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Analyzing traffic nuisance requirements during the construction phase of Dutch civil works

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Preface

Voor u ligt het laatste onderdeel van mijn opleiding Civil Engineering and Management aan de Universiteit Twente. Tijdens mijn studie heb ik twee masterrichtingen afgerond, namelijk: Transportation Engineering & Management en Construction Management & Engineering. Het verkozen afstudeerproject heeft als doel deze beide richtingen te combineren.

Ik heb me voor het onderzoek verdiept in de wereld van verkeershindereisen, kwaliteitssystemen en contractbeheersing. Het was een zeer leerzame periode dat zeer aansloot bij mijn interesses. Het onderzoek is verricht voor Ingenieursbureau Iv-Infra, vanwege hun belang om een beter inzicht te krijgen in verkeershindereisen tijdens de uitvoering.

Het project was onmogelijk zonder de begeleiding van mijn supervisors die me door het onderzoeksproces hielpen. Ten eerste gaat mijn dank uit naar Bertjan de Boer van Iv-Infra voor zijn begeleiding, steun en toewijding. Ik was altijd in staat om vragen te stellen en brainstormsessies te plannen om de goede richting op te gaan. Verder wil ik Marc van Buiten en Tom Thomas van de Universiteit Twente bedanken voor hun begeleiding en kennisuitwisseling. De feedback was altijd nuttig om het proces te verbeteren en om weer op het goede spoor te komen op de momenten dat ik vast kwam te zitten.

Ik ben ook de geïnterviewden dankbaar voor het mogen afnemen van een interview en een kijkje te nemen in de keuken van hun organisatie. De verkregen informatie is zeer belangrijk voor dit onderzoek.

Tot slot ben ik dankbaar voor de steun van mijn familie en vrienden, die mij tijdens het project voortdurend op alle mogelijke manieren hebben gemotiveerd en gesteund.

Ik wens u veel plezier bij het lezen dit rapport dat ik met veel enthousiasme heb samengesteld.

Hicham Zahri

Haarlem, 4 februari 2020

Summary

More and more attention is paid to limiting traffic nuisance during the construction phase. In order to limit traffic nuisance, the client can request certain traffic objectives or set traffic nuisance requirements for road work. Examples of traffic nuisance requirements are: guaranteeing a certain speed, road capacity, travel time or accessibility, etc. Limiting traffic nuisance used to be a task of the government, now it is increasingly being transferred to the market, and it becomes a task of the contracting industry. Limiting nuisance is more and more part of tendering procedures, in which a contractor can have an advantage if they can fulfill certain promises regarding traffic nuisance.

Quality assurance is part of the entire quality management process. Fulfilling traffic nuisance requirements is linked with the quality assurance system of an organization. The definition for quality assurance in the construction sector is the set of measures and activities where the quality of the to-be-delivered end product is tested, monitored and demonstrated. In case requirements are not met, it is likely there could be deficiencies in their quality assurance system.

Iv-Infra is an infrastructure consultancy agency that regularly gets hired by contractors and governments for contractual and/or traffic-related advice. Iv-Infra has expressed having difficulties fulfilling the traffic nuisance requirements during the construction phase in the past. Situations where these requirements are not met can cause uneasy situations where the contractor is forced to alter their traffic nuisance promises.

The research problem is defined as: *“Managing traffic nuisance during the construction phase is getting more and more important in the infrastructure industry in the Netherlands. Iv-Infra believes their quality assurance system regarding traffic nuisance requirements is insufficient, since they experience difficulties in fulfilling these requirements.”* The aim of this study is to assess Iv-Infra’s quality assurance system, detect possible insufficiencies and suggest improvements to their current system.

The research is divided into three parts: the framework, the case study analysis and the recommendations.

The developed framework is based on System Engineering (SE). SE is a commonly used tool in Dutch civil works for structuring and securing the quality within projects. The objective of SE is providing a quality product that meets the users’ needs. In our case, it is to fulfill the traffic nuisance requirements and wishes. Due to the scarce research on traffic nuisance during the construction phase requirement fulfillments, the framework is based on requirements of infrastructure projects. The framework is divided over three main components: requirement, design and system. Each main component has a set of characteristics that define the patterns in road infrastructure projects in accordance to the Systems Engineering (SE) methodology.

Since this research specifically analyzes the quality assurance system of Iv-Infra, a research of exploratory nature, a case study analysis seems appropriate. Based on selection criteria, three cases were selected for this research. The cases were analyzed based on the project documentations and in total of 10 interviews with key players of the cases. The earlier mentioned framework, was used to assess and structure the outcome of the within-case analysis. Afterwards, a cross analysis was used to compare the outcomes of the cases and try to identify possible patterns.

In all cases the client and contractor state the requirements were (mostly) met. It seems that the current internal quality assurance system of Iv-infra works properly regarding reaching the project goals, fulfilling of requirements and satisfying the stakeholders. The quality assurance system does not follow the System Engineering protocol at all times, however, this did not cause any problems. Nevertheless, there is a lack of (structured) documentation and system verification in the quality assurance system. It seems that the internal

quality assurance system is effective and reaches its goals. The deficiencies in the external quality assurance system had no consequences so far.

These deficiencies in the quality assurance system were tolerated due to the client trusting the contractor and low amount of complaints from the other stakeholders. It is recommended to properly document and perform the verification in case there will be a client that is strict about demonstrating quality. Properly carrying it out can ensure that a system is built according to the client's and users' requirements and needs, thereby preventing possible fines and discussions. Being familiar with this protocol is useful in case a client is stricter or deems the traffic nuisance very important.

This research recommends to develop clear agreements or set obligates if and how the traffic nuisance requirement fulfillments need to be demonstrated. Other recommendations are to perform System verifications, carry them out regularly and document it. Changes to the System should be officially documented and there should be a new verification to assess if the changed System complies with the set requirements. This research provides examples how to carry out the System verification. It depends how important the requirement is, how intensive it needs to verified and how much effort the contractor should/wants to put into it. The most objective way is to measure the traffic, simpler ways are performing visually verifications or perform test runs. This research also recommends to carry out a Validation plan to ensure the output satisfied the users' needs.

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1 Introduction

This chapter provides an introduction to the master thesis. In order to understand the reasoning behind this research, this section defines the problem statement, research objective, research framework, research questions and the managerial relevance of the topic.

1.1. Traffic nuisance in perspective

Mobility is an important factor within today's society. Mobility facilitates economic activities and gives people the opportunity to participate in society (Ministry of Economic Affairs and Climate, 2016). When there are road works, it means the availability of the road in construction and the availability of the road network as a whole is under extra pressure. Since the Dutch road network is already heavily loaded, a decrease in the availability of the road network results in traffic nuisance (Hermelink, Berkum, & Ter Huerne, 2010). For example, Koffrie *et al*'s research shows that fifteen to twenty percent of traffic jams are caused by road works (Koffrie, Hoernig, & Veen, 2012).

Traffic nuisance can be measured in various ways. The measurable nuisance caused by activities can be designated as objective traffic nuisance, when the deviations lead to negative effects (delay, stealth, etc.). In addition, there is a subjective component; the experience of traffic nuisance: the way people experience the nuisance (Directorate-General for Public Works and Water Management, 2007). This experience can be influenced by a proper provision of information (Boeschen Hospers, 2009). The experience of traffic nuisance is, in contrast with the objectively measurable nuisance, is difficult to (directly) measure. The objective and subjective nuisance together form the total traffic nuisance. It is possible that objective traffic nuisance is measured, while no nuisance is experienced by the driver and vice versa (Directorate-General for Public Works and Water Management, 2007).

More and more attention is being paid to limiting traffic nuisance during the construction phase (Hermelink, Berkum, & Ter Huerne, 2010). This can relate to traffic management directly, but also by making other choices in terms of execution or design. As reconstructing a road usually leads to extra traffic nuisance during the construction phase, it is possible that the responsible government wants to limit traffic nuisance for the road users as much as possible (Hilderink, Hoeven, & Loos, 2011). In order to limit traffic nuisance, the client can request certain traffic objectives or set traffic nuisance requirements. Examples of traffic nuisance requirements are: guaranteeing a certain speed, road capacity, travel time or accessibility (Ercan, 2009).

When reviewing the infrastructure industry in the Netherlands, governmental clients gradually emphasize their primary tasks and focus more on taking advantage of specific knowledge and services available from the market. This leads to a transfer of tasks and responsibilities from the client to the contractor (Makkinga, 2016). This shift goes hand in hand with the usage of new contract types, which permits the integration of multiple project phases. These 'innovative contracts', also called 'integrated contracts', have different formats, based on the amount of involvement of the client, of which Design & Construct (D&C) is an iconic example (Gieskens, Jager, Luttikhuizen, & Riezebos, 2007). Limiting traffic nuisance used to be a task of the government. Limiting traffic nuisance is increasingly being transferred to the market, and it becomes a task of the contracting industry (Geest, 2010). Limiting nuisance is more and more part of tendering procedures, in which a contractor can have an advantage if they can fulfill certain promises regarding traffic nuisance (Hermelink, Berkum, & Ter Huerne, 2010).

1.2. Quality assurance

Quality assurance is part of the entire quality management process. Fulfilling traffic nuisance requirements is linked with the quality assurance system of an organization. The aim of quality management is to ensure that products and services meet the quality requirements of the organization and to guarantee customer satisfaction (International Organisation for Standardisation, 2008). The definition for quality assurance in the construction sector is: *"the set of measures and activities where the quality of the to be delivered end product is tested, monitored and demonstrated"* (Manghani, 2011). In case requirements are not met, it is likely there could be deficiencies in their quality assurance system. A commonly used tool in Dutch civil works for structuring and securing the quality within projects is Systems Engineering (SE) (Gieskens, Jager, Luttikhuizen, & Riezebos, 2007). The objective of SE is providing a quality product that meets the users' needs (International Council on System Engineering, 2007). In our case, it is to fulfill the traffic nuisance requirements and wishes. This tool helps to map relationships in a project and thereby provide transparency. By implementing Systems Engineering within the civil engineering sector, the following goals are envisaged: efficiency, effectiveness and transparency (Directorate-General for Public Works and Water Management, 2009).

With the transfer of tasks and responsibilities from the client to the contractor, the transfer of the responsibility of the checking, testing and proving the quality and the fulfillment of the requirements is important (Gieskens *et al.*, 2007). Checking, testing and proving the quality and the fulfillments are important pillars of verification and validation in Systems Engineering. Verification and validation allow to compare what should be made and what has been made. The main reason why verification and validation are applied is to guarantee the quality by identifying possible deficiencies (Maropoulos & Ceglarek, 2010; O'Keefe & O'Leary, 1993; O'Leary, 1993). Multiple papers (O'Leary, 1993; Schipper, 2016; International Council on System Engineering, 2007; Bahill & Henderson, 2005) describe verification as *'building the system right'* and validation as *'building the right system'*. Building the system right means the system complies with the requirements, and building the right system means the system complies with the users' needs.

In the infrastructure industry, a project has three central elements: requirements, design and the system (Maropoulos & Ceglarek, 2010; Nagano, 2008; Schipper, 2016). To ensure the quality, the contractor has to prove that they are able to, and later on that they have actually fulfilled the requirements. An example of a traffic nuisance requirement is to have limited or no traffic delay during the construction phase. Verification is a measure to identify if the plans or executed constructions are according the requirements. For example, verification can be done via traffic simulations during the design phase and by monitoring the traffic during the construction phase. Eventually, the contractor has to validate if they fulfilled the agreements. According to Oberkampf and Trucano (2008), validation provides evidence or substantiation of how accurately the eventual outcome fulfills the users' needs and/or parent requirements. In short, verification means complying with the set requirements, validation means complying with the users' needs.

A crucial part is comparing what was promised by the contractor and what was eventually carried out. There is a possibility that there is a difference when comparing what was promised and what was eventually carried out. This could be caused by problems with reaching the traffic nuisance requirements, documenting the verification and validation, or providing proof of fulfillment of requirement(s).

1.3. Problem statement

Iv-Infra is an infrastructure consultancy agency that regularly gets hired by contractors and governments for contractual and/or traffic-related advice. In general, Iv-Infra has seen contractors that promise a certain traffic nuisance requirement, get the project rewarded because of that, and eventually do not fulfill this requirement. This is quite unfair to the competitors, clients and other stakeholders, such as the road users. Situations where these requirements are not met can cause uneasy situations where the contractor is forced to alter their traffic nuisance promises. This can be very time-consuming, and it can put pressure on the budget.

Iv-Infra has expressed having difficulties fulfilling the traffic nuisance requirements during the construction phase in the past. One example is a project where the client requested a certain traffic flow during the construction phase. It was very difficult to fulfill this requirement. It took them a lot of effort to align the wishes and requirements with the outcome and prove that they fulfilled it. Another example is a project where the client requested a certain road capacity during the construction phase. In this project, it was difficult to define, express and prove the amount of traffic nuisance.

Problem statement:

> *Managing traffic nuisance during the construction phase is getting more and more important in the infrastructure industry in the Netherlands. Iv-Infra believes their quality assurance system regarding traffic nuisance requirements is insufficient, since they experience difficulties in fulfilling these requirements.*

Existing literature on traffic nuisance requirement fulfillments during the construction phase is scarce. However, there is research on the insufficiencies in quality assurance systems regarding road infrastructure projects. According to Group (2013), the quality of infrastructural projects can be assessed based on how properly the defined system is verified, validated, documented, and to which extent it is delivered in compliance with defined specifications, including regulations, design codes and standards. The International Council on System Engineering (2007) adds achieving efficient deliveries of projects in compliance with the different requirements is an important and challenging task. This difficulty is often found out during the verification process, where the products or processes get tested if they satisfy the developed requirements. Elmeidaa (2019) states this causes extra (repair) measures to get the design and/or system comply with the requirements, which makes the verification phase a stressful and lengthy process.

In reality, there are many infrastructure organizations that experience difficulties with quality assurance. According to Schipper (2016), this might be caused because verification and validation are regarded as time-consuming and inefficient. Makkinga (2016) states that the possible problems are verification and validation being performed too late, incompletely, or not performed at all. This likely results in frictions between the contractor and the client, since the contractor is not able to prove that the requirements are fulfilled. Gieskens, Jager, Luttikhuizen and Riezebos (2007) state that this can result in the client refusing payments, which may lead to financial calamities for the contractor.

1.4. Research objective

With the increasing interest in the management of traffic nuisance, Iv-Infra sees an opportunity to distinguish themselves from competitors, and wants to improve their approach on managing traffic nuisance requirements during the construction phase.

Research objective:

> *This research aims to assess Iv-Infra's quality assurance system regarding traffic nuisance requirements, detect possible insufficiencies and suggest improvements to their current system.*

This research will assess Iv-Infra's quality assurance system in order to detect the possible deficiencies. In order to obtain this information, a set of cases will be examined to map out the current state of their system, and to assess if it is insufficient. This will be assessed with a developed framework of best practices based on the relevant literature. The next step is to identity the possible insufficiencies and based on that, the outcome is to provide a list of measures that will improve their current quality assurance system.

