijkswaterstaat utilizes a consistent definition for 'project phases' (See figure 11 below), which is to be abided by all the bidding consultancies/contractors in order to apply for the tender. It also promotes the guidelines for estimating costs which is regulated by CROW. The Standaardsysteem van kostenramingen : SSK, is utilized by all consultancies/contractors to bid for projects. For infrastructures commissioned by the province (provincial roads) and municipalities (municipal roads), the phase definitions and cost estimating system are almost the same as stated by Rijkswaterstaat. The phasing followed by the Rijkswaterstaat has its origins from the MIRT, (Meerjaren programma Infrastructuur, Ruimte en Transport) a program developed by the Ministry of infrastructure in the Netherlands. Projects which have spatial administrative and financial intervention from the government (central & provincial) are included in the MIRT scheme (MKBA-informatie.nl, sd).

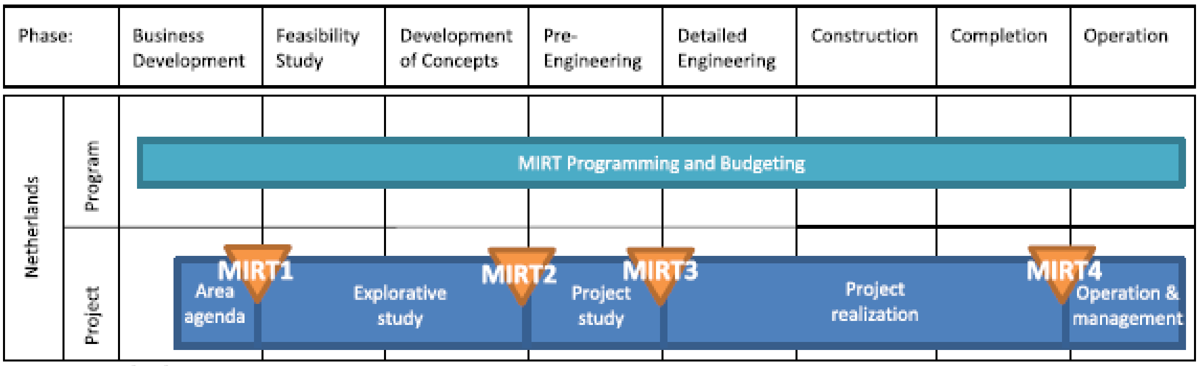

Figure 11 : The project phases. (Source : Klakegg, O. J., Williams, T., & Shiferaw, A. T. (2016)

The MIRT1 Gateway is the first gate where the project need is proposed by the concerned party/municipality/province/national govt. Here, the decision to build (DtB) is made by the decision makers if the project is more financially viable than other projects in consideration. After that, an explorative study is conducted and various options are explored with their costs and benefits. During this duration (feasibility study/HBS & Sketch Designing/SO), the client hires a design consultancy and prepares design alternatives with their respective pros and cons. The most favorable design is then approved in the gateway MIRT2. The selected alternative is then elaborated with some details (VO) and the decision to build is then taken at gateway MIRT3. The project is then detailed out (DO) and is put through EU tender procedure to invite contractor's bids (UO). The execution starts thereafter (Construction). Upon completion, MIRT4 gateway approves its quality and grants the permission to operate it.

3.3 The subjects of learnings within 3 KA's

The essence of cost control is to maintain the project baseline by taking preventive/corrective actions in response to the deviations from the baseline (Christensen,1994). 'Preventive' actions refer to the actions taken in advance by foreseeing a particular misconduct (deviation from the baseline) in the near future of the 'on-going' activities. 'Corrective actions' refer to the mitigation measures taken after a deviation from the baseline is suspected/reported. In order to capture the deviations, the project funds being consumed are related with the corresponding works being executed for expenditures. Updating the baseline budget is a crucial exercise in the process of cost control, which is exercised over certain activities for restoring the expenditures as per the baseline plan. In other words, project cost control helps in retaining the activities as per the agreed project baseline plan. For the design stages, the purpose of the 'cost control' cycle would be to retain the baseline cost plan which was approved at the time of DtB point.

The term 'knowledge area' is to not to be related to its counterpart used in the PmBOK, as they refer to different meanings. The PmBOK discusses 10 major focus areas of project management and cites them as the 'knowledge areas'. However, this thesis focuses only on 'cost control' and discusses the three knowledge areas within it (the inputs, tools & techniques, outputs).
The three knowledge areas will be discussed in this sub-chapter. The 'control' based technical factors were researched from the literature and were classified into the respective KA where they fit the most (explained in the next sub-chapter). These are in correspondence to the three steps involved in the process of cost control (See figure 12):

a) KA 1 - 'INPUTS' (Measuring/Estimating the as-built expense and reporting it). It refers to the 'Plan' & 'Do' of the Deming's circle.
b) KA 2 - 'TOOLS & TECHNIQUES' (Comparing as-built with the cost baseline). It refers to the 'Check' of the Deming's circle.

c) KA 3 - ‘OUTPUTS’ (Forecasting & Decision making): preventive/corrective actions for future projects / an immediate corrective action for the on-going project). It refers to the ‘Act’ of the Deming’s circle.

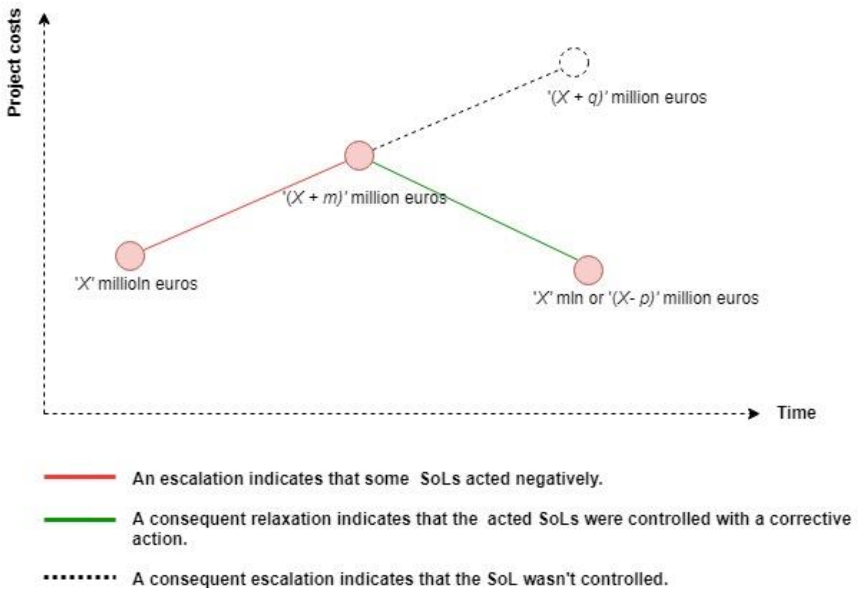

Figure 12 : Different ways a SoL can influence a project's costs (Self illustration. Some adaptations from Bhargava et. al, 2017)

Due to lack of literature on the conceptualization of ‘cost-control’ for the front-end phases, a short discussion was held within the Arcadis’s cost management team. The motive of this discussion session was to understand what do the cost engineers experience every day in terms of the front-end cost behaviour. It was also discussed how the behaviour could be understood in reference to the three KA’s of cost control. The discussion started with the different ‘factor’s that influence the cost curves of different design components. These ‘factors/subjects’ within these three KA’s can influence both positively & negatively to both the execution & front-end phases. A ‘negative’ behaviour of the ‘factor’ escalates the cost curve while a ‘positive’ behaviour’ relaxes the cost curve. It was realized that unlike for execution phase, not much is known over these ‘factors/subjects’ on how they can be steered to reduce the front-end escalations. So, these have been termed as the ‘Subjects of learnings/SoL’ in this thesis. The term ‘learning’ has been used in this thesis because not much is known on how these SoLs should be approached for ‘steering’ them. Learnings related to both ‘data retrieval’ & ‘data processing’ is to be made in order to ‘steer’ the SoLs. ‘Steering’ here refers to the design team’s intervention for changing the SoL’s behaviour from ‘negative’ to ‘positive’. The ‘negative’ and ‘positive’ behaviours of the SoLs have been explained in the next sub-section. In terms of the SoLs influence/behaviour, following points were concluded from the discussion & were considered as the concepts for this research:

- If the costs don’t escalate with time, that would mean that there are no SoLs acting in the project (quite unusual) or that they are acting neutrally/positively. It could also be that the acting SoLs have been already steered well through preventive measures.

- The ‘red’ line in the figure above depicts the negative behaviour of one or more SoLs. In case a SoL behaves negatively and escalates the project’s costs, it is likely that the SoLs from either of the three KA (or all the three KA) influenced negatively. This means that within the scope of ‘control-based factors’ :

a) either the costs were underestimated,
b) or wrongly compared with the base plan, or
c) that unnecessary actions were taken (like overdesigning/overestimation).

- As a next incident to this escalation, two consecutive situations are possible :

  a) Either a consecutive escalation would take place indicating that no action was taken to steer the SoLs, or that the taken action was unsuccessful. It is also possible that the trajectory is a straight line but then the current project costs would be still in escalations vis-à-vis the cost plan of DtB point ; or
  b) A consecutive relaxation would take place, indicating that a corrective action was taken on the acting SoLs.

  The next section discusses the two fundamental necessities which are required to formulate a steering approach for a SoL/factor : 'the method of data/information retrieval over the SoL' & 'the method to process the gathered information/data'.

3.3.1 Different approaches to steer the 'control' based factors.

All project management problems require an approach to gather needed 'data/information' and a suitable approach to 'process' the gathered data for taking decisions (Black, 2002). In terms of steering the SoLs/factors, it can be said that all SoLs demand a suitable 'data gathering' approach and also a suitable approach to 'process' these data.

The data for an ongoing project can be gathered from the project itself, or from the files of similar projects that have been executed in the past. Depending upon the accuracy of these two approaches, either of them are chosen depending upon the situation/design problem. Utilizing past project data for an on-going project is often referred as cross-project learning (CL) (Newell, S. ,2004 ; Finerty, T. ,1997). In the front-end phases, past learnings from a project are often utilized as not much project information is known. The later phases (detailed design & contracting) also often use past project data to prepare the detailed estimates. Project specific data on the other hand are utilized to design/estimate a highly unique feature in a project, which could not be extracted from past executed projects.

Similarly, the processing of these data/information/knowledge can be approached in two different ways : a holistic top-down processing & a much disaggregated bottom-up processing (Flyvbjerg, Garbuio, & Lovallo, 2009; Al-Reshaid, Kartam, Tewari, & Al-Bader, 2005). Each of them are widely utilized in different managerial tasks (design problem solving, strategic thinking, cost estimating, estimate comparing etc.) depending upon their suitability for the task. While the top down approach can design/estimate a task by breaking down the project into its constituents, the bottom-up approach aims to design/estimate by summing up the smaller pieces to give rise to a complex design (Black, 2002).

For steering each SoLs/'control' based technical factors, suitable approach for both 'data retrieval' and 'data processing' is required. This selection can be largely determined by the many characteristics of the SoL : *the nature of the SoL, how it influences, when does it acts in the front-end phase etc.* Such features of the Sol can be studied by a detailed ex-pose evaluation of projects, which this thesis conducts.

To start the empirical research, the SoLs known to the industry were listed out from the literature. The next section documents those SoLs and the existing know-how over the SoLs on approaching/steering them.

3.3.2 Existing knowledge over the SoLs : A literature study

After several discussion sessions with the Arcadis cost department, a short literature study was conducted to gather the past researches on the 'factors' leading to cost overruns in infrastructure projects (See table 3 below). Amongst them, the 'control' based technical factors were gathered. The current know-how over their influence on the project's front-end cost performance was understood. The existing knowledge over the possible steering approaches in terms of 'data attainability' and 'data processing' was also documented.

Table 3 : The SoLs/factors gathered from Literature

Subjects	Factor type	Reference
Knowledge Area - I (SoLs mostly influencing the 'MEASUREMENT OF ESCALATIONS')		
Scope additions	Technical	• Creedy, G. D., Skitmore, M., & Wong, J. K. (2010), • Cantarelli, C. C., Flyvbjerg, B., van Wee, B., & Molin, E. J. (2010), • Shane, J. S., Molenaar, K. R., Anderson, S., & Schexnayder, C. (2009).
Estimating methods	Technical	• Ling, Y. Y., & Boo, J. H. S. , (2001); • Staub-French et al., (2003); • Rónai, P. ,(2001).
Engineering miscalculations	Technical	• Paek, J. H. (1993) ; • Lopez, R., Love, P. E., Edwards, D. J., & Davis, P. R. (2010)
Time availability for each phase (SO-DO)	Technical/cognitive	• Cantarelli et. al. (2012) and Flyvberg et. al (2004). • Azhar et. al (2008); • Chan & Park (2005)
Knowledge of Cost benchmarks.	Technical	No literature available (The SoL was found through the discussion session with the cost team)
Accuracy of the risk analysis	Technical/Cognitive	• Love, P. E., Sing, C. P., Wang, X., Irani, Z., & Thwala, D. W. , (2014). • Cantarelli, C. C., Flybjerg, B., Molin, E. J., & Van Wee, B. , (2013), • (Ec.europa.eu, 2019)
Price Inflations	Technical	• Cantarelli, C. C., Flybjerg, B., Molin, E. J., & Van Wee, B. (2013) ; • Creedy, G. D., Skitmore, M., & Wong, J. K. (2010) ; • Mahamid, I., & Dmaidi, N. (2013).
PvACompletness (List Of Requirements by the client)	Technical/Cognitive	• Kamara, J. M., & Anumba, C. J. , (2000). • Tzortzopoulos, P., Cooper, R., Chan, P., & Kagioglou, M. , (2006)
Underestimation due to strategic political misrepresentation	Political	• Cantarelli, Chantal C., et al. (2013), • Flyvbjerg, B. (2004), • Flyvbjerg, B. (2009).
Knowledge Area - II (SoLs mostly influencing the 'COMAPRISON B/W As-Designed & Cost plan)		
The frequency of cost monitoring between Designers & estimators	Technical	• Houseman, O. et al. (2008)
The method of as-designed cost comparison with the cost plan	Technical	No literature available (The SoL was found through the discussion session with the cost team)
Comparison of inter-phase performance	Technical	No literature available (The SoL was found through the discussion session with the cost team)
Knowledge Area - II (SoLs mostly influencing the 'COMAPRISON B/W As-Designed & Cost plan)		
Control thresholds of the cleint	Technical/Cognitive	No literature available (The SoL was found through the discussion session with the cost team)
Integrated design change control process	Technical	• Diana Mbabazi, (2016), • Schulman, P. R., & Roe, E., (2007).
Knowledge of design based-Cost drivers	Technical	• Ojedokun, O.Y. Odewumi, T.O. Babalola, A.O. (2012)
Constructability Analysis	Technical	• Arditi, D., Elhassan, A., & Toklu, Y. C. , (2002).

Design Variants Appraisal.	Technical	• Brauers, W. K. M., Zavadskas, E. K., Peldschus, F., & Turskis, Z. , (2008).
Optimizing costs with construction planning	Technical	No literature available (The SoL was found through the discussion session with the cost team)
Adjusting estimates with the revealed information	Technical	No literature available (The SoL was found through the discussion session with the cost team)

The table hereafter shows the list of 19 factors/SoLs describes the known positive/negative influences of the SoL (as learnt from the company discussion). The known information over these SoLs have been classified into 4 columns (See Table 4) :

a) The first two columns indicate whether the very first influence is on the 'design' or the 'estimate' counterpart of the same design. In the estimate counterpart, a distinction was also made on whether the influence is on the 'price' (material costs, machinery costs, labour costs etc.) or on the 'quantity' (quantity of materials, manhours of machinery/labour).
b) The last two columns describe the 'positive' and 'negative' behaviours of the 'SoL's. The description has been colour coded to make a clear contrast in the behaviour. The text in '**Blue**' colour explains the 'event' caused by the SoL : 'Escalation/Reduction in escalation'. The description below the 'event' is classified in terms of the three possible negative/positive behaviours (either of them/all of them) of the SoL (as explained previously) :

*a) either the as-designed costs were underestimated due to the SoL, or (**Red** colour)*
*b) the as-designed costs were wrongly compared/ with the base plan, or (**Black** colour)*
*c) - Unnecessary actions were taken in the design (like overdesigning/overestimation)(**Green** colour) .*
*- Extra works were added by the client/designer (due to engineering misconducts) (**Brown** colour)*

*Some SoL's also facilitate/deter the 'optimization' process. (**Acqua** colour). The SoL which play a role in optimizing has been shaded with '**Orange** colour'.*

(I) refers that the SoL is facilitated by the consultancy, while (E) refers that the SoL is facilitated by the external parties like clients & other stakeholders.

The factors were classified into the three knowledge area, which they influence the most in the process of cost control.

Table 4: Positive and negative behaviours of the SoLs (Source : discussions with Arcadis cost experts)

SoLs	Influence on the project's front-end cost performance				
	Influences the 'Design' first	Influences the 'Estimate' first		Positive behaviour on cost curve	Negative behaviour on cost curve
		Qty.	Price		
Knowledge Area - I (SoLs mostly influencing the 'MEASUREMENT OF ESCALATIONS')					
	✓			**Reduces escalation :** **Removes extra works** due to scope removal	**Escalation :** due to **extra work additions.**

Scope additions/removal (E)				**Reduces escalation :** Even if a scope is added, further escalations can be reduced by **accurately estimating** it.	**Further Escalation :** It is also possible due to the **underestimation** of the added fresh work.
Risks analysis (I)		✓	✓	**Reduces escalation :** by **Accurating** the estimate	**Escalation :** due to **underestimation** the costs
Completeness of the design/Engineering calculations (I)	✓			**Reduces escalation :** by **Accurating** the estimate	**Escalation :** **Underestimates** the costs + **extra work additions**
PvA (plan van aanpak) / Requirement lists by client (I/E)	✓			**Reduces escalation :** by **Accurating** the estimate	**Escalation :** **Underestimates** the costs
Time available for each phase (SO-DO) (E)	✓	✓	✓	**Reduces escalation :** by **Accurating** the estimate / **optimizing** the estimate	**Escalation :** **Underestimates** the costs
Knowledge of cost benchmarks (I)		✓	✓	**Reduces escalation :** by **Accurating** the estimate	**Escalation :** **Underestimates** the costs/ **overestimates** the cost
Underestimation due to strategic political misrepresentation (E)		✓	✓	**Reduces escalation :** **Accurating** the estimate	**Escalation :** **Underestimates** the costs
Price Inflation (E)			✓	**Reduces escalation :** by **Accurating** the estimate.	**Escalation :** **Underestimates** the costs.
Estimation method for a particular phase (I)				**Reduces escalation :** by **Accurating** the estimate.	**Escalation :** due to **underestimation** the costs.
Knowledge Area - II (SoLs mostly influencing the 'COMAPRISON B/W As-Designed & Cost plan)					
The frequency of cost monitoring between D&E (I)		✓	✓	**Reduces escalation :** **Accurates the estimate/removes extra works** by **showing correct comparisons**	**Escalation :** **Underestimates** the costs/ **overestimates** the cost by **showing incorrect comparisons**
Method of as-designed comparison with cost plan (I)		✓	✓	**Reduces escalation :** **Accurates the estimate** by **showing correct comparisons** on the basis of which actions are taken.	**Escalation :** **Underestimates** the costs/ **overestimates** the cost due to actions taken on the basis of **incorrect comparisons.**
Comparing inter phase performance (I)		✓	✓	**Reduces further escalation :** **Accurates the estimate** by **showing correct comparisons** on the basis of which actions are taken.	**Escalation :** **Underestimates** further the costs/ **overestimates** further the cost due to actions taken on the basis of **incorrect comparisons.**

Knowledge Area – III (SoLs mostly influencing the attempts to 'RESPONSE ACTION')					
Cost control threshold of the client (E)	✓	✓	✓	**Reduces escalation :** **Accurates** the estimate/**Optimizes** the costs	**Escalation:** **Underestimates/ overestimates** the costs.
Optimizing time through construction schedule planning (I)			✓	**Reduces escalation :** **Optimizes** the costs	**Escalation :** **overestimates** the costs
Constructability Analysis/Clash Detections (I)	✓			**Reduces escalation :** **Accurates** the estimate/**Optimizes** the costs	**Escalation:** **Underestimates/ overestimates** the costs
Design Variants Appraisal (I)	✓			**Reduces escalation :** **Optimizes** the costs	**Escalation :** **overestimates** the costs
Knowledge of design-based cost-drivers (I)	✓			**Reduces escalation :** **Optimizes** the costs	**Escalation :** **overestimates** the costs
Aligning designs with the revealed information in each phase. (I/E)	✓			**Reduces escalation :** **Accurates** the estimate/**Optimizes** the costs	**Escalation :** **Underestimates/ overestimates** the costs
Integrated design - change control process (I)	✓			**Reduces escalation :** **Accurates** the estimate/**Optimizes** the costs	**Escalation :** **Underestimates/ overestimates** the costs

Considering only the 'control' based factors, the combined effect of all these SoLs may decide the net escalation in a project's front-end. If the number of negative influences are more than the positive influences, then the whole project would be in a net escalation by the time the project is ready for the tendering phase. If the number of positive influences are more than the negative influences, then the project's final estimate would be very closer to the very first estimate of DtB. It would be also optimized to the best possible extent. Conclusively, the project's B/C ratio would be preserved and most probably the project would be a success in terms of its 'value'.

3.4 Results & Discussions

Following conclusions were made from the literature study:

a) Only some researches have been done over the front end phases of transportation infrastructure projects (mostly in Norwegian/Swedish context).

b) Most attention has been paid to the governance/political reasons of front end cost escalations and not to the technical/cognitive reasons (specially 'control' based technical reasons)

c) Every researcher has found characteristic numbers representing the degree of escalations. But none of them have given an in-depth insight on solutions to the front-end cost escalations. No research has discussed steering approaches toward the 'control' based technical factors.

d) Through research over the 3 KA's, it was found that the steering approach is not known for most of them, due to which the cost control regime is not effective in design stages and projects suffer front-end escalations.

This literature study gave the current know-how over the 'control' based factors in the fornt-end phases of the projects. The know-how was found to be almost nil in the research library because of which experts discussion sessions were required to know more over the 'control based factors.

The literature helped in giving a hint to some of the ‘control’ based factors. But as it can be witnessed, there were some factors raised by the cost experts which were not found in any literature. With the information gathered over the ‘control’ based factors from the literature & the discussion sessions with Arcadis cost experts, the research was further taken towards the empirical methods. Considering the set of 19 ‘control’ based factors along with their positive & negative behaviour, the literature study helped to give an understanding over what could be the possible impacts of all these factors. In the coming chapters, the research would be first made sharper by filtering the most important ‘factors’ which should be studied. This filtering was done through a structured questionnaire survey. These filtered factors were then studied through the two case studies. Now that the ‘positive’ and ‘negative’ behaviour of the factors were understood, ex-post studies were performed on the fact that how these factors could have been steered towards their ‘positive’ behaviour, and escalations could have been possibly saved in both the case projects.

4

Structured Survey

The first step in the empirical research was to conduct a structured survey amongst the cost experts who had an experience in Dutch road projects. In terms of the 'problem line', the literature review only provided the list of the SoLs/factors, which are known to be influencing the front-end cost escalation. It didn't revealed how influential these SoLs are in relation to each other. Since the list of SoLs obtained was quite big and the research was exploratory, it was necessary to know which important (or crucial) SoLs should be carried forward for the case-studies. Prior to this, it was necessary to know what should be the criteria to tag them as 'important'!

This survey was intended to prioritize the SoL's in terms of their negative influence in the Dutch infrastructure market and also to know the extent to which they can be steered through past project's experiences/database/knowledge. 'Influence' here meant:

a) The probability of a SoL causing an escalation in a project, and
b) Also the probability it causing a bigger escalation than other SoLs, in case it acts in the front-end.

The SoLs which were most influential and least learnable from past projects were given the tag of 'important (or crucial). The figure below explains the research methodology for the 'structured survey' :

4.1 Questionnaire survey amongst experts

Many researchers who previously have collected the list of cost control factors through questionnaire method of survey, have also ranked them. But this research required a separate attempt to rank the factors through the practitioners' responses because of the following reasons:

- More clarity was required over the SoLs in terms of their influence intensity. The literature study wasn't enough to understand the issues/SoLs in terms of their influence.

- Most of the factor rankings produced by renowned research works on cost overruns like Hwang, B. G. et. al (2018); Moschouli, E. (2018); Memon, A. H. et. al (2011) ; Allahaim, F. D., & Liu, L. (2013) etc. consider the factors from the entire project journey. Unlike these researches, this thesis explicitly focuses only to the project control based factors in the front-end phase of the project.

- Such past researchers haven’t made an explicit demarcation of roads as the ‘asset type’ in their survey description.

- They didn’t ranked the relative ‘ease of control’ for these factors.

- To obtain the latest severity trends with the ‘SoL’s/factors’ in this research. The term ‘severity’ refers here to the situation of a factor being not only highly influential, but also highly difficult to learn from past projects.

- Also, to validate the problem statement of this research by finding out the state-of-the art influences of the 19 SoL’s/factors.

Since this survey explores both the ‘influence extent’ and ‘cross-project learnability’ for all the factors simultaneously in the same platform, the responses received from the responders would be accurate in terms of the relative scoring between the influence & control parameters for a factor. No survey was taken on the aspect of ‘data processing (TD/BU) for the SoLs. This was intended to be explored through interviews.

Through the results of this survey, this exploratory research got more focussed into the few selective SoL’s, which influence the most in the front-end cost control of the project. Given the short timeframe, a trade-off had to be conducted between the number of interview responses and the number of SoL’s under research. The decision outcome from the trade-off was to receive more interview responses for a selective important SoL’s, rather to receive less number of responses on all the 19 SoL’s. Another motivation and necessity for this survey was the broad spectrum of the research outcome being expected from each SoL. Achieving a set of information about the SoL/factor (as explained previously) through past projects for cost control is the objective of this thesis. Hence, it was a necessary move to proceed with the most crucial SoL’s, so that the research can fill the existing knowledge gap of at least these SoL’s completely.

4.1.1 Data collection

Along with the survey followed a short description of the research project and the research objective, so that the participants can understand the context and need for the market survey. The questionnaire was divided into three sets:

a) The first four questions targeted to gather the profile background of the responders such as : ‘role in the industry’ , ‘company/govt. affiliation’ , ‘years of experience with the Dutch road projects’ etc. Such a background was necessary to ensure the reliability of the scores as front - end estimation is highly determined by the practitioners past work experience. The summary of the respondent’s profile is as follows (Table 5):

Table 5 : Profile of the respondents

Industry Profile of the respondents		
Profile	*Frequency*	*Percentage*
Cost engineers	13	65%
Project Controller	4	20%
Project leaders/risk managers	3	15%
Work experience in the planning & construction of Dutch roads		
Years	*Frequency*	*Percentage*
<5 yrs	5	25%
5 to (=10) yrs	3	15%
10 to (=20) yrs	4	20%
>20 yrs	8	40%

b) The next four questions targeted to gather some characteristics of front-end overruns in road projects such as (See Appendix A):
- % of projects suffering front-end overruns in the participant's department ;
- percentage share of major construction items, optimization ;
- construction works which are generally underestimated and which offer most cost optimization possibilities.
The responses of these questions helped to enquire over the SoL's impact on diff. through interviews. The responses revealed that there are front-end escalations in road projects:

- 4 experts said that more than 40% of projects in their team suffer front-end escalations.
- 6 experts said that 30-40% of projects in their team suffer front-end escalations.
- 4 experts said that 10-20% of projects in their team suffer front-end escalations.
- 3 experts said that 5-10% of projects in their team suffer front-end escalations.
- 3 experts said that less than 5% of projects in their team suffer front-end escalations.

It was concluded that from the viewpoint of these 20 experts, front-end escalations are existent in Dutch road projects.

c) The last two questions were based to study the SoL's for their influence on the project's front-end phases and also to rank the extent of cross-project knowledge attainability that they offer.
These two questions represented the two different response categories: The first question was to rank all the SoL's on the basis of their influence extent in the front-end cost control process (1= least influence, 2=little influence, 3=medium influence, 4= high influence, 5=extreme influence). The second question was to rank the SoLs on the basis of their cross-learning attainability for better control over them (1= least attainability, 2=little attainability, 3=medium attainability, 4= high attainability, 5=extreme attainability). A high 'influence' score would refer that the SoL has high probability to enact in a project and can cause high cost escalation as well. A high 'attainability/learnability' score here would mean that the cross-project learning can steer the SoL by providing necessary data/information from past projects. It was mentioned in the survey brief that the respondents should rank the SoLs relatively, so that the data is analysed for ranking produces correct results.

In total, the survey was afloat for a duration of 2 months. Regular reminders were sent to the prospective responders & many referrals were also made through the senior Arcadis team leaders. Along with the responses, the respondents name and identity was also collected but has been kept anonymous in this report.

4.1.1.1 Data Reliability extent

Although, the survey wasn't targeting a definite number of response samples, but the total number of received response samples were 20. Excluding for the survey floating in the social media, the response rate from the one-on-one/Snowballing circulation was 44.4%, which was more than the existing response rate norm of 20%-30% with many surveys in the construction industry (Akintoye, 2000; Hwang et al., 2015). The widely utilized Cochran's formula (Cochran, W. G. ,1963) for calculating survey sample (number of required responses) can be used to testify what can be statistically concluded on the basis of these 20 responses. Generally, this formula is utilized to come up with the appropriate sample size of responses required for a specific confidence level and precision error. But in this survey research, the approach was other way around as the number of responses were kept open till the time frame permitted. After receiving all the responses, the observations on confidence level & precision error were made using the formula. The modified Cochran's formula for evaluating the survey sample size for a small population (~50 to 60) is :

$$n = \frac{n_0}{1+\left[\frac{n_0-1}{N}\right]} \quad ; \text{where} \quad n_0 = \frac{z^2 p(1-p)}{e^2} \qquad \text{(Israel G.D, 2003)}$$

'n' is the sample size (the group surveyed), z = z score (confidence level/probability), e = margin of error/desired level of precision, N = population size (the entire group over which the conclusion can be made), p = degree of variability in a population

The value of 'p' for this survey can be somewhere in the range [0.2,0.5) or (0.5,0.8] as the survey was sent to a population with a background in cost engineering (i.e. homogeneous population & not heterogeneous population). Still for a conservative calculation, the value of 'p' was taken to be the most heterogeneous one, i.e. 0.5. Upon running multiple simulations using the Cochran's formula in MS Excel for a value of 'n' being 20, the confidence level being at least 85%, the population size came out to be 50 (with a margin of error = 12.6%). But, the existing cost experts are way more than 50 in the Netherlands (may be 100 or 200, the exact number is not known). So, it can't be said that the results of the survey represents the voice of all the experts (the population). Hence, in terms of the results validity, no statistical significance were drawn out of this survey. The results were considered to be merely indicative & were not enforced with a statistical significance. Knowing the entire population (total number of cost experts in the Netherlands) and involving all of them in survey participation could have made the survey results eligible for any statistical introspection.

4.1.2 Data Analysis

The data were analysed in two ways, i.e for their 'statistical significance' and for their 'extremity' (See figure 13).

4.1.2.1 Analyzing data sets for statistical significance: Phase 1

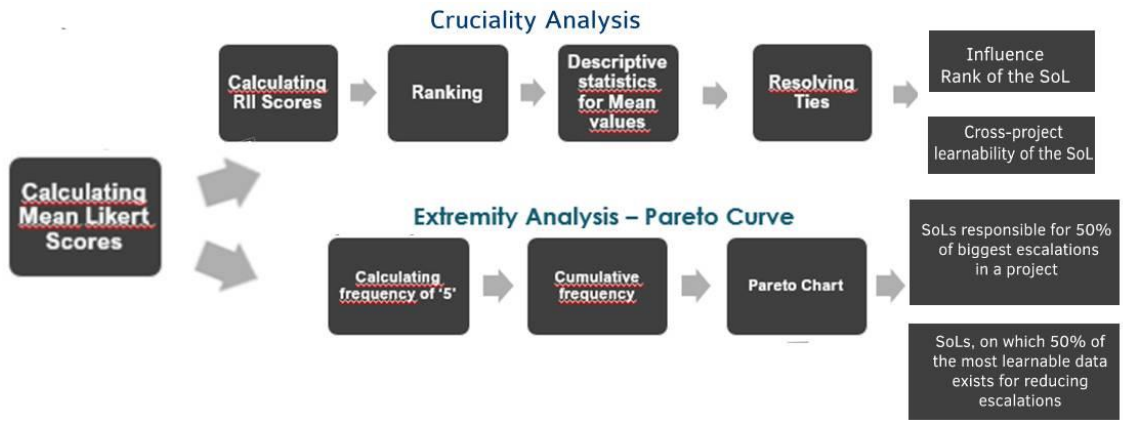

Figure 13 : Methodology followed for the questionnaire survey (Self-illustration)

The ranking of factors was possible with many methods like Kendall's coefficient rank (Elhag, T. M. S., & Boussabaine, A. H. ,1999 ; Elinwa, A. U., & Buba, S. A. ,1993), Rank Agreement Factor (Elinwa, A. U., & Joshua, M. ,2001), Relative importance index (Love, P. E. et al., 2017), Severity Index (Cheng, Y. M. ,2014). Amongst these, the RII method was utilized as it is a valuable tool for comparing independent variables (SoL's) and ranking them for both the scoring categories. Due to the chances of some SoL's obtaining the same RII, elements in the descriptive statistics (mean, SD, skewness & kurtosis) were also computed for each survey category of the SoLs. So the three major data analysis tools for this phase were:

a) The RII score: The RII score was calculated using the most common formula adopted by highly cited recent papers by Love, P. E., Smith, S. D., & Ackermann, F. (2017) ; Larsen, J. K.,et al.. (2015) :

$$\text{RII} = \frac{\Sigma x}{A\mathbb{N}} = \frac{5n_5+4n_4+3n_3+2n_2+n_1}{5N} \quad , \quad 0 < \text{RII} < 1$$

Where N = total number of respondents, n_1, n_2, n_3, n_4, n_5 are the frequency of the respective score represented by the subscript of 'n'.

b) The skewness : It gave the measure of positive/negative asymmetry of the curve around its mean value for each SoL. High positive skewness for a SoL would mean that it will mostly possess a score lesser than its mean score (and not more than the mean score). High negative skewness for a SoL would mean that it will mostly possess a score more than its mean value (and not lesser than mean value). A skewness very near to 0 means that the distribution is a normal distribution.

c) The kurtosis: It represented the peakness of the distribution for each SoL. More kurtosis would indicate more peakness than the normal distribution. So, high +ve kurtosis value for a SoL would mean that the SoL would mostly obtained a score very near to its mean value from every responder who scored it. A kurtosis very near to 0 means the distribution is a normal distribution

A combination of high -ve skewness and high +ve kurtosis would indicate that the SoL score has a high exceedance probability (due to -ve skewness), but with to a little range, i.e. from μ to (μ + 5%μ) (due to high kurtosis). So**, in case of a tie in the RII/mean score based rankings, the SoL with most -ve skewness and most -ve kurtosis would be leading in the raking than the others with the same RII/mean score**. In case, the reranking can't be done through this idea and the SoL competitors show mixed characteristics in their skewness & kurtosis, then the reranking was decided on by multiplying skewness & kurtosis after changing their signs. With the same ideology as risk, multiplying skewness (risk to exceedance) with kurtosis (major scores responsible for exceedance) gives the value of risk to exceedance from mean value of the SoL. The competitor with more risk value would be upgraded up into the rankings.