1.5. Research framework and scope

In the infrastructure industry, a project has three central elements: requirements, design and the system (Maropoulos & Ceglarek, 2010; Nagano, 2008; Schipper, 2016). Figure 1 provides a flow chart to demonstrate the relations between the elements. Figure 1 demonstrates that verification and validation are not only executed in the system phase, but also with the design and the requirements.

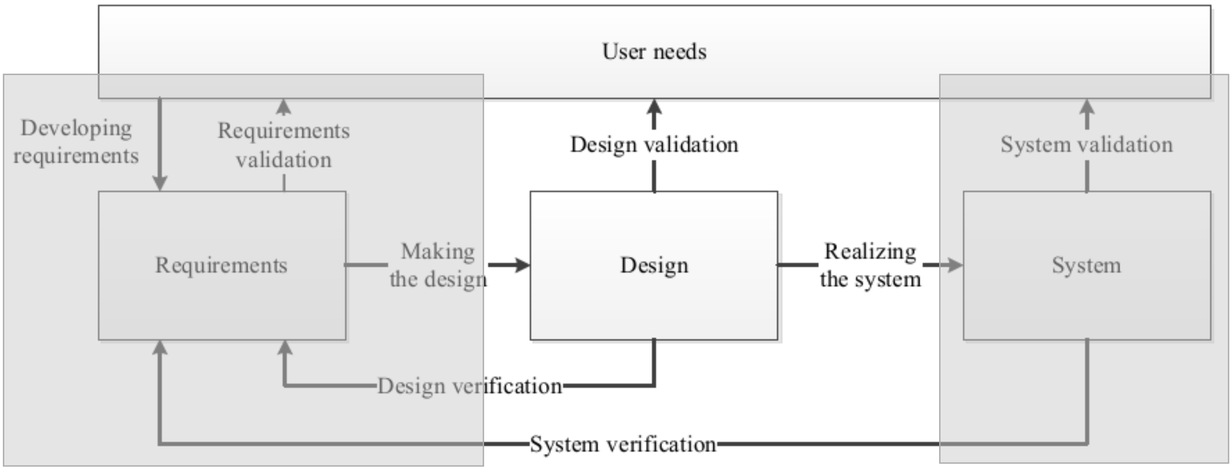

Figure 1: Flow chart of verification and validation elements (Schipper, 2016) used for the Research Scope

As mentioned earlier, in the infrastructure industry, a project has three central elements: requirements, design and the system. As visualized in Figure 1, the users' needs are translated into requirements. These requirements can be requests to have limited or no traffic nuisance at all. The client has three ways to make its requests known to the contractor in a project: as a requirement in a contract, selection criteria, or award (MEAT) criteria (Saes, 2015). It is up to the client how they want to define the traffic nuisance wishes/requests, it can be from abstract to very concrete. With innovative contracts, it is common that the client formulates the upper and less detailed requirements, in which the contractor further develops and finishes the requirements to the eventual detailed requirements (Gieskens, Jager, Luttikhuizen, & Riezebos 2007; Schipper, 2016).

To ensure the quality, the contractor has to prove that they are able to, and later on, that they have actually fulfilled the agreements. Figure 1 provides the research scope of this research. On the left side, the contractor has to prove whether their plans comply with the set requirements. On the right side, the contractor has to prove if the actual construction work complies with the set agreements.

The scope is to investigate, detect and understand the possible insufficiencies in the quality assurance system of Iv-Infra regarding traffic nuisance requirements. In order to determine the insufficiencies, the development of the requirements, design and system will be assed. The desired outcome of this research is an analysis of the current quality system of Iv-Infra and the detected (possible) insufficiencies. Further on, the research will determine possible improvements to the found insufficiencies in the quality assurance system. This research will not evaluate the traffic solutions, carry out traffic simulations or calculations.

Lastly, to develop a valid research, a more profound delimitation regarding traffic nuisance is required. This research will only focus on objective traffic nuisance due to being measurable, since there is no reliable and measurable indicator available for subjective traffic nuisance (Stallen, 1999, Heins *et al*., 2006). External effects such as noise nuisance, air pollution and vibrations are also left out in the research. Since the research is carried out for the Traffic department of Iv-Infra, their usual concerns are accessibility and traffic flow. In addition, when a client carries out a project request, the selection criteria or award criteria are usually not focused on those external effects.

1.6. Research questions

The mentioned research objective of "*[…] to assess Iv-Infra's quality assurance regarding traffic nuisance requirements, detect possible insufficiencies and suggest improvements to this system […]*" will be achieved by answering the general research question. This question is derived from the research objective as well as from the background of this research. The following question is leading in this research:

Research question:

Which measures can improve Iv-Infra's quality assurance system regarding managing traffic nuisance requirements during the construction phase?

This question can only be answered in a valid way by conducting a structured research. Therefore, the general question is divided into several, complementary sub questions. The combined answers of these questions will answer the general research question. The following sub questions are defined:

1. *Which approaches and tools in literature ensure how to reach the quality that complies with the defined requirements in road infrastructure projects?*
2. *How is the current quality assurance system of Iv-Infra defined?*
3. *What were the (possible) insufficiencies and what are recommendations to improve Iv-Infra's quality assurance system?*

Sub research question 1 is focused on the benchmark and how it should be according to literature, sub research question 2 is about the current situation and sub research question 3 is about the difference and how to bridge the gap.

1.7. Managerial relevance

This research is done from the point of view of the company Iv-Infra. As part of Iv-Groep, Iv-Infra is one of the top 10 Dutch engineering firms and have years of knowledge and experience in various markets. Iv-Infra as an engineering firm provides multidisciplinary services in the field of realization and maintenance of national and international infrastructural projects.

This research is conducted for the Traffic department of Iv-Infra. Since the research topic involves traffic and contract management, they are interested to know more about the managing requirements concerning traffic nuisance and reaching the promised quality.

1.8. Structure of the report

The first chapter provides the problem statement, the research objective, places the research questions in the context of the research framework, and defines the scope of the project. The next chapter, chapter two, describes the research design and the research material.

Chapter three provides the framework of best practices and its setup (sub research question 1). Afterwards, chapter four focuses on the findings of the case study and defining the current state of Iv-Infra's quality assurance system (sub research question 2). Afterwards, the found insufficiencies and corresponding recommendations are listed in chapter five (sub research question 3). Chapter six provides a summary of the main points of this research. Eventually, chapter seven discusses the outcomes of the research and includes the limitations and recommendations for further research.

2 Research Method

To reach the research objective by answering the main research question "*which measures can improve Iv-Infra's quality assurance system regarding managing traffic nuisance requirements during the construction phase?"* a research strategy is required. This chapter addresses the research design, which will illustrate the steps to be made to accomplish the research objective and to answer the sub research questions. This chapter will dissect the research strategy per research question. The Figure below provides the research setup.

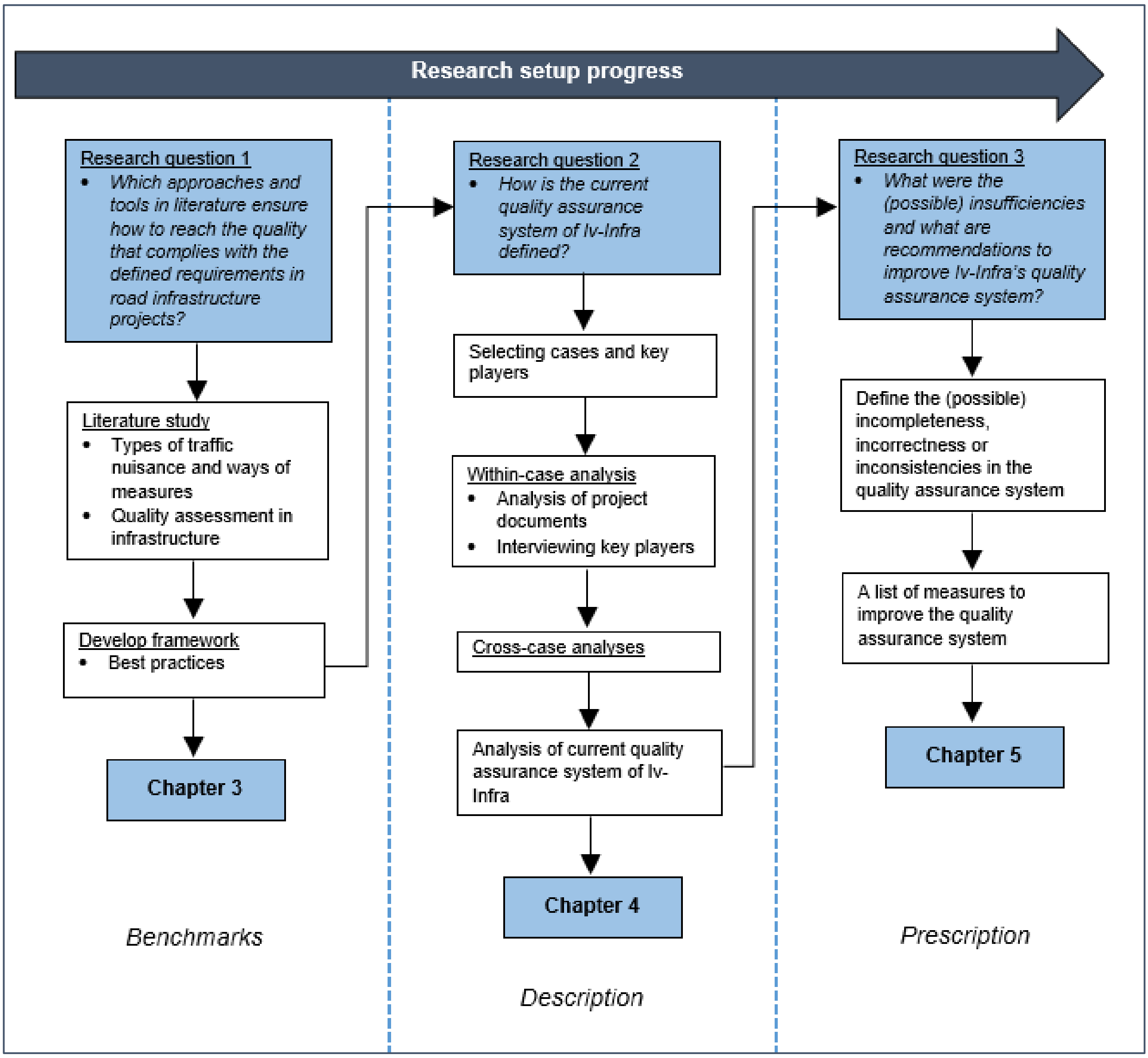

Figure 2: Research setup

2.1. Development framework

The purpose of this research is to assess the current quality assurance system of Iv-Infra regarding traffic nuisance during the construction phase requirements. Their quality assurance system will be assessed based on the comparison of best practices. In order to answer the first sub-research question one *"Which approaches and tools in literature ensure how to reach the quality that complies with the defined requirements in road infrastructure projects?"* a framework is developed.

The objective of the framework is to determine if the processes were clear, disciplined, structured and there are no misunderstandings. A quality assurance system is a set of measures and activities where the quality of the to be delivered end product is tested, monitored and demonstrated (Gieskens, Jager, Luttikhuizen & Riezebos, 2007). In order to test the quality assurance system of Iv-Infra regarding traffic nuisance, a framework is developed based on the System Engineering principles. The objective of SE is providing a quality product that meets the users' needs (International Council on System Engineering, 2007). In our case, it is to fulfill the traffic nuisance requirements and wishes.

When carrying out product that needs to comply with the specifications, they should be released throughout a system lifecycle (International Council on System Engineering, 2007). This helps support providing the quality assured products that satisfy the customers' wishes and needs.

The quality of an infrastructural project can be measured based on how well the established system is verified, validated, documented, and to which extent it is delivered in compliance with defined specifications, including regulations, design codes and standards (Group, 2013). In this case, the promises can be the promised traffic nuisance such as delay time, accessibility or capacity.

The developed framework for this research develops further on existing frameworks. There are two who are interesting for the research: Bahill and Henderson (2005) & Elmeidaa (2019). Bahill and Henderson (2005) have developed a system to classify problems in the cases based on System Engineering; System and Requirements Classification Model (SRCM). The framework puts the two concepts of requirements, development and system verification, and validation side to side. However, they do not differentiate between requirements or design and system, only requirements and system. The reason for this is that their focus was not on a specific industry. One typical infrastructure project is included: the Tacoma Bridge. The framework of Bahill and Henderson is shown in the Table below.

Table 1 Framework model of analysis of Bahill and Henderson (2005)

	Requirements		System
Valid requirements	A1	Verified and validated	C1
Incomplete, incorrect or inconsistent requirements	A2	Unverified and validated	C2
No requirement	A3	Verified and unvalidated	C3
Infeasible requirements	A4	Unverified and unvalidated	C4

Another found framework (Elmeidaa, 2019) was built from the System Engineering principles and partly based on the Bahill and Henderson (2005) framework. Her aim was to assess the performance infrastructure projects in developing requirements and designs to be in compliance with each other. This research was very focused on internal compliance with requirements regarding designs, and only analyzed the requirements and designs of infrastructure projects. The construction phase was not analyzed, which is a crucial phase regarding traffic nuisance research. Also, components such as demonstrability of quality, quality tests, providing proof, agreements on verification and validation are missing in this framework.

In order to make the framework more fitting for the research, the mentioned ‘missing’ attributes of other frameworks (Bahill & Henderson, 2005; Elmeidaa, 2019) were added to the framework for this research. As mentioned in Chapter 0, in the infrastructure industry, a project has three central elements: requirements, design and the system (Maropoulos & Ceglarek, 2010; Nagano, 2008; Schipper, 2016). In order to setup a framework of best practices, *Requirements, Designs* and *Systems* are chosen as the main components for this analysis. Examples regarding these components for this research could be: a certain traffic delay or minimum capacity as a (traffic nuisance) requirement, traffic management plans or calculations that prove how it theoretically will be met as design and the eventual outcome during the construction phase is seen as the System.

Each main component has a set of characteristics that define the patterns in road infrastructure projects in accordance to the Systems Engineering (SE) methodology. Figure 1 as shown in Chapter 0, provides a conceptual representation of the three components. The framework for this research concretizes these steps by adding elements such as providing proof, documentation of the verifications and validation, and also if the verification is clear, disciplined and ongoing. Due to the scarce research on traffic nuisance during the construction phase requirement fulfillments, the framework is based on requirements of infrastructure projects, as stated in the research question. The framework and its setup are described in Chapter 3.

All developed characteristics based on literature of infrastructure projects are applicable for this research. Every component (requirement, design and system) is important, since all steps are needed to be analyzed in order to assess the quality assurance system. However, traffic nuisance occurs during the construction phase. Therefore the System component, what is carried during the construction phase, should be the most interesting one of the framework. This component defines if the requirements were eventually met and if the users’ needs were satisfied.

2.2. Case study

2.2.1. Research method

In order to answer research question 2: *“how is the current quality assurance system of Iv-Infra defined?”,* using case studies is the chosen strategy for revealing the details of the way current practices are carried out in Iv-Infra’s projects. Case study is a form of qualitative research, in which one or a few manifestations are studied in-depth in its natural environment. By implementing the case study research method, it provides profound insights into one or several processes restricted in time and space (Yin, 2013). Since this research specifically analyzes the quality assurance system of Iv-Infra, a research of exploratory nature, a case study analysis seems appropriate. In a case study research, various research methods can be used, such as in-depth interviews and document analysis. A case study focuses on a broad problem definition. As a result, the research remains open to possible innovative insights. For each case study, multiple sources of information are sought to prevent that too narrow and possible one-sided data collection takes place (Leedy & Ormrod, 2013). This research will analyze each case on the basis of project documentations and interviews.

There are different variants within the case study method: a single case study and a multiple case study. This research chooses to have a multiple case study; meaning more than one case will be used. This offers the opportunity to assess the outcomes of different cases. For example, a project where the traffic nuisance requirements have been successfully met and projects where that did not go well. On the other hand, you can look for similarities between similar cases. If successful, the evidence is stronger than with a single case study.

First, the cases are examined individually and independent from each other. When the quality assurance system of Iv-Infra is assessed in every case, a cross-case analysis’ aim is to identity patterns (Leedy & Ormrod, 2013). Similarities in the management of traffic nuisance can appoint patterns or coincidences. To be able to see the difference and determine whether a similarity is random or structural, the reasons behind this similarity should be understood. When the same characteristics cause similar aspects, a pattern is more likely, but when the circumstances are totally different, it may be based on coincidences.

The other way around, differences can be based on coincidence. Differences may result in different outcomes of the data gathering, whilst the problem can be identical. Examples or differences that could cause similarities are the types of traffic requirements, indicators, road and project area. Hence the differences should be paid attention to, and the researcher should understand them to see how the deviating case fits in the identified problems and designed solutions.

Cross-case analysis will be used to assess whether the supposed causes of a problem are in line with the other cases and whether the designed solution is applicable in other cases as well. The comparison between cases will point out if the causes of a specific problem class are the same as in other cases. When a problem class did not occur in other cases, the comparison will point out in case the designed solution was already implemented.

2.2.2. Data analysis

The data collected from project documents and interviews are analyzed based on pattern matching. This is a core procedure in theory-testing with case study research according to Hak & Dul (2009). The main objective of pattern matching is to assess if the defined patterns, based on literature, comply with the detected patterns in current practices of Iv-infra.

As mentioned earlier, the pre-set defined patterns in the developed framework are clustered into three main components: *Requirement*, *Design* and *System*. Each component has a set of characteristics that define patterns of best practices in road infrastructural projects. The characteristics in the framework are defined in a qualitative manner (as presented in Paragraph 3.1). The current practices of Iv-Infra, which are the detected patterns, were analyzed and assessed with the defined patterns.

Regarding the within case analyses, the possible outcomes are a detected match, quasi-match or mismatch with the defined patterns. The grading of the outcome has been carried out via a three-point scale:

- \- means there is no match between the expected and observed patterns;
- \+ means there is a match;
- 0 means there is some kind match, but it does not cover all characteristics of the defined pattern.

Since a traffic nuisance requirement can be dealt with differently, a pattern matching is performed per indicator per case. The eventual outcome is a table that combines the defined patterns of characteristics, the observed pattern, the outcome of matching and explanation. There are different procedures in grading the patterns of the within case studies, there are four in total.

The first approach is grading certain characteristics based on the existence of them, such as the documentation of the traffic nuisance project goals, requirements, and design and system solutions. These usually have dedicated documents or dedicated chapters in documents. If they exist, they receive the grade +, if not, a - and, if partly, a 0. The next step is to also decide if a pattern based on a certain activity exists, however, this will need a more thorough analysis such as: if verification and/or validation (or multiple) has taken place, quality tests of the clients and updating of requirements, designs and systems. The analysis determines if they were (officially) carried out, if there is documentation of it and if it was done frequently. If it was done accordingly with these aspects, they receive the grade +, if not a - and, if partly a 0. Next, is the grading of applying a certain approach, such as implementation of SMART requirements, having traceable requirements and the usage of an accessible information source. These aspects are graded based on if they followed the System Engineer protocol. If they did, they receive the grade +, if not a - and, if partly a 0. Lastly, interviews are used to confirm the findings of the documents study and/or to assess characteristics that were not found in the documents. An example is if the made agreements on how the quality of the traffic nuisance requirements fulfillment will be demonstrated. If there are agreements on this matter or a ruleset on how the contractor needs to demonstrate the quality, it receives the grade +, if not a - and, if partly a 0. Appendices K, L and M present tables of the within cases pattern matching results with their explanations.

After the within case analyses, a cross case analysis is carried out that enables comparing the characteristics of projects to have a more comprehensive understanding of the current practices. The cross-case analysis' aim is to detect differences, similarities, and forms the basis for explaining the possible insufficiencies in Iv-Infra's quality assurance regarding traffic nuisance requirements. This analysis is to determine if characteristics' outcomes are actually patterns or coincidences. To be able to see the difference and determine whether a similarity is random or structural, the reasons behind this similarity should be understood. When the same characteristics cause similar aspects (such as only +'s or -'s), a pattern is more likely, but when the circumstances are totally different, it may be based on coincidences. An interesting analysis is to determine if the +'s and -'s occur on the same places or different places. Also, if a – occurs, what was the cause of it? Was something not carried out properly, and did it effect other characteristics' outcomes? A crucial part of the analysis is comparing what was promised by the contractor, and what was eventually carried out. There is a possibility that there is a difference when comparing what was promised, and what was eventually carried out. Perhaps there were problems with reaching the requirements, documenting the verification or providing proof. Also, different traffic nuisance requirements, process approaches and quality assurance setups can lead to different outcomes. It is interesting to research if the requirements are met, if the quality assurance system is sufficient, and if the work was carried out in a pleasant way for the client.

2.2.3. Case study selection

In order to perform the case study, relevant cases need to be selected. This research has developed criteria in order to select fitting projects for this research. There are seven criteria in total, which are shown in the Table below.

Table 2: Criteria selection cases

Criteria selection	Description
Type of client	The Dutch public infrastructure market (national, provincial or municipal)
Type of work	Infrastructural, specifically Dutch road work
Type of contract	Design and Construct
Set agreements	Having traffic nuisance requirements during the construction phase
Tendering process	Having traffic nuisance award criteria
Current stage of project	Finished
Iv-Infra involved	Yes

There were four cases available for this research. However, one case was still in the design phase, making it not finished and impossible to test the quality system during the construction phase. The remaining three cases fulfill all the criteria and were selected for this research.

The three cases all fulfill the selection criteria, yet they still differ in multiple areas. The most noticeable differences are:

- All projects had a different client, nonetheless, all of them were Dutch Provincial clients;
- All projects had a different contractor;
- The size of the projects differ (large vs medium-sized vs small);
- The different use of traffic nuisance requirements and indicators;
- Difference in the situation of the project area (rural or urban);
- Iv-Infra's role (either consultant of the contractor or the client).

Similar projects make it easier to compare and generalize the found insufficiencies and the possible causes. In this case, it is understandable the differences in cases occur since different projects from different clients have different problems and needs. It can be benedictional to study the differences in approaches if it resulted in different experiences and outcomes. It this case, the selected cases show many differences from each other. As written in sub paragraph 2.2.1, this makes it difficult to compare and generalize patterns or coincidences. Therefore, this research will mostly make assessments in case certain the same outcomes occurred (almost) all the time.

There are some similarities regarding the traffic situation in all cases. The first is that all roads are roads of Provinces of the Netherlands, also called N-roads. They are important roads, and have the objective to connect cities with each other; however, they are not part of the main Dutch traffic network. Another similarity is the common use of accessibility as a traffic nuisance requirement. All cases have a form of accessibility defined as a traffic nuisance that needs to be controlled during the construction phase. Keep in mind that case 1 and 3 also have other types of requirements. In case 1, the stores have to remain accessible. In case 2, the roads itself, the houses and stores have to remain accessible. In case 3, the road itself had to remain accessible. Next, this research will provide more background information per case.

Case 1

The case description has been left out of the report due to confidentially reasons.

Lastly, a set of key players from this case were interviewed to provide extra background information, why certain choices were made and possibly validate the findings. The interviewed key players are shown in the Table below.

Table 3: The key players that were interviewed of case 1

	Role
Expert 1	Traffic Advisor contractor (Iv-Infra)
Expert 2	Main Contractor
Expert 3	Traffic Manager contractor (Iv-Infra)
Expert 4	Contract Manager client
Expert 5	Traffic Designer contractor

Case 2

The case description has been left out of the report due to confidentially reasons.

Lastly, a set of key players from this case were interviewed to provide extra background information, why certain choices were made and to possibly validate the findings. The interviewed key players are shown in the Table below.

Table 4: The key players that were interviewed of case 2

	Role
Expert 1	Contract Manager client (Iv-Infra)
Expert 2	Project Leader client (Iv-Infra)
Expert 3	Technical Manager Contractor

Case 3

The case description has been left out of the report due to confidentially reasons.

Lastly, a set of key players from this case were interviewed to provide extra background information, why certain choices were made and to possibly validate the findings. The interviewed key players are shown in the Table below.

Table 5: The key players that were interviewed of case 3

	Role
Expert 1	Contract Manager client (Iv-Infra)
Expert 2	Senior Planner

2.2.4. Case documents

As mentioned earlier, the documents of cases will be analyzed. When the cases are selected, documented information will be used to get better understanding of the quality assurance system of Iv-Infra. The needed documents are divided over the three components of the developed framework.

In addition, complementary expertise from interviews was needed to receive information that was not clear or not mentioned in the project documentations. You can find more about the interviews in the next paragraph.

Requirements analysis
This component determines which project documents were needed per project:

- The client's project goals;
  - What is needed: the tender specification
- The client's traffic nuisance requirements/wishes;
  - What is needed: the tender specification
- The client's award criteria in the tender;
  - What is needed: the tender specification
- To determine if the requirements are traceable;
  - What is needed: the contract
- If there are any payments linked with not fulfilling traffic nuisance requirements;
  - What is needed: the contract
- The alignment of roles, responsibilities and risks in the process.
  - What is needed: the contract, risk matrix and an interface matrix

Design analysis
This component determines which project documents were needed per project:

- The contractor's interpretation of the traffic nuisance requirements;
  - What is needed: the contractor's offer in its bid. Also, the translations of the requirements, why certain design solutions were chosen, and if possible, the calculations on how they came to the measures.
- How the client assessed the traffic nuisance promises in the winning offer;
  - What is needed: the tender documents and the client's assessment
- How the contractor set up the processes in order to arrive at the requested end result and in which way the inspection will be carried out;
  - What is needed: project quality plan
- The report the contractor wrote, in advance, to explain how every wish and requirement of the client will be met;
  - What is needed: verification plan and/or contract management plan
  - The linked documents (the proof) that are mentioned in the plan that specify how a requirement will be met. This can be a monitoring plan, traffic management plan and its

annexes (elaborate on traffic management, construction logistics, plan of approach, risk management and communication).

- How the contractor eventually demonstrated that every wish and requirement of the client has been met.
    - What is needed: verification reports and/or progress reports
        - The carried out design verification(s)
        - The carried out design validation(s)
        - The provided proof that fulfills the requirements and users' needs. This can be a design or logistical plan.

System analysis

This component determines which project documents were needed per project:

- How the contractor eventually demonstrated that every wish and requirement of the client has been met;
    - What is needed: verification reports and/or progress reports
        - The carried out system verification(s)
        - The carried out system validation(s)
        - The provided proof that fulfills the requirements and users' needs. This can be a testing or a monitoring report, or based on videos or pictures.
- How the client assessed the quality of the contractor;
    - What is needed: the test reports, audits and the acceptance reports of the client
- The added changes after the project was rewarded.
    - What is needed: request for contract change(s) or deviations and possible project evaluations

2.2.5. Interviews

Besides the project report documents, interviews were carried out to find out more about the cases. As stated earlier, multiple sources of information are sought to prevent that too narrow and possibly one-sided data collection takes place. Talking to key players of a case provides their insight knowledge and understanding of the processes in the project. It might be possible that not everything is disclosed in the project documents, especially identifying why certain choices were made can be difficult to uncover via documentations. To add to that, interviews are also used to confirm a certain finding in the cases.

Another reason to conduct interviews is the diversity of available information, and the speed of obtaining that information. It improves the level of research if different people with specific roles are interviewed, who are working for various organizations, as they can provide several background information and insights, which is considered an advantage.

These interviews were held with key players within a project. Key players are experts with relevant knowledge about managing the traffic nuisance requirements in a certain case. Key players fulfill for example the role of project manager, contract manager or tender manager. It is likely that not every interviewee was involved in the whole process of the project; therefore they possibly do not have an integral overview of all the needed to know aspects. In case someone was not involved in the whole process, the focus was to include people who were involved per phase of the quality assurance cycle.

The interviews were conducted mostly face-to-face or via telephone in order to be able to give clarification for possible doubts if a question or response was not understood properly. This research used semi-structured interviews with the key players from different organizations. There was a structured outline that was applied for the interviews, however some space was left open for additional questions that seemed informative at that moment. This structured outline is shown in Appendix A. A semi-structured interview results in a deeper understanding of a situation because of the opportunity to identify new factors that can affect the current practices.

These interviews were carried out after the project documents' analysis per case. Therefore, the interviews were mostly used to obtain information that was not clear or not mentioned in the project documentations. It is important to mention that the interview questions are depending on the outcome of the document analysis, and the role of the person that is being interviewed.

There were several types of questions asked during the interviewed. One type is why certain choices were made, such as the type of traffic nuisance requirement or indicator and how the contractor decided to demonstrate the requirement fulfillment. Another type of question is to determine the importance levels, such as how important were the traffic nuisance requirements and the documentation of the verification and validation of the design and system. Another interesting type of questions are the compliance/satisfactory level, such as how was the celebration between the client and contractor, if the activities were carried out according to the plan, and if the outcome of the project met the expectations. In addition, there was the type of questions regarding if were any difficulties in fulfilling the requirements, why they were difficult; and how the outcomes were received by the client. At the end, the interviewees were asked for their suggestions to improve current practices in managing traffic nuisance requirements. You can find more about this in Paragraph 2.3. The complete transcripts of the interviews with key players are shown in Appendix G.