The table here under (Table 6) shows the descriptive statistics for response Category I:

Table 6: Descriptive Statistics for Response category: SoL 'influence extents'

SOI NO	SOLRANKING (IN ORDER OF THE RII RANKING FOR RESPONSE CATEGORY 1)	RII	MIN SCORE	MAX SCORI	MEAI	SD	SKEWNES	KURTOSI	RISK OF EXCEEDIN MEAN	FINAL RANKING
17	Scope additions by client	0.88	1	5	4.4	1.0677	-1.8337	3.8364		1
07	Risks/contingency calculation	0.84	2	5	4.2	0.9274	-0.7824	-0.3813		2
05	Completeness of the design/Engineering miscalculations	0.80	2	5	4	0.8944	-0.4193	-0.6869		3
10	PvA (plan van aanpak)/PvE	0.76	1	5	3.8	1.1225	-0.6618	0.1133		4
03	Time available for each phase (SO-DO)	0.71	2	5	3.55	0.8047	-0.1627	-0.2123		5

18	Knowledge of design-based cost-drivers	0.70	2	5	3.5	1.0247	0.0000	-1.0999		6
06	Knowledge of cost benchmarks for direct costs	0.68	1	5	3.4	1.1576	-0.2398	-0.7919	0.189	7
08	Underestimation due to strategic political misrepresentation	0.68	1	5	3.4	1.1136	-0.6170	0.3169	-0.196	9
12	Design Variants Appraisal	0.68	1	5	3.4	1.1136	-0.1825	-0.4972	0.09	8
16	Integrated design - change control process	0.66	2	5	3.3	0.9000	0.1975	-0.5945		10
02	Cost control thresholds	0.65	1	5	3.25	1.0428	-0.2480	-0.4306	0.107	13
04	The frequency of cost monitoring between D&E	0.65	1	5	3.25	1.2196	-0.6511	-0.4928	0.321	11
13	Optimizing time through construction schedule planning	0.65	1	5	3.25	1.0897	-0.0435	-0.5276	0.220	12
19	Aligning designs with the revealed information in each phase.	0.64	2	5	3.2	0.7483	0.3723	0.3659		14
11	Constructability Analysis	0.63	1	5	3.15	1.0137	-0.0151	-0.1796		15
01	Estimation method for a particular phase	0.58	1	5	2.9	1.2610	0.1885	-0.8285		16
14	Method of as-designed comparison with cost plan	0.55	1	5	2.75	1.1779	0.3098	-0.5374		17
09	Price Inflation	0.54	1	5	2.7	1.0050	0.3310	-0.0245		18
15	Comparing the current performance reporting with the previous reporting	0.52	1	5	2.6	1.1576	0.2398	-0.7919		19

Some results from the above analysis are:

- **Result 1 :** All the SoL's obtained at least a minimum RII value of 0.50, which infers that these 19 SoL's extracted from the Literature are the most influential factors to the front-end cost overruns, and that the extract from the literature study was valuable.
- **Result 2 :** The top five SoL's have a negative skewness indicating that it's highly likely that their score can exceed more than their mean value, making them even more closer to the score of 5 (extreme 'influence'). This statement is most effective for the top ranked SoL of 'Scope additions by client' which has the min. skewness of -1.83 with a mean value of 4.4. With the highest kurtosis of 3.83, it can be said that most responders agreed for this SoL holding a score of 4.4 to 5.
- **Result 3 :** The least effective 5 SoLs in the bottom list had a positive skewness indicate the they are most likely to have scores even lesser than their mean value, thereby inching them towards 2 (= little influence)

Now, the table here under (table 7) shows the descriptive statistics for response category II:

Table 7: Descriptive statistics for Response category II

SoL No.	SoLRanking (In order of their RII ranking for response category 2)	RII	Min	Max	mean	SD	Skewness	kurtosis	Risk of exceeding Mean	Final Ranking
07	Risks/contingency calculation	0.83	3	5	4.15	0.7263	-0.2369	-1.0428		1
06	Knowledge of cost benchmarks for direct costs	0.81	2	5	4.05	0.9206	-0.4835	-0.7930		2
01	Estimation method for a particular phase	0.76	1	5	3.80	1.1225	-1.2981	1.9859		3
02	Cost control thresholds	0.75	1	5	3.75	1.0428	-0.5456	0.5617	-0.306	5
03	Time available for each phase (SO-DO)	0.75	1	5	3.75	1.0897	-0.6520	0.3046	-0.199	4
14	Method of as-designed comparison with cost plan	0.74	2	5	3.70	0.9539	-0.0622	-0.9637	0.060	7
15	Comparing the current performance reporting with the previous reporting	0.74	2	5	3.70	0.9000	-0.1975	-0.5945	0.117	6
05	Completeness of the design/Engineering miscalculations	0.73	2	5	3.65	1.0137	-0.1231	-1.0688	0.132	8
13	Optimizing time through construction schedule planning	0.73	1	5	3.65	1.1079	-0.6017	-0.0022	0.001	9
04	The frequency of cost monitoring	0.72	1	5	3.60	1.2000	-0.5833	0.0949	-0.055	11
12	Design Variants Appraisal	0.72	1	5	3.60	1.0677	-0.3845	0.1041	-0.040	10
11	Constructability Analysis	0.69	1	5	3.45	1.0235	-0.4246	0.2109	-0.090	13
16	Integrated design - change control process	0.69	2	5	3.45	1.0712	0.0079	-1.2644	-0.010	12
18	Knowledge of design-based cost-drivers	0.67	1	5	3.35	1.2359	-0.3691	-0.6960		14
10	PvA (plan van aanpak)/Requirement lists by client	0.66	1	5	3.30	1.1000	-0.1623	-0.6023		15
17	Scope additions by client	0.65	1	5	3.25	1.4448	-0.1430	-1.3864		16
19	Aligning designs with the revealed information in each phase.	0.64	1	5	3.20	1.0296	-0.1319	-0.3372		17
09	Price Inflation	0.63	2	5	3.15	1.1522	0.4899	-1.2301		18
08	Underestimation due to strategic political misrepresentation	0.6	1	5	3.00	1.0954	0.4564	-0.2794		19

Results from the above analysis are :

- **Result 4 :** As compared to the response category I, the response category II had more number of tie in groups of two. This indicates that a lot of SoL's can be equally cross learnt to an equal extent if one goes by the average response/descriptive stats of the scores. But not a lot of SoLs have an equal influence.

- **Result 5 :** Only the bottom two SoLs have a significant positive skewness which means that their cross attainability may be even lower than their mentioned extents. Except these two , all other SoLs have a negative skewness mentioning that their cross-learning attainability can be even more that their mentioned extents

To test the significant differences between the influence scores and the cross learning attainability scores for all the SoL's, the Wilcoxon signed-rank test was used. This test can be generally used for test the existence of significant distribution differences between two matched sample data sets, each of which don't have a normal distribution (Derrick, B; Broad, A; Toher, D; White, P ,2017; Lowry, R. 2014).

For the 20 data samples of Category 1, the skewness & kurtosis were 0.28 & 0.16 respectively. For data samples of Category II, those values were -0.19 & - 0.42 respectively. Since these values were not very close to zero, both the data sets were not normally distributed. So generally utilized student t-tests wasn't applicable for this *'difference testing'*, but a non-parametric test like Wilcoxon signed rank test (See table 8).

Table 8: 'Difference testing' for both the response categories

SoLs	mean (C-I)	Final Rank (C-I)	Mean (C-II)	Final Rank (C-II)	$\mu_I - \mu_{II}$	Rank I - Rank II	p-value ($\mu_I - \mu_{II}$)
Scope additions by client	4.4	1	3.25	16	1.15#	-15	0.00222*
PvA (plan van aanpak)/Requirement lists by client	3.8	4	3.3	15	0.5#	-11	no acc. p value
Underestimation due to strategic political misrepresentation	3.4	9	3	19	0.4#	-10	no acc. p value
Knowledge of design-based cost-drivers	3.5	6	3.35	14	0.15#	-8	0.0232*
Completeness of the design/Engineering miscalculations	4	3	3.65	8	0.35#	-5	0.4902
Aligning designs with the revealed information in each phase.	3.2	14	3.2	17	0	-3	0.00338*
Integrated design - change control process	3.3	10	3.45	12	-0.15	-2	no acc. p value
Design Variants Appraisal	3.4	8	3.6	10	-0.2	-2	0.22246
Price Inflation	2.7	18	3.15	18	-0.45	0	0.63836
The frequency of cost monitoring between D&E	3.25	11	3.6	11	-0.35	0	0.26272
Risks/contingency calculation	4.2	2	4.15	1	0.05#	1	0.1556
Time availability (SO-DO)	3.55	5	3.75	4	-0.2	1	0.267
Constructability Analysis	3.15	15	3.45	13	-0.3	2	0.0035*
Construction Schedule optimization	3.25	12	3.65	9	-0.4	3	0.4777
Knowledge of cost benchmarks for direct costs	3.4	7	4.05	2	-0.65	5	no acc. p value
Cost control thresholds	3.25	13	3.75	5	-0.5	8	0.12602
Method of as-designed comparison with cost plan	2.75	17	3.7	7	-0.95	10	0.00672*
Estimation method for a particular phase	2.9	16	3.8	3	-0.9	13	0.44726
Comparing the current performance reporting with the previous reporting	2.6	19	3.7	6	-1.1	13	no acc. P value

* The data sets were significantly different at the significance level of 0.5.
# The positive difference indicates that the SoL more influential to cost control process, but less attainable through cross-learning. The magnitude of the difference indicates the severity of this difference. The maximum magnitude with a plus sign indicates the most crucial SoL.

a) The tests for all the 19 SoLs were conducted at the significance level of 0.05 and under the condition of 'two-tailed' testing. The validity of the sample size for a reliable test was also verified each time. Faul et al. (2013) identified that for a large Cohen's effect size (differences in mean of both the matched data sets) of 0.8, the desired sample size should be 15 for a valid testing.

Result 6 : There were only 20 samples for each SoL, which further got reduced in many cases due to a nil difference between both data sets. Also as seen from the table, the absolute mean difference of 0.8 in both data sets was only for 4 SoLs. So, the wilcoxon signed rank tests to find significance difference is valid mostly for these 4 SoLs. These SoLs are highlighted in grey. The two data sets for these 4 SoLs can be approved to be significantly statistically different i.e Statistically, their influence is not equal to their cross-learning attainability and so would need open approach. For other SoLs, the difference can't be statistically validated. More survey responses would have led to a successful validation of the 'difference' for the remaining SoLs.

Result 7 : Though , 'p' value indicates whether a significant difference exists or not, it doesn't indicates the size of the difference. In this regard, the difference of Mean was observed in the corresponding row. The values with a '#' indicate the most crucial SoLs, i.e. the SoLs which are highly influential, but are less attainable through cross-learning.

Result 8 : Unlike the column of mean differences, the rank difference column also indicates the cruciality. This cruciality order is though based on the ranks (or the risk adjusted RII scores). A difference can be seen in the cruciality order between the 'mean differences' based ordering & the 'rank difference' based ordering. This difference is possibly because the original ranking were readjusted due to ties. The SoL with a -ve sign and the greatest magnitude indicates the most crucial SoL.

4.1.2.2 Analyzing the responses for their extremity: Pareto Analysis

Unlike the minimum score for each SoL, the maximum score given for each SoL was 5 (by different respondents for all SoLs), which means each of these SoL was extremely influential in to the respective respondent's project. Therefore unlike the minimum influence, all of these SoLs have been of maximum influence in the overall experience of the responders. Simliar logic stands for the cross-learning attainability of all the SoLs.

Category I responses: The frequency of the score '5' for each SoL was plotted in the Pareto chart. For example: out of the 20 responses received for 'Scope additions', 14 of them were '5'. There were in total 74 responses with a score of '5' to the SoLs. It can be seen that 50% people out of these 74 considered the first 5 SoLs of Pareto chart as the most extreme (equivalent to score 5) causes of front-end cost control problems in road projects (See figure 14).

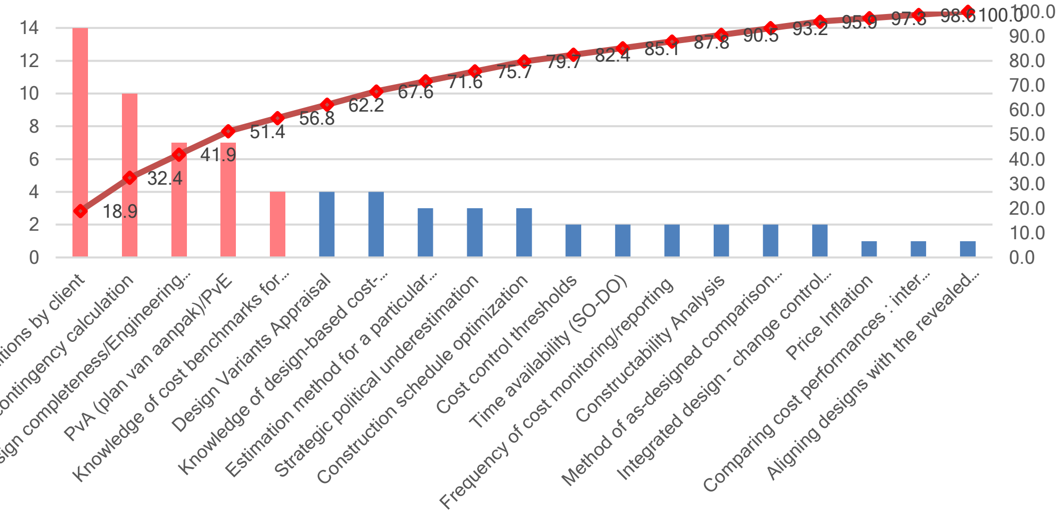

Figure 14: Pareto Chart for extreme values of each SoL for Category I.

Result 9: It can also be said that almost 50% of **extreme** (~Likert Score 5) problems/influences in front-end cost control of road projects are caused by these 5 factors only out of the 19 factors.

Category II responses: In total, there were 91 responses of '5' to the SoLs in Category II. Out of all the SoLs with 20 people scoring each of them, the *'knowledge of cost benchmarks'* received the most number of '5s' than other SoLs. From the Pareto Line, it can be assessed that 50% of the cross-learning over front-end cost control can be done by cross-learning the 8 SoLs shown below in green (See figure 15).

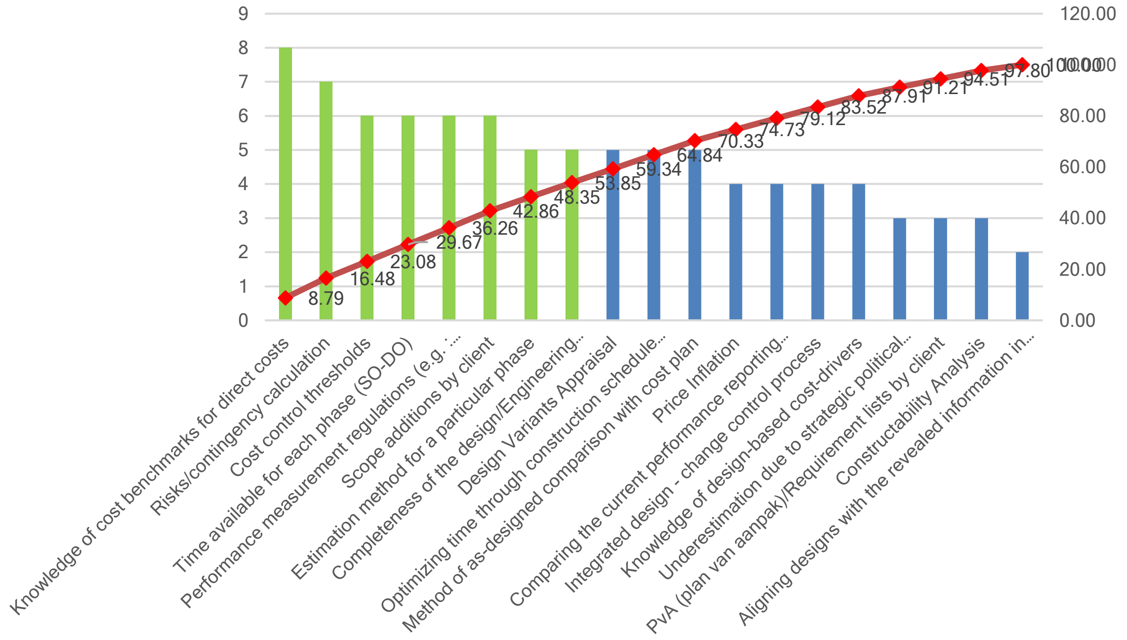

Figure 15: Pareto Chart for extreme values of each SoL for Category II.

Result 10 :
Almost 50% of the **most easy** cross-learning over the entire front-end cost control cycle (i.e over all 19 SoLs) comes from these 8 SoL's (highlighted in green) from past projects.

Upon comparing the previous Pareto chart with this one, it can be seen that except the SoL 'PvA/PvE by client' , all other extremely influential SoLs in 'red' are lying in the 'green' region. This means that 50% of the extreme issues in the front-end cost controlling can be solved easily by cross learning them

There were some differences with the results of Phase I analysis (statistical analysis) & Phase 2 (Extremity analysis). But three SoLs were promoted for the research in cross-project learning from both the analysis methods. These were : 'risk/contingency calculation', 'knowledge of cost benchmarks for direct costs', 'Time availability' & 'performance measurement : frequency of cost monitoring D&E'.

4.2 Survey : Results & Discussions

Upon analysing the SoL's scores for their statistical significance, following rankings were produced (See table 9).

Table 9: Rankings for survey category I & II

SoL : In order of their influence	**C-I Rank**	**SoL : In order of their cross-project attainability**	**C-II Rank**
Scope additions by client	1	Risks/contingency calculation	1
Risks/contingency calculation	2	Knowledge of cost benchmarks for direct costs	2
Completeness of the design/Engineering miscalculations	3	Estimation method for a particular phase	3
PvA (plan van aanpak)/Requirement lists by client	4	Time availability for each phase (SO-DO)	4
Time availability for each phase (SO-DO)	5	The frequency of cost monitoring between D&E	5
Knowledge of design-based cost-drivers	6	Comparing the current performance reporting with the previous reporting	6
Knowledge of cost benchmarks for direct costs	7	Method of as-designed comparison with cost plan	7
Design Variants Appraisal	8	Completeness of the design/Engineering miscalculations	8
Underestimation due to strategic political misrepresentation	9	Cost control thresholds	9
Integrated design - change control process	10	Underestimation due to strategic political misrepresentation	10
The frequency of cost monitoring between D&E	11	Optimizing time through construction schedule planning	11
Optimizing time through construction schedule planning	12	Integrated design - change control process	12
Cost control thresholds	13	Constructability Analysis	13
Aligning designs with the revealed information in each phase.	14	Knowledge of design-based cost-drivers	14
Constructability Analysis	15	PvA (plan van aanpak)/Requirement lists by client	15
Estimation method for a particular phase	16	Scope additions by client	16

The above rankings should be can't be generalized as the voice of all cost experts in the Netherlands. There could be projects, where some of the lower ranked SoLs in the category I would have been highly influential. This is a possibility because there are always extreme behaviour of any factor/SoL which can be observed in a project. For example : the Betuweroute & the North South Line, in which price inflation resulted in the biggest escalation. Thus, it was concluded that surveying more number of people may change the frequencies of each Likert score (1 to 5) that responders feed for each SoL (See Appendix A, last table).

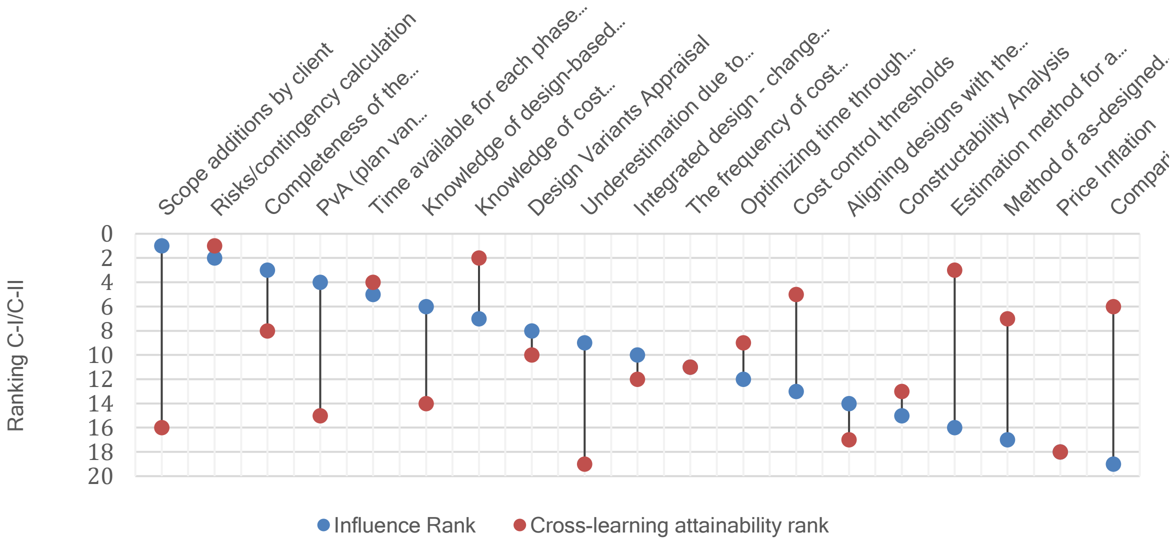

Figure 16: Mutual difference in the rankings for both the response categories

It was concluded that the SoLs that influence the most (say top 10 most influencing SoLs) have the most least cross-learning attainability (See figure 16 above). They are also very difficult in their cross-learning attainability vis-à-vis their influence extents. Exceptions are: ‘Risks/contingency planning’, ‘time availability’, and ‘knowledge for cost benchmarks’. In the similar fashion, the SoLs which have the least effect on the front-end cost control cycle have the most cross-learning attainability. . They are also very easy in their cross-learning attainability in contrast to the little influence they make in the process of front-end cost control. In this case the exceptions are: ‘aligning designs with the revealed information’ & ‘price inflation’. The pattern shown by this graph is exactly opposite to what would have been a favourable case for the industry. Or possibly, the survey participants thought that something that is most influential to front-end cost control, can’t be learnt through past projects. It should be observed that the top 10 influential SoLs were from the KA 1 & KA 3. This also infers that the participants didn’t feel the SoLs of KA 2 influence the project much i.e they feel that the existing systems of comparing the as-designed costs with baseline plan are working successfully.

Upon assessing the differences in mean scores, the cruciality Rank of the SoLs was obtained (See table 10). Cruciality here refers to the gap signed difference between the cross attainability extent and influence extent :

$$\text{Cruciality Score} = (\text{Rank C-II}) - (\text{Rank C-I})$$

A High cruciality score meant that the SoL is difficult to be cross-learnt and has high influence on the project costs in the front-end phases. A low cruciality score meant that the SoL is not much influential and can be largely cross-learnt from past projects. In case, two SoLs showed the same cruciality score (see the grey highlighted ones in Table 10), then the SoL which is more influential was given the preference for being more crucial.

Table 10: Cruciality ranking of the SoLs

SoLs	***Final Rank (C-I)***	***Final Rank (C-II)***	***Rank II - Rank I***	***Cruciality Rank***
Scope additions by client	1	16	15	1
PvA (plan van aanpak)/Requirement lists by client	4	15	11	2
Underestimation due to strategic political misrepresentation	9	19	10	3
Knowledge of design-based cost-drivers	6	14	8	4
Completeness of the design/Engineering miscalculations	3	8	5	5
Aligning designs with the revealed information in each phase.	14	17	3	6
Design Variants Appraisal	8	10	2	7
Integrated design - change control process	10	12	2	8
Price Inflation	18	18	0	9
The frequency of cost monitoring between D&E	11	11	0	10
Risks/contingency calculation	2	1	-1	11
Time available for each phase (SO-DO)	5	4	-1	12
Constructability Analysis	15	13	-2	13
Optimizing time through construction schedule planning	12	9	-3	14
Knowledge of cost benchmarks for direct costs	7	2	-5	15
Cost control thresholds	13	5	-8	16
Method of as-designed comparison with cost plan	17	7	-10	17
Estimation method for a particular phase	16	3	-13	18
Comparing the current performance reporting with the previous reporting	19	6	-13	19

The industry needs to focus on the cruciality ranking of the SoLs, as it shows the most influential SoLs with least cross-project knowledge to offer. The priority order for researches on steering the SoLs should taken from the cruciality ranking. But the further research in this thesis from here on was carried out as per the influence ranking. This is because the research also aimed to understand how the most influential SoLs interplay and escalate the project costs. The top 10 inluential SoLs were selected for Case studies because apart from these 10 SoLs, the other subsequent SoLs exhibit higher cross-learning ranks than their influence ranks The curiosity was now to explore how the 10 influential SoLs interfere in the front-end phases of the road projects and how are they being steered currently by the industry. Through case studies, explorations on the steering approaches [both knowledge farming (CL/OA) & its processing (TD/BU)] for these SoLs were done.

5

Case Studies

As explained in the chapter ‘Research Design’, the strategy of case study deployed two research methods: ‘The longitudinal observation studies & the interviews’ (See figure 18). Both of these methods were part of the triangulation research procedure. Each of them targeted to add some results to the whole thesis & also to validate each other’s outcome to some extents.

Both of the case projects had some maintenance part and some newly constructed part. In terms of total budget, these projects had significant differences in their total investment costs/investraming (client’s risks + land acquisition costs + contractors engineering costs + realization costs). The final DO estimate for Schiphol Landside was 46.5 million euros, while for N270 Helmond-Deurne-Limburg it was 18.24 million euros. The Schiphol Landside works was also significantly huge in terms of the scope of works than the N270 Helmond-Deurne project. Both of these project experienced different front-end journeys in regard to cost control.

Content analysis from the interviews produced the major results from the case-studies. The received responses were categorized into 9 categories. The first 6 categories captured the project specific facts. The last 3 categories captured the facts from the participant’s overall work experience. All these categories were understood through illustrative examples as given by the participants.

The first 6 categories were:
(i) **Event:** It explained the incident of escalation due to the ‘factor’/SoL
(ii) **How it was identified :** It explained how the team identified that the SoL./’factor’ is influencing the project.
(iii) **Cause:** It described the reason that caused the SoL to come into picture.
(iv) **Influence & its depth:** The *’influence’* described the cost types & CBS elements that were affected by the SoL. It also explained to what CBS depth did the ‘impact’ introduced by the SoL affected the elements.
(v) **Resulting escalation :** The probable escalation amount impacted by the SoL
(vi) **Actions taken :** It described the approach (TD/BU ; CL/OA) that was taken by the team as a corrective response to mitigate/reduce the escalation caused by the SoL The description also mentioned whether the action taken was successful or not.
Note: Only the corrective actions were asked to the participants, because the SoLs had caused the escalations. It is quite possible that the participants also took some preventive actions and those actions failed.

the last 3 categories were:
(vii) **Phase specificity:** The most probable phase in which the SoL acts generally.
(viii) **Demanded Phase specificity:** The phase in which the participant would like to deal with the negative effects of the SoL.

(ix) **Actions recommended:** It described the generic action recommended (TD/BU ; CL/OA) by the expert for dealing with the SoL and the reasoning for the recommendation. Both preventive & corrective approaches to steer the SoLs were described.

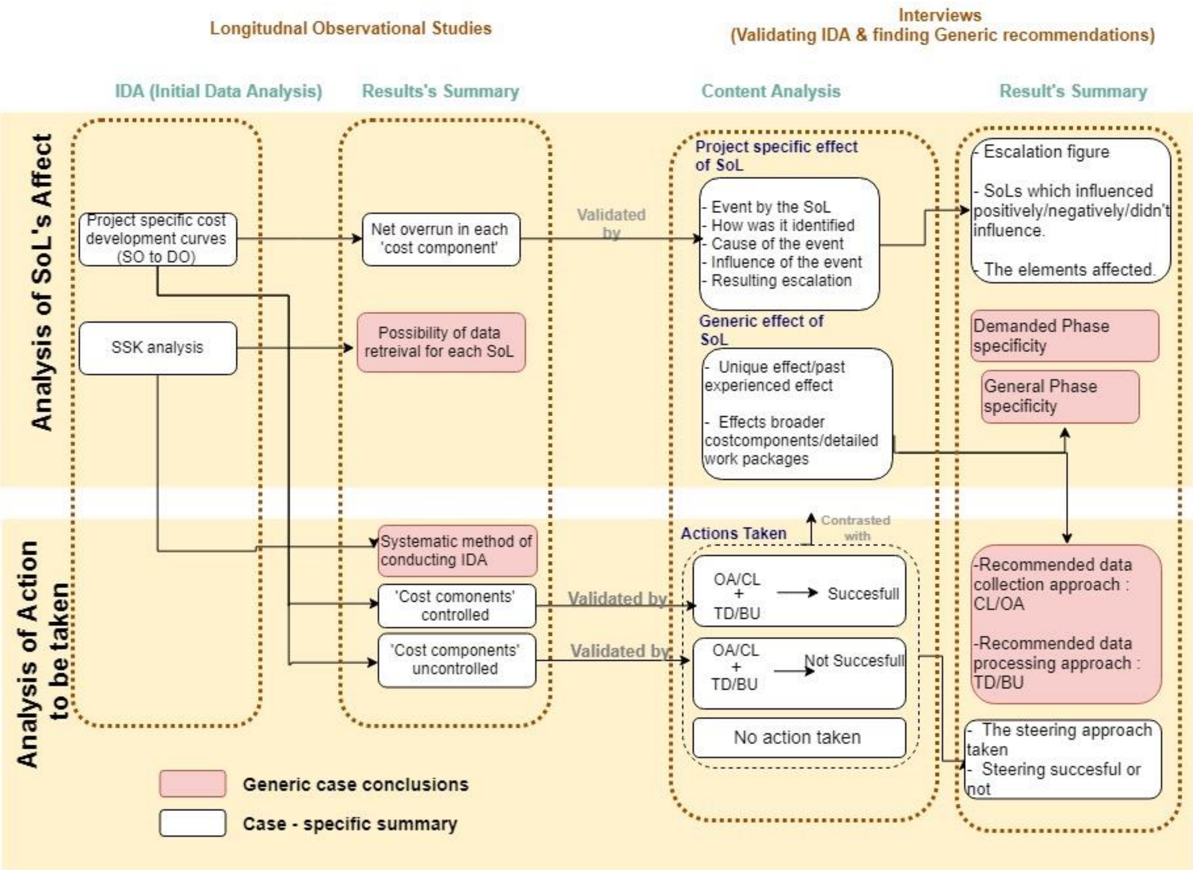

Figure 17: Case study execution (Self - illustration)

It was important to record both 'case specific actions' and the 'general recommended actions' as some generic conclusions were being expected out of this thesis. In case any amongst the top 10 influential SoLs didn't influence the project, then the responses analysed only in the last 3 categories. The main questions (See interview protocol) were basically the questions related to all the 10 SoLs. The content analysis was done in the above information categories for all the events described by the 6 participants for each SoL(written within different boxes in the report). Each participant added some extra information to each event and made all the 8 categories rich with information. The figure 17 summarizes the research methodology for the Case Studies.