A contractor and client can agree on certain traffic nuisance agreements. It is interesting to know if the eventual traffic nuisance during construction phase is was controlled by the implement requirements, design and systems. For this research, the most interesting thing to ask how the traffic nuisance was perceived and if the satisfied the users' needs.

2.3. Setup recommendations

This section explains the setup for the sub research question 3: *what were the (possible) insufficiencies and what are recommendations to improve Iv-Infra's quality assurance system?* The previous sub research question really focused on analyzing the current quality assurance system of Iv-Infra. This part of the research is meant to focus on the possible insufficiencies in Iv-Infra's quality assurance and recommend improvements.

In order to answer the question, existing literature and interviews are used to find recommendations to improve the quality assurance system of Iv-Infra. The existing literature mostly used to explore alternative options and to compare the decisions and outcomes with best practices. During the case study of research question 2, possible solutions will be explored via the interviews. Hence the researcher shall anticipate during the data gathering step on the analysis and adjust their questions to the ad hoc analysis of the previous answers of the interviewee. Besides the literature and interviews, it is also possible to use solutions taken from choices/decisions made in the other cases studies, if they are adaptable to the case in question. A list of measures to improve the quality assurance system is shown in Chapter 5.

2.4. Feedback group

This paragraph is not linked with any sub research question directly. This research had a feedback group and it was mostly used for their best practices and practical experience. These were not (formal) interviews, since these people's opinion was mainly used for a better understanding of the research scope. The Table below provides a list of the people in the feedback group.

Table 6: People in the feedback group

	Role
Expert 1	Senior Traffic Advisor Iv-Infra
Expert 2	Senior Project leader Iv-Infra
Expert 3	Senior Advisor Contract- and Risk Manager Iv-Infra
Expert 4	Senior Advisor Contract- and Risk Manager Iv-Infra
Expert 5	Independent Relatics advisor
Expert 6	Independent System Engineer advisor
Expert 7	Independent Contract and Process Management
Expert 8	Project Leader Accessibility

3 Setup framework

This chapter provides the answer to sub research question 1: *"Which approaches and tools in literature ensure how to reach the quality that complies with the defined requirements in road infrastructure projects?"* This chapter provides the framework of best practices, which is designed based on the literature view. First, the framework itself and an overview of the applicability is defined. Next, the key concepts are explained. Lastly, the theoretical background is provided of the three components (Requirement, Design and System) of the framework.

3.1. The framework of best practices

The main assessment is to determine if the processes were clear, disciplined, structured and there were no misunderstandings. As mentioned in the methodology, in order to setup a framework of best practices, *Requirements, Designs* and *Systems* are chosen as the main components for this analysis. Each main component has a set of characteristics that define the patterns in road infrastructure projects in accordance to the Systems Engineering (SE) methodology. The Table below provides the developed framework.

Table 7: The framework of best practices to test the quality assurance of a project

Requirement analysis	**Defined pattern**	**Literature**
	The project goals should be documented	(Kiviniemi & Fischer, 2004)
	The developed requirements should be based on the wishes and requests of (important) stakeholders	(Elmeidaa, 2019; Graaf *et al*., 2016; Graaf *et al*., 2017)
	The developed requirements should be SMART (Specific, Measurable, Acceptable, Realistic and Time-bound)	(Elmeidaa, 2019; Graaf *et al*., 2016; Graaf *et al*., 2017; Sparrius, 2014)
	The developed requirements should be documented	(Farnham, Aslaksen & Merz, 2009; Graaf *et al*., 2016; Graaf *et al*. 2017; Locatelli *et al*., 2014; Kiviniemi & Fischer, 2004; Marchant 2010)
	The updated requirements should be documented	(Farnham, Aslaksen & Merz, 2009; Graaf *et al*., 2016; Graaf *et al*. 2017; Locatelli *et al*., 2014; Kiviniemi & Fischer, 2004; Marchant 2010)
	The developed and updated requirements should be traceable	International Council on System Engineering, 2007; Farnham, Aslaksen & Merz, 2009; Graaf *et al*., 2016; Graaf *et al*. 2017; Locatelli *et al*., 2014; Kiviniemi & Fischer, 2004; Marchant, 2010)
	The developed requirements information should be stored in accessible sources	(International Council on System Engineering, 2007; Saes, 2015; Marchan, 2010; Elmeidaa, 2019)
	There are clear agreements or a defined ruleset on how the contractor will demonstrate the quality	(Oberkampf & Trucano, 2008; Gieskens *et al*., 2007)
Design analysis	**Defined pattern**	**Literature**
	The designs should be developed based on the defined requirements and other specifications	(International Council on System Engineering, 2007; Graaf *et al*., 2016; Graaf *et al*., 2017; Makkinga, 2016; Schipper, 2016)

	Decisions on the designs should be documented	(International Council on System Engineering, 2007; Graaf *et al*., 2016; Graaf *et al*., 2017)
	The descriptions of the design solutions should be stored in accessible sources	(International Council on System Engineering, 2007; Saes, 2015; Marchan, 2010; Elmeidaa, 2019)
	Verification of the designs with the developed requirements should be ongoing (not restricted to one specific moment in time)	(International Council on System Engineering, 2007; Marchant, 2010; Elmeidaa, 2019)
	Verification of the designs with the developed requirements should be a disciplined process (Verification and Validation plans with specific, clear roles and responsibilities)	(International Council on System Engineering, 2007; Marchant, 2010; Elmeidaa, 2019)
	Verification of the designs should include evidence that satisfies the requirements	(Bahill & Henderson, 2005; Oberkampf & Trucano, 2008)
	The provided proof is of the quality as agreed upon in advance	(Oberkampf & Trucano, 2008; Gieskens *et al*., 2007)
	The design solutions are validated (satisfy the users' needs)	(International Council on System Engineering, 2007; Graaf *et al*., 2016; Graaf *et al*. 2017; Schipper, 2016)
System analysis	**Defined pattern**	**Literature**
	The systems should be carried out based on the defined requirements, specifications and designs	(Elmeidaa, 2019; Graaf *et al*., 2016; Graaf *et al*., 2017)
	Decisions on the systems should be documented	(Farnham, Aslaksen & Merz, 2009; Graaf *et al*., 2016; Graaf *et al*. 2017; Locatelli *et al*., 2014; Kiviniemi & Fischer, 2004; Marchant 2010)
	Documentation on the system decisions should be stored in accessible sources	(International Council on System Engineering, 2007; Saes, 2015; Marchan, 2010; Elmeidaa, 2019)
	Verification of the systems with the developed requirements should be ongoing (not restricted to one moment in time)	(International Council on System Engineering, 2007; Marchant, 2010; Elmeidaa, 2019)
	Verification of the systems with the developed requirements should be a disciplined process (e.g. V&V reports with specific and clear roles and responsibilities)	(International Council on System Engineering, 2007; Saes, 2015; Marchant, 2010; Elmeidaa, 2019)
	Verification of the systems should include evidence that satisfies the requirements	(Bahill & Henderson, 2005; Oberkampf & Trucano, 2008)
	The carried out system should satisfy the requirements and other specifications	(International Council on System Engineering, 2007; Graaf *et al*., 2016; Graaf *et al*. 2017; Schipper, 2016)
	The provided proof is of the quality as agreed upon in advance	(Oberkampf & Trucano, 2008; Gieskens *et al*., 2007)
	The system is validated	(International Council on System Engineering, 2007; Graaf *et al*., 2016; Graaf *et al*. 2017; Schipper, 2016)
	The client performed quality inspections during the construction phase	(Kuijpers & Berg, 2007; Gieskens *et al*., 2007)

This paragraph will provide a short summary of the made framework. The theoretical background regarding the framework is explained in the paragraphs afterwards.

Requirement analysis
A project usually starts with very abstract requirements/wishes. These usually are the project goals and/or users' needs set by all the involved stakeholders. An example could be to have a limited amount of traffic nuisance. These goals and initial wishes can be used to reflect on and validate the project or an element from the project. The developed requirements should be based on the project goals, wishes and requests of the (important) stakeholders. Further developed requirements could be to express traffic nuisance into a minimum capacity (such as 800 motor vehicles per hour).

In order to classify if the traffic nuisance requirements are ambiguous, incorrect, unnecessary and/or incomplete, they will be assessed if they are SMART (Specific, Measurable, Acceptable, Realistic and Time-bound). Expectations are important to set when one party has to prove the reached quality. Therefore, the framework determines if there was a ruleset or any made agreements on how the contractor was going to prove the required fulfillment. This will assess if the client set any expectations on how the requirements will be proven during the construction phase, what type of measurements would be used and how detailed the documentations would be.

With Systems Engineering it is mainly about customer requirements, design/system considerations and the choices made. By storing this information properly, miscommunication will be prevented, and errors, delays and damage claims can be avoided. This is why (updated) requirements should documented, accessibly and traceable.

Design analysis
A logical first step is to determine if designs were based on the set requirements. To continue with the earlier example, the minimum capacity during the construction phase has to be the translation into the design. A design can be an actual design, a planning, logistical plan, calculation or simulation. The design process must be organized in a structured way, in order to give insight to the project team's progress of the design process and to be able to demonstrate that the design meets the requirements at the end of the design process. Documenting and recording every phase within design development is very important in order to have a traceable and logical set of solutions.

When the design is developed, there should be feedback loops, to verify if the outcome really meets the requirements and to validate if it satisfies the users' needs. Since the designs are usually developed over time, verification should be ongoing, which means performing it several times. In addition, verification should be a disciplined process: this means there is a structure on who and when performed the verification, the linked traffic nuisance requirement and the status of the verification. This is often provided in a Verification and Validation plan (V&V plan).

System analysis
System analysis is basically the part where the construction phase is analyzed. The first step is to determine if the contractor was able to perform the construction based on the set requirements, specifications and designs. Decision based on the Systems, including changes to the System, should be documented and accessible, this helps them to be structured, easy to find, possible to link with systems or processes, and to show externals how and why certain design steps were made.

When the Systems are developed, next is to have a feedback loop to verify if the outcome really meets the requirements and satisfies the users' needs. Since traffic nuisance is an ongoing activity, verification should be also ongoing, which means performing it several times. This verification should be a disciplined process: this means there are clear, specific roles and responsibilities. This is often provided in a Verification Report. In order to prove the System is according to the requirement and wishes, proof should be provided. This can be videos, pictures, traffic measurements, etc. An interesting addition to this component is the possibility of the client testing the quality. This research is very focused on the construction phase (and therefore the System), therefore the researcher added the ability of testing the traffic nuisance into framework.

3.2. Key concepts

This section provides the key concepts important to know for this research.

3.2.1. Measuring traffic nuisance

The literature review is aimed to find the possible ways of determining what kind of indicators are there, how they get measured, and if there are standardizations on traffic nuisance during the construction phase. As mentioned in Chapter 1.1, there are two types of traffic nuisance: objective and subjective. This research will only focus on objective traffic nuisance due to being measurable, since there is no reliable and measurable indicator available for subjective traffic nuisance (Stallen, 1999, Heins *et al*., 2006). There are different ways to measure objective traffic nuisance. Appendix B provides a list of options for traffic nuisance indicators. The list is extensive and varies from intensity/capacity ratio, speed, traffic congestion, travel time to capacity, etc..

When reviewing literature and available documents of Iv-Infra, an important finding is that there are no standardizations on how to measure traffic nuisance. Inherent to that means there are different ways to measure traffic nuisance. Since there are no standardizations, every client is allowed to prescribe different (types of) traffic nuisance requirements. It is even possible that a client can have different traffic nuisance requirements per project. Basically, a client can propose different traffic nuisance demands regarding what the client finds important at that moment.

Even though there are no standardizations on traffic nuisance, Directorate-General for Public Works and Water Management (in Dutch: *Rijkswaterstaat*), the largest client of the Netherlands regarding public works and water management, has published guidelines on how they measure traffic nuisance in Pol *et al*. (2010) and Koffrie, Hoernig & Veen (2012). In the mentioned guidelines, Directorate-General for Public Works and Water Management uses two dimensions to determine the impact of traffic nuisance: nuisance class and nuisance category. The nuisance class is a measure of nuisance for the individual road user, based on the delay time. However, the only found guidelines was not used in the studied cases. These guidelines are specifically used for motorways that are part of the main network. All cases were not part of the main network and there was no standardization found for the underlying network. This means all used indicators of the cases have to be assessed on their individual characteristics. More about the guidelines of Directorate-General for Public Works and Water Management are explained in Appendix C.

3.2.2. Contract type and procurement procedure

The explanation of a contract and the most dominant contract types are: Design-Bid-Build (also called traditional contract) and Design and Construct (also called integrated contract) are explained in Appendix E. Background information about the procurement procedure and award criteria are explained in Appendix F.

3.2.3. Verification and Validation

The general definition of verification and validation were giving in Chapter 1. What Figure 1 clearly displays is that verification and validation are not only executed in the system phase, but also with the design and the requirements. It displays three validation types and two verification types. As shown in the flow chart, there is: requirement validation, design validation, system validation, design verification and system verification. The explanation to these definitions are shown in Table 8.

Table 8: *Definitions of verification and validation types (Schipper, 2016)*

Definition	Explanation
Requirement validation	Ensuring that the set of requirements is complete, unambiguous, consistent, and represents a feasible and working system in the intended environment (Bahill & Henderson, 2005; Byun *et al*., 2013; Kotonya & Sommerville, 1998; Larsen & Buede, 2002; Marchant, 2010; Directorate-General for Public Works and Water Management, 2009; Sommerville, 2005; Zave & Jackson, 1997)
Design verification	Ensuring that the design complies with the requirements (Bahill & Henderson, 2005; ProRail *et al.*, 2013; Department of Defense, 2001)
Design validation	Ensuring that the design matches the intended use of the system and fulfils the users' needs (Larsen & Buede, 2002; Directorate-General for Public Works and Water Management, 2009).
System verification	Ensuring that the realized system complies with the requirements and the design (Bahill & Henderson, 2005; O'Keefe & O'Leary, 1993; U.S. Department of Transportation, 2009)
System validation	Ensuring that the realized system suits its intended use and fulfils the users' needs (Bahill & Henderson, 2005)

3.3. Requirement analysis

A requirement is "*a statement that identifies a system, product or process' characteristic or constraint*" (International Council on System Engineering, 2007). The defined requirements should be based on the wishes, requests and anticipations of the clients and the stakeholders (Elmeidaa, 2019; Graaf *et al*., 2016 & Graaf *et al*., 2017). Requirements are usually expressed on different levels of detail. When developing requirements, the upper and less detailed requirements derive to more detailed requirements (Gieskens, Jager, Luttikhuizen & Riezebos 2007 & Schipper, 2016). In the infrastructure industry, it is common that the client formulates the upper and less detailed requirements, in which the contractor further develops and finishes the requirements to the eventually detailed requirements.