5.1 Case study I: Schiphol Region A – Landside works

Schiphol is a world player in aviation and will remain so in the future. In order to be able to maintain this position, developments are supposed to be pursued continuously to improve the quality. The most recent one is the construction of a new pier and terminal. With the development and expansion of the One-Terminal, the concept for the 'Project Landside' was born. It is not an isolated project, but is a part of a wide range of alterations, modifications and improvements that are needed to prepare for the future Schiphol. The 'Landside works' is the most important project in the whole program, as it would allow Schiphol to take a significant step in capacity expansion and the quality improvement. In broad terms, the landside works were required in priority for other projects to begin: the new terminal, the new pier, a connecting corridor, a baggage route, and an additional parking deck. For the construction of the pier and terminal, the landside infrastructure was to be modified substantially. The table below (Table 11) describes the essential project information & progress details over the landside works:

Table 11: Project brief of Schiphol Landside works (Source : Interviews)

Project Specification	**Description**
Parent project (program)	Schiphol Terminal & Pier upcoming in 2023
Project Type	Road infrastructure
Budget approved (Dtb)	~ 40 mln. (Estimate prepared and approved during the pre-feasibility stage by Schiphol Capital Asset Programme) with 70% certainty that the as-built costs will lie in the range +/- 40% (i.e between €24 mln - €56 mln)
Final 'Investraming' by Arcadis	€ 46.50 mln (with 70% certainty of the final as-built costs being +/- by 18% i.e. within the range € 38.36 mln to € 54.64 mln)
Project Budget (winning bid by BAM)	~ € 41 mln (lesser than Arcadis due to cost optimization in phasing works & 'kunstwerken/viaduct works'
Client	Royal Schiphol Group
Consultancies involved	Arcadis, Heijmans (Cables & Pipes)
Principal Contractors	BAM infra BV
Feasibility study	Schiphol CAP.
SO (Sketch Phase)	20 Sept 2016 – 22 Nov 2016 (64 days)
VO (Preliminary Design)	23 Nov 2016 - 24 Feb 2017 (95 days)
DO (Detailed design)	25 Feb 2017 – 10 April 2017 (46 days)
UO (Tendering)	April 2017 – July 2017
Realization	Since Dec 2017 – on going
Current Status	Under construction (prospective completion by end of 2019). Current as-built forecast is far more than € 41 mln euros (~ €50 mln.) by BAM, due to unforeseen ground conditions not fully accounted by Schiphol, Arcadis & BAM. The expected overruns for the landside works would be around €9 mln, for which both Schiphol & BAM are sharing the liabilities, considering the cost-plus reimbursable contractual arrangement *(Source : Interviews).*
B/C ratio deformation	For Schiphol, the net expenditures on landside works eventually would be lot more than the forecasts at the decision to build. But considering the ever-growing benefits of the upcoming terminal in an already commercially operative surrounding, the project's C/B ratio still won't deform. The breakeven time of the investment will increase though. *(Source : Interviews)*

The 'Landside' project is majorly concerned with the development of the road facilities for an upcoming new pier and terminal (See figure 19). The project targets to redirect and facilitate the road connectivity due to the upcoming new pier & terminal. It involves both types of execution works: new realizations & modifications. The project includes the adjustment and / or implementation of :

- Roads for fast traffic;
- Entry / exit locations for car, group transport and OV;
- Sidewalks, including a pedestrian tunnel or bridge;
- Biking Trails;
- Landscaping;
- Removal of cables and pipes and installing new ones.

- Other art works.

The entire landside region was divided into 13 geographical regions (GO's) by the time it reached the DO phase. Each of these 13 areas included the above cited work packages. The final cost structure was set according to the SSK 2010 (CROW publication 137).

Figure 18: The yellow region embarks the upcoming terminal and the location of the landside works (Source : Schiphol)

Figure 19 displays the project phasing at 'Schiphol Capital Asset Program' (CAP) department. The first reliable estimate made for the project was in SO phase ('PID'). The feasibility phase is conducted by the CAP department itself, after which they present a 'project mandate' in front of the Schiphol board of directors. At Schiphol, the *'decision to build'* is taken at the 'Project Mandate'. Once approved by the decision makers at this stage, the project is kicked-off. Between the phase 'project mandate' & 'PID' , the 'procurement strategy' is made to procure required consultancy services. At 'PID', the design contract is awarded and the SO/VO/DO phase run till the phase 'Stage Plan I'. As soon as the 'Stage Plan I' ends, the UO phase is executed in which the contractor's bids are reviewed. From this milestone till 'End project report' runs the 'construction phase. Unlike general Dutch road projects/MIRT projects, the decision to build is not taken at the UO, but before the SO itself (at the milestone 'Project Mandate').

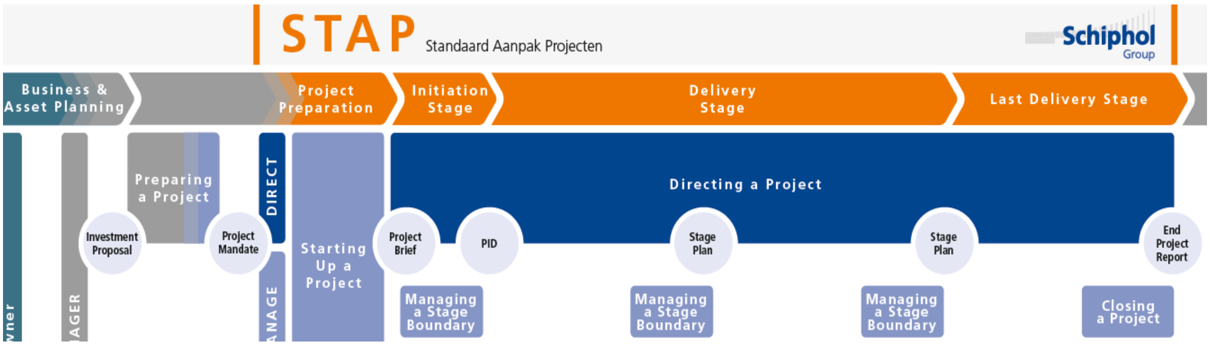

Figure 19: Project Phasing in Schiphol (Source: Royal Schiphol Group)

With a briefing over the project 'Landside-Schiphol' in the previous paragraphs, the coming sub-chapter explains the first research method adopted within this case study : the Longitudinal Studies.

5.1.1 Longitudinal Observational Studies

Firstly, the share of major 'works' within the cost component of 'construction works' were summarized in a pie chart to get the average cost weightage of each works. The costs utilized to calculate these percentages were the average costs of the 'works' from the SO till DO. This gave an idea on the major expenses of the project. Then secondly, the cost development curves were plotted for the major cost types (direct, indirect, risk reserves etc.). The reasoning behind a sharp rise or fall was speculated in terms of the SoLs that could have most probably caused the escalation/relaxation. Thirdly, the cost development curves for the 'cost components' were studied: both controlled & uncontrolled cost components were studied.

5.1.1.1 Data collection

All the estimates were the 'investraming' and not 'contractraming'. So they contained all possible costs which were to be incurred on landside works. The costs were summarized from the SSK sheets of the SO, VO & DO phases, which were the final versions delivered to Schiphol by SO. For understanding the SSK, the corresponding 'Kostennota' files were utilized to understand the starting points/scope of the estimates.

5.1.1.2 Initial Data Analysis: Speculating the SoL's

Below is a distribution pie chart showing the various work packages contributing to the overall project costs. These share are taken from the average of all the three phases The road infrastructure had the most share in the total costs, followed by the 'Integration services' (mainly cables & pipes : gas, ICT, electricity etc.) followed by the 'drainage works'. Within the road infrastructure, the major share was held primarily by the 'art works/subsidiary works' and then by 'roadway pavements' (See figure 20).

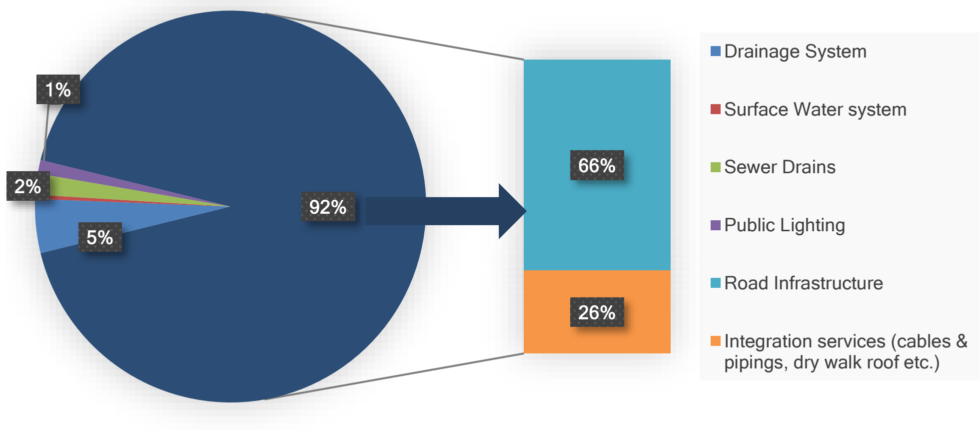

Figure 20: Major cost shares in 'construction works' (major indicators of the total project costs)

First, a closer look was given to the 5 different cost types, in which the final SSK was presented in the each phase (See figure 22 & table 12/13). The graph below describes all those 5 curves:

Some salient overall speculations are:

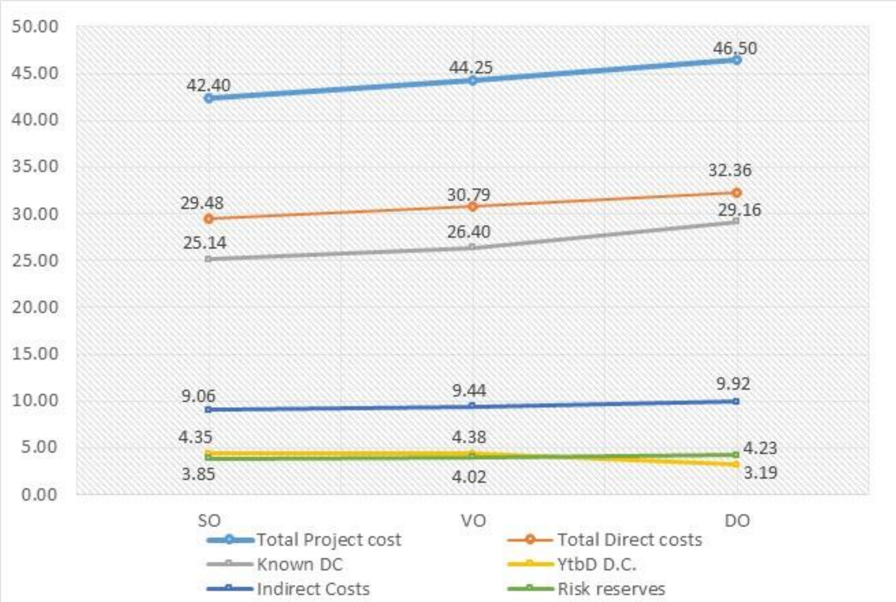

Figure 22: Cost development curves for the major cost types (SO to DO)

Table 12: Cost escalations in the different cost types (SO to DO) for Project Landside works

'Cost type'	**SO to VO**	**VO to DO**	**Net Escalation**
Total Project cost	**1.85**	**2.25**	**4.10**
Total Direct costs	1.30	1.57	2.87
Known DC	1.27	2.76	4.02
YtbD D.C.	0.03	-1.19	-1.15
Indirect Costs	0.38	0.48	0.85
Risk reserves	0.17	0.20	0.37

Table 13: Cost development in terms of 'cost elements' (SO to DO)

Cost component	**SO**	**VO**	**Diff. (VO-SO)**	**VO**	**DO**	**Diff. (DO-VO)**
Construction works	40.77	42.55	1.78	42.55	44.71	2.16
Engineering works	1.63	1.70	.07	1.70	1.79	.09
Land acquisition works	-	-		-	-	
other additional works'	-	-		-	-	
Objectoverstijgende risico's	-	-		-	-	

a) In the total project investment costs, there was a rise of 4.36% from SO to VO, and a rise of 5.08% from VO till DO.

b) This rise in the total costs was primarily due to a steep rise in the 'known direct costs' from SO till DO.

c) Even though the rise in the curve was reported from SO to VO, it wasn't controlled from VO to DO. Furthermore, the rise from VO till DO was much larger. This suggests that there was poor cost control initiatives and the frequency of comparison with the latest updated cost plan wasn't enough. (Speculation 1)

From SO to VO, we can make following speculations:

a) The 'YtbD direct costs' should decrease with coming phases as some information always gets revealed on the YtbD direct costs as the project progresses. The revealed part is then shifted into the known direct costs and so the 'total direct costs' still should have remained the same. Thus, rise in 'YtbD' from SO to VO clearly means that there were some fallacies in considering the 'known direct costs'. A combination of these three reasons are possible :
- extra scope addition from the client towards VO phase, or
- Overdesign/expensive designing by the designers towards the VO phase; or
- some elements of direct costs were missed out by the estimation team in the SO, which were found out in the VO (act of underestimation : strategic/unintentional).

b) Also, an increase in the indirect costs & risk reserves (SO to VO), suggests that there was some extra works accounted into direct costs. This is because the indirect costs & risk reserves always emerge as a percentage of the 'direct costs'.
c) It's quite unlikely that the designers overdesigned/made an expensive design than what they were asked for from the SO phase estimate. This is because designers themselves are bound with 'manhours', which are pre-determined based upon the 'quality' that has been finally agreed before.
d) Thus, the rise of 'total project costs' from SO to VO was a result of either underestimation of some direct costs or scope addition (Speculation 2).

From VO to DO, we can make following speculations:

a) The 'known direct costs' increased from 26.40 million to 29.16 million (2.76 million). However, there was a decrease in YtbD direct costs. It decreased from 4.38 million to 3.19 million (1.19 million). Had there been a decrease of 2.76 million, it would have been justified to conclude that there were no more additions to the direct costs from VO to DO. This is because the decrease in YtbD direct costs means that it has been confirmed as an 'expense' and has been shifted to the 'known direct costs'. Thus it can be concluded that there were some additions in the works of direct costs.

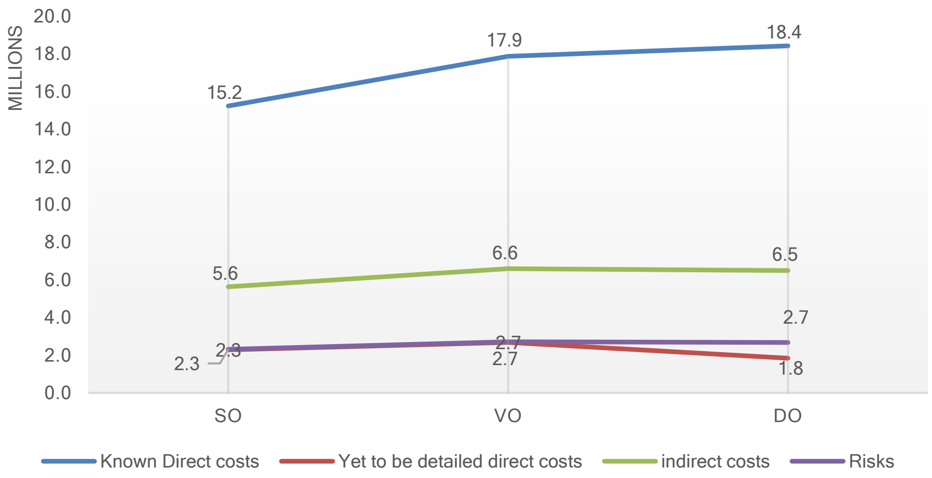

Figure 21: Cost development curves for 'Road infrastructure works' within the cost component of 'construction works'

b) Since, such an addition didn't bring any rise to the YtbD costs, it can be speculated that the additions were pretty obvious and were not newly developed (newly added scope).
c) Considering the three possible reasons for a rise in direct costs (as mentioned previously), it can be speculated that the rise in total investment costs from VO to DO was not due to scope addition and was missed by the estimators in the calculations (estimators are responsible for the rise). Also it is possible that the designs made available to the estimators were lacking those components of direct costs. (Speculation 3)

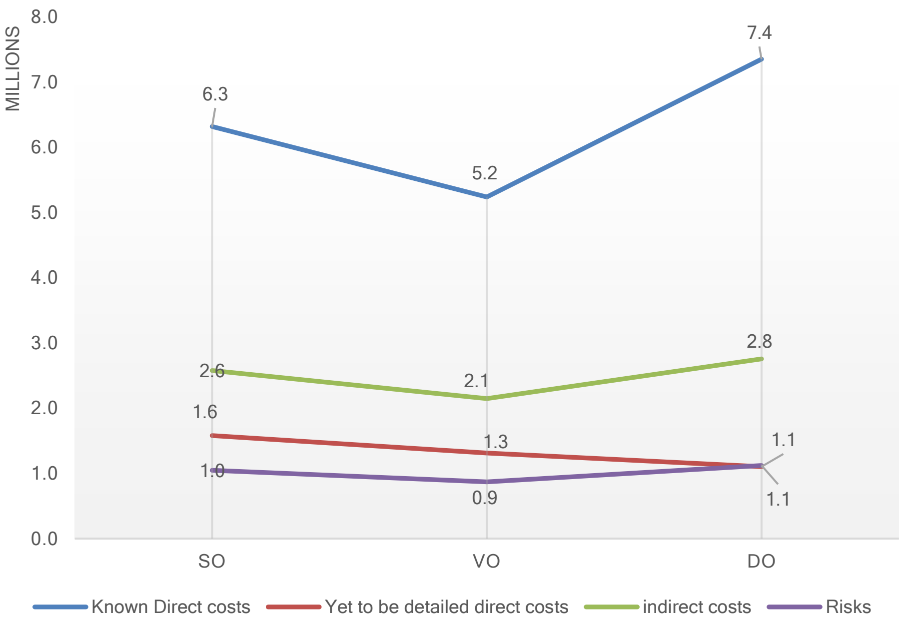

Figure 22: cost development curve for 'cables and pipes' within the cost component of 'construction works'

It was quite clear that, the major issues were possibly the new developments (scope additions) or improper identification of the direct costs throughout the project. These issues wered identified in detail through the development curves of the 'Road infrastructure works' & 'cables & pipes'.

- The 'road infrastructure' saw a rise of 2.7 million in 'known direct costs' from SO to VO, and a rise of 0.4 million in 'YtbD direct costs'. As described earlier, this means certainly that there was scope addition or underestimation (See figure 22).

- The 'cables & pipes' experienced a fall of 1.1 million at the same time. The YtbD direct costs fell by 0.2 million (See figure 23).

- Out of the 2.76 million rise in the total 'known direct' costs from VO to DO, the 'road infrastructure' works had a share of 0.5 million (i.e. 18.1%) in it. The 'integrated systems cables/pipes' had a share of 2.2 million (i.e. 79.7%) on it. In can be roughly concluded that the 'works' missed by the estimators/their responsible designers were mostly related to integrated works cables/pipes.

- Out of the 1.19 million decrease in the YtbD direct costs from VO to DO, the 'road infrastructure' works had a share of 0.9 million out of it (i.e 75.6 % of the total fall in the YtbD direct costs from VO till DO). The 'integrated systems cables & pipes' had a share of 0.2 million (i.e. 16.8%)

In can be concluded that from SO to VO, all of a sudden the direct costs of ‘cables and pipes’ were reduced which shows overestimation. But from VO to DO it rose back again sharply to eventually end at 7.4 million million, which is a total overrun of 1.1 million. Such a retouring clearly indicates that cables and pipes designing saw flaws in engineering calculations. (Speculation 4)

For ‘infrastructure works’ the rise in both ‘ known direct costs’ and ‘YtbD direct costs’ suggests that there was some extra scope addition or underestimation from SO till VO. Speculation 2 can be thus roughly detailed as : The rise in the total investment costs from SO till VO was majorly due to extra scope addition/ underestimation in the ‘road infrastructure’ works.

Also combining ‘known direct costs’ of ‘ infrastructure works’ and ‘cables and pipes’ from SO till VO, the net rise is 1.6 million. However, the net rise was 1.26 million as can be seen in the first cost development graph. This means that another work package saw a fall in the ‘known direct costs’ in a similar fashion to that of ‘cables and pipes’. This could be most probably the ‘drainage system’, as it is on the third major contributor in the total project costs. (Speculation 5)

It can be said that the YtbD direct costs for road infrastructure were almost detailed out and shifted to the ‘known direct costs’. But the rise in the known direct costs of the ‘integrated services cables/pipes couldn’t compensate for the fall in its YtbD direct costs. It can be roughly concluded that the team was familiar with these newly added works for cables and pipes amounting to around 2 million (2.2 - 0.2 million). This 2 million was the extra known direct costs which was mostly missed in VO, but was added in DO. Speculation 3 can be thus roughly detailed as: From VO till DO, the rise in the direct costs were majorly due to the estimators/designers missed out some cables/pipes works.

A rise in the engineering costs also suggests that the manhours efforts by the engineers were increasing with the coming period. This means the project saw many instances of extra scope addition & design reworks, as the estimated total design manhours kept increasing.

5.1.1.2.1 Net overrun in each cost component (SO till DO)

The previous paragraphs described the cost developments in the major ‘cost types’ of the project from SO to DO and made some speculations, which would be validated through interviews. Cost development in terms of ‘cost element’ was also shown. This section now explores deeper into the cost development trends by associating each ‘cost element’ with a ‘cost type’ : i.e. in terms of ‘cost components’ (like construction works – known direct costs). All the difference values were colour coded. The red ones depicted the escalated values while the green ones depicted relaxations.

The relaxations indicated that the SoLs behaved positively. The escalations indicate that the SoLs behaved negatively. The table above was considered as the base information and was presented to the interviewers in order to refresh their experiences with the project. It should be observed that the net escalation in the project was primarily due to an escalation of €1.49 mln in the total direct costs of construction works. (See table 25 in Appendix D1)

5.1.1.2.2 Cost components uncontrolled

All ‘cost components’ had cost escalations, so all of them were designated to be ‘uncontrolled’. Among them, only the ‘construction works’ was decomposed for further study as it was the major contributor to the overall project’s cost escalation. The longitudinal data sets for its constituting elements are presented in the table below. Both the known D.C & the YtbD D.C were required for the study as they together define the escalation in the total direct costs. :

Table 14: Cost development in different work packages within the 'cost component' of 'Construction works – Total D.C' from SO to DO.

	SO	VO	Diff.	VO	DO	Diff.	Net escalation
Total D.C. - Construction Works	**28.00**	**29.24**	**1.24**	**29.24**	**30.73**	**1.49**	**2.73**
Drainage System	1.49	1.11	-0.39	1.11	1.32	0.21	-0.18
OBAS system	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Surface Water system	0.15	0.15	0.00	0.15	0.00	-0.15	-0.15
Sewer Drains	0.62	0.53	-0.09	0.53	0.38	-0.15	-0.24
Public Lighting	0.33	0.35	0.02	0.35	0.32	-0.03	-0.01
Road Infrastructure	17.51	20.55	3.04	20.55	20.26	-0.29	2.75
Integration services (cables & piping, dry walk roof etc.)	7.90	6.55	-1.35	6.55	8.46	1.91	0.56
Known D.C - Construction Works							
Drainage System	1.19	0.88	-0.31	0.88	1.15	0.26	-0.05
OBAS system	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Surface Water system	0.13	0.13	0.00	0.13	0.00	-0.13	-0.13
Sewer Drains	0.49	0.42	-0.07	0.42	0.33	-0.10	-0.17
Public Lighting	0.29	0.30	0.02	0.30	0.29	-0.02	0.00
Road Infrastructure	15.23	17.87	2.64	17.87	18.42	0.55	3.19
Integration services (cables & pipings, dry walk roof etc.)	6.32	5.24	-1.08	5.24	7.35	2.11	1.04
YtbD D.C - Construction Works							
Drainage System	0.30	0.22	-0.08	0.22	0.17	-0.05	-0.13
OBAS system	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Surface Water system	0.02	0.02	0.00	0.02	0.00	-0.02	-0.02
Sewer Drains	0.12	0.11	-0.02	0.11	0.05	-0.06	-0.07
Public Lighting	0.04	0.05	0.00	0.05	0.03	-0.02	-0.01
Road Infrastructure	2.28	2.68	0.40	2.68	1.84	-0.84	-0.44
Integration services (cables & piping, dry walk roof etc.)	1.58	1.31	-0.27	1.31	1.10	-0.21	-0.48

It can be realized that the escalation in the D.C. of 'road infrastructure' from SO to VO was the primary reason for the overall project's net escalation in total costs (See table 14). The works of 'road infrastructure' & 'integration services' were further studied (See table 26 & table 27 in Appendix D1) as they were the primary cause for the net escalation of 'construction works'.

From the IDA, it can be hence concluded that the escalation in the pavement works (€ 1.48 mln euros) from SO to VO was the major contributor to the overall net escalation in the total project costs.

5.1.2 Interviews: Content Analysis

In reference to the observations & speculations obtained from the IDA, the semi-structured interview was executed with the 6 project participants of the Schiphol Landside project. With the project description and its front-end cost performance in hand, the interviews were conducted to study how the SoLs lead to the escalations (which were identified in the IDA), and what actions were taken in terms of data retrieval & data processing for steering them. All the SoLs that were found to be negatively influential in this project were in the list of top 10 crucial SoLs (and also in the list of influential SoLs as well). The content analysis for the interview responses for the 10 SoLs under study is described in this section. *(Note: While reading the content analysis, the reader should keep an eye on the summaries of the IDA presented previously for better understanding).*

Scope additions (Influenced negatively)	
D1 D2 E1	**Event:** From SO to VO, extra scopes were added by the client on pavement works as the project developed from a sketch design to a preliminary design. **How it was identified:** By forecasting the vehicular load into the upcoming roads. **Cause:** As the design unfolded, the client revealed some other requirements. The asphalt thickness was demanded to be 3 times more than the general design standard followed by Arcadis. Some roads were also widened. Due to the kind of traffic flow in the Schiphol region (shuttle buses, heavy logistics van, towing carts etc.), extra road thickness & width was demanded by Schiphol after the SO phase. **Influence & its depth:** The costs for pavement works within 'road infra. works' increased. This increase also influenced the costs for sidewalk pavement works due to a change in levelling and slope gradients. So, this scope addition affected the detailed work packages as well. **Resulting Escalation:** The €1.48 mln escalation in pavement works consisted mostly the extra pavement material costs & the extra machinery manhours. **Action taken (Successful) :** The scope was calculated and the designs were changed in a bottom-up (BU) approach as a lot of design elements associated to the pavement works also changed. The newly added design data was calculated using project specific data (OA) because Schiphol road cross-sections are not the same like other Dutch roads. The action was successful in estimating the SoL accurately and so the SoL was steered. The escalation due to this added scope wasn't compensated by removing any minor work packages.
E1 E2 C1	**Event :** From SO to VO, extra security polls & systems were added in the scope. **How it was identified :** Upon a re-analysis of the HSE risks. **Cause** : With the 2 terrorist attacks in brussels airport in Zaventem on March 2016, the Schiphol authorities & stakeholders demanded extra security measures on the construction site. This was an unforeseen cost, which wasn't covered up as there were no 'object transcending risks' allocated in this project's designing process. The widening of roads was required **Influence & its depth:** The known direct costs for 'traffic control' (within 'road infra works') increased. The addition didn't disturb any other 'work package' and number of security portals to be purchased was a fixed number. **Resulting Escalation:** The 0.25 mln escalation in 'traffic control' costs. All other cost types also increased for 'road infra. works' as they were a percentage of known direct costs. **Action taken (Successful) :** A BU approach was taken to calculate the added scope's cost influence as it was definite and to implement it. The action was successful in estimating this SoL accurately. Cross-project data (CL) was utilized as the team wanted to compare prices & designs of the past vendors who delivered it. However, no efforts were made to compensate the escalation by removing any minor scope of work.
D1	**Event :** From VO to DO, some scope additions were made on the drainage system.

C1 C2	**How it was identified :** Upon final superimposition of the drainage drawings with the road cross sectional drawings. **Cause :** A part of Drainage works was removed from SO and was tendered separately from Landside works, as it demanded immediate execution. But some of them were added back to the landside works due to their functional dependence on the whole landside works. **Effect & its depth:** The addition led to some revisions in the whole underground works. The effect was on the detailed designing of the sidewalks and the position of manholes. **Resulting Escalation :** 0.21 mln **Action taken (Successful) :** BU approach was followed to estimate the effect of this addition as detailed calculation was required to estimate the cost impact. And so project specific data (OA for data extraction). The action was successful in estimating the influence of the SoL.
General Phase specificity: Scope additions were prevalent in all phases of this project. **Demanded phase specificity:** The broader scopes should be added as early as possible, as they are associated to many design elements. Adding such broader scopes in the later phases creates too many design reworks. **Actions recommended:** In a corrective approach: a TD approach must be taken to estimate for broader scope additions & a BU approach should be taken for finer scope additions. The information data should be extracted from past projects (CL) for a TD approach and should be openly generated (OA) for a BU approach (as said by all 6 participants). The added scopes can't be relaxed down most of the times. Sometimes it can be compensated by decreasing the quality of some minor works. In a preventive approach: Cost-quality trade-off sessions should be held with the client to acquaint him with the repercussions of scope additions. All possible scope additions should be considered in the estimate preparation by using past experiences. The estimate can be uplifted by a percentage, which represents escalations due to scope additions from past projects, *(as said by all 6 participants).*	

Risks/Contingency analysis (Influenced negatively)	
D1 D2 E1 E2 C1	**Event :** From VO to DO**,** the major increase in the costs can also be regarded to insufficient contingency planning for the 'cables and piping', which were within the cost component of 'construction works'. The direct costs for cables & pipes increased because of the risks associated with the ground works were highly underestimated in the VO. The groundworks were calculated with more risks in the SO, but were reduced in the VO considering an overestimation. **How it was identified :** From soil inspections and geotechnical surveys. **Cause :** The uncertainties with the cables & pipings were known to the project team. But, the contingency reserve for cables & pipings was allocated by considering only the risks that shall unfold once the construction starts. The risks revelation in the design phase wasn't considered. **Effect & its depth:** The insufficient risk allocation affected not only the in-depth work packages of cables & pipes (like welding pits, ground & soil works, 'mantelbuizen' etc.), but also the other design elements in the same/upper CBS levels which were associated

	with underground works (like sewer lines, catchment basin for stormwater). **Resulting Escalation :** The escalation of € 1.91 mln in cables & piping. **Action taken (Unsuccessful) :** The increased costs for groundworks were estimated in a BU approach by using past data (CL) fearing further underestimation in future! . As reported by the participants representing the client's side, the project currently is in overruns already specially due to the groundworks for cables & piping. This means that even the re-calculation in DO was underestimated.
D1 D2 E2 C1 C2	**Event :** The known direct costs for 'kunstwerken' saw a heavy increase from SO to VO due to insufficient risks allocation. The 'kunstwerken' mostly consisted of miscellaneous concrete works, staircases, viaduct, concrete pavement and art installations. **How it was identified :** Upon Schiphol's notice to focus on viaducts/underpasses. **Cause :** There were risks of more concrete works in the tunnels that run beneath the runways. With the new Tunnel act, new safety systems, fire extinguishers etc. were to be added in VO, which demanded more concrete works. Due to the entire focus over the cables & piping works, less attention was given to the 'kunstwerken' in terms of risk analysis. By VO, the need of more concrete works in several viaducts like the Buitenveldert was realized. **Effect & its depth:** The SoL just escalated the costs of 'kunstwerken' and didn't affect much other design components. Also these 'kunstwerken' were very less complicated in terms of the constituting work packages. **Resulting Escalation :** € 1.06 mln. This figure could have been reduced in case 'kunstwerken' was considered as a separate element under the cost component of 'construction works', and more risk reserves were allocated to it. **Action taken (Successful) :** After this increase in the VO, the risk reserves for 'road infrastructure' under the cost component of 'construction works' were increased to € 2.7 mln from 2.3 mln as a preventive measure for future escalations due to this SoL. The escalation due to this event was calculated in a top-down (TD) approach by using cross-project learnt (CL) data, as there were very less sub-components in 'kunstwerken' and were not exactly known.
Phase specificity : Generally, insufficient risk allocation can be experienced in any of the design phases in a project. **Demanded phase specificity :** A very intensive or may be an overestimated risk allocation should be done in the very early phases (feasibility & SO). **Actions recommended :** An intensive bottom-up (BU) approach should be applied to estimate the risk reserves associated with individual work packages. Works with similar type of risks should be grouped together under the same cost-component. Past project data should be used to estimate such individual risks. But for overall project risks ('object transcending risks'), a top-down approach should be applied as the exact events related to such risks can't be exactly known and they are specific for every project. Open generated project data can be utilized to calculate sufficient reserves for such risks. This approach can be applicable for both preventive/corrective action. *(As said by all 6 participants).*	

Engineering calculations (Influenced negatively)

D1 D2 E1 C2	**Event :** Extra 'public lighting' (within the cost component : construction works) was added by the time the project reached the VO. It was previously miscalculated in the SO. **How it was identified :** Upon quantity surveying the MEP facilities of the site. **Cause :** These were miscalculated due to misinformation with the existing 'public lighting' facilities in the landside area. **Effect & its depth:** This engineering corrections did disturb the designing of other project elements. The cost impact of the corrections was also known exactly in terms of the detail breakdown. **Resulting Escalation :** € 0.02 mln. **Action taken (Successful) :** The affect was estimated in a BU approach, by utilizing the cost data from past projects (CL), as the vendor-based price data/price list wasn't available. The action successfully calculated the 'costs' incurred due to engineering mistakes. Anyhow, some of the 'public lighting' systems were removed in the DO phase due to the proposal to reuse some existing ones (optimization was advised to the client).
D1 C1 E1 E2	**Event :** From VO to DO, direct costs of cables and pipes increased also because of wrong engineering calculations. **How it was identified :** Upon quantity surveying the MEP facilities of the site. **Cause :** Heijmans did the layout of the cables & piping long back in the existing area**.** A lot of information was not known over the existing underground layout. From SO to VO, a lot of cables were removed from the design as they were already existent on site. But upon detailed examination of the existing cables & pipings, a lot of removed cables had to be added back to the design. **Effect & its depth:** The influence of the SoL was on the detailed work packages of 'cables & pipings'. Some other design components like 'sewer lines' also got rerouted due to these engineering corrections. **Resulting Escalation :** € 1.91 mln **Action taken (Successful) :** Some of these cables/pipes to be added/rerouted were a specialization of very few vendors/subcontractors. Since the changes affected the CBS till its bottom elements, A BU approach with open generated data (OA) was utilized to estimate the miscalculations.
General Phase specificity : Engineering miscalculations influence the project costs tremendously in the later phases (DO/Tendering), and not in the early phases. **Demanded phase specificity :** The current phase specificity of this factor/SoL is acceptable, as verifying engineering calculations in the early phases wouldn't make any sense as the designs keep changing. **Actions recommended :** For identifying the cost impact of engineering miscalculations and correcting them, a BU approach should be followed to estimate it. An open generated data (OA) should be utilized for the BU calculation approach, depending upon the need.. The mistakes should then be identified in a BU approach and should be corrected. (As said by 6 participants). Cross-project data (CL) with a BU approach can be adopted as a preventive measure to calculate the possible overestimation/underestimation in the project due to engg. miscalculations. *(As said by 6 participants).*	

Completeness of the PvA/PvE (Influenced negatively)	
E1 E2 D1 D2 C1 C2	**Event :** From SO to VO, some road cross sections were changed in order to converge them with the existing roads in and around Schiphol. **How it was identified :** upon BIM modelling. **Cause :** The earlier design conceptualization in the SO was erroneous for Schiphol landside works. The reference drawings utilized to prepare the designs for Schiphol were from past govt. road projects. The existing roads in and around Schiphol were of different design standards and had different cross-sections. **Effect & its depth :** The roads were in their sketch phase and were not detailed in SO. The influence of this miscalculation was not on the in-depth elements of the roads. **Resulting Escalation :** € 3.04 mln. **Action taken (Successful) :** The drawings were revised as per the newly surveyed Schiphol standards. The changes were calculated in a TD approach, and all the data was openly generated (OA) by the quantity surveyor at the site. The action was successful.
General Phase specificity : Generally the problems with incomplete PvA occur in SO/VO, when some crucial information is urgently required to proceed further with the designing. **Demanded phase specificity :** All the requirements should be presented to the consultant with the very first information delivery. Other important requirements should be queried by the consultant. **Actions recommended :** In general, the cost impact of a left out PvA/PvE specification should be calculated in a BU approach because the missed out PvA information is generally a specific detail, which the client couldn't think of. The data should be openly generated in conformance to the project's specific need. (BU+OA) *(as said by 4 participants).* The cost impact of a newly discovered project requirement should be calculated in a top-down approach (TD) because a requirement's first emergence is not very specific in nature in terms of its details. The data should be cross-learnt from past projects (CL) as the existing project information may not provide crucial data *(as said by 2 participants).* In a preventive approach, the consultant should properly survey the site & extract the information from the past consultants who were associated with the siteworks.	