Important to know is that a functionally described building question is less specific than a building question in the traditional way (Maliqi, 2013). The SE process requires an adequate and complete translation of the requirements and wishes in a building question. This is usually time-consuming and requires expertise and experience (Gieskens *et al*., 2007). In the infrastructural sector, the building question is called the tender specification. The client can prescribe traffic nuisance requirements in the tender specification. An example of a functional described requirement is that a client demands there is no traffic delay during the construction phase. A technical specification is when the client specifically prescribes the technical measures; e.g. the road has to be at least 8,00 meters. It is important that the client has to be very clear on what they want on this manner.

Specifying requirements

The client must formulate the traffic nuisance requirements very complete and accurate. The building question must have such a quality and depth that the quality and functionality desired by the client can actually be achieved. If the building question is not adequately drawn up, it is more likely that the Design and or System does not match the wishes and requirements of the client (Masterman, 2002). In practice, it appears that many clients have difficulties in specifying functionality properly (Beard, Loulakis & Wundram, 2001). It is not an easy task to clearly document all wishes and requirements at an early stage in a demand specification before a design has been made (Chritamara, Ogunlana & Bach, 2002).

A requirement ought to be "*unambiguous, clear, unique, consistent, stand-alone (not grouped), and verifiable, and is deemed necessary for stakeholder acceptability*" (International Council on System Engineering, 2007). There are multiple studies (Elmeidaa, 2019; Graaf *et al*., 2016; Graaf *et al*., 2017 & Sparrius, 2014) that agree upon this statement, and also mention that the requirements should be SMART, which means Specific, Measurable, Acceptable, Realistic andTtime-bound. The literature also defines 'poor' formulated requirements as ambiguous, incorrect, unnecessary and/or incomplete requirements statements (Marchant, 2010).

According to the SE protocol of the Department of Defense (2001), the project team has to carry out the Requirements Breakdown Structure (RBS) and Verification & Validation plans that are consistent with the developed SMART requirements. A Requirements Breakdown Structure (RBS) is a hierarchical, usually tree-shaped description of all requirements which must be present in the end product in order to deliver the expected quality (International Council on System Engineering, 2007). The verification and validation plan provides insight into which requirements apply to the object, and how and when these requirements are going to be verified (Schipper, 2016).

Documentation
It is important to document and communicate the requirements and any updates regarding them, this is mentioned in several studies (Farnham, Aslaksen and Merz, 2009; Graaf *et al*., 2016; Graaf *et al*. 2017; Locatelli *et al*., 2014; Kiviniemi and Fischer, 2004 & Marchant 2010). In case there is incomplete documentation and/or ineffective communication regarding the development or possible changes in requirements, it could lead to a potential shift from the original project goal(s). The outcome can lead to developing a solution that does not comply with the original set of requirements.

Managing and the documentation of the requirements are critical procedures for a successful development of solutions that satisfy the users' needs. Collecting and organizing the updated requirements can be a challenging task. Elmeidaa (2019) declares it is because of the fact that requirements are not necessarily fixed throughout the life cycle of a project. This means requirements change dynamically and possible changes are unavoidable until the project is finalized.

Traceability
Several studies (International Council on System Engineering, 2007; Farnham, Aslaksen and Merz, 2009; Graaf *et al*., 2016; Graaf *et al*. 2017; Locatelli *et al*., 2014; Kiviniemi and Fischer, 2004 & Marchant, 2010) state that the input for the verification process should contain traceable requirements and that this traceability should be documented. Malsane *et al*. (2015) provides the definition of requirements traceability: "*Requirements traceability refers to the ability to describe and follow the life of a requirement, in both forwards and backwards direction, in other words from its origins, through its development and specification, to its subsequent deployment and use, and through all periods of on-going refinement and iteration in any of these life cycle phases.*"

According to Elmeidaa (2019), there is an increase for demand for traceability in practice. In the research of Elmeidaa, she refers to a survey carried out by Winkler and Pilgrim (2010) that provides identifying shared aims and differences in multiple areas; requirements engineering and model-driven development. Traceability is important to identify what can be affected if there are changes to requirements and other important components. In order to be able to introduce requirements' traceability, Tvete (1999) states as cited in Elmeidaa (2019) that "*traceability requires a good understanding of a clearly documented development process, with all phases and phase transitions well defined.*"

A method to ensure the requirements' traceability is to setup a Verification Requirements Traceability Matrix (VRTM) that classifies the (planned) verification or validation method and the linked pass/fail (Saes, 2015; Marchant, 2010). The implementation of VRTM is also mentioned in International Council on System Engineering (2007), in which they emphasize on the needed inputs for the execution of the verification. A VRTM provides a structure on who and when performed the verification, the linked traffic nuisance requirement, what the proof is (calculation, design, etc.) and what is the status of the verification. Elmeidaa (2019) explains that traceability is not an end goal in itself, but rather a tool to improve the integrity and accuracy of all requirements. It allows tracking the development and distribution of the project.

Besides having traceable requirements, the requirements should be stored and maintained. It useful if the requirements and connected information is accessible, with the ability to share and exchange data across multiple platforms (International Council on System Engineering, 2007). It is possible to use technical systems that can help manage the information. An example is Relatics, it is a database that combines, structures and manages various information flows. Requirements, control measures and other documents can be linked and saved to the tests to be performed for contract management (Antea Group, 2016).

Structuring processes
Marchant (2010) and Elmeidaa (2019) state that the verification process flowing through the system hierarchy from the bottom up should be performed in a disciplined manner. As mentioned earlier, the Verification & Validation plans should be consistent with the defined SMART requirements. It provides insight into which requirements apply to the object and how and when these requirements are going to be verified throughout the design and system levels (Schipper, 2016). Elmeidaa (2019) specifically mentions the measure of cross-referencing the Verification & Validation plan to the requirements hierarchy before finalizing either of them. Marchant (2010) states that ongoing verification and updating requirements is part of the SE process. Since traffic nuisance is an ongoing process, it is useful to verify it several times during the process.

3.4. Design analysis

As defined previously, "*design is the process of defining, selecting, and describing solutions to requirements in terms of products and processes. A design describes the solution (conceptual, preliminary or detailed) to the requirements of the system*" (International Council on System Engineering, 2007). According to the SE protocol of the Department of Defense (2001), designers are required to convert the defined requirements and specifications into a design solution. This development of solutions takes place in the Synthesis process after the start of the *Requirements Analysis* and *Functional Analysis/Allocation* processes (Department of Defense, 2001). With innovative contracts, the design phase is often carried about by both the client and contractor. The client usually is responsible for developing an abstract and less detailed design that is used for the tendering process (Schipper, 2016). The contractor further develops and finishes the design into a more detailed design.

Regarding this research, a client could have a requirement to limit or prevent traffic nuisance during the construction phase. The constructor has to translate the given traffic nuisance requirements into the designs and/or the construction plan. The constructor has to prove that the chosen measures fulfills the client's requirements. The contractor has to verify whether the solution complies with the requirements. Proving this can be done by calculations, simulations, etc.

Documentation solutions
When developing the design, the project team must be able to demonstrate that the functional requirements from the contract have been correctly translated into the design (Gieskens *et al.*, 2007). The quality of the design must be assured by constantly monitoring the relationships between the functional requirements drawn up by the client and the design. To that end, the design process must be organized in a structured way, in order to give insight to the project team's progress of the design process, and to be able to demonstrate that the design meets the requirements at the end of the design process. Documenting and recording every phase within design development is very important to have a traceable and logical set of solutions (Elmeidaa, 2019).

When dealing with functional specifications, the requirements of the client are called 'solution-independent requirements' (in Dutch: *oplossingsongebonden eisen*) (Straatman, 2006). As a result, the contractor has a certain freedom to determine the solution and if the knowledge of the market is being (optimally) utilized. However, the disadvantage of this freedom to determine the solution is that the effects of the solution-independent requirements (the results) can lead to disappointing results. The client might have had a different expectation and their requirements could have been interpreted by the contractor in a different way (Spekkink & Kuypers, 2002).

In an ideal situation, the design(s) complies with all the set requirements of the stakeholders (International Council on System Engineering, 2007, Graaf *et al*., 2016; Graaf *et al*., 2017; Makkinga, 2016 & Schipper, 2016). This can be a challenging task, due to the nature, limitation or contradiction of certain requirements. In addition, not properly implementing requirements documentation on ensuring that the right designs are being developed do not make the task easier (Kiviniemi and Fischerm, 2004; Larsen and Buede, 2002).

It is possible that designers develop new or improved ideas as design solutions, this can lead to having to update the requirements (Graaf *et al.* 2017). According to Elmeidaa (2019), this means the designs are developed based on two foundations: the requirements specified in earlier processes and the requirements derived during the design process. Examples are design decisions that take place later, such as maintenance activities.

Linked products
As mentioned earlier, the developed designs should satisfy the defined requirements and satisfy the users' needs (International Council on System Engineering, 2007; Graaf *et al*., 2016; Graaf *et al*. 2017 & Schipper, 2016). The data regarding the design and other specifics should include the design decisions, which should be documented and stored. International Council on System Engineering (2007) and Elmeidaa, (2019) are backing this ideology by stating that the output of the design progress and decisions should include the system elements' detailed descriptions with documented justification for concept selections. Both papers mention that the design output should include requirements assigned to system elements and documented in a traceability matrix. As mentioned at the requirement analysis, a logical choice is to have a database where all the information can be stored and reached.

Design verification
Carrying out design verification can prevent developing designs that do not comply with the developed requirements. Verification should be an ongoing process and structured, rather than spontaneous (Elmeidaa, 2019). Setting up a Verification and Validation plan from the starting of the project helps structure the verification process (International Council on System Engineering, 2007; Marchant, 2010 & Elmeidaa, 2019). This approach has the main objective of a delivering a product (or process) to meet the stakeholders' requirements and expectations and part of the quality assurance system.

3.5. System analysis

According to International Council on System Engineering (2007), a system is "a combination of related elements that are organized to fulfill one or more functions". It is possible that the requirements and the design activity are carried out simultaneously. Usually the development of the system can only start when the design is finished.

The system is the eventual activities carried out during the construction phase. Regarding this research, these are the activities that should limit or prevent traffic nuisance during the construction phase. The final output of the process should represent the product that the client intended to get. The SE model includes the System Validation step to ensure that the system does what it is supposed to in its intended environment (Schipper, 2016).

Just as mentioned in the design development, the system solutions should be carried out based on the defined requirements and specifications (and the developed designs) Documentation of the system decisions is very important, in which verifying systems with the defined requirements should be an ongoing process throughout the project phase. To add to that, this section will provide information on two topics regarding the System development: quality checks and providing evidence when verifying a process or product.

Quality checks
The construction company should frequently check whether the desired quality is achieved during the construction phase (Gieskens *et al.*, 2007). The quality system of the construction company must guarantee that the inspections and tests are carried out, also for the parts that are carried out by subcontractors. The contractor therefore must demonstrate to the client that he/she performs the quality assurance in the correct manner. This is also called external quality assurance (EQA). On the one hand, the board of the project organization is given insight as to whether the intended quality is being carried out, on the other hand it proves the client that the contractual obligations are met. In order to achieve this, Kuijpers & Berg (2007) advises applying system-oriented contract management (SCM). Large Dutch public clients (such as ProRail and Directorate-General for Public Works and Water Management) use this systematic check on the functioning of the quality system of the contractor (Gieskens *et al.*, 2007).

In the infrastructural sector, it is common that SCM is being applied to all contract forms of which purchases take place under quality management (Kuijpers & Berg, 2007; Antea Group, 2016). SCM is a process that is established to provide what the client requested for. As part of the agreement, the contractor must carry out a project quality plan that must be based on the ISO 9001 standard. The ISO 9001 is the international standard for quality management systems. The project quality plan is the basis for the SCM. Within the project quality plan, the contractor must provide a description of how the processes will be set up in order to arrive at the requested end result and in which way the inspection will be carried out.

Working according to SCM requires a different attitude and adapted behavior from the client and the contractor (Kuijpers and Berg, 2007; Antea Group, 2016 & Gieskens *et al.*, 2007). For example, the client is not checking the contractor's every step. The client only checks the progress on the basis of the system, the process and the product tests. However, the contractor must be critical of its own work and approve this as described in the project quality plan.

The contractor manages the quality of their products. The client performs risk-based tests (or inspections) and uses certified (lead) auditors, who can be assisted by specialists in the subject matter to be tested (Saes, 2015). In order to perform the "correct" testing, it is possible to use the identified risks with control measures. On the other hand, craftsmanship plays an important role. If a certain activity is viewed as a "standard" work, no testing will be done under normal circumstances. If the risk analysis shows that the activity is complex due to the circumstances, it is possible to decide to have an inspection carried out. By offering the inspection plans to the client for acceptance, it is ensured that the client's expectations regarding the inspections are also met, thereby preventing discussions arising during the delivery.

Evidence method
The same as with the Design development, verification within the SE principal is a continuing process during the course of the project, and should be structured rather than once-only. It is the client's duty to verify (and later validate) the System in order to check if they met the requirements and the users' needs (Schipper, 2016). According to Bahill and Henderson (2005), a requirement can be verified by logical argument, modeling, simulation, analysis, expert review or inspection.

As mentioned earlier, to be able to efficiently verify the compliance with the defined requirements, a structured verification and validation plan should be developed and followed from the beginning of the project. The same applies to developing a verification report. The verification and validation plan provides insight into which requirements apply to the object and how and when these requirements are verified (International Council on System Engineering, 2007). After the design or implementation work has taken place, the verification results are recorded in a verification report. It proves that each requirement has been satisfied in practice. The collection of verification reports leads to a verification note that is part of the delivery file (Saes, 2015). The verification of the requirements consist of at least one project phase (Design, Construction, Maintenance, etc.) and the evidence method. According to Oberkampf and Trucano (2008), the verification during the construction phase should provide evidence or substantiation of how accurately the system satisfied the real world for system responses of interest. This can be a measurement, document inspection, inspection, etc. In case there are traffic nuisance requirements, an example could be to monitor the traffic to provide (objective) proof.

4 Case study analyses

This chapter provides an overview of the study analysis in order to answer sub research question 2: "*how is the current quality assurance system of Iv-Infra defined?*"

This section provides the most important findings of the case study analysises. All cases have been assessed via the developed framework. A complete overview of the outcomes are shown in Appendices K, L and M. Appendices H, I and J provide more background information of each case and Appendix G can viewed for interviews with key players. Appendices H, I and J.

4.1. Outcome framework assessment

This paragraph will provide a brief overview of the outcomes regarding the framework assessment. The Table displays the scores of the cases. The cases will be first analyzed separately, and eventually with the cross-case analysis.