Time availability for each Phase (from SO to DO) (Influenced negatively)	
D1 D2 E1 E2 C1 C2	**Event :** The escalations in 'pavement works', 'kunstwerken' & 'cables & pipings' can also be attributed to the 'less time availability' for the front-end designing (SO to DO). **How it was identified :** Upon revising the schedule planning. **Cause :** Schiphol operates really fast with its capital projects, because the site surroundings in which they work should always be operational. Rerouting/laying out new cables will surely have implications on the ATC tower, ICT systems and information displays, which are quite basic to keep an airport functional. So, Schiphol wanted to execute the landside works as soon as possible. The construction of the new terminal would not start as well until and unless the new cables are laid and the groundworks with necessary pavement works are completed. This further imposed time constraints. Also, since Schiphol already owns the land in which they are building the new Terminal, their front-end planning proceeded very fast as they had less obligations towards the

	govt./society (for example : there was no need of land expropriation). **Effect & its depth:** The per day working hours of the designers/estimators increased in order to fulfil the required manhours for the project in less time. Such a fastrack planning merely gave time to conduct an intensive risk analysis for crucial elements like 'cables & pipings'. Less time also decreased the frequency of monitoring the design by the estimators. Less time availability didn't allow the project team to focus on specific risks/details that require attention. Ultimately, the costs kept escalating for cables & pipings due to underestimation. **Resulting Escalation :** The net escalation of 2.75 mln in 'road infrastructure' can also be attributed to the less time availability, which didn't allow Arcadis to question the PvA/to conduct in-depth risk analysis. **Action taken (No action) :** There was no change in the time planning strategy. Even though very less time was available for risk intensive design components, not much attention was given to them.
	Phase specificity : Time unavailability in all front-end phases is a common feature with projects which are financed and commissioned by private entities like Schiphol. This is not very common with govt. road projects, which offer a lot of time during its very initial stages (like the feasibility & the SO stage). **Demanded phase specificity :** A specific phase can't be demanded for this 'factor'. The client should provide sufficient time to the consultancy in all the front-end phases. **Actions recommended :** The estimators should more often keep a check on the designer's schedule as a preventive measure. In case time scarcity affects severely, Also the consultancies can demand sufficient time for the front-end designing depending upon their perceived project complexity/definition The underestimation effects of 'time scarcity' due to steadfast designing/estimation can be cross-checked in a Top-down approach. A Top-down approach towards the CBS would reveal which component would have been most probably missed in terms of design/estimation. *(as said by 4 participants).* A bottom-up approach should be taken to find out the possible underestimation due to time scarcity, because the influence of 'time scarcity' on the design could be unique and may not be predicted from past experiences. As a preventive approach, the consultancies can give more time to imp. tasks which are more complex. *(as said by 2 participants)*

Knowledge of design-based cost drivers (didn't influence the project)	
D1 D2 E1 E2 C1 C2	**Event :** This 'factor' didn't influence the project**.** There was no strict need to reduce component B's costs stringently as a response to a rise in component A's costs. This attitude of the client was primarily because of the limited time availability and the desire for the best quality irrespective of the costs incurred. **Cause :** Generally the knowledge of design-based cost drivers is utilized, when a cost reduction has to be made in the whole design as a response to an escalation in the costs of some elements. **Effect & its depth:** - (The factor didn't influence the project) **Resulting Escalation :** - (The factor didn't influence the project) **Action taken :** - (The factor didn't influence the project)
	Phase specificity : Design teams only utilize their knowledge of cost drivers, when they are facing escalation situations in the final phases VO & DO. During budgeting process the final project costs turn out to be very high and then the estimators are asked to reduce

	project costs. **Demanded phase specificity :** The knowledge should be utilized in all phases, but they are ore impactful in the very early phase. Project teams should try to compensate an unavoidable cost escalation by compromising with the quality of minor works i.e. reducing the costs of minor works by using their knowledge of design-based cost drivers. **Actions recommended :** If the knowledge of design-based driver is utilized in a project, it should always be top-down oriented, and the influence of the action should be also estimated in a TD manner to estimate what amount can be possibly reduced still in a project. Past project data can be utilized to calculate this amount *(said by 5 participants).* The knowledge of design - based cost drivers can also be used in a BU approach for the final phases by utilizing project specific data (OA). This is because each project's design gets unique by the time it reaches DO, and exhibits special design-based cost drivers which are not generally found in other road projects. For instance, generally separate costs are allocated for preparing temporary roads for the vehicles to pass. By the DO, the exact quantity of the scrapped off pavement surfaces was known. This quantity was sufficient enough to cover up the temporary roads via a meagre recycling, and this also contributed to the € 1mln savings *(said by 1 participant).*

Knowledge of cost benchmarks (Influenced negatively in the project)	
D1 D2 E1 E2 C1	**Event :** The design/cost benchmarks utilized for 'pavement works' were not corresponding to the road design standards at Schiphol landside (SO till DO). **How it was identified :** The presence of wrong cost/design benchmarks in the CBS was identified in the course of designing the roads for the landside periphery. While designing the 'merging' of the upcoming new roads with the existing ones, an abruptness/mismatch was observed in the cross-sections of the designed roads with the existing ones. **Cause :** For the very first time in its history of development projects, Schiphol had commissioned Arcadis for landside works. The engineers/estimators didn't had any acquaintance to the existing design standards at Schiphol landside. **Influence & its depth:** Wrong cost/design benchmarks led to underestimation in pavement works. All the designed pavement were as per the govt. roads' pavement standards. But the pavement structure for Schiphol landside roads was eventually found to be more dense and layered with more coarse aggregates. Also the slope gradients were different for Schiphol standards. **Resulting Escalation :** The regular escalations in pavement works were also due to wrong design/cost benchmarks. The resulting escalation as a result of this 'factor' was a % of the net escalated value for pavement works i.e. a % of €1.77 mln. **Action taken (Successful) :**. The new benchmarks were prepared for Schiphol landside works. The new benchmarks were applied into the CBS in a top-down approach by using project specific data (OA), and so were the resulting escalations calculated. (Participant C2 didn't have any response on this 'factor')
	Phase specificity : This 'factor' generally interplays negatively in the feasibility & SO phase. **Demanded phase specificity :** No demand as the 'benchmarks' should be always correct. **Actions recommended :** Both preventive & corrective actions can be recommended to steer this 'factor'. Upon realizing the presence of wrong design/cost benchmarks, the new benchmarks

	should be estimated in a top-down approach by using past project's data (CL) and the resulting escalations/relaxation should also be calculated in a TD approach. *Preventive measures –* *a)* In a preventive action, the benchmarking pyramid should be filled in a TD approach for different types of road in the Netherlands. All possible existing road types should be covered in the benchmarking and these should be regularly revised with the changes in their respective design regulations/CROW regulations. *b) If there are some unavoidable escalations due to data benchmark inaccuracy, the estimate provided to the decision makers should be uplifted by the avg. amount escalated due to this SoL in past projects. (all 6 participants)*

Design-Variants Appraisal (Influenced positively)	
D1 D2 E1 E2	**Event :** In some instances, the project team (designers/estimators) were able to reduce some costs to little extents by utilizing their knowledge of design-variants. Most remarkable optimizations were in the 'Road infrastructure' costs (VO to DO), 'Public lighting' (VO to DO). **How it was identified :** by exploring multiple design options. **Cause :** The 'factor' was utilized as a strength in this project and was necessary because of repetitive escalations due to other 'factors'. It helped to compensate the net escalations to some extent. **Effect & its depth:** The influence of 'design-variants can be both in preliminary designing & in-depth designing. **Resulting Relaxation :** some % of € 0.29 (road infrastructure) and some % of € 0.03 (Public lighting) respectively were reduced. **Action taken (Successful) :** In very first design, some costs were optimized by choosing cheaper junction designs like (T-junctions over round-about junctions) in a TD approach with project specific dimensions (OA) as the site region was very tight. In the detail designing phase, some optimizations were made in traffic control systems by designing single entry/exit routes. Optimization is public lighting systems were made by reusing some existing ones and purchasing more cheaper ones. BU approach was used as the lighting systems were easily measurable & past project data were used to find the most cheapest prices & vendors. But design-variants have more impact in reducing the costs if they are applied in the sketch designs, because most cost optimizations can be made with modifications in shape/size/layout. In detailed designing, the major optimizations can be made with innovative construction methods/phasing methods and not much with material type.
D1 C1 C2	**Event :** Some optimizations were also done in the works of 'sewer drains' (SO to DO). **How it was identified :** By comparing the existing sewer drawings with the proposed drawings. **Cause :** There were some possibility to optimize the costs in 'sewer drains', which gave some opportunity to compensate the net escalations caused by 'road infrastructure' works. **Effect & its depth:** Optimization was more effective in the detailed designing phase (a reduction in €0.15 mln), than in the sketch phase (a reduction in €0.09 mln).

	Resulting Relaxation : a percentage of €0.24 mln. **Action taken (Successful) :** In the sketch design, some costs were saved by reusing some existing sewer lines by rerouting them. Also some damaged ones were proposed to be repaired instead of placing new ones.
	Phase specificity : Generally, this 'factor' is utilized to reduce the costs in the final design phases because the team is done with the problem solving and starts to try their hands on cost optimization. **Demanded phase specificity :** It is high time to realize that the maximum opportunity for costs reduction is in the very early stages like the feasibility studies or the SO. This also means that the team should think over 'problem solving' and 'cost optimization' at the same time. **Actions recommended :** As a preventive approach, the project team should always be acquainted with the possible design variants and the cost reductions they offer. In case the dilemma of different design options encounters in the design phases, the designers should always follow a Top-down approach to find out most economic design options. This is because a top-down approach helps in recalling past design experiences for the same job, and depicts the opportunities where costs can be saved. Project specific (open generated) data should be used for calculations as it will tell the exact savings possible. *(As said by all 6 participants).*

Strategic misrepresentation (didn't influence the project)	
D1 D2 E1 E2 C1 C2	**Event :** There was no strategic misrepresentation in the project at the point of DtB. This is because Schiphol has a lot more autonomy than what the municipalities/provinces have for getting their project approved. This is the benefit of an autonomous governance. The stakeholders of Schiphol don't have much contrasting opinions over a project, as any misrepresentation/misleading would be a loss for the entire Schiphol group as a whole. So, misrepresentation would not benefit any stakeholder. Also since every capital project in Schiphol provides a high probability of returns due to numerous commuters, merchandises etc., there is no competition between projects for funding. **Cause :** - **Effect & its depth:** - **Resulting Escalation :** - **Action taken :** -
	Phase specificity : This 'factor' generally influences in the feasibility stages, when the very first estimate is prepared and its B/C ratio is analysed in contrast with the other projects competing for the funding. **Demanded phase specificity :** No demand. This 'factor' should be eradicated completely through strong policy & strategic measures enacted by the fund granter. **Recommended steering actions :** Both preventive & corrective actions can be recommended to steer this 'factor' a) Corrective action - The intentional underestimation in the 'feasibility' estimates should be corrected by the consultants. A top-down approach should be followed to prepare a new estimate by using data from the final 'investraming' of past projects (CL), that the consultancies have delivered to their clients. A top-down approach would be preferable also because of its less time-taking nature. b) Preventive action – As a preventive action, the decision makers should compare the presented estimate with those past projects, in which the figure of the 'final contracted budget' was the same as that of the 'presented estimate' at the time of Dtb. This comparison should be done in a top-down approach to get an quick insight if some costs have been manipulated. As-built estimates of contractor should not be used for comparison as they could be adulterated with reworks/delays incurred due to the contractor. *(said by all 6 participants)*

Change management processes (influenced positively)	
D1 D2 E1 E2 C1 C2	**Event :** There were no escalations due to improper change management/communication. **Cause :** All the changes were regularly monitored and communicated to all the team members. **Effect & its depth :** Most changes were in the final phases (VO to DO). So design changes did took place even at the very bottom CBS level and any escalation due to improper communication was saved. **Resulting Escalation :** No escalation. **Action taken :** a BU approach with project specific data (OA) was utilized in order to make sure each change is communicated accurately.
	Phase specificity : All phases. Changes can occur in any phase. **Demanded phase specificity :** All phases **Actions recommended :** Changes should always be communicated/implemented in a bottom-up approach (BU) because 'changes' are specific in nature. The data utilized would be off course a project specific data (OA).This should be followed both as a preventive approach & also as a corrective approach in case there are escalations due to miscommunications in changes. *(said by all 6 participants)*

5.1.3 Case Study I: Results

Case - specific results :

a) The escalations (in order of their influence) which led to a net escalation of € 4.10 mln in the overall project's costs were :

- €1.48 mln in 'pavement works' under 'Road infrastructure works' (SO to VO)
- € 1.06 mln in 'kunstwerken' under 'Road infrastructure works' (SO to VO).
- € 0.87 mln in 'groundworks' under 'Integration services – cables & pipes' (VO to DO).
- € 0.66 mln in 'laying cables' under ''Integration services – cables & pipes' (VO to DO).

So, an escalation € 1.48 mln euros in 'pavement works' can be held as the major reason for the project's net front-end cost escalation of € 4.10 mln. The root work package within it causing this escalation wasn't explored due to time limitations.

b) From the interview results, it can be said that all the speculations made from IDA studies were true. This can be verified from the table 15 below.

Table 15: The front-end escalation summary of Project Schiphol.

Phase	Influence	SoL that acted	Scope of work affected	Steering Approach	Steering Successful (Y/N)
From SO - VO	Some % of €1.48 mln	Scope Additions (unintentional & could have been foreseen)	Pavement Works	BU + OA	Successful. Accurately estimated & No further underestimation
	Some % of 0.25 mln	Scope Additions (Unintentional & unforseen)	Traffic control (Security Systems)	BU + CL	Successful. Accurately estimated & No further underestimation
	€ 0.21 mln	Scope Additions (Unintentional &	Drainage Works	BU + OA	Successful. Accurately estimated &

		unforseen)			No further underestimation
	€ 1.06 mln	Risks/Contingency analysis	‘kunstwerken’ (concrete works for viaduct)	TD + CL	Accurately estimated & No further underestimation
	€ 0.02 mln	Engineering calculations	Public lighting	BU + CL	Accurately estimated & No further underestimation
	Net escalation of 2.75 mln	Time availability	All works specially cables & pipings	No action	
From VO - DO	a % of €1.77 mln.	Knowledge of cost benchmarks	Pavement Works	TD+ OA	Accurately estimated & No further underestimation
	€ 1.91 mln	Risks/Contingency analysis	Cables & pipings	BU + CL	Not successful, as the project currently is in overruns due to underestimated ‘ground works’
		Engineering calculations		BU + OA	Accurately calculated & estimated, but still in underestimation due to poor risk analysis.
	some % of € 0.29	Design-Variants Appraisal	Traffic control	TD + OA	Successful. Costs were reduce to some extent
	€ 0.03		Public lighting	BU + CL	Successful. Costs were reduce to some extent
		Change management process	Mostly pavement, cables & piping works	BU + OA	Successful. No escalations were experienced due to proper change communication between teams.
From SO - DO	€ 3.04 mln.	Completeness of the PvA/PvE	Entire ‘Road infrastructure works’	TD + OA	Accurately estimated & No further underestimation
	0.15 mln (from VO to DO) & a % of €0.09 mln (from SO to VO)	Design variants appraisal	Sewers	TD + OA	Successful. Costs were reduce to some extent

The SoLs, which were negatively influencing but were steered positively. (Scope additions : partially positively steered because the entire newly added works was not fully compensated by the removal of some minor works).
The SoLs which were positively influencing.
The SoLs which were negatively influencing , and the team failed to steer them positively.
The SoLs, whose final behaviour couldn’t be concluded.

c) SoLs amongst the ‘top 10 influential list’ that didn’t influenced (neither positively nor negatively) : Strategic political misrepresentation, Knowledge of design-based cost-drivers.

d) The reasons for the above mentioned major escalations can be understood from the table. The SoLs of KA-2 (not under the case study scope) also influenced negatively because there were repetitive escalations due to the SoLs, which means that inter phase performance wasn’t being compared. Leaving apart ‘Scope additions’, many other Sols caused repetitive escalations indicating that inter phase cost comparison/monitoring wasn’t practiced. There were no attempts to steer the SoLs of KA-II (or there were attempts which were unsuccessful).

e) As found from the literature study, a ‘cost’ of an element gets controlled when all the SoLs of all the 3 KA’s are steered positively. In case only the SoLs of KA-1 are steered positively by taking a corrective action, then the ‘cost’ of the element won’t get a relaxation in future because the SoLs of KA-3 weren’t positively steered for the element’s cost curve. Due to the huge negative impacts of ‘scope additions’ than the SoLs of KA-3, there was a net escalation in the whole project. The range of optimization through the SoLs of KA-III was not enough to compensate the added scope. This led to a net escalation in the project. What best the team did as a corrective action was that they estimated the added scope accurately.

f) It can be observed that most of the data retrieval approaches to achieve a 'cost control' regime was an 'open approach/project specific data usage' (applied to 8 SoLs). This indicates that the road design for this project was quite different & unique than other roads. Also, the most common approach followed for data/information processing was a 'bottom-up' approach (applied to 8 SoLs). This infers that the changes/influences occurring into the an element due to the SoLs were very specific and had wide implications on many other design elements. In a nutshell, the past experiences of the consultancy were not much useful for reducing the front-end escalations.

g) BAM Infra had bid for a much lower costs (bid was equal to the Arcadis's SO estimate) than what Arcadis proposed in the investraming, and so they were awarded the project. Since the project is in overruns now, it can be concluded that both BAM Infra. & Arcadis underestimated the total costs (or may be BAM Infra strategically used its expertise & bid lower with their proposed optimizations. May be BAM was aware of some future scope additions which would be added by Schiphol for sure.

Generic results :

d) Private road projects are characterized by their stringent planning schedule due to strict targeted opening dates . The cost benchmarks/design benchmarks for their assets are also different than the benchmarks of other assets of the same infrastructure type. Another feature is that phasing costs for private funded projects are very higher as compared to other road projects due to the heavy operational surrounding in and around the site. The available site working area is also very tight which demands extensively accurate planning to reduce the costs of phasing works (to reduce the risks amounts associated with running traffic i.e VVU costs.)

e) The front-end decision making in pvt. funded projects is very fast due to the land ownership and no 'selection' competition at the DtB stage.

f) Cost escalations in private projects like the landside works for airports always ensure high benefits & Internal rate of return due to numerous merchandises & high public dependency on the asset. So even though there are escalations in the front-end of the project due to scope additions, it always ensures added quality and so added benefits. The B/C ratio doesn't distorts much henceforth due to front-end cost escalation in such projects.

(Note : The generic conclusions obtained on the steering approaches to the SoLs are discussed in Chapter 7).

5.2 Case Study II: N270 Deurne – Helmond provincial road

The (N270 / A270) is a motorway cum provincial road in the provinces of North Brabant and Limburg , which connects their cities of 'Well' & 'Eindhoven' respectively (See figure 24 & table 16). With a span of 45 kilometer as a partly provincial road and partly motorway road, the N270/A270 passes through the municipalities of Gerwen & Nederwetten, Eindhoven, Nuenen, Helmond - Deurne, Bergen and Venray. The span of 3.4 km between Eindhoven & Helmond is designated as a motorway (A270) part and the remaining as the provincial road (N270). So, the (N270/A270) starts from the Eindhoven ring (province North Brabant) and ends by intersecting N271 in the city of 'Well' (province Limburg). The province of North-Brabant along with the municipalities of Helmond & Deurne prepared the refurbishment of the N270 in the following spans :

i) between Helmond and Deurne (including the crucial intersection with N279). Also called as the west part of the A/N270. This west part was excluded from the project scope after the feasibility study due to lack of available funds.

ii) between Deurne - Walsberg and the Limburg border (25-30 kms) : In response to the consecutive accidents and deaths, the zoning plan N270/Langstraat was prepared by the municipality of Deurne for making this portion of N270 more safe to travel. The objective was to improve the road safety, traffic flow and liveability. During the reconstruction of the N270, following changes are being included:

- Making three intersections at the Oude Graaf/Riet, Nachtegaalweg and Kraaienhut (near the Limburg border). The crossing points are provided with traffic lights.
- Making the road safer by reducing the number intersections and construct parallel roads on the route Deurne-Nachtegaalweg.
- Improving bicycle routes.
- Maintenance of the main carriageway of the N270.
- Development of a landscape vision for organizing the green zones.
- Renewing public lighting and signage.

The project was divided into following geographical regions :

- WV1 (Km 25.3-27) – Roadway between Aansluiting walsberg and Kruising oudegraaf/Riet (KP-1)
- KPNT 1 (Km 26.900 - km 27.100) - Kruispunt Oudegraaf/Riet
- WV2 (Km 27-28,6) – Roadway between Kruising Oudegraaf/Riet (KP-1) and Kruising Nachtegaalweg (KP-2)
- KPNT 2 Km (28.650 - km 28.800) – Padbrugsweg - Nachtegaalweg
- WV3 (Km 28,6-30) – Roadway between Kruising Nachtegaalweg (KP-2) Kruising Kraaienhut (KP-3)
- KPNT 3 (29.800 - km 27.100) - Kruispunt Kraaienhut

Figure 23: Project N270 (Deurne - Helmond) geographical regions (Source : Arcadis)

Table 16: Project information (Source : Interviews)

Project Specification	Description
Parent project (program)	Project Helmond-Deurne-Limburg Border

	Link : https://www.brabant.nl/dossiers/dossiers-op-thema/verkeer-en-vervoer/wegen/wegenprojecten-in-brabant/n270-helmond-deurne-limburgse-grens
Project Type	Provincial road maintenance & surrounding enhancement
Budget approved (DtB	13.92 mln euros (70% certainty of the final costs being +/- by 25% i.e. within the range €10.43.44 mln to €17.39 mln)
Final Estimate by Arcadis (Investraming)	18.24 million euros (70% certainty of the final costs being +/- by 25% i.e. within the range €13.63 mln to €22.80 mln)
Current Status	Under Tendering (UO)
Client	Province of North Brabant
Consultancies involved	RHDHV, Arcadis , DTV Consultants
Principal Contractor	TBA
Feasibility study	RHDHV
SO (Sketch Phase)	October 2013 – February 2014 (RHDHV)
VO (Preliminary Design)	January 2018 - May 2018 (Arcadis)
DO (Detailed design)	September 2018 - March 2019 (Arcadis)
UO	Ongoing
Realization	2020 onwards
Current Status	The project is under tendering phase but running behind schedule due to the objections on the land-use plan imposed by the society around the site.
B/C ratio deformation	The B/C ratio might have deformed a little because there is a net escalation of 4.32 mln euros which is a big rise for provincial/municipal projects. In terms of the range bandwidth associated approved at the DtB, the final costs presented by Arcadis were not within the bandwidth.

5.2.1 Longitudinal Observational Studies

In similar lines with the previous case study, longitudinal observational study was conducted for this case study as well. Different project estimates prepared in course with time were collected and analysed through IDA. Unlike the previous case study (3 estimate versions), more number of project estimates were collected for this case study (6 estimate versions : 2 for each phase). The reason for studying this project at a much frequent interval was the fluctuating front-end nature of this project. This project experienced both escalations and relaxations in its front-end journey in contrast to the Schiphol landside projects, which experienced only escalations throughout. So more number of estimates were required for studying the fluctuations, which would not have been possible with only three estimates. Another reason for conducting the longitudinal observations more frequently for this project was the different nature of the prepared estimates. While some of the prepared estimates were the ‘contractraming’ (costs to be incurred by the contractor), others were ‘investraming’ (costs incurred by the client in overalls). Also, taxation was added in some phases. Such differently calculated estimates for each phase were identified in the data collection process. As a result of this identification, the data was corrected accordingly during analysis in order to avoid any distortion in project specific conclusions.

5.2.1.1 Data collection

Although there were many estimate versions available, only the ones suggested to be suitable for research have been used for the longitudinal observational studies. These suggestions were taken from the project cost leader of Project N270.

However some important remarks are to be clarified regarding the data collection for this case study. The figure shows the various estimates with their consisting cost types for different phases. But the differences between these estimates can’t be directly concluded as an ‘overrun’ due to some distortions in the plotted estimate of each phase. During the case study selection for a govt. road project, these distortions were found to be applicable to almost every govt. road projects done by Arcadis :

- The very first feasibility study and the estimates for the SO phase were done by RHDHV. The estimates for the SO phase were collected from RHDHV. These two estimates, namely for SO1 & SO2 were made as an investment estimate and are mutually comparable. The CBS of these estimates was also different from that of Arcadis. This made it unjustified to compare the estimates of Arcadis with RHDHV at the 'work package' CBS level. Even though there were some work package with similar 'titles', but both the bureau's hold different definition for different 'work packages'. This made it difficult to trace how each estimate developed from SO2 to VO1. However, a comparison on the 'cost component' and 'cost element' level was made.

- Arcadis's initial contract with the Province was to prepare only the contract estimates (costs charged by the construction company/principal contractor to the province). So in terms of total project costs, VO1 & VO2 don't represent the total project costs as they don't contain land acquisition costs, contractor's engineering costs.

- Later on by DO, the province also demanded Arcadis to prepare the whole investment estimates (contract estimate + other costs for client such as design costs, land purchase costs etc) along with their contract estimates. So, only two investment estimates (DO1 & DO2) that were available were rich in data. The DO1 estimate was made from the detailed engineering design and the DO2 estimate was presented to the client as the total project's final budget. A contract estimate corresponding to DO2 (final budget) was also available with the DO2 estimate.

- As per the cost leader of N270, many versions were made for the sake of Arcadis' internal testing as the engineering designs kept changing due to lack of clarity in client's own perception. Since this research considers to study even the slightest differences within the estimates developed with time for a project, every N270 estimate was a potential data source for the study. But a selection was necessary because only the versions with interesting events were being targeted for the research due to the time constraints. The research scope was hence limited to only those estimate versions that experienced most significant variations (as per the cost leader of N270).

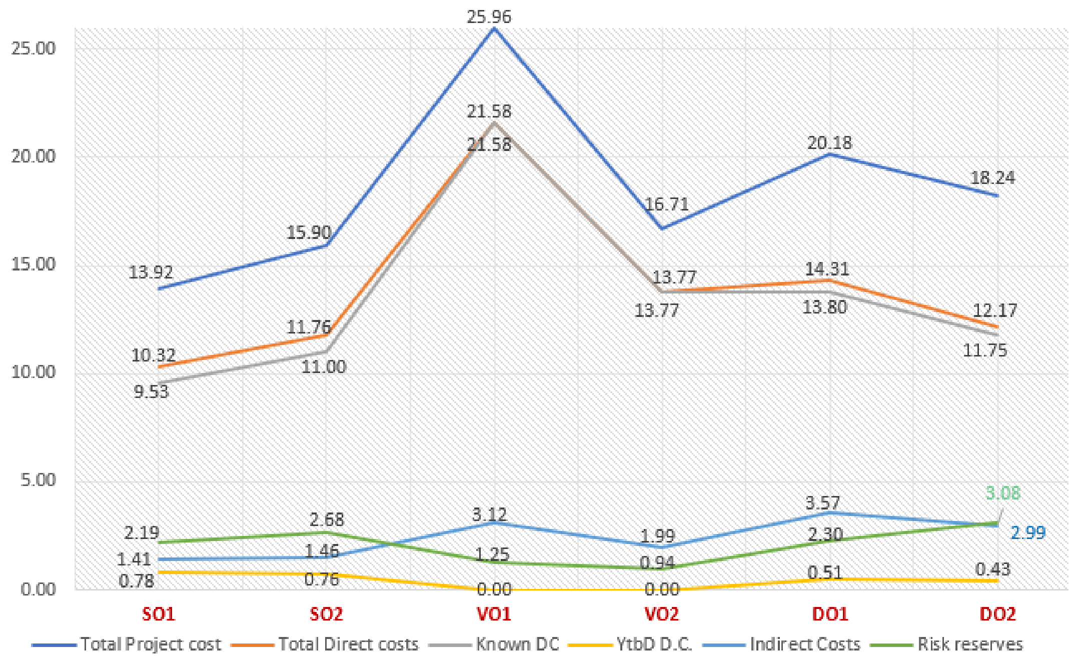

Figure 24: Cost development curves for major cost types in Project N270

5.2.1.2 Initial Data Analysis : Exploring the SoL's

All the different cost types experienced different fluctuations. The figure below demonstrates how different costs performed in the front-end phase of this project. The final budget made for this project was 18.24 million euros, which was around 4.32 million euros more than the very first estimate ever made for this project (13.92 million euros). As per one of the interview respondents from the Province of North Brabant, the decision to build was taken on the basis of this estimate. This is a rise of 31.03% of the originally proposed budget (See figure 25 & Table 17)

Table 17: Cost development in the major 'cost types' for project N270.

Cost Types	SO1 to SO2	VO1 to VO2	DO1 to DO2	VO1 to VO2	DO1 to DO2	Net Escalation
Total Direct costs	1.45	9.82	-7.81	0.54	-2.14	1.86
Indirect Costs	0.06	1.66	-1.13	1.57	-0.58	1.58
Risk reserves	0.48	-1.42	-0.31	1.36	0.78	0.88
Total Project costs	1.98	10.06	-9.25	3.47	-1.94	4.32

In terms of 'cost type', following first set of observations were speculated:

a. The *'total costs'* curve has rise of various degrees from SO1 till DO2, except from VO1 to VO2 & DO1 to DO2. This indicates that there were some attempts to control the costs vis-à-vis the first initial cost plan.

b. A major deflection in the *'known direct costs'* took place between SO2 to VO2. A huge increment and an immediate fall in this duration suggests the most probable reason as a '**design or estimation error'** in the estimates of VO1 (Speculation 1). The net escalation was *2.21 million euros.*

c. The '*YtbD Direct costs'* kept decreasing and plunged to zero at VO1 & VO2. However, they rose again in DO1 and then lowered back a little again by DO2. This infers that there was scope addition between VO2 to DO1. This could be either by the client or some design additions by engineers which were missed early. Since, this addition wasn't recognized in the early stages, it can be most probably speculated to be '**scope additions by the client**' (Speculation 2). The YtbD direct costs ended with 0.43 million euros, which were not detailed into the known direct costs.

d. The overall '*contingency reserves'* decreased from SO2 to VO2, which increased again from VO2 to DO2. The reason for a decrease from SO2 to VO2 could be that as the project unfolded, the uncertainty extent decreased. However, an increase again from VO2 to DO2 could be because of two reasons:
(i) these risks were underestimated previously (less likely, as the estimators had enough time) ; or
(ii**)** Scope additions by client, which brought more risks with it (Speculation 3).
The net escalation from SO1 till DO2 was *0.88 million euros.*

e. The '*indirect costs'* followed the same trajectory pattern as the total direct costs. As mentioned earlier, the indirect costs components were calculated as a percentage of direct costs. Upon close inspection, it can be noticed that the indirect costs consistently changed as a percentage of direct costs :

(i) SO1 : 13.5% of total D.C ; SO2 : 12.41% of total D.C.
(ii) VO1 : 14.45% of total D.C ; VO2 : 14.44% of total D.C.
(iii) DO1 : 24.59% of total D.C ; DO2 : 24.52% of total D.C.

Such an increasing percentage factor indicates that there were additional indirect costs' components accounted as the project progressed. The rise in indirect costs due to the rise in direct costs is obvious, but this project experienced that rise also due to increasing percentage factor for indirect costs [change in 'the estimation method' (Speculation 4)].