Table 9: Overview of all the cases scores based on the developed framework

		Case 1	Case 1	Case 1	Case 2	Case 3	Case 3
Type of traffic nuisance requirement		Traffic time improvement	Avoiding construction traffic	Accessibility of stores	Accessibility of roads, stores and houses	Accessibility of N-road	Travel distance
Requirement analysis	**Defined pattern**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**
	The project goals should be documented	+	+	+	+	+	+
	The developed requirements should be based on the wishes and requests of the (important) stakeholders	+	+	+	+	+	+
	The developed requirements should be SMART (Specific, Measurable, Acceptable, Realistic and Time-bound)	-	-	-	+	+	+
	The developed requirements should be documented	+	+	+	+	+	+
	The updated requirements should be documented	0	+	+	+	+	+
	The developed and updated requirements should be traceable	-	-	-	+	+	+
	The developed requirements information should be stored in accessible sources	+	+	+	+	+	+
	There are clear agreements or a defined ruleset on how the contractor will demonstrate the quality	-	-	-	-	-	-

		Case 1	Case 1	Case 1	Case 2	Case 3	Case 3
Type of traffic nuisance requirement		Traffic time improvemen t	Avoiding construction traffic	Accessibility of stores	Accessibility of roads, stores and houses	Accessibili ty of N-road	Travel distance
Design analysis	**Defined pattern**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**
	The designs should be developed based on the defined requirements and other specifications	+	+	+	+	+	+
	Decisions on the designs should be documented	+	N/A	N/A	+	+	+
	The descriptions of the design solutions should be stored in accessible sources	+	N/A	N/A	+	+	+
	Verification of the designs with the developed requirements should be ongoing (not restricted to one specific moment in time)	+	+	+	+	+	+
	Verification of the designs with the developed requirements should be a disciplined process (Verification and Validation plans with specific, clear roles and responsibilities)	-	-	-	+	+	+
	Verification of the designs should include evidence that satisfies the requirements	+	N/A	N/A	+	+	+
	The provided proof is of the quality as agreed upon in advance	N/A	N/A	N/A	N/A	N/A	N/A
	The design solutions are validated (satisfying the users' needs)	0	0	0	0	0	0

		Case 1	Case 1	Case 1	Case 2	Case 3	Case 3
Type of traffic nuisance requirement		Traffic time improvemen t	Avoiding construction traffic	Accessibility of stores	Accessibility of roads, stores and houses	Accessibili ty of N-road	Travel distance
System analysis	**Defined pattern**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**
	The system should be carried out based on the defined requirements, specifications and designs	0	0	N/A	0	0	0
	Decisions on the systems should be documented	0	0	N/A	0	0	0
	Documentation on the system decisions should be stored in accessible sources	+	+	+	+	+	+
	Verification of the systems with the developed requirements should be ongoing (not restricted to one moment in time)	+	+	+	0	0	0
	Verification of the systems with the developed requirements should be a disciplined process (e.g. V&V reports with specific and clear roles and responsibilities)	0	0	0	-	+	+
	Verification of the systems should include evidence that satisfies the requirements	+	-	-	-	-	-
	The carried out system should satisfy the requirements and other specifications	0	0	0	0	0	0
	The provided proof is of the quality as agreed upon in advance	N/A	N/A	N/A	N/A	N/A	N/A
	The system is validated	0	0	0	0	0	0
	The client performed quality inspections during the construction phase	-	-	-	-	+	+

- no match, + matching patterns, 0 quasi-matching and N/A not available results

Next, a brief overview of the outcome of the framework assessment will be given.

From the 26 total different characteristics, Case 1 has 14 +'s with the travel time improvement requirement, 11 with the avoiding of construction traffic requirement and 11 with the accessibility requirement regarding stores. Case 2 has 14 +'s with the accessibility requirement regarding of roads, stores and houses. Case has 16 +s in both set requirements, which are the accessibility of the N-road and travel distance. Based on the framework, case 3 scores the best. It has the most amount of pluses and least minuses. Case 1 scores, especially in the second and third requirement, the worst based on this framework. It received the least amount of pluses and most amount of minuses.

In general, most pluses are in the requirement component: all cases have 48 requirement characteristics combined, and 35 of them are assessed with +. The second most pluses are in the design component: all cases have 48 design characteristics combined, and 29 are assessed with +. Lastly, the system component has the least amount of pluses: all cases have 60 system characteristics combined, and 17 are assessed with +. The next paragraphs will zoom in on the case study analyses.

When reviewing the Requirement component, all cases documented their project goals, the developed requirements were stored in an accessible source and based on the wishes and requests of the clients and other stakeholders. Most of the cases developed SMART requirements that were traceable and documented the updated requirements. None of the cases made clear agreements how the requirements' fulfilments would be demonstrated.

When reviewing the Design component, in all cases the design solutions were developed based on the developed requirements and were verified several times. In most of the cases, the design decisions were documented, the design solutions were stored in accessible sources, the designs were verified with the defined requirements in a disciplined process and included evidence that it satisfied the requirements. None of the cases had an official validation of the design solutions, however, they were all implicitly validated.

When reviewing the System component, in all cases the system decisions were stored in accessible sources. All cases somewhat documented the system decision, satisfied the requirements and carried out the system based on the defined requirements, specifications and designs. In one case, the system was verified several times (case 1), included evidence that it satisfies the requirements (for one requirement in case 1), verified the system in a disciplined process (case 3) and the client performed quality inspections during the construction phase (case 3). None of the cases had an official validation of the system, however, they were all implicitly validated.

4.2. Case 1 analysis

The quality assurance approach of Case 1 has been tested with the developed framework. A complete overview of each characteristics' defined pattern, detected pattern, score and explanations is shown in Appendix K. This section will provide the most important findings and will focus on the received minuses in the framework assessment.

Requirement analysis
There were three requirements: 5 minutes of travel time improvement, avoiding construction traffic and keeping the stores accessible. As shown in the overview, there were some deviations from the framework and therefore also the System Engineering principles. Not using SMART requirements could lead to ambiguous, incorrect, unnecessary and/or incomplete requirements statements. In this case, the requirements were left abstract on purpose. The client chose to not to specify the traffic nuisance requirements in order to give freedom to the contractor to come with a solution on its own with a matching traffic indicator. The set traffic nuisance requirements in this case are the promises in the Plan of Approach by the contractor. After the project award, this plan that included the traffic nuisance requirements became part of the contract. These requirements were documented, stored in accessible sources and were based on the wishes and requests of the clients and other stakeholders.

The client did not prescribe or request the contractor to further specify the requirements. It was not set as an obligation, and the contractor never did it voluntary. The reasoning behind this approach is that the client was very focused on receiving an innovative solution, rather than the quality assurance system afterwards. This lead to some deviations from the System Engineering protocol. The contractor never further specified the traffic nuisance requirements, did not apply a numbering system that was related to functions, objects and system elements nor used the Verification Requirements Traceability Matrix (VRTM). The traffic nuisance requirements were therefore never implemented in a Verification and Validation Plan and a Verification Report.

In addition, there were several changes to the requirements, such as the travel time improvement got an extra 2 min buffer time and the construction traffic received some exceptions to use the main road. This was partly due unforeseen circumstances and having ambiguous expectations. This had no further consequences, the client was still very satisfied with the new scenario.

However, these were not officially registered as a deviation or a change to the contract. Therefore, the managing and verifying of the requirements were not traceable and not in a disciplined process. According to the SE protocol, by storing information properly, miscommunication will be prevented, and errors, delays and damage claims can be avoided. This is why (updated) requirements and decisions should be documented, accessible and traceable. There is no proof this project’s approach caused miscommunication, errors, delays or damage claims. Via interviews it became clear that the client, contractor and users are very satisfied with the project process and the eventual outcome. However, when reviewing these project documents, it would have been easier to find the needed information if the SE protocol was used to storage the documents.

Design analysis
The contractor developed design reports, construction plan, traffic management plans and phasing plans that explained the design steps and choices in order to fulfill the traffic nuisance requirements. The plans of the contractor were carried out based on the set traffic nuisance requirements. The designs were verified multiple times, however, not all design documents and decisions were provided for this research, especially for two out three traffic nuisance requirements (limiting construction traffic and accessibility of the stores).

Managing and verifying the design solutions (traffic nuisance measures) was not in a disciplined process. This project did have a Verification and Validation plan, however, the traffic nuisance requirements were not implemented in this plan. Therefore, it was not clear by who, when and how the traffic nuisance requirements would be verified. This made it difficult to trace back if there was information about design verification and where to find it. If a verification has taken place, it is not clear when was it performed, who performed it, what is the status of it and what is the connected proof that the requirement is met. This lack of traceability and storage was no issue for the client. The plans gave the client satisfaction that the plans of the contractor comply with the requirements and they officially approved/accepted the plans.

System analysis
For this research, the Progress Reports were used to inform the contractor about important updates, verifications and requirement fulfillments on the traffic nuisance during the construction phase requirements. Via these Progress Reports, the traffic nuisance requirements were regularly verified over the course of the construction phase.

From the three traffic nuisance requirements, traffic was monitored for the travel time improvement requirement. Therefore, there is substantial information on the regular verification, fulfillment and proof for this requirement. This requirement was not always met. The main reasons for not always reaching it were: overestimations of the traffic measures: one traffic measure was not implemented, and the route attracted more traffic due its traffic flow improvements. Since the client was still satisfied with the outcome, not always reaching the fulfillments had no consequences.

For the remaining traffic nuisance requirements (construction traffic and accessibility of the stores), it was difficult to determine if these requirements were met. The contractor did deviate from the construction traffic nuisance requirement: this was due to new insights, and it was accepted by the client. Other than that, there is a lack of documentation, and besides the opinions and observations of the contractor, client and stakeholders, there is no (objective) proof available that the requirements were met during the construction phase. The lack of official verification and documentation is partly to be blamed on not having any set ruleset on how the quality will be demonstrated. There were no agreements made how the requirements need to be proven during the construction phase, what type of measurements would be used and how detailed the documentations should be. The client was satisfied with how the work was carried out, and there were hardly any complaints from the local residents and other road users, therefore the client saw no need for the contractor to provide more proof or officially verify the requirements. The client deemed these two requirements less important and did not see any potential risks in them. This was confirmed by the client by not performing any inspections or carry out fines during the whole project phase.

The design and system solutions were never formally validated. There was no formal validation at all, no validation plan setup and no documentation about it. It was difficult to track back why the designs and construction phase were never validated. The most obvious reasons are it being deemed not needed, not important enough, being time consuming and/or it being simply forgotten. However, via interviews it became clear that, according to the client and the contractor, the users were satisfied with the design and system, which can be seen as it being validated implicitly.

To conclude, the first requirement was not always met, however that was not an issue for the client. There is no sign that the second and third requirements were not met, due to the lack of official verifications and objective proof. If the SE protocol was used more, there would have been an improvement on the external quality features, however, there is no sign that if the SE protocol was applied, the outcome of the project (the actual traffic nuisance) would have been better than it was.

4.3. Case 2 analysis

The quality assurance approach of Case 2 has been tested with the developed framework. A complete overview of each characteristics' defined pattern, detected pattern, score and explanations is shown in Appendix L. This section will provide the most important findings and will focus on the received minuses in the framework assessment.

Requirement analysis
The project goals were documented, and the requirements were SMART, documented, traceable, stored in accessible sources and based on the wishes and requests of the clients and other stakeholders. The requirements specified which and when certain roads, intersections and locations should be accessible, when is it allowed to coagulate/close one lane (In Dutch: *stremmen*) and when the closures of roads are possible. There was one change in the requirements, and this was updated and documented. There was one road that required more capacity during the construction phase. The amount of traffic was more than expected, and this was changed to only allowing the road to be partly closed at night.

There were no clear agreements made on how the contractor needed to prove that they fulfilled the traffic nuisance requirements in advance. More about that later.

Design analysis
During the design phase, the contractor provided a project plan, several designs, phasing plan and planning that were based on the traffic nuisance requirements. These documents provide evidence on how the traffic nuisance requirements will be met during the construction phase. These design solutions were documented, stored in accessible sources and verified multiple times in disciplined processes by using V&V plans with specific and clear roles and responsibilities. The plans gave the client the satisfaction that the plans of the contractor comply with the requirements, and they officially approved/accepted these plans.

There was one design change, and this was updated and documented. Initially, the contractor had a phasing plan that consisted in total of five phases. Based on new insights later on in the project, the fifth phase was processed in phase 3 and 4, and therefore not needed. This was implemented to make the phasing more efficient and would help to finish the project on time.

System analysis
There were two changes to the System regarding traffic nuisance: to improve the planning and traffic safety, these were officially registered as a deviation or change in the contract, and they were documented and stored in accessible sources. The first change was to increase the amount of traffic controllers. During the construction phase, it became clear that there were not enough traffic controllers to guarantee the traffic safety. The client requested to raise it with 16 more traffic controllers. There was one store that was not satisfied with the accessibility of their store. This led to an improvement to the diversion (in Dutch: *omleidingsroute*), and more traffic and text signs.

An important finding is that there is no evidence that any system verification has taken place regarding the traffic nuisance requirement. This automatically means the verification was not carried out in a disciplined matter and was not ongoing. It was difficult to track back what the exact reason was for this requirement never being officially verified. The most obvious reasons are it being deemed not needed, not important enough, being time consuming and/or being simply forgotten.

The purpose of the verification process is to confirm that all requirements are fulfilled by the developed designs of the system elements. Since no official verifications have taken place, it is not possible to assess if the requirements were met. There is a lack of documentation and besides the opinions and observations of the contractor, client and stakeholders, there is no (objective) proof available that the requirements were met during the construction phase. The lack of official verification and documentation on it is partly to blame on not having any set ruleset on how the quality will be demonstrated. There were no agreements made how the requirements need to be proven during the construction phase, what type of measurements would be used and how detailed the documentations should be.

According to the contractor, there was a 'check' at every phase of the construction to ensure if all the traffic measures are carried out as according the traffic management plans. However, these verifications are neither documented nor found in the database.

However, not performing a verification was not an issue for the client. The client was satisfied how the work was carried out and there were hardly any complaints from the local residents and other road users, therefore the client saw no need for the contractor to provide more proof or officially verify the requirements. In theory, the client could have obligated the contractor to verify the requirements. The client did not see any potential risks in the requirements, did not perform any official inspections and also did not carry out any fines during the whole project phase. It also helped that the client was often at the project area, so they would be able to notice if there were any complications.

According to the client and the contractor, they regularly had meetings where they discussed the most important matters, this included traffic nuisance requirements. According to them, these meetings were used to discuss the implemented traffic management measures, since the traffic nuisance requirements were one of the most important requirements of the project. These are seen as informal verifications.

The design and system solutions were never formally validated. There was no formal validation at all, no validation plan setup and no documentation about it. It was difficult to track back why the designs and construction phase were never validated. The most obvious reasons are it being deemed not needed, not important enough, being time consuming and/or it being simply forgotten. However, via interviews it became clear that according to the client and contractor, the users were satisfied with the design and system, which can be seen as it being validated implicitly.

To conclude, there is no sign that the requirements were not met, due to the lack of official verifications and objective proof. Therefore, there is no sign that if the SE protocol was more applied, the outcome of the project (the actual traffic nuisance) would have been better than it was. If the SE protocol was used more, there would have been an improvement on the external quality features, such as the demonstrability of reaching the requirement fulfillments

4.4. Case 3 analysis

The quality assurance approach of Case 3 has been tested with the developed framework. A complete overview of each characteristic's defined pattern, detected pattern, score and explanations is shown in Appendix M. This section will provide the most important findings and focus on the received minuses in the framework assessment.

Requirement analysis
There were two requirements: one is keeping the N-road always accessible, the other is ensuring the cyclists and pedestrians not have more than 150 meter of extra travel distance.

The project goals were documented and the requirements were SMART, documented, traceable, stored in accessible sources and based on the based on the wishes and requests of the clients and other stakeholders. The requirements specified which and when certain roads, intersections and locations should be accessible, when it is allowed to coagulate/close one lane (In Dutch: *stremmen*) and when the closures of roads are possible. There was one change in the requirements and this was updated and documented. Initially, the requirement stated to have a traffic controller to help cyclists and pedestrians cross the road. This was changed to applying a traffic control installation instead of a traffic controller. The client insisted on using a traffic control system. The underlying idea was that a traffic control system, unlike a traffic controller, is a static object and therefore it is less likely to cause suffer human injury.

There were no clear agreements made how the contractor needed to proof how they fulfilled the traffic nuisance requirements in advance. More about that later.

Design analysis
The contractor provided a project plan, several designs, traffic management plans, a planning and calculations that explain the design steps and choices in order to fulfill the traffic nuisance requirements. These documents provide evidence on how the traffic nuisance requirements will be met during the construction phase. These design solutions were documented, stored in accessible sources and verified multiple times in a disciplined processes by using V&V plans with specific and clear roles and responsibilities. The plans gave the client the satisfaction that the plans of the contractor comply with the requirements and officially approved/accepted these plans.

System analysis
The contractor could not completely carry out the plans according to the designs. The new routes were according to the plans, but the traffic users were not complying with the traffic rules and causing unsafe situations. This is something they could have not foreseen in the design phase. The contractor changed one of its traffic management plan to improve the safety and therefore changes the places signs and obstacles. These changes were registered with the requirement number, linked objects, motivation, the needed change and possible extra fee charge.

Managing and verifying of the traffic nuisance measures during the construction phase was carried out in a disciplined process by using a Verification Report with specific and clear roles and responsibilities. However, it is unclear if the contractor performed several verification during the construction phase. The requirements were verified at least once in the Verification Report.

An important finding is that the verification performed the Verification Report, is not a system verification. The provided 'check' in the Verification Report refers to the Construction Nuisance Plan. This plan provides how their work will be according the traffic nuisance requirements. It does not explain if these requirements were actually met during the construction phase. In other words, the provided proof does not proof the requirements were met during the construction phase.

The purpose of a verification is to confirm that all requirements are fulfilled by the developed designs of the system elements. Similar to case 2, it is not possible to assess if the requirements were met since there was no system verification. There is a lack of documentation and besides the opinions and observations of the contractor, client and stakeholders, there is no (objective) proof available that the requirements were met during the construction phase. The lack of official verification and documentation on it is partly to blame on not having any set ruleset on how the quality will be demonstrated. There were no agreements made how the requirements need to be proven during the construction phase, what type of measurements would be used and how detailed the documentations should be.

According to the contractor, there was a 'check' at every phase of the construction to ensure if all the traffic measures are carried out as according the traffic management plans. This can be viewed as a verification, however, these checks are not found in the database and were not used to verify the requirements in the Verification and Validation plan and the Verification report and were not mentioned in the Progress reports. Also, verifying a system with the design is not a System verification. A system verification is verified via the requirements.

It was difficult to track back what the exact reason was why there was no System verification. The most obvious reasons are it being deemed not needed and being time consuming. However, not performing this verification was not an issue for the client. The client was satisfied how the work was carried out and there were hardly complaints from the local residents and other road users, therefore the client saw no need for the contractor to provide more proof or officially verify the requirements. In theory, the client could have obligated the contractor to verify the requirement. The client did not see any potential risks in the requirements, did not perform any official inspections and also did not carry out any fines during the whole project phase. It also helped that the client was often at the project area, so they would be able to notice if there were any complications.

The client performed several inspections to check if system complied with the set requirements. During the inspection, the client saw no indication that the requirements were not met. As mentioned earlier, the road users were putting themselves into unsafe situations by not complying with the contractor's set traffic rules and routes. This outcome has caused the contractor to perform extra measures to make sure the traffic users comply with the rules and routes, such as placing more traffic obstacles and signs.

Lastly, the contractor did not perform any validations. There was no formal validation at all, no validation plan setup and no documentation about it. It was difficult to track back why the designs and construction phase were never validated. The most obvious reasons are it being deemed not needed, not important enough, being time consuming and/or it being simply forgotten. However, via interviews it became clear that, according to the client and contractor, the users were satisfied with the design and system, which can be seen as it being validated implicitly.

To conclude, it is no sign that the requirements were not met, due to the lack of official verifications and objective proof. Therefore, there is no sign that if the SE protocol was more applied, the outcome of the project (the actual traffic nuisance) would have been better than it was. If the SE protocol was used more, there would have been an improvement on the external quality features, such as, the demonstrability of reaching the requirement fulfillments.

4.5. Cross-case analysis

This section presents the cross-case analysis. This contains the most important findings when comparing the outcomes of the within-case analyses. The next paragraph provides an assessment of the quality assurance system of Iv-Infra.

4.5.1. Overview outcome

In case 1, the most important requirement was to improve the travel time between two large cities. The contractor chose travel time as an indicator to express traffic flow, since it evidently demonstrated travel flow differences. In case 2, the requirements were very focused on reaching the local destinations, in this case the residents' accommodations and stores. They applied the accessibility indicator, the focus was making sure the destinations are accessible, whereas the travel time and road capacities are increased during the construction phase. However, since the project area was in an urban area and dealing with mostly destination traffic, the amount of traffic much substantial lower than in case 1 and therefore less important. In case 3, the requirements were very focused on the accessibility of the main road and travel distance of cyclists and pedestrians. The situation is very similar to case 2, where the project area was in an urban area and dealing with mostly with destination traffic. Therefore the chosen requirements and indicators were logic in this case.

From the 26 total different characteristics, Case 1 has 12 +'s with the travel time improvement requirement, 9 with the avoiding of construction traffic requirement and 9 with the accessibility requirement regarding stores. Case 2 has 14 +'s with the accessibility requirement regarding of roads, stores and houses. Case has 16 +s in both set requirements, which are the accessibility of the N-road and travel distance. Based on the framework, case 3 scores the best. It has the most amount of pluses and least minuses. Case 1 scores, especially in the second and third requirement, the worst based on this framework. It received the least amount of pluses and most amount of minuses.

In general, most pluses are in the requirement component: all cases have 48 requirement characteristics combined, and 35 of them are assessed with +. The second most pluses are in the design component: all cases have 48 design characteristics combined, and 27 are assessed with +. Lastly, the system component has the least amount of pluses: all cases have 60 system characteristics combined, and 14 are assessed with +. The next paragraphs will zoom in on the case study analyses.

4.5.2. Requirement analysis

When reviewing the Requirement component, all cases documented their project goals, the developed requirements were stored in an accessible source and based on the wishes and requests of the clients and other stakeholders. Most of the cases (case 2 and 3) developed SMART requirements that were traceable and documented the updated requirements. None of the cases made clear agreements how the requirements' fulfilments would be demonstrated.

The approach of Case 2 and 3 are more in line with the System Engineering principle. Case 1 deviated from this principle and therefore scored the least in few characteristics. The client chose to not to specify the traffic nuisance requirements, in order to give freedom to the client to come with a solution on its own with a matching traffic indicator. This approach led, in comparison with the other cases, the managing and verifying of the requirements were lacking traceability and it was less in a disciplined process. There is no proof this project's approach caused miscommunication, errors, delays or damage claims. Via interviews it became clear that the client, contractor and users are very satisfied with the project process and the eventual outcome. However, when reviewing these project documents, it would been easier to find the needed information if the SE protocol was used to storage the documents.

There were no clear agreements made how the contractor needed to proof how they fulfilled the traffic nuisance requirements in advance. More about that later.

4.5.3. Design analysis

When reviewing the Design component, in all cases the design solutions were developed based on the developed requirements and were verified several times. In most of the cases, the design decisions were documented, the design solutions were stored in accessible sources, the designs were verified with the defined requirements in a disciplined process and included evidence that it satisfied the requirements. None of the cases had an official validation of the design solutions, however, they were all implicitly validated.

As described in the requirement analysis, the approach of Case 2 and 3 are more in line with the System Engineering principle. Case 1 had a different approach, which caused to score the worst in the verifying designs in disciplined approach. This different approach did not specify the requirement, they were not traceable and eventually caused them not be in the Verification and Validation plan. This project did have a Verification and Validation plan, however, the traffic nuisance requirements were not implemented in this plan. Therefore it was not clear who, when and how the traffic nuisance requirement would be verified. As mentioned earlier, this approach did not cause any negative outcomes and the client accepted this approach.

4.5.4. System analysis

When reviewing the System component, in all cases the system decisions were stored in accessible sources. All cases somewhat documented the system decision, satisfied the requirements and carried out the system based on the defined requirements, specifications and designs. In one case, the system was verified several times (case 1), included evidence that it satisfies the requirements (for one requirement in case 1), verified the system in a disciplined process (case 3) and the client performed quality inspections during the construction phase (case 3). None of the cases had an official validation of the system, however, they were all implicitly validated.

In all cases, the systems were not carried out based on the initial defined requirements, specifications and designs. All cases scored a 0 on this characteristic. This means changes had to be made during the construction phase. Such as, for case 1, not being able to carry out certain traffic measures and not being able to reach the ship to transport goods. In case 2, there were not enough traffic controllers and one store was not accessible. In case 3, extra traffic measures had to be implemented due to the traffic not complying with the traffic rules. Most of the changes were caused by unforeseen circumstances and the clients accepted these changes. There is no proof that if System Engineering was implemented more these changes would have been spotted earlier.

Case 3, scored the best in the System analysis. Compared to the other cases, this case had a + in verifying in a disciplined process. When interviewing the key players, it came to conclusion this was partly caused by a stricter client. This client obligated the contractor to verify the traffic nuisance requirements in the verification report via a structured outline. The strictness of the client translated to the performed inspections. There were only inspections performed in this case.

In all cases, the satisfactory level of the client was very important in accepting not fulfilling requirements and performing verifications. The satisfactory level of the client was due to a pleasant collaboration with the contractor, the contractor earning trust of the client and the road users being happy about the outcome or not complain to the client. Hence why validating the requirements is a crucial aspect of reaching the satisfactory level. Validating means the outcome fulfills the user needs. Since the requirements are a translation of the project goals/wishes, it is very important that the initial projects goals/wishes are fulfilled. If these are initially fulfilled, the client is less strict when requirements are not verified nor fulfilled. An example, the client in case 1 wanted to have no traffic delay during the construction phase. The contractor promised a travel improvement requirement of 5 mins. This requirement was not always met, however, there always a travel time improvement, hence this was no issue and the client was still satisfied.

Five out of the total six requirements did not perform a system verification. It was mostly carrying out the construction activities based on the designs, which is not a system verification. Figure 3 provided an overview of the feedback loops, in red the system verification is shown. In case 2 and 3, the contractors state there were several informal verifications performed, however, this was not documented. Since there were no official system verifications, there is also no evidence provided if the requirements were fulfilled. This makes it very difficult to track back if the requirements were fulfilled. Reasons for not verifying the requirements are: it was not needed, not important enough or it was forgotten. There is a strong believe that the contractor would only perform it if it was requested. If the client does not specifically request it, the contractor would not do it on his/her own. They view the verification as something not useful or needed. Nevertheless, not performing verifications caused for no issues. As stated earlier, as long as the client trusted the contractor, there was a pleasant collaboration and the users were happy, the client did not mind there were no verifications.

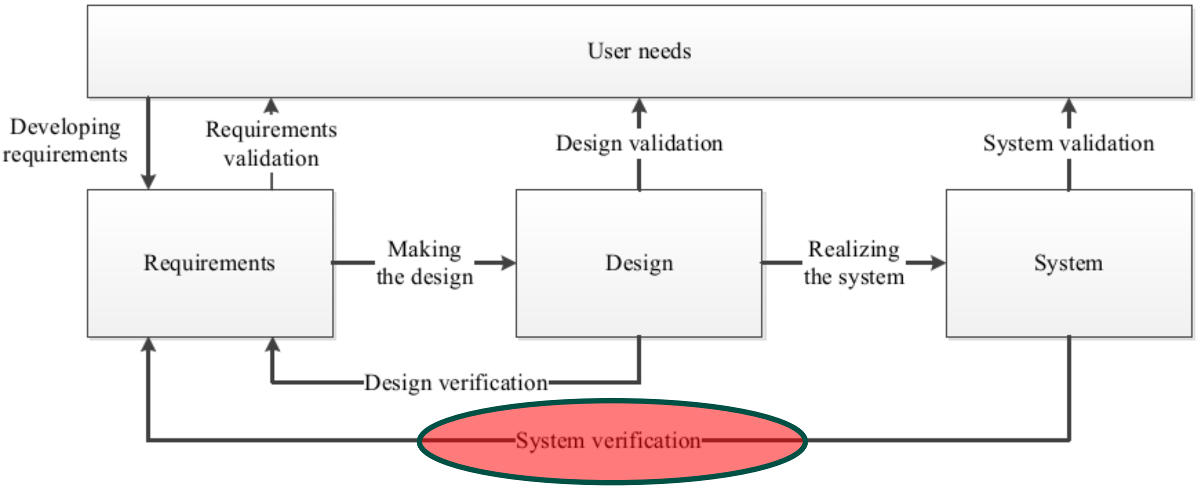

Figure 3: Flow chart of verification and validation elements (Schipper, 2016) in red the System verifcation

It seems that the previous mentioned five out of the total six requirements are more viewed as a formality and it is only an issue if the road users start to complain. The amount of complains were indicators for the client to measure if things were going well or not. This is not a reliable indicator, therefore the researcher has a strong believe the main objective of the clients is to not receive complaints instead.

Only the travel improvement requirement of case 1 performed official system verifications. This requirement scored the best out of all requirements in this department. In general, there is a hierarchy in requirements and this one was deemed important. This was the only requirement in all cases were the contractor provided traffic calculations and setup a Monitoring plan that detailed how the traffic would be measured during the construction phase. This is also the only requirement of all cases were the traffic was monitored, in which this data was used as proof. Another factor is that is it reasonable to measure the traffic to define the travel time change. The other requirements were mostly accessibility oriented and were focused on keep roads or destinations accessible. It is unknown to determine if measuring the accessibility would have been difficult, since they have not measurement has taken place.