The indirect costs showed the most fluctuated trajectory with consecutive increases and downfalls. Still there was a net escalation of *1.58 million euros.*

In terms of *'cost element'*, the escalations in each phase were summarized as under (See figure 26 & table 18) :

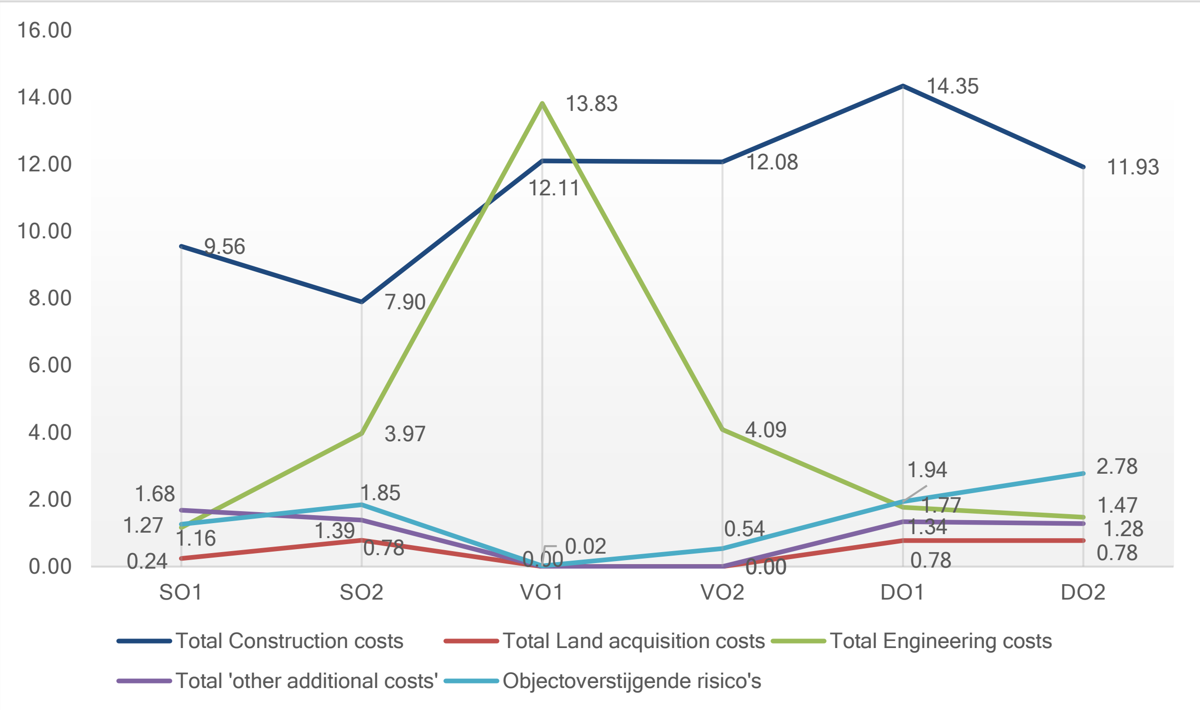

Figure 25: Cost development curves for different cost elements in Project N270

Table 18: Cost developments in different 'cost elements' (SO to DO)

	SO1 to SO2	SO2 to VO1	VO1 to VO2	VO2 to DO1	DO1 to DO2	Net Escalation
Total Construction costs	-1.66	4.21	-0.03	2.27	-2.42	2.37
Total Land acquisition costs	0.54	-0.78	0.00	0.78	0.00	0.54
Total Engineering costs	2.81	9.86	-9.74	-2.32	-0.30	0.31
Total 'other additional costs'	-0.29	-1.39	0.00	1.34	-0.06	-0.40
Objectoverstijgende risico's	0.58	-1.83	0.52	1.40	0.84	1.51

Unlike project Schiphol, this project had both escalations and relaxations. In order to understand the 'cost-control' extent in the front-end phases of the project, a Monte Carlo simulation was performed on the different cost estimates prepared from SO1 to DO2. Apart from the six different versions plotted in the above graph, 9 more estimate versions were utilized for the sampling. In total, 15 versions of estimates that were prepared throughout the front-end of the project were utilized. The 15 different samples gave a mean value (μ) of €17.28 mln. The standard deviation (σ) was found out to be € 36.20 mln euros using the relation:

$$\sigma = \sqrt{\frac{1}{14}\sum_{i=1}^{15}(x_i - \mu)^2}$$

Using the inverse function of a normal distribution, random samples were developed using the plugin @RISK in MS Excel. The simulation was done by considering 5000 random samples with the given mean & S.D. value. Following observations were made from the plotted normal distributions :

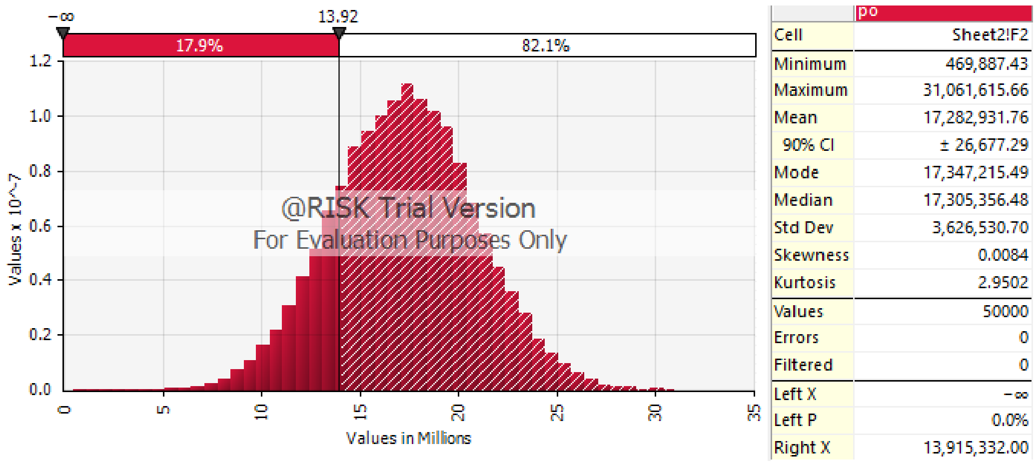

Figure 26: Probability distribution for possible total project costs for Project N270 (Source: Simulations)

a) All the factors (SoLs) were influencing the project in such a way, that there was a 82% chance for the project to exceed the cost plan which was approved at the Dtb point (€13.92 mln). In other words, it also means that it was likely by around 18% that the final budget will revert back to (€ 13.92 mln) by DO2, despite of all the ups & downs throughout the front-end phase. These probability results give indications about the team's response to all the factors/SoLs which were influencing the project's front end costs. (See figure 27)

b) The mean value of € 17.28 mln was quite close to the final 'investraming' in the DO, i.e. 18.24 million. This means that there was a 50% chance that the budget could have been more than € 18.24 mln. (See figure 28).

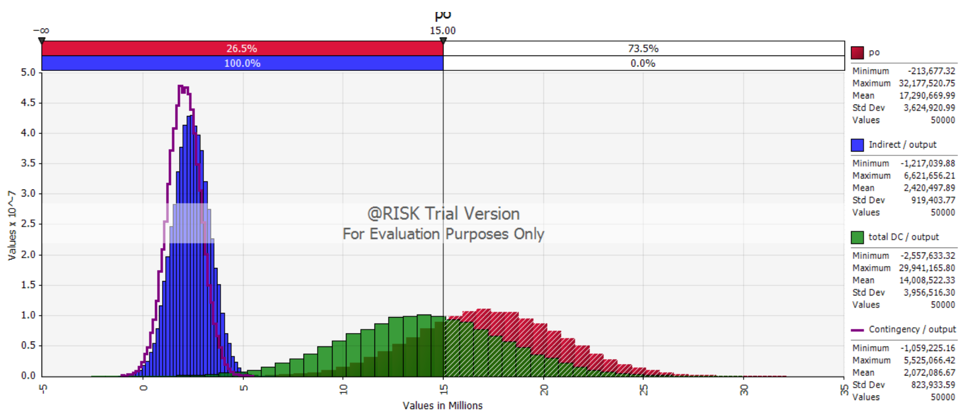

Figure 27: Probability distribution for different cost types for Project N270 (Source : simulations)

c) The indirect costs & the risks reserves curves were more skewed with less standard deviations than the total direct costs. This indicated that the factors (SoLs) affected the direct costs with more impact, than the other cost types.

5.2.1.2.1 Net overrun in each cost component (SO1 till DO2)

Table 19 & Table 28 (See Appendix D.2) explodes all the 5 different cost types depicted in the figure X and represents the escalations/relaxations for each cost component in each phase transition. The 'red' cells represent the most severe escalation and the 'green' cells represent the most severe relaxation in the costs. The figures in '+' represent an *'escalation'* in costs and the figures in '-' represent a *'relaxation'* in costs.

Table 19: Net Escalation in different cost elements/types for Project N270

Cost elements	Net Escalation (Value at DO2 – Value at SO1)			
	Total D.C.	Indirect Costs	Risk Reserves	Subtotal
Construction works	€ 1.63	€ 1.23	-€ 0.50	€ 2.10 mln
Land acquisition	€ 0.56	€ 0.00	-€ 0.01	€ 0.50 mln
Engineering works	€ 0.19	€ 0.19	-€ 0.06	€ 0.32 mln
other additional works	-€ 0.53	€ 0.16	-€ 0.07	-€ 0.43 mln
Objectoverstijgende risico's			€ 1.51	€ 1.51 mln

From Table 28, following observations can be made :

- It can be speculated that some KA-I SoLs influenced the components with a positive escalation. Also KA-III SoLs influenced negatively or had no influence at all over these elements, as they didn't get fully rid of their escalated values. These components were majorly responsible for a net escalation of 4.32 million euros in the total project costs. The major components were :

  a) 'Construction works' Total Direct Costs (+ *€ 1.63 mln euros).*
  b) Object transcending risks (not directly attributable to work packages/cost elements) (+ €1.51 mln euros).
  c) 'Construction works' indirect costs (+ € 1.24 mln euros).

  Also, the minor components responsible for the net escalation were :
  a) 'Land acquisition works' Total Direct Costs (+ € 0.51 mln)
  b) 'Engineering works' Total D.C. (+ € 0.19 mln)
  c) 'Engineering works' indirect costs (+ € 0.19 mln)
  d) 'other additional works' indirect costs (+ € 0.16 mln)

Apart from these components which were in a net escalation by the end of DO2, the left over other components were in a net downfall. These influence of the SoL's in these components was either zero or was properly steered in totality. Also a net negative figure means that the SoLs of KA-III were positively influential for these cost components as the final costs were lesser than the initial costs. These components were:

a) 'Other additional works' -Total Direct costs (- € 0.53 mln).
b) Construction works - Risk reserves (- € 0.49 mln).

c) Land acquisition - Risk reserves (- € 0.01 mln).
d) Engineering works - Risk reserves (- € 0.06 mln)
e) Other additional works – Risk reserves (- 0.07 mln)

Unlike sub-chapter 5.2.1.2.2, this case study doesn't presents the further breakdown of 'construction costs' in a detailed discussion. The cost data for further deeper CBS level was extracted from the files and was analysed for variations in their values in different project phases (See Appendix D.2), and was occasionally used while interviews whenever required. :

5.2.3 Interviews: Content Analysis

The content analysis for the interview responses for the 10 SoLs under study is described in this section. (Note : While reading the content analysis, the reader should keep an eye on the summaries of the IDA presented previously for better understanding).

Scope additions from the client (Influenced negatively)	
D1 D2 E1 E2 C1 C2	**Event :** Lot of instances with 'scope additions' were witnessed. One such addition raised the known direct costs from SO2 to VO1. **How it was identified:** It was realized from the results of the traffic density calculation, which was too high though the roads were being widened. **Cause:** The client proposed the 'scope addition' as a requirement for resolving the region's traffic problems. Addition of 'parallel ways' to the main traffic road was found necessary for the heavily loaded agricultural vehicles. **Influence:** The scope addition immediately increased the direct costs for 'construction works' (mostly for pavement, ground works, cables & pipes), It also raised land acquisition costs as the added scope demanded expropriation, and the people living around protested against this as well. **Resulting Escalation:** Escalations in total direct costs €2.48 mln (excl. tax) of. It was the second biggest escalation in the whole project, which didn't relaxed ever. Generally, the engineering costs also increases with the increase in project scope. But in this case, it didn't increase as the engineering was already known for the added scope. For example : Widening the road lanes would require more engineering, but stretching the road lanes to few more kilometres won't increase the engineering costs, but will increase groundworks' costs. The rise that is seen from SO2 to VO1 in the 'raming' was due to 'wrong cost benchmarks' and not due to this scope addition. **Action taken (Successful):** The added scope was calculated in a top-down approach (TD) by using the data from the CBS of main roads (CL). Since the added scope was already engineered and was within the knowledge of the team, a top-down approach to estimate the escalation gave accurate results. The action was successful as the added scope was accurately measured and estimated with no further escalations on it.
D2 E1	**Event :** From VO1 to VO2, there were scope additions in terms of additional sound screens. A 1.5 kms stretch of 2 m high sound screens were added. Also it is to be noted that the additions were only in the geographical region of WV1 (Aansluiting walsberg and Kruising oudegraaf) & Kruising Oudegraaf/Riet (KP-1) and Kruising Nachtegaalweg (KP-2). These additions were unjustified. **How it was identified:** The exactly same amount of scope was freshly insisted by the client to the consultancy.

	Cause : The extra addition of 'sound screens : 2m high' were perceived to be a strategic move, which wasn't necessarily a need of the project. Addition of a scope of exactly same amount in two different phases didn't make sense. **Influence:** The influence of the addition didn't disturb the designing of other elements, though the project was in a DO phase. This was due to the nature of scope added (discrete 'kunstwerk' were added)**.** **Resulting Escalation:** € 1.25 mln rise, which was a bit relaxed by downfall in some other element's costs in VO2. This element was the 'sound barriers - 5m high', which was totally removed as the design moved from VO1 to VO2 due to visual hindrance. **Action taken (Successful) :** As a corrective approach, they estimated the new additions in a BU approach using project specific data (OA) because the added scopes were in the DO stages. Fearing further scope additions, the 'risks reserves' for the 'construction works' in each geographical region were also recalculated & increased in a BU approach (as it can also be seen in the 'raming'. Past project data were utilized using the 'final investraming' repository which showed what was the amount of added scope on an average in every govt. road project. This was a preventive approach.
D1 D2 E1	**Event :** There was also a viaduct renewal (viaduct of Walsberg) & bypass widening from VO2 to DO1. These additions were justified & could have been foreseen in the beginning by Arcadis. **How it was identified :** When the focus got shifted to minor works. **Cause :** The current artworks got unfit for the newly proposed widened roads. **Influence:** The influence was on Kunstwerken/concrete works. These were discrete works and didn't have any design interdependency on other elements. So this scope addition didn't influence any other design element. **Resulting Escalation :** a % of €0.53 mln **Action taken (Successful) :** A BU approach with project specific data (OA) was used as the bypass & viaduct were existing on the site and had unique dimensions.
	Phase specificity : Scopes are added in every phase of a project. **Demanded phase specificity :** All the scopes should be added by and before SO itself. **Actions recommended :** As a preventive approach, the decision makers should calculate reserves for the risk of scope additions in a TD approach using past project's knowledge (CL). As a corrective measure, the added scope should be calculated in a TD/BU approach depending upon the type of scope added. CL should be used if the added scope is experienced in the past. Some efforts should be also made to reduce the costs of minor works, with which the client is ready to compromise. *(all 6 participants)*

Risks & contingency analysis (Influenced negatively)	
D1 D2 E1 E2 C1	**Event :** The escalations from VO2 till DO2 were also due to the rise in risk reserves. **How it was identified :** With the detailed designing and soil inspection, many 'unknown unknowns' were suspected for the ground works. It was highly likely that the underground was contaminated with explosives (buried during the time of World war II). Also upon the

C2	risk analysis of the newly added scope, some contingency amounts were determined. **Cause :** Improper risk analysis in the beginning of the front-end phase. **Influence:** The influence was on the 'unknown unknowns/objectoverstijdende risicos'. **Resulting Escalation :** The resulting escalation was of €2.24 mln (= 1.40 mln from VO2 to DO1 + 0.84 mln from DO1 to DO2). **Action taken (Unsuccessful) :** As a corrective measure, the revealed risk was calculated in a top-down approach using the past bid files of contractors for groundworks (CL). The contractor risk analysis for ground works are more realistic than what the consultant prepares. As a preventive measure for further possible escalations due to unforeseen risks, extra risk reserves were added to the works of all 6 geographical regions by calculating them in a BU approach, as they are the individual risks associated with respective works. The action was unsuccessful because the same set of costs escalated again in DO2.
	Phase specificity : Risks are misinterpreted in almost all project phases. **Demanded phase specificity :** No demand was made by the participants because this 'factor' should be eradicated completely and it should not become a reason of any escalation. **Actions recommended :** A top-down approach (TD) with past data (CL) should be taken for calculating the 'objectoverstijdende risicos', but a bottom-up approach (BU) with project data (OA) should be followed to calculate the individual risk reserves in all the cost elements. This practice should be followed for both preventive & corrective measures *(all 6 participants).*

Completeness of the design/Engineering calculations (Didn't influence the project)	
D1 D2 E1 E2 C1	 **Event :** This 'factor' didn't influence the project. **How it was identified :** - **Cause :** - **Influence:** - **Resulting Escalation :** - **Action taken :** -
	Phase specificity : This 'factor' generally escalates the project costs in the final design phases, like in the DO or while the investraming is being prepared. **Demanded phase specificity :** No demand was made because the engineering calculations evolves by the DO, and can't be figured out early. **Actions recommended :** As a corrective measure, a bottom-up (BU) approach should be followed to check and estimate the cost changes due to wrong engineering. Since, every project's engineering calculation is different a BU approach over the project specific data (OA) is the best approach. As a preventive approach, relations between different engineering disciplines should be develop by structural engineers to cross-check the engineering. For-example : A mathematical relation between the diameter of the sewer line & storm water line. A relation between the volumes of different sizes of aggregates utilized for sub-surfacing *(5 participants).* (C2 didn't properly respond to this SoL)

Completeness of the PvA (Influenced negatively)	
D1 D2 E1 E2	**Event :** From VO1 to VO2. Some escalations could have been avoided by being extra particular with the site requirements, which the client didn't mention to the consultants by mistake. Through the scope addition of 'parallel roads' was added from SO2 to VO1, there were again some additions in the same work from VO1 to VO2 due to lack of site information in VO1. **How it was identified :** As the design unfolded and the need for more information emerged, many specific needs of the site emerged out which weren't mentioned in the PvA/PvE. At some places, the available area for parallel roads was very less due to the existing plantations which weren't supposed to be removed. Due to the emergence of this information, the design changed. **Cause :** The cause of this factor was the client's irresponsibility to inform the consultant. Also the consultants were not pro-active enough to extract the site-specific information. **Influence:** A fresh addition of asphalt hardening & foundation works for the parallel roads. Generally these are the work packages related to site preparation works. **Resulting Escalation :** € 0.53 mln = € 0.29 mln (added in WV1 region) & €0.24 mln added in WV3 region. **Action taken (Successful) :** A BU approach was applied to the unique site data (OA) and the new additions were calculated accurately.
	Phase specificity : Incompleteness of the PvA is revealed generally in the final phases. **Demanded phase specificity :** All the PvA information should be delivered and discussed by the client. **Actions recommended :** As a preventive approach, the client should be questioned repeatedly by the consultant in the very initial phases for a detailed PvA clarifications. In a corrective approach, the newly added PvA information should be processed in a BU manner by using project specific information (OA). This is because the missed out PvA items are generally site specific details which the consultant can't predict from his past experience. *(as said by 4 participants)* (participant C1, C2 didn't had any proper response for this SoL)

Time availability (Influenced negatively)	
E1 E2 C1 C2	**Event :** Less time was made available between the phases SO2 & VO1. It lasted from January '18 till March'18, which was quite less for revising the designs & estimates. **How it was identified :** Upon updating the schedule planning. **Cause :** The major scope addition of 'parallel roads' was added as the project moved from SO2 to VO1. The client wanted to know the cost impact as soon as possible because the added scope was to be approved by the province decision makers. **Influence:** The sharp rise in the total engineering costs as a result of wrong cost benchmarks could also be attributed to the less time availability. Enough time wasn't available to extract the correct cost benchmarks for some detailed engineering costs which will be performed by the contractor upon project execution. **Resulting Escalation :** €7.53 mln, but it was relaxed in the very next phase. **Action taken :** Corrective approach was taken to find the influence of time shortage because there was no sufficient time available even for taking preventive approaches!

	With less time available, there is always a suspicion that some estimation errors would have been made. However, in the project's case this was not a suspicion but quite obvious because the total costs rose drastically. So a top-down (TD) approach was enough to immediately locate in the CBS level, where the drastic escalation happened. No need of recalculating was necessary as the mistake was big enough to be observed through the eyes. (participant D1 & D2 didn't had any proper response for this SoL)
	Phase specificity : During the last final phases when the budgeting date is near, this time scarcity is usually a common thing. **Demanded phase specificity :** No demand. Proportionate time should be given to the consultants in each phase. **Actions recommended :** Calculation mistakes due to time scarcity won't be as evident every time as it was in this project. Specific things are missed out due to a rush work and so a BU approach is recommended to steer this SoL.in a corrective action. Cross - learn't (CL) or project specific data (OA) can be used, depending upon what have been utilized in the estimate which is being re-checked. *(as said by 4 participants).*

Knowledge of design-based cost drivers (influenced positively)	
D1 D2 E1 E2 C1	**Event :** From SO2 till VO1, some optimizations were made by optimizing phasing works & reusing some items. **How it was identified :** the consultants identified many existing items which were suitable for reuse & made the whole work package a little cheaper. **Cause :** with many scope additions on board, specially the addition of 'parallel roads', some efforts were required to reduce some costs. **Influence:** Some existing bus halts, CADO (road barriers), signages were re-used. A part of soil scooped from some areas were reused for site grading & landscaping. **Resulting Escalation :** An exact figure from the SSK wasn't pointed out (because the CBS changes as the project moved from SO2 to VO1). **Action taken (Successful) :** TD approach with the team's past experience and project data (CL) to find the available room for costs reduction. It can be learnt from past projects how a work package can be made a little cheaper.
	Phase specificity : Currently, the cost experts try to use their knowledge of cost drivers from SO till DO. In SO, they advise the client to choose for suitable feasible designs while in DO, they try to reduce the costs by thinking in terms of material costs, labour costs and machinery costs. **Demanded phase specificity :** No demand. The knowledge should be applied in all the stages of the project as every stage reveals some project information, which may hint towards an optimization by making a design/work package more economic. **Actions recommended :** A TD approach should be taken with past project data (CL) to compare how some work package in past projects were cheaper than the project under consideration. In case this SoL behaves negatively, this approach should be taken as both preventive & corrective approach. *(as said by 5 participants)* (participant C2 didn't had any proper response for this SoL)

Knowledge cost benchmarks (Influenced negatively)

D1 D2 E1 E2 C1 C2	**Event :** From SO2 to VO1, the sharp rise in total costs was because of wrong costs benchmark were taken. **How it was identified :** A sudden increase in overall estimate, which, resembled as overdesigning to the client. The client immediately interrogated. **Cause :** less time availability. **Influence:** The SoL affected the the direct for engineering works. **Resulting Escalation :** € 7.53 mln, but it was relaxed immediately thereafter. **Action taken (Successful):** All the engineering costs were recalculated with the latest '% factor' in a BU approach using past contractor's bids. The direct costs were calculated using the latest pricelists for engineering manhours.
	Phase specificity of the SoL : Very early phases : Feasibility, SO. **Demanded phase specificity :** No demand. All the benchmarks should be accurately used in all the phases. **Actions recommended :** In a preventive approach, cost benchmarks should be collected and updated for all different types of road structures. Collecting benchmarks is not enough. Efforts should be also made to update them with the innovations in the market & the design standards. These efforts should be made for direct costs & indirect costs. The final budgets & pricelists prepared by the consultancy for past projects (CL) should be referred and the % or 'factors' should be used in a top-down (TD) approach as a corrective measure. *(as said by 6 participants)*

Design variants appraisal (Influenced negatively)	
D1 D2 E1 E2 C1	**Event :** Major design variants were compared in the SO1. Variants were analysed for the intersections of all crossing points (KP-1, KP-2 and KP-3), which was quite crucial for an economic design. A complex crossing is more safe but requires more VRI's/traffic lights which makes a crossing expensive. The most complex crossing was chosen for KP-3 as it was the one most prone to accidents. **How it was identified :** A detailed traffic safety audit was conducted by DTV consultants B.V. Based upon their results, the types of crossing for each Crosspoint was decided. **Cause :** The client wanted to have an economic design layout to make sure the best design-alternative has been chosen in terms of safety, engineering & costs. **Influence:** It influenced mostly the costs of VRI's, cables & pipes & pavement. **Resulting Escalation :** However the amount saved as a result of this effort can't be traced from the SO1 estimate. The exercise was brainstormed and the SO estimate only shows the final variant adopted. **Action taken (Successful) :** The consultants were able to save a considerable amount of money. The approach taken was a BU approach and past projects (CL) were utilized to find out the best possible variant. (C2 didn't gave a proper response for this SoL).

	Phase specificity : Design variants are generally compared in the very early phases, when two different options for the same problem really make a difference. **Demanded phase specificity :** All the design variants should be compared and weighted before the VO starts. **Actions recommended :** TD approach with cross project data (OA) should be utilized for comparing design variants, as most room to optimize a design depends upon the form & shape factors like surface area, length, volume etc. *(2 participants)* An outside approach (TD) with cross project data (CL) can always provide opportunities to reduce costs in a project, because variants develop at the layout level and not at the material type level.*(3 participants)*

Strategic misrepresentation (influenced negatively)	
E1 D2	**Event :** Some of the added scopes were felt to be early recognizable (Specially the 2m & 3m high added sound screens when the project moved from VO1 to VO2). In the VO, there was a 1.23 km stretched sound screening. It was removed in the VO. Instead 2m high (1.5 kms stretch) & 3 m high (60m stretch) were added as a replacement. Such an abrupt change didn't make any sense to the consultants. Sound screens are quite basic for roadworks and so this should have been included in the estimate which was presented to the decision makers at the time of the decision to build. **How it was identified :** It was just a demand from the client. **Cause :** It was a client requirement. **Influence:** This addition could have been added when the estimates were presented to get the project approved at the Dtb point. **Resulting Escalation :** €1.25 mln **Action taken :** The newly added items were estimated in a TD manner with project specific data (OA) as a corrective measure.
	Phase specificity : Costs are misrepresented when they are presented to the decision makers at the time of Dtb. **Demanded phase specificity :** No demand. This SoL should be completely eradicated as it has no benefits. It can't be steered positively to the project's benefit. **Actions recommended :** Preventive approach should be taken by the decision makers to verify the accuracy of the presented estimate and the funding for scope additions should be approved if a strong reason is justified. In a corrective approach, the misrepresented costs should be checked for their accuracy in a top-down approach (TD). Special attention should be given to the amount of added scopes. In past projects (CL). The original estimate should be raised by this amount.*(as said by 2 participants)* (D1,E2,C1,C2 didn't give a proper response for this SoL)

Change - management processes (influenced negatively)	
D1 D2 E1 E2 C1	**Event :** Due to a slight disruption in the change management, some escalations can be attributed to it. There were often changes which were not communicated to the minor works due to all the variations/influences in the major works. For example : the idea is always to collect all the sewers from the different lanes into a single lane (within the ground). That reduces the complexity of multiple groundworks & manhole placings. Due to

C2	the inclusion of 'parallel ways' from SO2 to VO1, two more line connectors had to be placed between the parallel sewage line and main sewage line. This change wasn't communicated immediately. **Cause :** Disintegrated working between different engineering disciplines. **Effect & its depth :** The influence very unique because it involved detailed engineering. **Resulting Escalation :** The changes in the sewer layout were identified a bit later on after VO1. The escalation in YtbD costs €0.51 mln from VO2 to DO1 was because this change was realized. **Action taken :** BU approach + project specific data (in % form) was utilized to estimate the additions as they were very specific. It was a successful addition as these YtbD costs decreased in the next phase (and didn't increase).
	Phase specificity : It is more problematic in final phases, when changing a slight design has a huge impact on every other design element. **Demanded phase specificity :** No demand. Change mismanagement should be totally eradicated. **Actions recommended :** All changes should be separately managed by a different team as a preventive measure. A separate heading can be made in the SSK which can only comprise of the newly changes in a phase. This would not only keep a record of the changes, but would also efficiently communicate it to all teams. In case any change is left miscommunicated, its cost impact should be checked in a (BU) approach within the design. A BU approach also would help to see the side-impacts on other design components. Off course project specific data (CL) should be used to accurately measure and implement the uncommunicated changes. *(As said by all 6 participants)*

5.2.4 Case Study II : Results

Case specific results :

a) The escalations (in order of their influence) which led to a net escalation of € 4.32 mln in the overall project's costs were (see table : 14) :

- An escalation of €4.22 mln incl. tax (€2.48 mln excl. tax) in 'total D.C. for construction works' (from SO2 to VO1). This was primarily due to a scope addition of 'parallel ways'. The addition was unintentional and a genuine need of the project. But it could have been foreseen earlier. This addition could have been foreseen at the time of DtB by conducting the traffic audit much earlier. This can be held as the major reason to the project's net front-end escalation of € 4.32 mln. The SoL that negatively behaved and led to the escalation was : Scope additions.

- An escalation of € 1.40 mln inc. tax mln in 'object transcending risks' from VO2 to DO1. This was primarily due to some unaccounted risks within 'groundworks' due to the suspected presence of explosives. This addition couldn't have been foreseen. But the contingency amount allocated for such unforeseen revelations could have been a bit higher The SoL that negatively behaved and led to the escalation was : Risk Analysis. Object transcending risks had the second most severe net escalation in terms of figures (i.e. 1.51 mln euros). This infers that the 'control' over this cost component was the weakest.

- An escalation of € 1.69 mln inc. tax in the indirect costs for construction works (from VO2 to DO1). The indirect costs were no in the scope of the study so the reason can't be elaborated. It is determined from the total direct costs of 'construction works', which didn't escalate much from VO2 to DO1. It can be so concluded that the % factors utilized for the components of indirect costs (One-off costs, contractor profits, contractor's risk' etc.) were taken relatively higher in DO1 due to which a sudden escalation of 1.69 mln can be seen. The SoL that negatively behaved and would have led to the escalation was : Knowledge of cost benchmarks.

- An escalation of € 0.53 mln inc. tax in 'total D.C. for construction works' (from VO2 to DO1). This was primarily due to the addition of 'kunstwerken' like viaduct renewal & bypass widening. This addition was also unintentional and a genuine need of the project. But it could have been also foreseen at the time of DtB point. The SoL that negatively behaved and would have led to the escalation was : Scope additions.

b) From the interview results, it can be said that all the speculations made from IDA studies were true. This can be verified from the table 20 below :

Table 20: Cost escalation summary for Project N270

Phase	Influence	SoL that acted	Scope of work affected	Steering Approach	Steering Succesful (Y/N)
Before SO	Not possible to locate in th SO1, SO2 SSK.	Design – variant appraisal	Pavement works, VRI's	TD + CL	Successfully optimized.
From SO2 to VO1	€ 7.53 mln	Time availability	Engineering works – D.C.	BU (No need recalculation using CL/OA was required as the influence was big enough to be seen).	Successful. Accurately estimated & No further overestimation. The escalation was relaxed as well.
		Knowledge of cost-benchmarks	Engineering works	TD + CL	
	Little more than € 2.48 (excl. tax)	Scope addition (unintentional but could have been foreseen)	Pavement works, cables & pipes	TD + CL	Successful. Accurately estimated & No further underestimation
	Wasn't figured out as the CBS changed and the packages were very minor	Knowledge of design-based cost drivers	Ground works, Landscaping	TD + CL	Successfully optimized.
From VO1 to VO2	€1.25 mln	Scope addition (intentional & unnecessary)	Sound barriers	BU + OA	Successful. Accurately estimated & No further underestimation. The escalation effect was relaxed by some other element's (sound barriers 5m high) cost downfall.
		Strategic misrepresentation		TD + OA	Successfully estimated as there were no further escalations in it

	€ 0.53 mln = € 0.29 mln (added in WV1 region) & €0.24 mln added in WV3 region.	Completeness of the PvA	Pavement works (Asphalt hardening & foundation works)	BU + OA	Successful. Accurately estimated & No further underestimation. The escalation effect was relaxed by some other element's (sound barriers 5m high) cost downfall.
From VO2 to DO1	a % of €0.53mln	Scope addition (unintentional & could have been foreseen)	Viaduct, cycle bypass (kunstwerken)	BU + OA	Successful. Accurately estimated & No further underestimation
	€1.40 mln	Risks & contingency analysis	Groundworks	TD + CL	Not successful, as the objectoverstijdende risks increased again from DO1 to DO2.
	€ 0.51 mln	Change manaagement	Sewers	BU + CL	Successful. Accurately estimated & No further underestimation
From DO1 to DO2	€0.84 mln	Risks & contingency analysis	Groundworks	TD + CL	No comments. The project hasn't yet entered the construction phase. So, the future extrapolation on the objectoverstijende risks costs can't be made now.

The SoLs, which were negatively influencing but were steered positively. (Scope additions : partially positively steered because the entire newly added works was not fully compensated by the removal of some minor works).
The SoLs which were positively influencing.
The SoLs which were negatively influencing and the team failed to steer them positively.
The SoLs, whose final behaviour couldn't be concluded.

c) The SoL amongst the 'top 10 influential list' that didn't influence (neither positively nor negatively) : Completeness of the design/Engineering calculations.

d) The reasons for the above mentioned major escalations can be understood from the table. The SoLs of KA-2 (not under the case study scope) also influenced positively to some extent because there also relaxations in the total costs curve. This meant that the team was focusing on inter phase comparisons, but only to some extents.

e) There was one SoL which also had a negative influence in the project, but was not amongst the top 10 most influential SoLs. It was 'Price inflation'. Due to a huge time difference between the Sketch phase and the later phases, price inflation was also a reason in the escalation of project costs from SO2 to VO1. Also there was a new SoL which had a great impact on the project's costs in different phases. It was 'Taxation'. A 21% taxation was applied to the estimates of only some phases: SO1, VO1, VO2 and DO1. The reasoning behind the inconsistent consideration of Tax wasn't explored as this SoL wasn't in the scope of the study.

f) It can be observed that most of the data retrieval approaches to achieve a 'cost control' regime was based on cross-learning/past project database (CL). Also, most of the approaches followed to process the data was top-down based (TD). This infers that the team had quite some past experience with a project like N270. All the influences (positive/negative) acting on the project were mostly steered in a top down approach.

g) The accuracy of the final investraming (€18.24 mln) can't be assured to be an accurate & optimized estimate. This is because the average value of the tender bids from different contractors is not yet known to Arcadis.