In general, there is a lack of documentation during the construction phase. Often there are no documentation on system changes and decisions, providing evidence, progress and fulfillments. The most important reasons for the lack of documentation is due to the clients not asking for it and not prescribing it in advance. In all cases, there were no clear agreements if the contractor needed to demonstrate the fulfillments, how it needed to demonstrated and how detailed the proof needed to be. The most common reason given why this was not carried out, is to give the contractor the freedom on how he/she want to proof the quality.

If activities were not accordingly to the System Engineering protocol, it did not cause problems. There is no indication it caused miscommunication, errors, delays and damage claims. To add to that, the project goals were met, the clients were satisfied and the road users were satisfied. It appears that the internal quality assurance systems of the clients are properly working. The external quality assurance systems, meaning demonstrating the quality, are lacking. The design and system processes could be more organized in a structured way, in order to give insight to the project team's progress and to be able to demonstrate that the output meets the requirements.

4.6. Quality assurance assessment

This section gives answer to research question 2: "*how is the current quality assurance system of Iv-Infra defined?*"

In general, it was difficult to determine if the requirements were met or not. Since there is no objective evidence, except for opinions and observations from the client, the researcher cannot verify these outcomes. The biggest issue seems to proof that the requirements are met rather than fulfilling them. This due the structural lack of documentation and verification.

It seems that the current internal quality assurance system of Iv-infra works properly regarding reaching the project goals, fulfilling of requirements and satisfying the stakeholders. In all cases the client and contractor state the requirements were (mostly) met. The quality assurance system does not follow the System Engineering protocol at all times, however, this did not cause any problems. Nevertheless, there is a lack of (structured) documentation and system verification in the quality assurance system. It seems that the internal quality assurance system is effective and reaches its goals. The deficiencies in the external quality assurance system had no consequences so far.

5 Recommendations

Based on the finding of research question 2, this section the outcome of research 3: *"what were the (possible) insufficiencies and what are recommendations to improve Iv-Infra's quality assurance system?"*

As described in Paragraph 4.6, there are no issues with the internal quality assurance system. However, there are flaws with the external quality assurance system, the way the company demonstrates the quality. The flaws are mostly regarding the documentation and System verifying.

These flaws were tolerated due to the pleasant collaborations with the contractors, the contractors earning trust of the clients and the road users being happy about the outcome and did not complain to the client. In case you are facing a client that is stricter or deems the traffic nuisance very important, it is more likely this client will want the contractor to proof every requirement fulfillment. This is also more likely in a case the client only wants to remotely monitor the work of the contractor and not physically be at the project, whereas in the researched cases the client was regularly at the construction site. This is why it is recommended to follow the methodology of the developed framework, which is established from the System Engineering (SE) principle. By following the SE steps, the documented steps can also form as 'protection' to demonstrate the fulfillments to other stakeholders or to a client that is not satisfied with the managing of the requirements.

What contributed to the found flaws are the not clear set obligations or desires by the clients in advance. The client did not set any expectations or desires how the requirements need to be proven during the construction phase, what type of measurements would be used and how detailed the documentations should be. It is advised to properly define these obligations or desires as early as possible in a project phase, in order to not to face unwanted surprises in a later phase (Oberkampf and Trucano, 2008; Gieskens *et al*., 2007). Since it is not easy to clearly document all wishes and requirements at an early stage (Chritamara, Ogunlana & Bach, 2002), or if the client prefers not to impose such (detailed) obligates in advance, an option could be to obligate the contractor to develop a Monitoring plan after the project award. This is a plan developed for one requirement in case 1, in which the contractor has to explain how the requirement fulfillment will be measured and will be proven during the design phase.

Managing requirements and its documentation are critical procedures for a successful development of solutions that satisfy (Elmeidaa, 2019). Instead of not verifying or having informal verifications of the System, it is advised to perform official verifications and to document them. Marchant (2010), Elmeidaa (2019) and Graaf *et al*. (2017) state that verification should ongoing and performed in a disciplined manner. Since traffic nuisance is an ongoing process, it should be verified several times during the construction phase. In addition, when there is a change to the System, this should be officially documented and there should be a new verification to assess if the changed System complies with the set requirements.

Carrying out system verifications can be done in different ways. It depends how important the requirement is, how intensive it needs to verified and how much effort the contractor should/wants to put into it. An objective way is to measure traffic, since "*measure is to know*". There is the more traditional way measuring the traffic via counter loops or pneumatic detector. There is also the option to implement Implementing Intelligent Transport System (ITS) to monitor the traffic. Examples are the implementation of sensors, cameras or Floating Car Data. For example, Floating Car Data via GPS could have been a way to verify and demonstrate the requirement regarding avoidance of construction traffic on main network (Case 1). The choice of measuring the traffic should be based on the feasibility, available material and software.

A less frequent and simple way is performing the verification visually and documenting the findings. The contractor can develop checklist with the requirements and other specifications that needs to be filled in and signed. Additional proof can be to attach pictures and videos. Another option is to perform test runs and document the outcome. Again, this can be based a checklist and/or captured via visual material.

In all cases, there were no official design and system validations. A design validation ensures that the design matches the intended use of the system and fulfils the users' needs (Larsen & Buede, 2002; Directorate-General for Public Works and Water Management, 2009). A system validation ensures that the realized system suits its intended use and fulfils the users' needs (Bahill & Henderson, 2005). There is a possibility the output fulfills the requirements, but not the users' needs or intended needs, goals, and expectations (Department of Transportation, 2009).

This extra feedback loop did informally take place during the cases. There were stakeholders meeting, however these were not documented and none of the cases had a Validation plan. Another way how the validation was indirectly determined was by hardly getting complaints for the users. This research advices the contractor to develop a Validation plan. In this plan, the contractor needs to explain if and how the plans and if the carried out system validate the expectations intended needs, goals, and expectations (Graaf, 2014). This plan should also provide the actual validation of the carried out System. This plan should also contain Plan of Approach how the contractor will involve the users in assessing if the design and system are according their needs.

6 Conclusions

This chapter provides the main points of the research and gives answer to the main research question: *"which measures can improve Iv-Infra's quality assurance system regarding managing traffic nuisance requirements during the construction phase?"*

The research objective of this search consists of several aims of which the first to setup a framework based on best practiced in literature, for ensuring that the designs and systems are developed in compliance with the setup requirements in the infrastructural sector. The other objective has been to make recommendations to improve current practices in the quality assurance system of projects at In-Infra. A literature review has been conducted to develop the framework of best practices, which has been applied to current practices in three case studies implementing traffic nuisance during the construction phase requirements.

The performance of all projects in requirements, design and system were assessed and compared with each other. In general, it was difficult to determine if the requirements were met or not. In all cases the client and contractor state the requirements were (mostly) met. Since there is no objective evidence, except for opinions and observations from the client, the researcher cannot verify these outcomes. The biggest issue seems to proof that the requirements are met rather than fulfilling them. This due the structural lack of documentation and verification.

In all cases the client and contractor state the requirements were (mostly) met. It seems that the current internal quality assurance system of Iv-infra works properly regarding reaching the project goals, fulfilling of requirements and satisfying the stakeholders. The quality assurance system does not follow the System Engineering protocol at all times, however, this did not cause any problems. Nevertheless, there is a lack of (structured) documentation and system verification in the quality assurance system. It seems that the internal quality assurance system is effective and reaches its goals. The deficiencies in the external quality assurance system had no consequences so far.

These deficiencies in the quality assurance system were tolerated due to the client trusting the contractor and low amount of complaints from the other stakeholders. It is recommended to properly document and perform the verification in case there will be a client that is strict about demonstrating quality. Properly carrying it out can ensure that a system is built according to the client's and users' requirements and needs (International Council on System Engineering, 2007, Graaf *et al*., 2016; Graaf *et al*., 2017; Makkinga, 2016 & Schipper, 2016), thereby preventing possible fines and discussions. Being familiar with this protocol is useful in case a client is stricter or deems the traffic nuisance very important.

This research recommends to develop clear agreements or set obligates if and how the traffic nuisance requirement fulfillments need to be demonstrated. Other recommendations are to perform System verifications, carry them out regularly and document it. Changes to the System should be officially documented and there should be a new verification to assess if the changed System complies with the set requirements. This research provides examples how to carry out the System verification. It depends how important the requirement is, how intensive it needs to verified and how much effort the contractor should/wants to put into it. The most objective way is to measure the traffic, simpler ways are performing visually verifications or perform test runs. This research also recommends to carry out a Validation plan to ensure the output satisfied the users' needs.

Compared to other available literature, this research contributes by integrating two important aspects of the infrastructural industry: traffic nuisance and quality assurance. Since the specific characteristics of traffic nuisance during the construction phase can play an important role in infrastructural projects it is useful to consider how these requirements can be fulfilled and proved to be fulfilled.

Applying thresholds and other set rules can be seen as a tool the client uses. In theory, if you reach this goal, the client is satisfied with the work produced. When viewing this case, it tells you do not have to fulfill every exact agreement in order to satisfy the client's needs. This case tells you that when the client is satisfied you not have to fulfill the agreements. The contractor fulfilled the client's needs, which was no travel time reduction. The contractor offered something that was better than what the client asked for. Eventually, there was always a travel time improvement, it just did not reach the threshold every time. Another very important aspect was the local residents and store owners being happy with the work of the contractor. When there are no complaints from them to the client, this indicates the work organized well.

7 Discussion

This section provides the discussion of the research report.

7.1. Traffic nuisance terminology and standardizations

During this research, what stood out is the usage of the term 'traffic nuisance'. The usage of the term was confusing and not consistent. The clients never specified what the term means for them. In the clients' documents, there was an overuse of the terms 'no traffic nuisance', 'limiting traffic nuisance', 'minimal traffic nuisance', 'maximizing accessibility' and 'maximum traffic flow'. It can be contracting generalizing the term if the travel distance remains the same and on the other hand, travel time and capacity are lowered. It is also noticeable that when the clients are not consistent, the contractors' use of the term 'traffic nuisance' is also contracting and confusing.

There is very diverse use of traffic nuisance indicators in the analyzed cases. As found in the literature review, there are no recommended indicators or standardizations how to define and measure traffic nuisance. Every client can prescribe different (types of) traffic nuisance requirements. It is even possible that a client uses different traffic nuisance requirements per project. Basically, a client can propose different traffic nuisance demands regarding what the client finds important at that moment. This is line with the cases, since different projects from different clients have different desires and wishes.

One guideline was found, which is developed by Directorate-General for Public Works and Water Management. However, this guideline was not suitable for this research. The mentioned guideline is specifically used for motorways that are part of the main network. All cases for this research were not part of the main network and there was no standardization found for the underlying network.

7.2. Validation outcome

When assessing the cases, the outcome was that the System Engineering protocol was not always followed. The biggest issues are the lack of documentation, verification and validation. Verifying the System was not always carried or even an ongoing process.

Bahill and Henderson (2005) mention that System Engineering is a difficult concept in the construction sector that many companies are not yet able to implement in the right way, according to Schreinemakers, Erich and Vullings (2012). They indicate that there is often a lack of coherence between specification, verification and validation, and therefore the process does not go well. This is caused by unclear made agreements and interpretation of responsibilities. Makkinga (2016) states that possible problems are verification and validation performed too late, they are performed incompletely or not performed at all in infrastructural projects. It occurs that the contractor does not recognize the full importance of the verification processes and spends too little time and budget on these processes.

According to Schipper (2016), many organizations in the civil engineering industry experience difficulties with verification and validation, whereas verification and validation are regarded as time consuming and inefficient. Schipper adds that the quality assurance approach is not integrated in contractors' daily design and realization work. It seems that lack of incorporation occurred in the studied cases of this research. Managing requirements should not be a separated task from the designing activities but rather be incorporated in the exploration of the design solutions, assisting the process and enhancing the verification and validation activities (Ozkaya & Akin, 2007).

Integrated contracts, such as Design and Construct, require more effort on the verification and validation. Not only that, it also requires a specific way of working. Organizations are still not used to these new types of contracts and their way of dividing the tasks (Schipper, 2016). The client still wants to see what is being built on-site, therefore the contractor does not recognize the need for verifying and validating so severely. This is similar in the outcomes of the cases of this research. In addition, the current practices are slowly improving: 9 years ago, not even verification plans were used, while it is now usually obligatory in projects.

7.3. Limitations and future research

It was quite difficult to obtain case study documents for this research. Since Iv-Infra usually is hired as a consultant in a project, they often have no access to the documents when the project is finished. As mentioned in the problem statement, Iv-Infra had encountered projects in the past where the traffic nuisance requirements were not met. These projects were not available for this research.

It would have been more interesting if a case was studied where it was known that the traffic nuisances were not met. Therefore the current outcome of the project is contradicting with the problem statement. The researcher expected that the traffic nuisance requirements would have not been met. However, it seems there were no (big) issues with these requirements.

It is possible that the available cases for this research might not represent the company's quality assurance system. To further improve the company's assessment in order to suggest more or better improvement, it is advised to use a larger scale of cases. As mentioned earlier, it is advised to find cases where the traffic nuisance requirements were not met. In this case, the cases were very different from each other as described in Chapter 2. This made it difficult to compare and generalize the captured findings. In this research, findings were based only if a certain activity happened (almost) all the time.

This research focused only on objective traffic nuisance, reasons for that was the possibility of measuring it. The research found out that the subjective traffic nuisance is very important. If the road users are happy and do not complain, it indirectly means the performed road work and managing of traffic nuisance is performed accordingly. In all cases when the road users were happy, the client was also happy. For future research, it is advised to analyze the subjective traffic nuisance.

This research mostly focused on identifying the insufficiencies in Iv-Infra's quality assurance system. In order to improve the demonstrability of traffic nuisance requirement fulfillments, it is advised to research the opportunities of implementing Intelligent Transport Systems (ITS) technologies and applications during the construction phase.

Due to the scarce research on traffic nuisance requirement fulfillments during the construction phase, the developed framework was based on requirements of road infrastructure projects. It is possible not all the characteristics related to the defined elements are included in the developed framework. For example, the framework does not analyze the specific competences pf team members and the satisfactory level in the project. It is advised to cover other characteristics in order to improve the framework and results.

The framework defines the steps of System Engineering in order to fulfill the requirements and reach the promised quality. The researcher expected if characteristics were not carried out according that principle (score -), it would have consequences. However, this usually did not happen. Ultimately it comes down to whether people are satisfied, and for example, not performing certain verifications is not an issue. Therefore it seems that the framework is a bit of a mismatch. However, the outcome of the framework is very useful to improve the external quality assurance system, which are the features that show the requirements are met.

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APPENDIX