Generic Results :

a) Unlike privately funded projects, the front-end phases of a govt. project are more lengthy and require more stakeholders due to many reasons:

- Land of multiple administration are involved in the project. For example : Municipality of Helmond, Deurne & the Province of North Brabant etc.
- Land acquisition and expropriation takes a lot of time as the spatial land-use plan may not be favourable for the people living in the surroundings.
- The involvement of public money further makes the process more steady and the client gets liable for any escalations.

b) Unlike roads at the commercial/aviation hubs like Schiphol, provincial/municipal roads don't have many sources of benefit returns from a project. Therefore, each and every cost escalation endangers the B/C ratio. It is not very likely that every scope addition would also bring extra benefits to the project. So, front-end escalations in govt. road projects is a more serious issue than in commercial road projects like the Schiphol landside works.

c) Involving multiple consultancies in a same project does brings different expertise. But attention should also be given to the standardization. The CBS agreed in the very beginning of the project should be continued till its execution. If the CBS changes multiple times in the front-end journey, the SoLs of KA-II may not be successfully steered because the inter phase cost comparison becomes a cumbersome process for project teams.

(Note : The generic conclusions obtained on the steering approaches to the SoLs are presented in Chapter 5).

5.3 Case Study I & II : Results & Discussions

Results & Discussions from IDA :

Conducting a systematic IDA requires a top-down approach. It is important to study the correct plots to know the escalations/SoLs principally responsible for the project's net front - end overrun**.** Some key points realized by attempting an ex-post evaluation through IDA were :

- This IDA should be conducted in a top-down approach :
  i) first study: plots of cost types (like direct costs, indirect costs).
  ii) second study : plots of cost elements (like construction works, engineering works etc.).
  iii) third study : plots of cost components (like construction works – total direct costs).

  For example : in the IDA conducted for N270, the initial speculations made by studying the 'cost type' curves were changed after the plots for 'cost components' were made. The 'construction works' (level 2) was in a net escalation of € 1.70 mln, but not necessarily all the cost components within it (construction works risk reserves had a net overrun = - € 0.49 mln). Similarly, a cost type like 'risk reserves' was in a net escalation of € 0.89 mln, but plotting all five cost components of 'risk reserves' showed that only 'objectoverstijgende risicos' was in a net positive escalation (1.51 mln), while other four components were in a net relaxation.

- It was also realized that the biggest overrun in any phase of the front-end journey may not necessarily be responsible for a net overrun in the front-end of the project. For example : in project N270, the duration between SO2 to VO1 experienced the biggest escalation of €7.53 mln in the 'total D.C. of Engineering works', but was controlled in the very next duration (VO1 to VO2).

- Some 'cost component' curves could be in a net negative escalation, and contribute to macro cost controlling. This macro cost controlling could be an intentional effort by project team or it could also be a coincidence.

  Therefore, the principal cause/SoL for the project's net front end escalation is :

  "The SoL causing the biggest escalation in the curve of a 'cost component' with a net positive escalation. Within this cost component, all the work packages with an escalation can be traced and can be held as root cause for the project's net front end overrun."

Results / Discussions from the interviews:

- With the coming next projects, the interview participants are expected to perform better with less front-end cost escalations. As concluded from the interviews, Arcadis's team in future would consider all the unavoidable SoLs which they experienced despite of their estimation/design planning expertise. They would give preference to preventive measures to steer the SoL :

  a) by depositing the data into their KA-1 repositories for future use to steer SoLs like Cost benchmarks, design variants etc.
  b) By considering an 'uplift' in the estimates for unavoidable SoLs like Scope additions, risks etc. which they can't estimate/forecast in the beginning. The teams wish to gather the amount by which the uplift should be made by conducting more ex-post analysis of the front-end phases of past projects.
  c) Corrective approaches were also gathered for each SoL from the participant's overall work experience in the interviews. The interview participants preferred 'preventive' over 'corrective measures'.

- All the top most influential SoLs which were found through survey were found to be influential in both the case studies. Only one SoL had no relevance in case study II : Engineering miscalculations.

- An influence ranking of all the SoLs can be made by summing up the respective escalations caused by them and then arranging them in the descending order of the escalated value. But such a case specific ranking won't correspond to the ranking obtained through the surveys. This is because the surveys were taken from a population who had experience with many projects.

- In this case study, the study was done in terms of 'SoLs' and not in terms of 'design elements'. So it can't be speculated which design elements were completely controlled and had a net 0 escalation (i.e all SoLs steered). However, such a speculation can be made from the IDA. Table 9 shows that all the 'cost components' had a net positive escalation. This means that from SO1 till DO2, not all the 10 SoLs were successfully steered for each of them, specially the SoLs of KA-III (but only some SoLs might have been steered).

- It can be seen that a bottom -up information processing approach doesn't necessarily applies always to an open-farmed data (unique project data). It is possible that a cross-learnt data is required to be processed through a top-down approach.

- The impact of the KA-1 SoLs was mostly on 'Cables & piping' & 'risk & contingency amount' in both the case studies (See 'red' highlights in the case study result's table'. In other words, these are the elements which are generally underestimated. This observation from the case study can also be validated from the survey response to Q7 of Part I (See Appendix A). In a similar fashion, the responses to Q8 (regarding optimization) can also be validated, but only to some extents.

- The generic actions recommended for steering the SoLs are tabulated as under :

Table 21: Genric recommendations for 'steering' the influential SoLs/factors

Top 10 most influential SoL / 'control' based factors	Generic 'steering' recommendations		Majority Consensus
	Project Schiphol participants	Project N270 participants	
Scope additions by client	TD+CL (6) ; BU+OA (6)	TD+CL (6) ; BU+OA (6)	TD+CL/ BU+OA
Risks/contingency calculation	TD+CL (6) ; BU+OA (6)	TD+CL (6) ; BU+OA (6)	TD+CL/ BU+OA
Completeness of the design/Engineering miscalculations	BU + OA (6)	BU+OA (5)	BU+OA
PvA (plan van aanpak)/Requirement lists by client	TD+CL (2) ; BU+OA (4)	BU+OA (4)	BU+OA
Time available for each phase (SO-DO)	TD (4) /BU (2)	BU+CL/OA (4)	TD + CL/OA
Knowledge over design-based cost-drivers	TD+CL (5) ;BU+OA (1)	TD+CL (5)	TD+CL
Knowledge of cost benchmarks for direct costs	TD+CL (6)	TD+CL (6)	TD+CL
Design Variants Appraisal	TD+OA (6)	TD+OA (2) ; TD+CL (3)	TD+OA
Underestimation due to strategic political misrepresentation	TD+CL (5) ; TD+OA (1)	TD +CL (2)	TD+CL
Integrated design - change control process	BU+OA (6)	BU+OA (6)	BU+OA

The first sub-column shows the recommendations given on the basis of the general experiences by the participants from the Schiphol Project. The second sub-column depicts the same thing from the participants of Project N270. The number in the brackets represent the number of participants who recommended the respective approach action to steer the SoL. It is to be noticed that most of the 'factors' have been recommended to be steered by approaching the design/WBS in a holistic top-down manner. Also, cross-project learning is leading as the suitable data collection approach to steer most of these 'factors/SoLs'.

- The most affected cost type from the front-end cost escalation is the 'Direct costs & risks'. The most affected cost element from the front - end cost escalations is generally the 'construction works – pavement works, ground works & cables & piping'.

- It terms of savings, it can't be speculated based upon this research that how much escalation savings can be achieved. This is because this research didn't find the characteristic escalation figure that is caused by a SoL, in case it influences the front-end of a project. For finding that escalation figure, almost more than 100 projects with front-end escalations would be required to be studied. Each SoL can lead to a different escalation figure in different projects.

5.4 Desired front-end journey

Upon condensing the recommended generic approaches, an ideal front-end journey of an infrastructure project can be drawn. The circles represent the top 10 control-based SoLs/factors which, if not steered properly, can lead to front- end escalations in transportation infrastructure projects.

The size of the circle determines its influence extent. Darker circles reflect 'open data farming/approach' while the fair circles reflect cross-project farming. It is hence understood that the darker circles indicate that even if data is framed from past projects, a lot of corrections would have to be made on it which eventually results in the same effort as in open data farming (See figure 29). It can be seen that the top ten SoLs are distributed evenly almost in the entire front-end phase (See the phase specificity of the SoLs). It can be seen that as a preventive measure, the demanded phase specificity by the experts mostly intends to deal with the problem at a much earlier stage (than on the phase where it is currently prevalent).

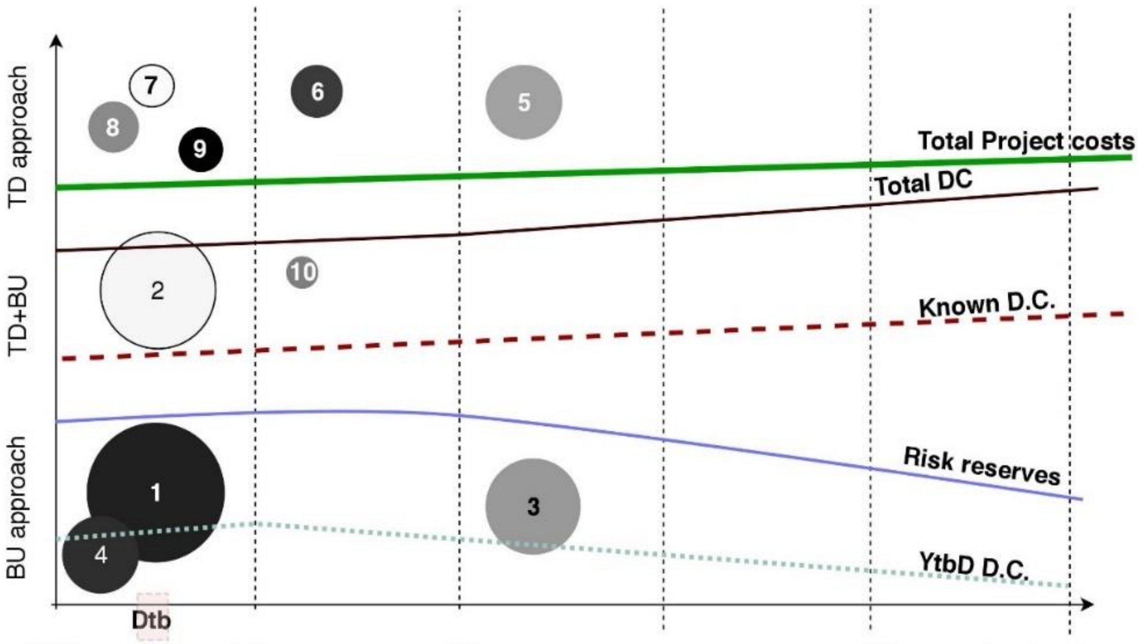

Figure 28: Framework of an ideal front-end journey (Self illustration)

Following are the salient features of this proposed framework which explains how an ideal transportation infrastructure project should run. This has been envisioned based upon the first indications on how the SoLs should be dealt in a preventive/corrective approach:

a) *Before (the feasibility stage) :*

- At the very beginning, the client (RWS/province/municipality) comes up with the problem statement and the main objective of the project: traffic congestions, accidents, economic development. Based upon the problem statement, feasibility analysis should be done either by the consultant or by the client himself. In the feasibility analysis, a high risk amount should be kept apart from the regular risk analysis for strategic scope additions by citing past project front-end journeys as evidence. The bandwidth associated with the final project costs should be taken as (+/- 40%).

- The problem and proposed solution should be explained to the decision makers with the estimated benefits & project costs.

- After the decision to build (Dtb) is taken, the project should be awarded to the same consultant who conducted the feasibility and evaluated the possible design options.

b) Feasibility - SO (the sketch design phase) :

- The client should have a clear PvA/PvE, and a clear threshold to overruns. As an expert, the consultant should present a design-cost tradeoff matrix to give indications to the client in case he wants some more additions in the PvA. The client should conduct stakeholder analysis as well in order to receive the demands of the nearby habitants and the involved stakeholders. The additions should be analyzed in a bottom-up approach with open-data farming. Any genuine '*scope addition'* by the client should be acceptable to the consultant till the final version for the SO is prepared (but not beyond that). This should be assessed in a TD/BU approach with open-data farming/past project data (point SO in the x-axis).

- The many versions of the sketch design should be prepared in order to make the client and the stakeholders realize in case they wish to add any new scope element. *'Design variants'* should be appraised/compared in a top-down approach using open data farming, to come up with the most functional yet economic design.

- The already considered high risk% for scope additions would prevent the client from strategically adding unnecessary scopes, rather than the much deserved scope additions from the stakeholders. With this, a pre-approved % risk allocation for so called 'necessary' scope addition would be judiciously used by the client. They would prefer to get the needs of the society considered first in the project than that of the project promoters.

- The final estimate for the chosen design should be prepared using the 'knowledge of cost-benchmarks'. The approach should be top down using cross-project data farming. This estimate should be of (+/- 30% variance) and should have a structured CBS. This should be considered as the final baseline for controlling the costs from here onwards.

c) SO - VO (the preliminary-design phase) :

- The real coordination between all the engineering disciplines and the estimating team would start from here. The work packages breakdown should be identified and the possible optimizations should be identified at the work package level. Overdesigning should be kept in check by restricting to their allocated man-hours. The same check should be kept by a '*frequent monitoring'* in a top-down approach.

- In case of exceedance, *'knowledge of the design-based cost drivers'* should be used to decide upon the restoring actions in a Top - down approach by using past project data/knowledge

VO - DO (the detailed-design phase) :

- This detailed work packages are freezed in this phase and their direct costs are calculated using detailed price books for labour costs, material costs, machinery costs & subcontractor's profit.. Constructability analysis should be conducted using clash detection platforms like BIM Tekla, Autodesk Navisworks etc. and final optimizations should be made using a bottom-up approach through both cross-learning and open data farming.

Upon approaching the encountered SoLs with the recommended approaches, it would be highly likely that the final budget doesn’t deviates much from the cost plan of the Dtb point, Also it can be ensured that the budget is optimized to its maximum extent.

6

Expert Judgement

An expert judgement panel was formed to testify the findings from the previous research methods. As explained in chapter 2, an expert panel of seven members was created. A 2 hour session was held as a validation meeting. The session was initiated with a 15 minute short presentation over the conducted research. This was followed with an interaction session with the experts, which was organized in three phases. The first phase targeted to receive the expert's opinion on the results of the survey. The second phase targeted to receive the expert's opinion on the derived steering approaches for each SoLs/factors. The third phase targeted to discuss the framework for achieving a cost-conscious designing environment, which was framed from the learnings of the case studies.

First phase: The expert's team agreed with the top ranks in both the ranking categories, though they felt the exact ranking structure may not hold a full validity and generalisability. The reason given for this was that every project experiences different SoLs with different intensity. So one cannot come up with an exact ranking of the SoLs, because the ranking won't be the same for every project. In order to have a more realistic ranking, it would require a wider sample of survey responses from experts with experiences in varied kinds of projects. The panel also highlighted that for such a survey, it would be very important to ensure that the survey participants have an experience with diverse range of projects. Following were the key observation points from the first phase:

a) Scope additions, Poor risk analysis, engineering miscalculations & incomplete PvA were regarded as the biggest issues. 'Efficient communication & knowledge sharing' was mentioned as the common solution for these problems.

b) Some new 'control'-based SoLs were mentioned by the experts' team which, if gathered, could have been in the top ranks in the 'influence' list. Those factors were:

- Surveying the site for its existing geological condition before designing was mentioned as one of the big factor/SoL. A lot of existing site information is physical in nature and requires intensive surveying.

- Organizing design reworks is also a challenge that most design consultancies face. A systematic approach to reworks can save time and can counter mistakes caused due to the attempts to rework.

- ‘Location of a project’ was also cited as an important ‘factor’ demanding attention. Although it doesn’t influences dynamically the entire front-end phase of the project, but it determines the costs of the project for its land acquisition costs, permit costs, and the local market conditions.

c) Some panel members disagreed that there are not much issues when it comes to comparing cost performance between different phases. They expressed that due to the involvement of multiple consultancies, it often becomes difficult to exactly compare the current performance with past performance. Data transparency and standardization also reduces if all consultancies don’t agree on a common project execution plan.

d) In terms of cross-project learning, the panel insisted that availability of past project data is not sufficient for a proper cross-learning. Many of the project data are recorded unsystematically and therefore are not reliable. For the SoLs that were found to provide cross-learnability, it is to be further researched whether the data available from past projects have reliability or not. This was regarded as a further research area by the experts.

Second Phase: This phase was meant to discuss the different steering approaches obtained for different SoLs/factors. The panel members were asked to individually infill the appropriate data collection/processing approaches for the SoLs, and then motivate their answers. In majority, the response received by each SoL was same to what was received from the case studies. Following were the noticeable observations from their feedbacks in the second phase:

a) For some SoLs, the responses by the expert panels were hugely varying in contrast to the results obtained from the case studies (for example : ‘Time availability for each phase’). As per the experts, the possibility of estimation errors due to lack of time availability should be always checked in a top-down approach, as it would be more efficient in a time scarce situation. This will help in identifying the major mistakes first and then the minor mistakes.

b) A BU approach with project specific data (OA) was strictly recommended for the SoLs like engineering miscalculations & change management. The reasoning behind this recommendation was that these SoLs can escalate the same project by varying intensities. An engineering mistake upon correction doesn’t ensures that another won’t happen. So, the team should be always prepared for such project specific challenges, as they may not have been handled by the team in the past.

c) In totality, the expert team also mentioned that all the gathered top 10 SoLs are related to each other i.e. emergence of one SoL leads to the emergence of other. For example: Missed out items in the PvA will surely be added in the scope, leading to scope additions. Furthermore, adding extra scopes sometimes bring new works, whose prices could be more prone to inflations.

d) In terms of overalls, some experts advised to always adopt a top-down approach to steer the control-based factors. A top-down approach according to them can provide the best results in uncertainty but should involve only experienced designers/estimators. In their opinion, a bottom-up approach may lead to further corrections, if gone wrong due to sudden changes in the design components. But a top-down approach never goes wrong and requires less manhours, but needs detailing in order to be produce the most accurate results.

e) Emphasis was laid on the need to find more design-based cost drivers in a project type. This is because only the cost drivers can offer the opportunity to reduce the heavy escalations caused due to scope additions.

f) Almost all experts expressed 'data management' as the research topic which should be paid immediate attention. As per them, implementing BU approaches with past project data is being hindered due to poor data management.

Third Phase: This phase of the discussion involved the 'front-end framework', which was prepared from the outcomes of the case studies & questionnaire survey. It aimed to discuss the validity of the framework on following criteria: correctness, reproducibility, validity, practicality & implementation ease. A structured rubric was given to the experts. Out of the seven experts, four experts gave detailed feedbacks through the rubrics (see Appendix C). In summary, the experts agreed that the framework, if applied, can reduce the problems (but can't eliminate the whole problem of front-end cost escalations). Following were their points of conformance/non – conformance:

a) The team stipulated that almost for every project, they are unaware of the budget which was approved at the time of Dtb point. So they don't control the project costs in reference to that budget, but they do it in reference to the very first estimate that they provided to the client. So comparing the project cost performance vis-à-vis the budget of Dtb point is not a daily affair with the consultancies. But the team did agree that the true escalation figure would be given by considering the approved cost at DtB as the reference point.

b) For the sake of winning the design tender, the consultancies can't put high risks for the future scope additions as that would make the bid too expensive. Such a practice would be good for the sake of the project's success, but is not good for the consultancy's daily business.

c) The framework considers only 'control' based technical factors acting in the front-end. But in real projects a lot of other factors also enact (though not directly into the CBS), into the project. For example: site climate and conditions, contractual disputes or site accidents. The framework would fail if all these factors are considered as well. So the applicability of the framework was said to have only some significance.

d) One of the expert cited early project information as the key to reduce the front-end escalations in the projects. He proposed mock exercises in replacement to the framework for reducing front-end escalations. The consultancy should have mock exercises on making a budget. Some individuals can behave as a client, while the others can behave as consultants. In the process of the exercise, they can understand what early project information is essential in order to prepare a cost plan for the Dtb point.

7

Thesis Results & its Implications

7.1 Result collection & cross analysis

Through the research strategies of structured survey & case studies, a lot has been explored over the SoLs within the three knowledge areas of cost control. Following were the set of results out of this thesis :

- The questionnaire method under the research strategy of 'survey' helped to prioritize the SoLs of the three knowledge areas into several rankings. The generic results were :

  a) *influence rankings of the SoLs*
  b) cross-learning attainability ranking.
  c) Extremity analysis for the SoLs.
  c) Cruciality ranking for the SoLs

- Through the IDA analysis within the research strategy of case study cost development trends were analyzed for the different CBS levels of the case projects.
  The project specific results were:

  a) Net overruns in each cost components.
  b) Controlled cost components.
  c) Uncontrolled cost components.

  The generic results were :
  a) *The possibility of data retrieval for the important SoLs ,*
  b) Method steps to find the root SoL responsible for front-end escalation in a past project.

- Through the interviews under the research strategy of case studies, the top 10 influential SoLs were investigated by using content analysis.
  The project specific results related to the case projects were:

  a) The resulting escalation caused due to the SoL
  b) The SoLs with influenced positively/negatively/didn't influence.
  c) The elements effected.
  d) The steering approach.

e) Successful steering (Y/N)

The generic results were :

a) The general phase specificity of the SoL
b) Demanded phase specificity for the SoL
c) Generic Actions recommended for the SoL.

- Through expert validation, the results from the questionnaire survey and the case studies were ratified from the experts.

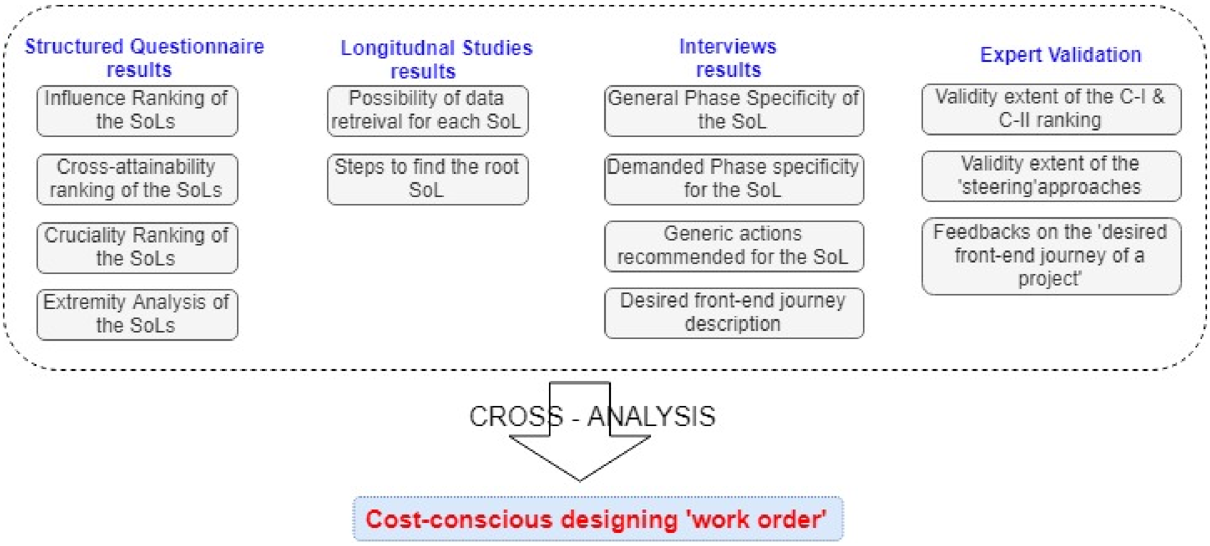

Figure 29: Set of generic results from the research

The three different research methods not only validated each other's results' to some extent, but produced new results as well. The generic results from the questionnaire survey, case studies & the feedbacks from the expert validation were taken forward as the final thesis results. The final results for the thesis were tabulated as under (See table 22):

Table 22: Final Results table

SoL/'control' based factors	**Influence ranking**	**Cross-learning attainability ranking**	**Phase specificity**	**Demanded phase specificity**	**Majorly agreed 'steering' approach**
Scope additions by client	1	16	SO,VO,DO	SO	TD+CL/ BU+OA
Risks/contingency calculation	2	1	SO,VO,DO	SO	TD+CL/ BU+OA
Completeness of the design/Engineering miscalculations	3	8	SO,VO,DO	VO	BU+OA
PvA (plan van aanpak)/Requirement lists by client	4	15	VO,DO	HBS, SO	BU+OA
Time available for each phase (SO-DO)	5	4	VO,DO	Proportionate to all phases	TD + CL/OA
Knowledge over design-based cost-drivers	6	14	SO,VO	Proportionate to all phases	TD+CL

Knowledge of cost benchmarks for direct costs	7	2	HBS, SO	HBS, SO	TD+CL
Design Variants Appraisal	8	10	SO	SO	TD+OA
Underestimation due to strategic political misrepresentation	9	19	VO,DO,UO	SO,VO	TD+CL
Integrated design - change control process	10	12	SO,VO,DO	SO,VO,DO	BU+OA

The last column depicts the generic 'steering' recommendation, which were given by the participants (refer to content analysis of case studies for a detailed explanation). All the approach actions mentioned here are the corrective actions. Considering the more negative prevalent negative behavior (than positive) of the SoLs in both the case projects despite the team's efforts, corrective actions have been given more emphasis in the above table. Nevertheless, preventive actions should be the first preference.

Some key analysis from the thesis' overall results are as follows:

<u>Regarding 'steering' the 'factors' :</u>

- The top 10 most influential SoLs are mostly related to knowledge area 1: estimating the as-designed. Only 3 out of these 10 ('Integrated design - change control process', 'design variants' & 'Lack of knowledge over design-based cost-drivers') belong to the Knowledge Area 3 : Taking change actions.

- Top – down approach can be seen to be leading by a small margin. It can be roughly said that generally, a top-down approach can help in reducing the front-end escalations because it can steer most of the SoLs positively.

- It can be observed that these generic steering approaches given by the project participants were strikingly different than the corrective actions that were taken by the same participants in the respective projects. While project Schiphol deployed mostly BU approaches, Project N270 deployed mostly TD approaches. Such different responses by same set of participants clearly indicate that every project is different. It can be said that the generic steering approaches given by them is on the basis of their overall past experience. If the participants had an experience in diverse kinds of projects, then the generic 'steering approaches given by them can be said to steer the most influential SoLs in a wide range of projects.

- Based upon the reasoning given by the interview participants for the above tabulated generic approaches, following line of reasoning can be established:

  a) A top-down approach should be generally followed to deal with those situations which the estimator/designer has experienced in the past. If the SoL causes a very specific negative influence to the project's front-end by attacking the designs/estimates, then the escalation effect should be calculated and corrected in a bottom-up approach. This is because a very specific influence can't be steered by using past experiences.

  b) **If the influence of a SoL on a design/estimate element also has side impacts on other elements, then a bottom up approach should be utilized for calculating the influence and correcting it**. This is because a bottom -up approach will ensure that all the finer elements are added together.

  c) **The initial phases are generally characterized by a top-down approach while the later phases generally need a bottom-up approach. But deep inside the CBS elements, this pattern can invert (depending upon how fast does a project unfolds).** In the front-end of many projects, the design is not detailed to a lot extent even by the DO phase due to several project complexities which require a contractor's expertise. In such cases, the project's entire front end would mostly involve a TD approach as the detailed engineering would not be done by the consultancy.

d) **Very initial phases may sometimes utilize a bottom up approach with project specific data to estimate the negative influence of the SoL.** For example : presence of toxic chemicals in the soil layers may require a specific study with a bottom up approach to estimate all the costs incurred due to it. Similarly, later phases may also involve cross-data farming and its processing in a top down fashion to estimate the influence of a SoL. For example: past project data may be used in a top down approach to optimize the cost of laying pavement blocks. By looking into different types of pavement materials used in the past projects, the designer can choose a suitable one for the detailed designing of an on-going project.

e) **A past project data may not necessarily be subjected to a top-down approach.** There can be situations when the past data for both direct and indirect costs are utilized in a bottom up approach to calculate the exact expense for constructing a cost component. For example: piling works are generally estimated by using past data of man-hours and processing them in a bottom up manner. This is because the detailed type of pile may not be in the knowledge of the designer, and he has to use the past benchmarked data in a bottom up approach to calculate the most accurate estimate.

f) Top-down & bottom-up approach can also have implications on the respective accountability of the different actors in a project team. Top down approach is effective when the actor has past experiences with the 'factor'. In such case the senior cost experts & clients should deal with the main decisions on the situation, and the other novice team members should detail out the action and regularly report them.
In case of applying a bottom-up approach, more responsibility should be taken by the daily engineers and junior cost engineers who are involved in the detailed drafting of the design. The estimates produced for major cost components should be then rectified by the senior team members.

- In order to have a net zero escalation, all the SoLs (KA-1, KA-II, KA-III) acting throughout the front-end journey should be steered positively to an equal extent. But as learnt from the survey & case studies, scope additions are the biggest negative influences in the front-end cost performance of a project. The impact of scope additions affects the costs in two negative ways: Firstly it escalates the costs. Secondly it poses the threat of further escalation because the estimation of the added scope may have been underestimated. Even by utilizing the positive behaviour of the SoLs from KA-III, the negative impact of scope additions is difficult to recover. This is the reason why most project suffer a net front-end escalation. Through this research, the issue of 'scope addition' was identified to be generally of two types:

  a) Unforeseen & unintentional: Scopes which were difficult to be predicted by any actor. These scopes emerge as a genuine necessity of the project as the project unfolds with time. Such additions could be a demand of the stakeholder, general public or environmental regulations. Strong contingency reserve should be the preventive measure for such additions.
  b) *Foreseen & strategic:* Scopes which could have been added in the very beginning, but weren't added by the client to keep the estimates low at the time of DtB. Since contractors may charge sufficiently high price for scope additions, the client ensures maximum scope additions in the project's front-end. This could be another reason for strategic front-end escalations.

In a nutshell, scope additions may also increase the benefits in a project, and thus may not harm the feasibility of a project. But they may harm the feasibility to a lot extent in case the added scopes don't return any extra benefit from the project. In terms of controlling, consultants can at most reduce the negative impacts for scope additions by estimating them accurately and by giving some efforts on compensating the resulting escalation by removing some minor unessential work packages.

<u>Regarding reducing/controlling the net front-end escalation:</u>

Indications towards compensating the escalations caused due to the negative behaviour of the SoLs can be explored with the table below (Table 23). The SoLs of KA-III generally didn't behave negatively in the case projects and so more focus has been given to the SoLs of KA-I.

Table 23: Possibility of compensating the escalations caused due to the SoLs via corrective measures

SoLs/'factors'	Influences the 'Design' first	Influences the 'Estimate' first		Possibility of compensating the escalation using KA-III SoLs and corrective measures		
		Qty.	Price	Through the same work package	Through some other work package	At the end of designing
Scope additions/removal	✓			**Not possible** An added scope is hardly removed in the very next phase	**Partially Possible (**Partially, not completely as the escalations caused by this SoL is generally high)	**Not possible** as an added scope is generally not scrapped off till the end
Risks analysis		✓	✓	**Possible :** Generally the perception of a risk is more than what it actually is	**Partially Possible (**Partially, not completely as the escalations caused by this SoL is generally high)	**Possible :** Generally the perception of a risk is more than what it actually is
Completeness of the design/Engineering calculations	✓			**Possible** Escalation can be compensated completely by correcting the mistakes	**Possible, but not required :** The escalations can be removed by correcting the same work package	**Possible/but not recommended :** The escalation should not be waited to be relaxed in the last
PvA (plan van aanpak) / Requirement lists by client	✓			**Not possible** An added requirement is hardly removed in the very next phase	**Partially Possible (**Partially, not completely as the escalations caused by this SoL is generally high)	**Not possible** as an added requirement is generally not scrapped off till the end
Time available for each phase (SO-DO)	✓	✓	✓	**Possible** Escalation can be compensated completely by correcting the mistakes caused due to time shortage	**Possible, but not required :** The escalations can be removed by correcting the same work package which got wrong due to time scarcity	**Possible/but not recommended :** The escalation should not be waited to be relaxed in the last
Knowledge of cost benchmarks		✓	✓	**Possible** Escalation can be compensated	**Possible, but not required :** The escalations can be removed by	**Possible/but not recommended :** The escalation

				completely by correcting the mistakes caused due to time shortage	correcting the same work package which got wrong due to time scarcity	should not be waited to be relaxed in the last
Underestimation due to strategic political misrepresentation		✓	✓	**Possible** Escalation can be compensated completely by correcting the mistakes caused due to time shortage	**Possible, but not required :** The escalations can be removed by correcting the same work package which got wrong due to time scarcity	**Possible/but not recommended :** The escalation should not be waited to be relaxed in the last
Design Variants Appraisal	✓					
Knowledge of design-based cost-drivers	✓					
Integrated design - change control process	✓					

By recognizing the extra efforts required in order to systematically steer each 'factors' & eventually control the overall project costs, it can be emphasized that the consultancies require extra man-hours for such efforts. From the conducted case-studies, some pre-requisites can be laid for a win-win situation of all parties:
a) the total costs of the project should be controlled by the consultancy in reference to the approved estimate at the Dtb point.
b) the consultancy should control its own expenses and the consultancy fees that it bid to the client for handling the front-end phases of the project.
The escalations and value distortion that the project suffers can be reduced, but for extra costs: The extra costs that the client should provide to the consultants to spend man-hours on strictly controlling the approved budget. This extra addition to the total project costs would be very meagre for the huge amounts that can be saved from projects.

7.2 Discussions: Filling the research gap

Reference class forecasting has been successfully estimating the costs for the decision makers in the recent years. However post RCF & project approval, the front-end is influenced by many dynamic influences/'factors', which is difficult to predict in the beginning by the decision makers. As a result, the project experiences front-end cost escalations which distorts the project value and erupts debates within the decision makers. As explained in chapter 1, there are almost no researches on improving the front-end cost performance. The only existing knowledge is over the different types of factors which result in the front-end cost escalations. Due to the totally contrasting environments of the front-end phases and the execution stages, the applicability of the PMBoK cost control method has been always doubted. Also the inaccessibility to front-end project data and the tight schedule of projects never led to a systematic ex-post studies.

This led to the need of this research, which not only confirmed the influence of such 'factors' in the front-end, but also studied their influence intensities and gave preliminary steering approaches for them. A first explorative study over the 'control' based technical factors was conducted through ex-post studies for gathering more information over them. Being explorative in nature, the objective of the thesis was not to establish a hard core solution to eradicate the entire problem of front-end escalation, but to explore whether the principle of 'cost control' can help in reducing the front-end escalations or not. The effectiveness of the PMBoK cost control approach in the execution stages was a motivation to test the relevance of the 'control principle (PDCA cycle)' in the front-end phases.

The research explored the topic for both facets: problem line & the solution line. In recognizing the problem, the research highlighted the relative influence intensities of different 'control' based factors and the relative cross-project learnability that they offer. In terms of the solution line, the research gave first indications on what the practitioners advice for positively steering them. Differences were observed in the steering approaches towards the SoLs for both the case projects. Differences were also observed in the approaches that the participants took in the case projects, and the approaches that they recommended in general.

The research provided indications that it is difficult to estimate everything in the beginning, and so teams need to adapt themselves for a much situation-based 'control' approach. Through two recent case projects, it highlighted how even a robust approved estimate can get underestimated/can get scope additions in the front-end journey. By studying the influencing 'factors' from a 'control' perspective, this research showed the possible relevance of the 'control' concept in the front-end phases. This relevance hasn't been discussed in the past researches. The research found preventive & corrective approaches to 'steer' the factors influencing the cost control regime in the front-end. In terms of main finding, the research laid first indications on how these 'factors' should be steered by suitable data collection/processing approaches. Some speculations (not detailed) were also made on which design components are mostly affected by a certain factor. In case some escalations are still not recovered through best of the 'control' efforts, future estimates can be uplifted in the RCF calculations with these escalated figures. This is because these escalations are certain and are almost difficult to control even through situation specific 'control approaches' (for example: due to political scope additions). Though the research is explorative because of its first attempts in the topic, but it has some implications (both to the industry & academia).

7.2.1 Findings & Implications

Implications on the academic fraternity:

The research can be seen to have some implications on the existing literature & knowledge over the subject of front-end cost escalations. Unlike the construction phase, not much information is known over the 3 knowledge areas of 'cost control' for the front-end in terms of the subjects/SoLs contained within it, their influence extents and plausible indications to steer them. This was the first explorative attempt to classify the front-end cost influencing factors in cost control knowledge areas. Past researches of Hwang, B. G. et. al (2018); Moschouli, E. (2018); Memon, A. H. et. al (2011) ; Allahaim, F. D., & Liu, L. (2013) etc. focused on a wide range of factors, and not explicitly on 'control' based technical factors. So, the thesis has added some research value to the fraternity researching on the front-end cost escalation factors. The thesis also showed the first attempts to rank the 'control' based factors after Iyer, K. C., & Jha, K. N. (2005), who did it in a much more general context within India. No other researcher had ever ranked the 'control' based factors in terms of their influence to the front-end cost escalations. With the longitudinal studies, first attempts to conduct an ex-post study was also exhibited by the thesis through two recent case studies in the Netherlands. This fulfilled the stipulation of Torp O., ThodesenC. (2016), Cantarelli C., Molin E., van Wee B., Flyvbjerg B., (2012) who intensively demanded studies on how costs develop in the front-end of an infrastructure project. The research queried the experts to give their preliminary indications over the behavior of the factors and the approaches to steer them, which fills the research demand by Nijkamp, P., & Ubbels, B. ,1999.

In a nutshell, a total of 39 experts (20 survey participants, 12 interview participants & 7 validation experts) were involved in this research. This research tried to fill the gap amongst past researches on two intensely detached themes: 'Factors causing front-end cost escalations' & 'Solution to reduce front-end cost escalation'. By identifying the indepthness of the factor's influence on the CBS and identifying the correct data source for measuring this effect, this research gives first indications on what should be the preventive/corrective 'approaches' in a loose project information surrounding like the front - end phases. Unlike all past researches which were conducted in the governance setting of Nordic countries, this research produces the same counterpart but for the Dutch road projects (may be not the megaprojects, but everyday provincial/municipal road projects). It is possible that upon surveying 100-200 experts, the most influential factor still emerges out to be 'political' based, which would be coherent to the findings of Cantarelli, C. C., Flyvbjerg, B., van, W. B., Molin, E., (2008). But this research shows that 'control based technical factors can also be the biggest problem for atleast the projects with small budgets. The way of conducting an ex-post analysis of projects in this thesis was first of its kind and was detailed enough in this thesis to be reproducible in future. Further academic students can perform ex-post studies for more projects and can bring out their analyses on the 'control' based/other types of cost influencing factors. The realization that ex-post analyses and the project team's tacit knowledge complement each other was also one revelation for the academia fraternity. The escalations as recorded in the cost files aren't of any use to the experts until they get to know the true explainations behind it by the involved project members. These explainations are tacit within the memory of the project members and get faded with time.

Implications on the industry :

As envisioned by Arcadis, 'Cost-conscious designing' would be a skill that the project team can use:
a) to accurately estimate the project costs for approval at the DtB point.
b) to control & optimize the project costs with respect to the approved costs in the front-end phases.
This thesis aimed to research over the component 'b'. By researching on it through the 'control' based factors, the thesis collected information over the factors which escalate the project costs by directly influencing a design/estimate. The project teams of different engineering consultancies can acquaint themselves more with these factors by utilizing the information produced over them. They can get first indications on how steering each such factors can reduce the net cost escalations in the front-end. Most importantly, they can realize the relevance of the 'control' concept for the front-end phases and can start implementing it within their teams by utilizing the approaches recommended in this thesis.

The 'control' based factors identified from the literature study was the starting point for this study. But a discussion session with the senior cost experts also brought up some more control based 'factors', whose influence they have been experiencing within their projects. The cost experts also stipulated over the 'positive' and 'negative' behavior of the 'factors/SoLs', which would be an important input for the engineering/project management professionals reading this research.

The results from the survey showed the most important factors which are the leading reasons for the front-end escalations in infrastructure projects. The survey was realized to be highly influenced by the project diversity that the participants held. This gave an important learning for the consultancies: The results of the surveys conducted within their organization would hold true only for the type of projects in which the participants have been involved. This was also agreed by the validation expert panel, who found the survey very relevant especially for the types of projects Arcadis have been doing. But the outcome that the most influential 'factors' are most difficult to be cross-learnt was hugely accepted to be an outcome with a widespread validity and generalizability. The rankings produced in this research are the relative rankings for the 19 identified factors and gives indications (at least to Arcadis as most respondents were from different Arcadis offices) on the factors which should be given more attention & research.

The ex-post studies conducted for Project Schiphol & Project N270 projects first of all gave concrete explanations on how the total project costs escalate in the front-end phases. The longitudinal studies conducted on these two projects are the first of its type, and the consultancies can conduct similar studies on every project once it closes. It gave insights on what could have been done better and how much costs could have been saved from getting escalated. The studies proved the widely accepted fact, that the front-end phases always provide the most opportunities to reduce the project costs. The longitudinal studies also showed the different levels of the CBS, in which an escalated amount can be relaxed/restored. This is an important outcome for senior cost experts, who are responsible for making strategies on reducing the cost escalations. The numerous bottlenecks faced in conducting the IDA for Project N270 also gives concerns on the standardization of CBS, which is generally disturbed due to the involvement of multiple consultancies on a single project. The process of IDA also highlighted the lack of proper data management, which is one of the reasons hindering regular ex-post studies within consultancies. By revealing the many escalations that a project may undergo in its front-end, the thesis also raises the concern of knowing the true value of cost overruns in a project. It prompts the academicians to accept that front-end escalations are quite significant and the correct reference point of overrun measurement is the approved budget at the Dtb stage.

The interviews revealed the desired approaches that the project team members advised on steering the 'factors'/SoLs. This outcome is essentially significant for consultancies as it brings up the learnings from the project members, who often don't get a platform to advise on improvements once a project is completed. By addressing over the suitable data collection & data processing approaches, the project participants also indirectly indicated over the accountability roles of different team members. By involving the client, designers & the estimators, the interview sessions also explored how these three actors interact in the front-end decision making and who can steer which 'factor'. The difference in the governance setting of both the case projects further highlighted the behavior of the 'factors' in these two scenario. This analysis would important for the consultants as the privately governed infrastructure projects are generally less in number and the consultancies need more experience with it. The utility of this research can be determined with the fact that with future Schiphol projects, Arcadis can organize the project's front-end in a much better manner by taking the learnings from the ex-post study of the ongoing Schiphol landside works.

<u>*Overall implications:*</u>

In a nutshell, this research initially the practitioners over the issue of front-end cost escalations and the causes/factors behind it. Through ex-post studies, it gives first indications on how these factors can be envisioned from a 'control principle' perspective. Considering these factors as 'Subjects of learning', it gathers many information over it like its phase specificity, its influence on certain project costs, approaches to steer it etc. Principally, it gathers the preliminary answers on how each of these important factors should be steered by adopting suitable data collection & processing approaches for each of them. Through the case projects, the relevance of these factors proved that a systematic 'control' tool method could have helped in reducing the front-end cost escalations of Project Schiphol & N270.
The research is then also relevant from a 'solution' viewpoint. From an overall experience, the project members of the studied case projects recommended a mixture of both BU & TD approaches for steering all the important factors. A suitable approach to steer a 'factor' was found to be more determined by the influence of the factor on the design/CBS and the team's experience with it. It was found that unlike execution phases, a bottom-up approach for steering the factors won't work in the front-end phase. Neither does an entirely top-down approach works. All of this indicated that the bottom-up based PMBoK cost control method may not be applied to the front-end phases, but the principle of 'control/PDCA cycle' can have a big impact in reducing the front-end cost escalations. So, the various information gained over the factors through this research is the key deliverable for the industry. These information can be considered as the starting points for future researches. Now that the relevance of the 'control principle' has been identified in this research, specific 'tool/method' can be devised by the consultancies which are based on a 'control/PDCA' cycle. The various information gathered (especially data

collection/processing approaches) over the 'factors' can be utilized to make the method/tool and different responsibilities can also be allocated within the project teams. From this research it can be emphasized that the consultancies should target three main features in such a method/tool: Data management, Person's Accountability & Efficient communication. This would lead to the envisioned practice of 'cost-conscious designing' within Arcadis/any other consultancy, through which the team can accurately & economically cost a design & also design a cost!

7.2.2 Reflection on the research methodology:

Every explorative study closes by emphasizing whether the chosen line of research can solve the targeted problem or not. The objective of an explorative study is not to solve the problem completely, but to sharpen the direction of research for problem solving. As mentioned in chapter 1, the topic covered in this thesis has never been conducted in the Netherlands, except for the research done by Nijkamp & Ubbels (1999). They conducted ex-post analysis on some of the Dutch infrastructure projects and found out the casues/factors that led to their front-end escalations. However, they didn't specifically researched on steering these factors. Other researches have identified and classified such factors under categories, for example : reseaches by Cantarelli, C. C., Flybjerg, B., Molin, E. J., & Van Wee, B. (2013), Moschouli, E. (2018) etc. They also didn't discuss explicitly on which category of factors are the most influential and how they should be steered. For conducting a research, on how can the front-end escalations be reduced, the existing literature library provides no motivation/clue on what should be the suitable research approach : it is not known which category of 'factors' should be considered for further research and which research methods should be deployed to research on them.

From a non-partisan attitude, a research to resolve front-end cost escalations should be approached by considering all categories of 'factors'. A wider public of experts should be involved to grasp over the different categories of 'factors'/issues. The experts should be then queried on how this factor could be steered. Given the limited time for this research, it was practically not possible to first conduct such a public survey just to decide the research approach & scope of the factors to be studied. Doing so would have reduced the time available for empirical research. Therefore, an approach of exploratory research was chosen. The setting of exploratory study gives every researcher the freedom to assume a certain direction of research, in case none of the existing literature provides any specific direction to consider. But in this research, the reason for proceeding towards a certain preferred category of factors ('controls' based factors) was not just due to the unavailability of a specific proven direction of research. This research also had some other motivations for making this priori choice on proceeding with the category of 'controls' based factors :

a) The existence of many tools/methods based on the principle of cost control gave some confidence on the fact that the principle of controls has been successfully managing the costs as per the budget. It was interesting to explore whether such tools, for example: the PMBoK cost control method, would work in the front-end phases or not. Basically the curiosity was to see whether the principle of 'cost control' has some relevance in the front-end phases or not. The industry's hesitation for using the term 'control' for the front-end end further intensified the curiosity to research towards the direction of 'controls' based factors.

b) Amongst all categories of 'factors' identified in the past researches, 'project/cost controls' based factors are the only ones that are tangible and can be studied through project files/ex-post studies. The impact of such factors can be directly seen and studied from the WBS/CBS. Upon considering other categories of factors, it was found that they would be difficult to study through project documents as they won't be directly visible in the WBS/CBS of the ex-post project files. For example:

- 'Project Financing' based factors: consists of factors related to project financing which can lead to cost escalation amidst project. Back out by any financier, less project benefits etc. are such factors. It is difficult to study over these factors from the resources available at the consultancy.

- 'Climate/site conditions' based factors: Factors such as 'soil conditions', rainfall intensity', 'heavy traffic flow' etc. are some factors which can also escalate a project's costs in the front-end phases. It was difficult to study them just by utilizing the project files/experts available with the consultancy company.
- 'Contractual' based factors: It refers to the factors such as 'contractual dispute', 'failure of the consultancy in design-contract compliance' etc. They were also difficult to be studied from the project cost files available for research
- 'human/social' based factors: Factors like 'lack of trust', 'inefficient communication' etc. are also intangible and difficult to measure through a research.

c) Existing tools for the betterment of estimation include RCF, Activity based costing etc., but they can estimate a situation and can't control situation specific scenario caused by the 'factors' leading to cost escalations. This has been also motivated by recent researches by Love, et. al (2011) & Love et. al (2002). They have instigated that researches should move beyond RCF & strategic misrepresentation and more project based factors should be studied. A study on such factors can reason 'why' and 'how' projects suffer cost escalations.

d) It was pre-considered that even if the followed direction of research doesn't solves the problem, it would considered as a research outcome and future researchers will get to know at least what direction is not to be taken. But in case if the chosen direction can reduce the problem even to a slight extent it would help in better decision making with projects (which seems to be possible from this thesis).

Conclusively, it is to be observed that the conducted research doesn't solves all the problem but gives important indications on further researching towards 'control' based factors. Researching on this direction can reduce only the escalations caused due to inefficient working of the consultant teams. Alternatively, it should be also noticed that this research doesn't undermines other ways of conducting the research on reducing front-end escalations i.e. considering other approaches/types of factors in the research can also lead to efficient results. Eradicating the whole problem of front-end cost escalations is a long way to go.

7.2.3 Research limitations & possible biases

Every research has some limitations and bias. An exploratory research like this is definitely prone to some bias and limitations. The identified limitations during the research journey were:

- The research may not have captured all the events describing the influence of a particular 'factor'. This is because of two reasons:
  a) Firstly, the interview participants had to recall over the project incidents which was time taking. In this process, it was difficult for them to remember all possible 'factors' that led to a particular escalation.
  b) It is possible that the estimators have worked on the same estimate sheet for several times before it is finally released. So it is highly likely that the number of times the same estimate sheet was being changed, it was due to some SoLs/factors acting in the project. This thesis wouldn't have traced all those events as it studied only the released versions of the estimates.

- In both the case studies, many instances were found when an escalation in a work package was compensated due to a relaxation in another work package. It was not known whether this relaxation was an intelligent effort to reduce the overall escalation effect, or was it just a matter of coincidence and the estimators had no idea over the implications of it. In that case, the team can't be applauded for their control efforts and the studied projects should have been in a much more net escalation (in case there was no – coincidence).

- For project N270, no speculations could still be made over the accuracy of the final estimate, as no contract bids have been received yet. The appraisals done in favour of the project would go wrong then. It is possible that the final estimation is highly underestimated!

- The interview study was conducted by using the projects of the same Arcadis dept. Also the 8 participants were from the same office (except the two form the client's side). It could be possible that the conclusions made from this thesis would apply only to this particular department because the issues and the recommended solutions come from the people of the same team. The thesis results can't be generalized to other consultancies in that case.

- The exact data retrieval method wasn't researched for those SoLs/factors, whose data has been recommended to be attained through past projects.

- More complex case projects should be studied. Also, between each phase (say SO to VO), there are many intermediate phases as well. Plotting the cost development curves for all such phases will give quite a detailed ex-post analysis of the case project.

8
Conclusions & Recommendations

8.1 Answers to research questions

The answers to the research sub-questions are:

a) *What are the crucial ‘control’ based technical SoL’s/factors leading to the front-end cost escalations?*

The most crucial ‘control’ based technical factors refer to the ones which are not only most influential in causing front-end cost escalations, but are also difficult to cross-learn from past projects. The ranking as obtained from the survey is as under:

SoLs/’control’ based technical factors	***Cruciality Rank***
Scope additions by client	1
PvA (plan van aanpak)/Requirement lists by client	2
Underestimation due to strategic political misrepresentation	3
Knowledge of design-based cost-drivers	4
Completeness of the design/Engineering miscalculations	5
Aligning designs with the revealed information in each phase.	6
Design Variants Appraisal	7
Integrated design - change control process	8
Price Inflation	9
The frequency of cost monitoring between D&E	10
Risks/contingency calculation	11
Time available for each phase (SO-DO)	12
Constructability Analysis	13
Optimizing time through construction schedule planning	14
Knowledge of cost benchmarks for direct costs	15
Cost control thresholds	16
Method of as-designed comparison with cost plan	17
Estimation method for a particular phase	18
Comparing the current performance reporting with the previous reporting	19

b) What suitable data collection & processing approach can be recommended to steer these crucial SoLs in order to reduce the front-end cost escalations?

Upon analysing the generic recommendations obtained from this exploratory research, there are indications that most of the factors from the three KA's can be steered through a top-down approach. So, a top-down approach can be said to be a suitable method for reducing the front end cost escalations. The data collection approach was found to be a mixture of cross-project data/openly generated data.
However, due to the identified differences in the case specific 'actions' (that were taken by the project teams in the studied case projects), vis-à-vis the generic recommended actions, it can be concluded that there can be no universal data capturing/data processing approach to reduce the net front-end escalation. The selection of the approach can be decided depending upon the very situation created by the emergence of the 'factor':

a) If the influence of the factor is very specific & affects the vicinity design components, a bottom-up approach should be adopted. In most of the situations, project specific data should be used for this processing.
b) If the estimator/designer can relate the influence of the factor form his/her past project experiences, then a top-down approach should be adopted. In most of the situations, past project data should be used for this processing.

A suitable approach can be defined to steer a particular escalation situation by using the above criteria.

Main R.Q.: How can the front-end cost escalations in transportation infrastructure projects be reduced by conducting their ex-post evaluation?

Preventive approaches should be first taken firstly for the most crucial factors, with the commonly found being: Scope additions by client, incomplete PvA, underestimation due to strategic misrepresentation, & incompleteness of the design & poor risk/contingency analysis (as they were found influential in both the case studies).

In case despite of the preventive approaches the 'factors' lead to front-end escalations, then corrective approaches should be used. A bottom-up approach for specific/unique influences & a top-down approach for a past experienced influence should be used for 'steering' the KA-1 'factor' effectively. This will accurately measure the escalation caused due to the 'factor'. Past project data or openly generated data should be used depending upon the specificity of the impact and the team's experience with it.

The impact on the total project costs should be assessed. Finally, efforts should be made to compensate the caused escalation by positively steering the KA-III 'factors' mostly in a top-down approach. This compensation can be done through three different opportunities: compensation within the same work package, within a broader cost component or by the end of the entire design phase. In case it is not possible to fully compensate the escalated amount, the reasoning should be researched. If it is found unavoidable, preventive approaches should be taken again by uplifting the future base estimates with the average value of all such unavoidable escalations from different projects.

More experts with diverse project backgrounds should be surveyed for gathering different types of 'factors' which influence in the front-end. More ex-post studies should be then conducted on the front-end of infrastructure projects and the newly discovered factors should be explored on how they can be steered through suitable data collection/processing approaches.With time, the net front-end escalations with infrastructure projects (at least small budgeted projects) can be possibly reduced.

8.2 Assumption's validity

Finally, the validity of the initially stated assumption can also be commented upon. The assumption was:

'The PMBoK based cost control approach for the execution phases also has some relevance/ applications to the front-end phases and it can reduce the problem of front-end cost escalations'

The researched argument over the validity of this assumption is as under:

There are indications from this research that 'control' based technical factors have got some relevance/importance for reducing the front-end cost escalations. The exact PMBoK based cost control exercise may not hold a validity for the project's front-end phases. However, the principle (PDCA cycle) & the three knowledge areas of cost control do have relevance for the project's front-end cost performance. This can be assured because all the factors within the 3 KA's were found to be quite influential in determining the front-end costs escalation of projects. So, the application of the cost control principle can reduce the problem of front-end cost escalation in infrastructure projects. New tools based on the principle of cost control should be developed by the consultancies and the academia can be recommended to research in areas of 'control' based factors in the coming future.

8.3 Recommendations

Getting profits at the end of the project is like a light at the end of the tunnel for every actor in the project. Everyone tries to obtain it. But being part of the same economic system of the country, a win-win ideology should be adopted. This is because the taxpayer's money and the national govt.'s funds are involved in the project. Controlling the cost escalations at the right phase in the front-end is the key to achieve such a win-win situation: a successful project with the desired benefits. Following set of recommendations were derived finally out of this thesis:

8.3.1 Recommendations for consultancies

- Consultancies should adopt an acquaintance over the different factors/SoLs which influence the front-end phases of an infrastructure project. More ex-post analysis should be conducted by the consultancies in order to find out more SoLs/factors. These newly found factors should be arranged in the respective 3 knowledge area of cost control. The steering approaches for both 'data attainability' & 'data processing' should also be explored by them.

- The consultancies can prepare a standard format which would reduce the complexity of comparing the cost development of different costs from SO till DO. Lots of efforts were made in this research for preparing such a format during the process of IDA. With this initiative, the consultancies can easily compare inter-phase data for their on - going projects as well.

- It is very difficult to estimate the project with 100% accuracy in the beginning. There are some SoLs, which escalate the costs tremendously and the corresponding cost curve can't be relaxed back within its own CBS level. For example: Scope additions, & incomplete PvA. It is sometimes though possible to relax such escalations by reducing the costs of some other work package/cost component in the CBS. Statistical studies should be done on such escalations from wide range of projects & the average escalation caused by these SoLs should be recorded. As a preventive measure, the future estimates presented at the DtB point should be given an 'uplift' by this avg. value.

- There are some SoLs which do cause escalations, but still offer some possibilities to relax it back. For example: Engineering miscalculations. The escalations caused by such SoLs can be relaxed back. Both preventive & corrective approaches should be taken for such SoLs.

- Conducting an IDA for the ex-post analysis can't provide the exact SoL/event/factor that led to the escalation. This is because many factor can act at the same time and the real factor can't be virtually identified by looking into the cost sheets. The 'tacit' knowledge over the true cause lies within the memory of the project teams, which also fades with time. It can be thus advised to the consultants to conduct a quick ex-post analysis of the projects soon after the project unfolds with its front-end phases.

- For collecting the data through CL, the past 'investraming' sheets should be used as it depicts the final costs after the project was fully designed. Contractor's as built files should not be used as they may be adulterated with various market influences & reworks due to the contractor's own mistakes. However, the contractor's initial bids in the tendering phases can be utilized to enrich the data repository: especially for risk reserves, object transcending risks & indirect costs. All indirect costs & the direct engineering costs for the contractor are quite difficult for the consultancy to estimate

8.3.2 Recommendations for policy makers

- The design consultancies aren't aware of when the decision to build is taken. So the reference point to evaluate the front- end overruns is still a big question for them. Policies can be made which could allow the consultancies to go through the estimate presented at the DtB stage. The consultants can then also comment over the accuracy/feasibility/extent of unrealism in the estimate.

- Consultancies generally have no incentive to control the project costs vis-a-vis the approved cost plan at the time of DtB point. They are busier in resolving the design problem and correcting the mistakes that they do internally. In case time allows, they experiment with optimizations as well. Some incentives should be prepared so that the consultancies also show their concern to control the costs in reference to the Dtb point.

8.3.3 Recommendations for researchers: further research

- Further researches are required now to expand the exploratory attempt made by the thesis. A list of research sequence was presented in Chapter 1, Figure 1.3.

- It should be researched that what is the average value of the escalations caused due to each 'control' based factor. This would give the characteristic figures by which a factor escalates a project's costs.

- Estimating and controlling of the 'benefits' have an equal importance as that of the estimating & controlling of the 'project costs'. Since, the ultimate objective is maintain a good B/C ratio throughout the project front-end, researches on the escalation/relaxation of the benefits should also be studied in correspondence to the escalations/relaxations of the project costs.

- The engineering consultants envision their profit margin in terms of the number of man-hours they spend on a project. So, they mostly care for their man-hours spent on a project which, if exceeded, would incur a loss for the company from that project. In contrast to this, the contractor calculates his profit margin in terms of all direct costs, indirect costs, risks etc. that he spent into the project. If he bids high project costs, he won't win the contract. If he bids too less, then he faces losses and eventually bankruptcy.

  It can be thus understood that the contractors are more careful in estimating the total project costs as their profit is dependent on that calculation. This is not exactly the case with the engineering consultants, which may sometimes make them little unconcerned towards front-end cost escalation. More researches on front-end cost control practices needs to be done considering this reasoning. The use of 'control' term should be advocated not only for the execution phases, but also for the front-end phases.

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Appendices

Appendix A: Online Questionnaire Survey (Responses)

Introductory Note :

Dear,
Road designers/engineers/cost experts & project controllers !

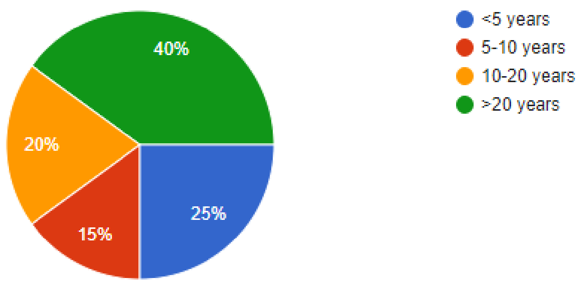
This survey targets to study the 'factors' influencing the costs of a road infrastructure in the early phases (SO/VO/DO). The factors are design/estimating related (not contractual/financial related). The objective of this survey is to study how can we design road infrastructure in a cost-conscious manner.

Section 1 : General questions related to road infrastructure.
Section 2 : Please rank them on behalf of your work experience with road infrastructure projects (government/private).

The identity of the respondent will be kept anonymous.

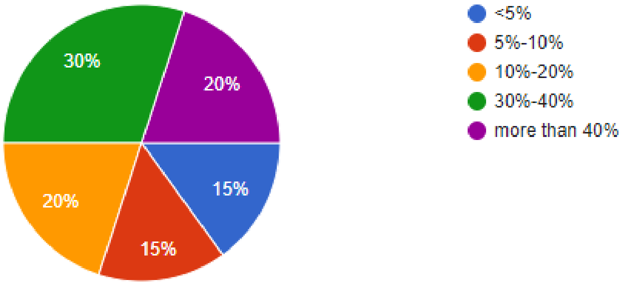
Questions – (Section 1)
Q1 : Please enter your full name.
Q2 : Please enter your company/organization's name.
Q3 : Please enter your job role in the company.
Q4 : Please choose your work experience in the Dutch infrastructure industry.
a) <5 yrs.
b) 5-10 yrs.
c) 10-20 yrs.
d) >20 yrs.

Response :



Q5 : Out of the road projects in your team, how many of them suffered cost overruns in the planning phases (SO/VO/DO)?
a) <5%
b) 5%-10%
c) 10%-20%
d) 30%-40%
e) more than 40%

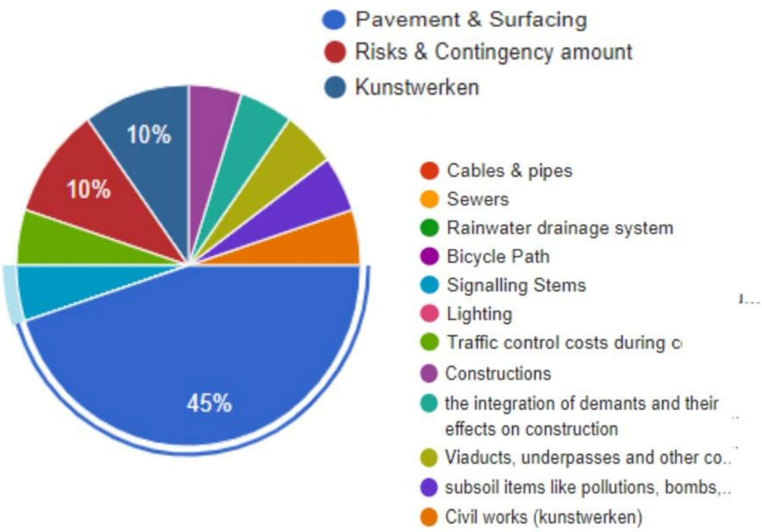
Response :



Q6 : Which component generally holds the maximum share in the overall project costs of a road project?

a) Pavement & Surfacing.
b) Cables & pipes
c) Sewers
d) Rainwater drainage system
e) Bicycle Path
f) Signalling Stems
g) Lighting
h) Traffic control costs during construction (VVU)
i) Risks & Contingency amount
j) Other: ________________________________

Response :

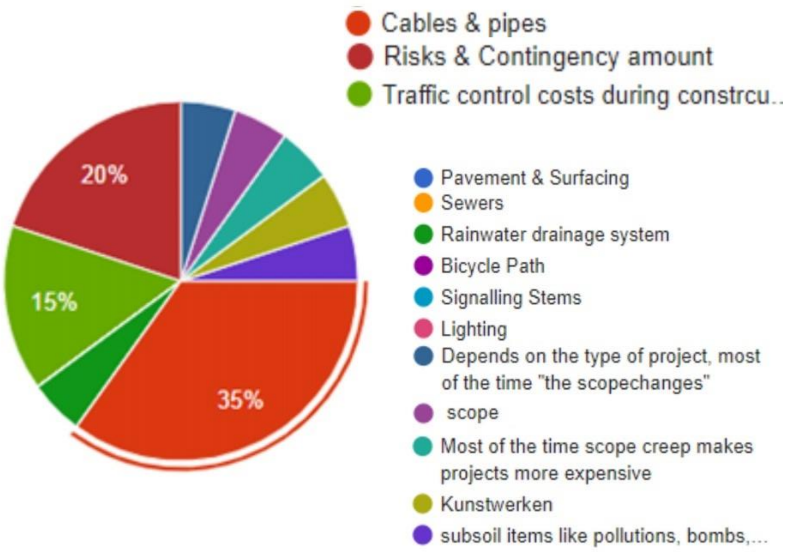


Q7 : Whose costs are generally underestimated in the early phase (SO/VO/DO) estimates?

a) Pavement & Surfacing.
b) Cables & pipes
c) Sewers
d) Rainwater drainage system
e) Bicycle Path
f) Signalling Stems

g) Lighting
h) Traffic control costs during construction (VVU)
i) Risks & Contingency amount.
j) Other: ________________________________

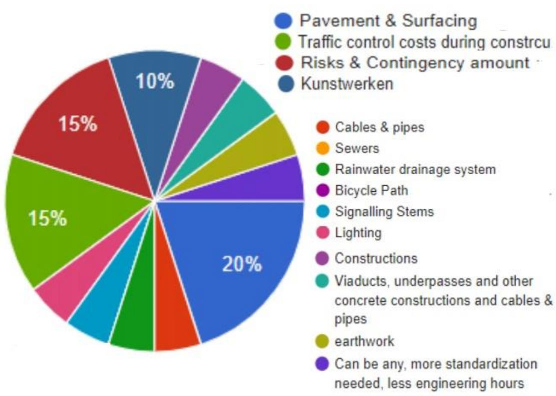
Response :



Q8 : Which component of the road infrastructure can be most optimized in terms of costs through economic designing?

a) Pavement & Surfacing.
b) Cables & pipes
c) Sewers
d) Rainwater drainage system
e) Bicycle Path
f) Signalling Stems
g) Lighting
h) Traffic control costs during construction (VVU)
i) Risks & Contingency amount.
j) Other: ________________________________

Response :



Q9 : Rank the following 19 'factors' on their impact on a design estimate in the front-end phases (SO/VO/DO). (1-less impact ; 5- huge impact)

Q10 : Now rank the same 19 'factors' to express if they can be learnt/controlled by using past experiences/past project knowledge. (1-can't be learnt ; 5- can be learnt from past projects)

Response :

Sr. No.	SoLs	Influence of the SoL Frequency					Cross-project learnability of the SoL Frequency				
		Score "1"	Score "2"	Score "3"	Score "4"	Score "5"	Score "1"	Score "2"	Score "3"	Score "4"	Score "5"
1	Estimation method for a particular phase	3	5	6	3	3	2	0	3	10	5
2	Cost control thresholds	1	4	6	7	2	1	0	8	5	6
3	Time available for each phase (SO-DO)	0	2	7	9	2	1	1	6	6	6
4	Performance measurement regulations (e.g. : The frequency of cost monitoring)	3	2	4	9	2	2	0	8	4	6
5	Completeness of the design/Engineering miscalculations	0	1	5	7	7	0	3	6	6	5
6	Knowledge of cost benchmarks for direct costs	1	4	5	6	4	0	1	5	6	8
7	Risks/contingency calculation	0	1	4	5	10	0	0	4	9	7
8	Underestimation due to strategic political misrepresentation	2	1	7	7	3	1	6	8	2	3
9	Price Inflation	2	7	7	3	1	0	8	5	3	4
10	PvA (plan van aanpak)/Requirement lists by client	1	1	6	5	7	1	4	6	6	3
11	Constructability Analysis	1	4	8	5	2	1	2	7	7	3
12	Design Variants Appraisal	1	3	7	5	4	1	1	8	5	5
13	Optimizing time through construction schedule planning	1	4	7	5	3	1	2	5	7	5
14	Method of as-designed comparison with cost plan	3	6	6	3	2	0	2	7	6	5
15	Comparing the current performance reporting with the previous reporting	4	6	5	4	1	0	2	6	8	4
16	Integrated design - change control process	0	4	8	6	2	0	5	5	6	4
17	Scope additions by client	1	0	3	2	14	3	4	4	3	6
18	Knowledge of design-based cost-drivers	0	4	6	6	4	2	3	5	6	4
19	Aligning designs with the revealed information in each phase.	0	3	11	5	1	1	4	7	6	2

Appendix B: Semi-structured interviews

B.1 Interview Protocol

A structured interview protocol is a pre-requisite for increasing the quality of the data obtained from it. An interview protocol is a framework that refines the interview process and makes it capable of eliciting best possible experiences of the respondents. It defines out the main interview components such as : Selecting participants, location & time length of the interview, the order & perspicuity of the questions and the interview analysis method (Rubin & Rubin, 2012);(Adler, Adler, & Weiss, 2006); (Welch & Patton, 1992). Castillo-Montoya (2016) researched on the key four stages for refining an interview protocol. These stages are sequential and successively mould the interview in congruency with the aim of the research (Jones, Torres, & Arminio, 2011).

A semi-structured interview method was utilized where all participants shall answer similar open-ended questions, with a room to elaborate and enquire. Keeping the questions similar throughout all interviews helped in post analysis & maintaining the objectivity (Olawale & Sun, 2015). Audios of all interviews were recorded and some notes were maintained for understanding. Upon completion, the session was documented and was sent for verification to the concerned participant. The identity of the participants was kept anonymous. All the interviews were face to face and were taken one at a time for maintaining the interview quality (Collis & Hussey, 2014). Jargons were avoided in question framing & only one question was asked at a time.

The interview protocol for the case projects chosen for this research was prepared through these four stages.

a) Aligning interview questions with the research questions: The conclusions from the literature study determined what is yet to be explored. In other words, it defined the boundaries, within which the research sub-questions have to be explored. So firstly, the interview questions were prepared in the first stage of protocol formulation. These questions were made congruent to the research sub-questions. With this aligning process, it was clear that which interview questions are of prime necessity, and which are not. Following steps were taken in this stage :

i) Preparing Interview Questions :
For preserving both the 'inquiry' & 'conversational' goals in the interview, the questions were characterized with four different rounds: introductory questions, topic transition questions, main questions & wrap up questions (Creswell, 2007; Krueger, R. A. & Casey, M. A. ,2009). The *'introductory'* questions aimed to set the context with the respondent and start a narration. The *'topic transition'* questions helped in moving towards the main questions, as they bridged the main questions with the introductory questions. After these two rounds, the respondents were ready for a series of *'main questions',* which discussed over the thesis research sub-questions. The main questions were most in number. The final round consisted of some closure questions which provided an reflective & conclusive experience to the respondents. These questions were much simpler and helped the respondent to express any unaddressed issue from their own behalf.

- First Round (Introductory questions) : A set of questions to gather an overview over the project : parties involved, project objective, scope of works etc.
- Second Round (Topic transition questions): A set of questions aiming to collect the justifications behind the IDA observations (Observations related to underestimation & non-optimization of costs).
- Third round (Main questions) : A set of questions exploring the influence of each SoL and the suitable approach to steer them.
- Fourth Round (Wrap up questions) : A set of questions to gather recommendations and close the interview.

ii) Reordering as per the research sub-questions :
The interview questions were now mapped with the three research sub-questions and the final sequence was prepared. It was also assured that the interview questions are distinct, yet relatable to the research sub-questions. The language was kept simple, lucid and not technical like that of the research sub-questions.
iii) Deciding the respondents number :
The respondents number was decided on the basis of the key project roles that are generally responsible for cost management in a project. Within the limited research time, it was decided that 2 engineers/designers, 2 cost managers & 2 client members will be interviewed for each case project. Therefore 6 interviews were taken from each case project which equals to a total of 18 interviews for this research. The work experience with early project phases was also considered as a criteria for choosing the participants.

This number is sufficient enough to conduct a qualitative research and deliver a process (not data) oriented outcome. Data convergence has been achieved in past such interview attempts by the 11th (Alashwal et al., 2011), 12th (Saunders et al, 2016) & 13th interview (Ye et al.).
iv) The duration of the interview : The minimum duration of the interview was set to be 1 hour, which is adequate for a semi-structured interview

b) Implementing attributes of 'inquiry' into the conversations :
i) **Follow up questions :** In order to retain the 'inquiry' nature of the interview, it was decided to put certain impromptu follow up questions for better solicitation. These impromptu questions were asked depending upon the need of further clarifications.
ii) **Key words used** : The key words used for framing questions were chosen judiciously to frame the questions clear & self-explanatory. Framing questions with 'why' was avoided as unlike normal conversations, using 'why' multiple times in an interview makes the interviewee judgemental in the respondent's vision (Rubin & Rubin, 2012). This can distort the responses as

the conversation trust breaks. Instead terms like ‘what caused’, ‘what determines’ etc. were used to obtain the tacit experiences, and to also maintain the conversational tone.

iii) **Scripting :** While switching from one round to the other round, a short script was necessary to be inserted in order to brief the respondent over the new round (Kvale & Brinkmann, 2009). The opening of the interview also began with a short script briefing over the interview rounds and respective durations.

c) Peer-review/Feedbacks over the interview design : Getting feedbacks from various sources strengthens the iterative nature of a qualitative research, in which the researcher continuously improves the questions sets in order to solicit more reliable and focussed answers (Hurst et al., 2017). Patton (2015) insisted on performing a review for strengthening the reliability of the interview protocol. The interview questions should be circulated amongst the fellow colleagues (ones not involved in the interviews) in the department to receive their feedbacks from a listener’s perspective (Maxwell, J. ,2013). They are also termed as practice-participants who role play and respond to the questions as pseudo participants. The reviewers are experienced and can speculate on whether the participants can provide reliable answers to the questions or not. The colleagues reviewing should have the same profile as that of the interview participants. It can then be asked how these practice-participants come up to a certain answer while reviewing the questions. This peer-review can thus present the thought-process of the colleagues and can prepare the interviewer to face the participants. Querying the participants upon how they are reaching to a particular answer wouldn’t be a necessity then as the interviewer gets a brief over how the thought process of project/cost managers work. As a result, this per-review can help in avoiding unnecessary ‘why’ questions and can keep the respondents free from any confusion (Willis, G. B.,1999). Following points were ensured through the peer review feedbacks :
i) Protocol structure : Clarity of the questions, ordering of the questions, conversational flow & intention to follow up in case of doubts.
ii) Writing : Error free spellings, Simple words, Non-judgemental statements, Repetitive questions are avoided, Academic language is avoided

Piloting : A pilot study helps in assessing the flow of the questions through a mock interview (Goh & Rahman, 2013). This piloting was performed with 2-3 department colleagues, who had gone through such interviews for other graduate interns in the company.

B.2 Informed consent agreement between the researcher & the interview participants

1. Note that this is a template to assist researchers in the design of their informed consent forms. It is important to adapt this template to the outline and requirements of your particular study, using the notes and suggestions provided.

2. The informed consent form should be accompanied by an information sheet that describes adequately (for the participants)
- Purpose of the research
- Benefits and risks of participating
- Procedures for withdrawal from the study
- Whether any personal information about the participant will be collected, processed and how and for what purpose; the right of the participant to request access to and rectification or erasure of personal data
- Usage of the data during research, safeguarding personal information, maintaining confidentiality and de-identifying (anonymising) data, controlled access to data, especially in relation to data archiving and reuse, ways of dissemination, data archiving and possible publishing
- Retention period for the research data, or if that is not possible, criteria used to determine that period
- Contact details of the researcher (or his/her representative), contact details of the data protection officer, institution, funding source, how to file a complaint.

3. Under the forthcoming General Data Protection Regulation (GDPR), consent needs to be:
- affirmative
- granular, seeking consent for different forms of data and for different use purposes

4. In this template:
- square brackets indicate where specific information is to be inserted
- black text forms the standard content of a consent form
- red text is notes to help the researcher finalise the form, not to be included in the consent form.
- grey text indicates extra optional questions

Please tick the appropriate boxes

	Yes	No
Taking part in the study		
1. I have read/listened and understood the research information dated 8th May 2019, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction. *(Separate 'yes/no' tick boxes allow the researcher to make sure that the participant is actively affirming their consent. If the participant wants to tick the no box this allows the researcher to clarify any points the participant is unsure about. If this is not applicable for your study, then remove the 'no' box.)*	□	□
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	□	□
3. I understand that taking part in the study involves *an audio-recording (destroyed post thesis completion) and scripting*	□	□
Use of the information in the study		
4. I understand that information I provide will be used for student research purpose which will be reported	□	□
5. I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	□	□
6. I agree that my information can be quoted in research outputs. I agree that my real name can be used for quotes	□	□
7. I allow the student to copyright the *specific data* as a Schiphol's property	□	□
Future use and reuse of the information by others		
8. I give permission for the information that I provide to be archived in *TU Delft's data repository* so it can be used for the future research and learning.	□	□

Signatures

Name of participant [printed]

and legal representative If applicable) Signature Date

For participants unable to sign their name, mark the box instead of sign

I have witnessed the accurate reading of the consent form with the potential participant and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely.

Name of witness [printed] Signature
Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Atul Pathak
Researcher name [printed] Signature Date

Study contact details for further information:

Atul Pathak,
MSc. Construction management & Engineering
Stevinweg 1, 2628 CN Delft, TU Delft
+31-649090964
Email : A.Pathak-1@student.tudelft.nl

B.3 Interview questions

Subject Brief

Cost-conscious designing (as defined by Arcadis), is the implementation of cost-control processes in front end phases by utilizing suitable approaches to gather & process the data in order to achieve a realistic & optimized budget..
As per past researches, an ex-post study of the front-end cost development curves can give salient recommendations on how the net cost overruns can be reduced. Such a study can reveal at what point the costs were unrealistic/unoptimized, and could have been controlled better through design actions. Researchers in the past have demanded an in-depth study into the front-end phases in order to take learnings on the key 'factors' causing it, and how these 'factors' can be steered. Till now research has only been done on 'political' & 'cognitive' factors. Less researches have been done on 'project control' based 'factors'. Unlike execution phases, design phases don't have a constant design/estimate. The designs and their respective estimates keep changing, and so the approach of steering the 'factors' is not yet known to the industry. An approach towards cost estimation/control has two main facets : the approach of information gathering (cross-project learning or open data generation using specific project documents) and the approach of information processing (top-down/bottom up). The approach could be both preventive & corrective. This interview aims to find the most preferential approach for steering the most crucial 'factors' found through the literature study & ranked through a questionnaire survey (ROUND III questions) :
a) Firstly the 'factor' should be described by you in the case-project's context by using the cost summaries of the project presented to you
b) Then, the suitable 'approach' taken in the project to steer this 'factor' should be explained.
c) Finally, the suitable approach on the basis of your general work experience should be explained.

Round I : Introductory Questions - These first set of questions aim to capture a brief insight over the project

Q-1 : What was the project objective/purpose?
Q-2 : Can you describe the planning phase in your words in contrast to the govt. projects?
Q-3 : Which phase experienced more overruns and why : front-end or execution?
Q-4 : In short, can you describe the designing process vis-à-vis the interaction with the estimators & client?

Round II : Transition Questions - These set of questions would discuss the cost development curve in the planning phases.

Q-5 : How do you explain this rise in the cost development curve?
Q-6 : What were the major causes these underestimations : strategic/political misrepresentation, cognitive/optimism bias or technical issues?
Q-7 : Was cost optimization applied at the very WBS level ?
Q-8 : With the project costs rising after the project was approved by the client, the pre-calculated feasibility is no more valid and the project approval could be a wrong choice. What is your interpretation on this?
Q-9 : How do you explain the approximate difference between the UO final budget & contractor's bid?
Q-10 : Do you think the 'cost control' process can be implemented in the 'design phase'?

Round III : Main Questions - These questions would discuss the 'SoL's' involved in the process of cost control. Their attainability from cross-project learning would be the point of interest.

Q-11 : How did the 'Scope additions' influenced the project costs in the front-end phases. What should be the correct approach to reduce the influence of this factor?
Q-12 : How did the 'risks analysis' influenced the project costs in the front-end phases. What should be the correct approach to reduce the influence of this factor?
Q-13 : How did 'Engineering calculations and design completeness' influenced the project costs in front-end phases. What should be the correct approach to reduce the 'influence' of this factor?
Q-14 : How did 'Completeness of the PvA/PvE' influenced the project costs in front-end phases. What should be the correct approach to reduce the 'influence' of this factor?
Q-15 : How did the 'time availability' influenced the project costs in the front-end phases. What should be the correct approach to reduce the 'influence' of this factor?
Q-16 : How did the 'knowledge of design-based cost drivers' influenced the project costs in the front-end phases. What should be the correct approach to reduce the 'influence' of this factor?
Q-17 : How did the 'knowledge of cost-benchmarks' influenced the project costs in the front-end phases. What should be the correct approach to reduce the 'influence' of this factor?
Q-18 : How did the exercise of 'design-variants appraisal' influenced the project costs in the front-end phases. What should be the correct approach to reduce the 'influence' of this factor?
Q-19 : How did the 'political strategic misrepresentation' influenced the project costs in the front-end phases. What should be the correct approach to reduce the 'influence' of this factor?
Q-20 : How did the 'change control process' influenced the project costs in the front-end phases. What should be the correct approach to reduce the 'influence' of this factor?

Round IV : Closure Questions.

Q-21 : Do you feel that these approaches can reduce the front-end cost escalations in transportation infrastructure projects?
Q-22 : What initiatives can consultancies & govt. take to facilitate the efforts on front-end cost control.

Appendix C: Expert Panel Judgement (Response sheets by participants)

Questions	Score (1 -5) (1- Strongly No; 5- Strongly Yes)	Reason
RESULTS		
Correctness	(How correct are the results ? You may mention the SoLs whose results aren't correct.)	
Are the SoL influence & cross-attainability ranking satisfactory to you?	4	SCOPE ADDITION + INSIGHT OF EFFECT ON COST AND SCHEDULE AT MANAGEMENT LEVEL IS SOMETHING TO BE LOOKED AT. DIFFERENT (JOINT) APPROACH REQUIRED?
Is the information collected about each SoL correct as per your overall experience.?	4	
Reproducibility	Mention if you suggest any other method as well which can make this research better	
Do you think more survey responses would have changed the pattern of mutual rank difference?	4	EXTREMITIES MIGHT BE EVEN CLEARER. GOOD START FOR NEW STUDY
Do you think that more survey responses would have changed the major rankings ? (top 5 and bottom 5 for both response categories)	2	NO
Do you think that IDA can contribute to learn more about the SoLs ?		WHAT IS 'IDA' ?
Do you feel that more interviews in a similar manner can produce more information about each SoLs?	4	
Validity		
Would the results be valid for other transportation infrastructure projects?	4	MOST ITEMS WILL BE GENERIC, HOWEVER APPROACH PER CLIENT WILL BE DIFFERENT TO SOME EXTEND.
Would the results be the valid for projects of all budget sizes?	2	SMALLER PROJECTS ARE MORE LIKELY TO VARY. THE MARGINS ARE SMALLER, THUS THE EXTREMITIES CLEARER.
FRMAMEWORK		
Practicality	How practical do you find the recommended framework approach?	
Do you find the framework practical enough for design consultancies ?	3	A PRACTICAL EXERCISE WOULD HELP TO UNDERSTAND THE PROCESS. FOR EXAMPE: PROVIDE INFORMATION FOR A PROJECT (LIMITED). LET THE GROUP AGREE ON A 'BUDGET' THEY FEEL COMFORTABLE WITH. PROVIDE MORE INFO, LIKE SOIL CONDITIONS, UTILITIES WITH COST IMPACT. DO THEY STILL FEEL COMFORTABLE WITH GIVING AN EARLY 'BUDGET'? → WHAT INFORMATION IS REQUIRED TO PREVENT FRONT-END COST OVERRUNS?
Do you find the framework practical enough for govt. decisionmakers?	3	
Do you feel the framework can help reduce front-end cost overruns?	4	SEE ABOVE
Implementation Ease	What efforts/resource/incentives are needed for the implementation of the framework?	
What major efforts will the framework require to get implemented : money, more workforce, data management ?		DISCUSSION BETWEEN CLIENT/CONSULTANT BEFORE FREEZING THE SCOPE. JOINT APPROACH BY PROVIDING GOOD INFO TO BASE DECISIONS ON.

Signature with Date : [signature] 22 . 07 . 201[illegible]

Figure A.1: Validation response sheet by Expert 1.

Research Validation Rubric for Expert Panel - VREP©

By Marilyn K. Simon with input from Jacquelyn White

Questions	Score (1 -5) *(1- Strongly No; 5- Strongly Yes)*	*Reason*
	RESULTS	
Correctness	(How correct are the results ? You may mention the SoLs whose results aren't correct.)	
Are the SoL influence & cross-attainability ranking satisfactory to you?	2-3	Do compare with "the piramid"
Is the information collected about each SoL correct as per your overall experience.?	2-3	Do Compare with the "piramid"
Reproducibility	Mention if you suggest any other method as well which can make this research better	
Do you think more survey responses would have changed the pattern of mutual rank difference?	2	The same outcome
Do you think that more survey responses would have changed the major rankings ? (top 5 and bottom 5 for both response categories)	2	the same outcome
Do you think that IDA can contribute to learn more about the SoLs ?	5	I do think so, need new methods
Do you feel that more interviews in a similar manner can produce more information about each SoLs?	-2	No, I think the cost drivers is more important than interviewing. Every one has his own way of looking to a problem
Validity		
Would the results be valid for other transportation infrastructure projects?	4	But depends within experience, project are not similar
Would the results be the valid for projects of all budget sizes?	4	idem
	FRMAMEWORK	
Practicality	How practical do you find the recommended framework approach?	
Do you find the framework practical enough for design consultancies ?	4	yes, but within experience so, the cost engineer can find the difference.
Do you find the framework practical enough for govt. decisionmakers?	2	Projects are influenced by decision makers, always yell instead of [illegible]
Do you feel the framework can help reduce front-end cost overruns?	4	yes, analyze cost overruns previous projects so you can advise the client.
Implementation Ease	What efforts/resource/incentives are needed for the implementation of the framework?	
What major efforts will the framework require to get implemented : money, more workforce, data management ?	4	Data mngt. is more important.

nature with Date : 22/7/19

Figure A.2 : Validation response sheet by Expert 2.

Research Validation Rubric for Expert Panel - VREP©
By Marilyn K. Simon with input from Jacquelyn White

Questions	Score (1 -5) (1- Strongly No; 5- Strongly Yes)	Reason
	RESULTS	
Correctness	(How correct are the results ? You may mention the SoLs whose results aren't correct.)	
Are the SoL influence & cross-attainability ranking satisfactory to you?	4	
Is the information collected about each SoL correct as per your overall experience.?	4	
Reproducibility	Mention if you suggest any other method as well which can make this research better	
Do you think more survey responses would have changed the pattern of mutual rank difference?	2	expected results.
Do you think that more survey responses would have changed the major rankings ? (top 5 and bottom 5 for both response categories)	2	
Do you think that IDA can contribute to learn more about the SoLs ?	3	
Do you feel that more interviews in a similar manner can produce more information about each SoLs?	3	don't know
Validity		
Would the results be valid for other transportation infrastructure projects?	4	Every project is unique, but results are as expected
Would the results be the valid for projects of all budget sizes?	4	Cost control is largely dependent of project processes rather than cost estimating, the results support this.
	FRMAMEWORK	
Practicality	How practical do you find the recommended framework approach?	
Do you find the framework practical enough for design consultancies ?	3	is already daily business
Do you find the framework practical enough for govt. decisionmakers?	4	By analyzing one can make predictions in budgets based on past projects.
Do you feel the framework can help reduce front-end cost overruns?	2	
Implementation Ease	What efforts/resource/incentives are needed for the implementation of the framework?	
What major efforts will the framework require to get implemented : money, more workforce, data management ?	X	Data management → manhours.

Signature with Date : [signature] 22-07-2019

Figure A.3 : Validation response sheet by Expert 3.

Research Validation Rubric for Expert Panel - VREP©

By Marilyn K. Simon with input from Jacquelyn White

Questions	Score (1 -5) *(1- Strongly No; 5- Strongly Yes)*	*Reason*
	RESULTS	
Correctness	(How correct are the results ? You may mention the SoLs whose results aren't correct.)	
Are the SoL influence & cross-attainability ranking satisfactory to you?	3	
Is the information collected about each SoL correct as per your overall experience.?	4	
Reproducibility	Mention if you suggest any other method as well which can make this research better	
Do you think more survey responses would have changed the pattern of mutual rank difference?	3	
Do you think that more survey responses would have changed the major rankings ? (top 5 and bottom 5 for both response categories)	3	
Do you think that IDA can contribute to learn more about the SoLs ?	4	
Do you feel that more interviews in a similar manner can produce more information about each SoLs?	4	
Validity		
Would the results be valid for other transportation infrastructure projects?	3	
Would the results be the valid for projects of all budget sizes?	3	
	FRMAMEWORK	
Practicality	How practical do you find the recommended framework approach?	
Do you find the framework practical enough for design consultancies ?	3	
Do you find the framework practical enough for govt. decisionmakers?	1	
Do you feel the framework can help reduce front-end cost overruns?	1	
Implementation Ease	What efforts/resource/incentives are needed for the implementation of the framework?	
What major efforts will the framework require to get implemented : money, more workforce, data management ?	1	I TINK OF ALL 3 CATEGORY. BUT I HAVE SERIOUS DOUDTS AS TO WHETHER THIS METHOD IS GOING TO CONTRIBUTE TO ALLOWING POLICY-MAKERS TO MAKE CHOICES. BECAUSE IN THESE TYPES OF MODELS YOU CAN NEVER HAVE THE CONSTRUCTION CONDITIONS TAKEN INTO ACCOUNT. AND THESE NOW DETERMINE THE LARGEST SHARE OF THE COSTS

…ure with Date : [signature] 22-7-2019

Figure A.4 : Validation response sheet by Expert 4.

Appendix D: Detailed I.D.A for "Construction works: known direct costs"

D.1 Project Schiphol Landside works

Table 24: Net escalation in each 'cost component': Total project costs breakdown

Cost Components	SO to VO			VO to DO			Net Escalation
	SO	VO	Diff.	VO	DO	Diff.	
Total Project cost	**42.40**	**44.25**	**1.85**	**44.25**	**46.50**	**2.25**	**4.10**
Total Direct costs	**29.48**	**30.79**	**1.30**	**30.79**	**32.36**	**1.57**	**2.87**
Construction works	28.00	29.24	1.24	29.24	30.73	1.49	2.73
Land acquisition							
Engineering works	1.48	1.55	0.06	1.55	1.63	0.08	0.14
Other additional works'							
Known DC	25.14	26.40	1.27	26.40	29.16	2.76	4.02
Construction works	23.65	24.86	1.20	24.86	27.53	2.68	3.88
Land acquisition works							
Engineering works	1.48	1.55	0.06	1.55	1.63	0.08	0.14
other additional works'							
YtbD D.C.	4.35	4.38	0.03	4.38	3.19	-1.19	-1.15
Construction works	4.35	4.38	0.03	4.38	3.19	-1.19	-1.15
Land acquisition works							
Engineering works							
Other additional works'							
Indirect Costs	**9.06**	**9.44**	**0.38**	**9.44**	**9.92**	**0.48**	**0.85**
Construction works	9.06	9.44	0.38	9.44	9.92	0.48	0.85
Land acquisition works							
Engineering works							
Other additional works'							
Risk reserves	**3.85**	**4.02**	**0.17**	**4.02**	**4.23**	**0.20**	**0.37**
Construction works	3.71	3.87	0.16	3.87	4.06	0.20	0.36
Land acquisition works							
Engineering works	0.148	0.155	0.006	0.155	0.163	0.008	0.01
Other additional works'							
Objectoverstijgende risico's							

Table 25: Cost development in 'Road infrastructure works'

Known D.C. - Road infrastrucutre	SO	VO	Diff.	VO	DO	Diff.	Net Escalation
Bicycle stand	0.57	0.51	-0.06	0.51	0.54	0.03	-0.03
information provision/signages	0.50	0.38	-0.12	0.38	0.40	0.02	-0.10
phasing costs	1.38	1.37	-0.01	1.37	1.44	0.07	0.06
traffic control	0.86	1.11	0.25	1.11	0.11	-1.00	-0.75
signals	0.01	0.01	0.00	0.01	0.03	0.02	0.02
walkpath	0.01	0.01	0.00	0.01	0.00	0.00	0.00
Exit lane	0.05	0.13	0.08	0.13	0.00	-0.13	-0.05
buslane	0.05	0.05	0.00	0.05	0.20	0.15	0.15
Bicycle path	0.04	0.04	0.00	0.04	0.00	-0.04	-0.04

crossings	0.09	0.09	0.00	0.09	0.10	0.01	0.01
Insert Lane	0.06	0.02	-0.04	0.02	0.00	-0.02	-0.06
Pavement works	3.03	4.52	1.48	4.52	4.81	0.29	1.77
‘kunstwerken’/viaduct	8.58	9.64	1.06	9.64	9.84	0.20	1.27

Table 26: Cost development in 'Integration Services'

Integration services (Total Direct costs)	SO	VO	Diff.	VO	DO	Diff.	Net Escalation
Cables and pipes	**6.42**	**4.83**	**-1.59**	**4.83**	**6.53**	**1.70**	**0.11**
Remove and install slot cover	0.18	0.13	-0.05	0.13	0.13	0.00	-0.05
Groundwork	1.09	0.93	-0.15	0.93	1.80	0.87	0.72
Remove cables	0.33	0.16	-0.17	0.16	0.25	0.09	-0.08
Laying cables	3.86	3.33	-0.52	3.33	3.99	0.66	0.13
Remove pipes	0.30	0.00	-0.30	0.00	0.02	0.01	-0.29
Installing pipes	0.44	0.14	-0.30	0.14	0.19	0.05	-0.26
Mantle tubes	0.15	0.01	-0.14	0.01	0.01	0.00	-0.14
Welding pits		0.00	0.00	0.00	0.01	0.00	0.01
Connections to existing network		0.06	0.06	0.06	0.08	0.02	0.08
Maintenance during the implementation phase	0.08	0.08	0.00	0.08	0.08	0.00	0.00
Putting 'white' tents	**0.05**	**0.05**	**0.00**	**0.05**	**0.13**	**0.08**	**0.08**
Traffic measures	**0.85**	**0.35**	**-0.49**	**0.35**	**0.50**	**0.15**	**-0.35**

Table 27: Detailed IDA for construciton works : Known direct costs

Name	Cost (SO)	Cost (VO)	Difference (VO-SO)	Cost (DO)	Difference (DO-VO)	Net Escalation (DO-SO)
Benoemde directe bouwkosten	**15.229**	**17.873**	**2.6438**	**18.42**	**.5483**	**3.1921**
AFRIT	.0533	.1311	.0778	.0000	-.1311	.0000
AFSCHERMINGSCONSTRUCTIE	.0000	.0000	.0000	.0000	.0000	.0000
AUTOWEG	3.0350	4.5177	1.4828	4.809	.2920	1.7747
BUSBAAN	.0494	.0474	-.0020	.1959	.1485	.1465
FIETSENSTALLING	.5725	.5100	-.0625	.5400	.0300	-.0325
FIETSPAD	.0408	.0408	.0000	.0041	-.0367	-.0367
INFORMATIEVOORZIENING	.4973	.3795	-.1179	.3981	.0187	-.0992
KRUISING	.0903	.0863	-.0040	.0987	.0124	.0083
KUNSTWERK	8.5788	9.6436	1.0648	.0000	-9.6436	-8.5788
KUNSTWERK 41	.0000	.0000	.0000	.0000	.0000	.0000
TOERIT	.0641	.0250	-.0392	.0000	-.0250	-.0641
SIGNALERING	.0061	.0061	.0000	.0250	.0189	.0189
FASERINGSKOSTEN	1.3792	1.3729	-.0063	.0000	-1.3729	-1.3792
Verleggen afrit HHH-knoop naar maaiveldniveau	.1170	.0000	-.1170	.0000	.0000	-.1170
Tijdelijke barrier op kunstwerk	.0182	.0960	.0778	.0961	.0001	.0779
Tijdelijke afzetting rijstroken op kunstwerk	.0055	.0055	.0000	.7555	.7500	.7500
Exceptioneel vervoer in de nacht	.0844	.0844	.0000	.0844	.0000	.0000
Kunstwerk toeslag tbv fasering	.2384	.2076	-.0308	.0000	-.2076	-.2384
Tijdelijke brug	.7500	.7500	.0000	.0000	-.7500	-.7500
Fase 1: Tijdelijke herinrichten Havenmeesterweg Oost	.0624	.0624	.0000	.0000	-.0624	-.0624
Fase 2: Tijdelijke herinrichten Havenmeesterweg Oost	.0183	.0335	.0152	.0000	-.0335	-.0183
Tijdelijk verplaatsen parkeerplaats Marechaussee	.0152	.0152	.0000	.0000	-.0152	-.0152
Fase 1: Tijdelijke herinrichting kruispunt	.0560	.0000	-.0560	.0000	.0000	-.0560

Handelskade – Havenmeesterweg						
Fase 2: Tijdelijke herinrichting kruispunt Handelskade – Havenmeesterweg	.0139	.0000	-.0139	.0000	.0000	-.0139
VERKEERSMAATREGELEN	.8560	1.1063	.2503	.0000	-1.1063	-.8560
Extras in VO						
Voetpad		.0065	.0065		-.0065	.0000
Overige tijdelijke voorzieningen		.0180	.0180		-.0180	.0000
			.0000		.0000	.0000
Extras in DO						
Sloopwerk kunstwerk			.0000	.0347	.0347	.0347
Aanbrengen kunstwerk			.0000	9.809	9.8095	9.8095
Voetpad			.0000	.0031	.0031	.0031

D.1 Project N270

Table 28: Cost development trend in all the 'cost components' for Project N270 (SO1 to VO2)

Cost Components	SO1 to SO2			SO2 to VO1			VO1 to VO2			VO2 to DO1			DO1 to DO2			Net Escalation
	SO1	SO2	Diff.	SO2	VO1	Diff.	VO1	VO2	Diff.	VO2	DO1	Diff.	DO1	DO2	Diff.	
Total Project cost	13.92	15.90	1.98	15.90	25.96	10.06	25.96	16.71	-9.25	16.71	20.18	3.47	20.18	18.24	-1.94	4.32
Total Direct costs	10.32	11.76	1.45	11.76	21.58	9.82	21.58	13.77	-7.81	13.77	14.31	0.54	14.31	12.17	-2.14	1.86
Construction costs	7.36	5.85	-1.51	5.85	10.07	4.22	10.07	10.29	0.22	10.29	10.81	0.53	10.81	8.99	-1.82	1.63
Land acquisition costs	0.23	0.78	0.56	0.78	0.00	-0.78	0.00	0.00	0.00	0.00	0.78	0.78	0.78	0.78	0.00	0.56
Engineering costs	1.11	3.97	2.86	3.97	11.51	7.53	11.51	3.48	-8.02	3.48	1.55	-1.93	1.55	1.29	-0.26	0.18
Other additional costs'	1.62	1.15	-0.46	1.15	0.00	-1.15	0.00	0.00	0.00	0.00	1.17	1.17	1.17	1.11	-0.05	-0.50
Known DC	9.53	11.00	1.46	11.00	21.58	10.58	21.58	13.77	-7.81	13.77	13.80	0.03	13.80	11.75	-2.05	2.21
Construction costs	6.58	5.09	-1.49	5.09	10.07	4.98	10.07	10.29	0.22	10.29	10.30	0.01	10.30	8.56	-1.74	1.98
Land acquisition costs	0.23	0.78	0.56	0.78	0.00	-0.78	0.00	0.00	0.00	0.00	0.78	0.78	0.78	0.78	0.00	0.56
Engineering costs	1.11	3.97	2.86	3.97	11.51	7.53	11.51	3.48	-8.02	3.48	1.55	-1.93	1.55	1.29	-0.26	0.18
other additional costs'	1.62	1.15	-0.46	1.15	0.00	-1.15	0.00	0.00	0.00	0.00	1.17	1.17	1.17	1.11	-0.05	-0.50
YtbD D.C.	0.78	0.76	-0.02	0.76	0.00	-0.76	0.00	0.00	0.00	0.00	0.51	0.51	0.51	0.43	-0.09	-0.35
Construction costs	0.78	0.76	-0.02	0.76	0.00	-0.76	0.00	0.00	0.00	0.00	0.51	0.51	0.51	0.43	-0.09	-0.35
Land acquisition costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Engineering costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other additional costs'	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indirect Costs	1.41	1.46	0.06	1.46	3.12	1.66	3.12	1.99	-1.13	1.99	3.57	1.57	3.57	2.99	-0.58	1.58
Construction costs	1.41	1.29	-0.12	1.29	1.46	0.17	1.46	1.49	0.03	1.49	3.18	1.69	3.18	2.64	-0.54	1.23
Land acquisition costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Engineering costs	0.00	0.00	0.00	0.00	1.67	1.67	1.67	0.50	-1.16	0.50	0.22	-0.28	0.22	0.19	-0.04	0.19
Other additional costs'	0.00	0.17	0.17	0.17	0.00	-0.17	0.00	0.00	0.00	0.00	0.17	0.17	0.17	0.16	-0.01	0.16
Risk reserves	2.19	2.68	0.48	2.68	1.25	-1.42	1.25	0.94	-0.31	0.94	2.30	1.36	2.30	3.08	0.78	0.88
Construction costs	0.80	0.76	-0.04	0.76	0.58	-0.19	0.58	0.30	-0.27	0.30	0.36	0.06	0.36	0.30	-0.06	-0.50
Land acquisition costs	0.01	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
Engineering costs	0.06	0.00	-0.06	0.00	0.66	0.66	0.66	0.10	-0.56	0.10	0.00	-0.10	0.00	0.00	0.00	-0.06
Other additional costs'	0.07	0.07	0.00	0.07	0.00	-0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.06
Objectoverstijgende risico's	1.27	1.85	0.58	1.85	0.02	-1.83	0.02	0.54	0.52	0.54	1.94	1.40	1.94	2.78	0.84	1.51