Successful verification of subcontracted work in the construction industry

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ABSTRACT

Due to specific characteristics of the construction industry, such as a highly fragmented supply chain, suppliers play an essential role in construction projects. A major shift in tasks and responsibilities in the construction industry from client to contractor, has an effect on the verification problems contractors face when subcontracting work to suppliers. To manage the design and verification process, systems engineering is increasingly used in the construction industry. This paper explores, by using a literature review and case study, which verification problems are faced. A conceptual framework is applied to categorize these problems and to find suitable solutions, using systems engineering tools, for improving a contractor's procurement strategy and for solving verification problems once they do occur.
The major finding in this paper is that causes of verification problems can be found at both the contractor and the supplier side. Some improvements are suggested for both these sides.

Key words: construction industry, subcontracting, verification

Systems engineering knowledge areas: SEE07 System Integration, SEE08 Verification/Validation

Systems engineering application area: AS08 Infrastructure & Resource Management

1. Introduction

In the construction industry, clients increasingly focus on their core business and more attention is paid to exploiting specific knowledge and skills available on the market. This results in a shift in tasks and responsibilities from the client to the contractor. To accommodate this shift, new types of contracts, which allow the integration of a larger part of the project life cycle, are used. These integrated contracts are, for example, Engineering & Construct (E&C), Design & Construct (D&C) and Design, Build, (Finance), Maintain & (Operate) (DB(F)M(O)) (Van de Rijt, Hompes, & Santema, 2010; Winch, 2010). Although the client, in these new types of contracts, is responsible for a smaller part of the project life cycle, the client still wants to keep control over its construction projects. Systems engineering (SE) is seen as a way to outsource a larger part of the project life cycle, e.g. design, engineering and construction, while still keeping control.

Important elements of SE are the iterative requirements specification, functional analysis and design processes and hierarchically structuring the requirements, system and activities (INCOSE, 2015). The iterative nature of the requirement specification, functional analysis and design processes allows the distinction of different levels of detail, as the requirements for the system are described on an abstract level in the first iteration and in more detail in subsequent iterations. This enables the client to choose a certain level of detail, or several levels of detail for different parts of the system, for the contract that is tendered, possibly leaving out the prescription of (technical) solutions and thus maximizing the opportunities for the contractor to use its knowledge and optimize solutions. This also enables the client to procure a larger part of the project life cycle and to focus on its core business.

Part of these integrated contracts and the application of SE, is the shift in the responsibility for verifying and validating the quality and compliance to the requirements of the work. Where in the case of the more traditional contracts, in which the client prescribes in detail what has to be done by the contractor, this is the responsibility of the client, in the integrated contracts the contractor also becomes responsible for verification and validation. The responsibility for potential problems regarding verification and validation therefore also shifts to the contractor. Due to this major shift in tasks and responsibilities from client to contractor, most research focuses on the client-contractor relation (Dainty, Millett, & Briscoe, 2001; Eom, Yun, & Paek, 2008).

The contractor, however, is not the only organization that executes design or construction tasks. The supply chain in the construction industry is highly fragmented and knowledge, materials, components, information and skills are dispersed among many different organizations (Rutten, Dorée, & Halman, 2007). Many companies mainly focus on a geographically limited

area, which further strengthens the fragmentation of the supply chain (Segerstedt & Olofsson, 2010). This fragmented supply chain and the geographical focus create the need to subcontract parts of the work to suppliers (Gadde & Dubois, 2010). The term supplier in this case covers subcontractors, material suppliers, service suppliers, etc. Since contractors sometimes subcontract up to 90 percent of the total project turnover, suppliers have a large impact on project performance (Bemelmans, Voordijk, & Vos, 2013; S. Y.-L. Yin, Tserng, Toong, & Ngo, 2014).

Due to this large part of the work being subcontracted, the suppliers play an important role in the verification and validation process. Although the main contractor bears the final responsibility towards the client, it may be expected that, in line with the shift in responsibilities from client to contractor, the supplier verifies and validates its own work. This makes the application of SE also required further down the supply chain. However, many problems are experienced with allocating these verification and validation responsibilities to the suppliers and with the verification and validation of subcontracted work. Verification and validation are finished too late, incompletely executed, incorrectly executed or simply not done at all. This results in verification problems between the supplier and the contractor, and the contractor not being able to prove to the client that all specified requirements are met. This can lead to the client withholding payments and finally causes adverse financial consequences for the contractor.

The specific research question answered in this paper is therefore: *Which verification problems do contractors face when outsourcing work to suppliers?* Recommendations are given to overcome these problems. This paper can practically contribute and help contractors to develop their procurement strategy to prevent problems with the verification of subcontracted work and increase project performance. This paper theoretically contributes by combining the construction supply chain, systems engineering and verification and validation, a combination not addressed in research before.

The paper begins in section 2 with a description of the research methodology. Section 3 describes the verification process, the verification problems experienced and introduces a conceptual framework to categorize verification problems and provide possible solutions. Section 4 describes the results of a case study conducted among seventeen contractor-supplier relations and links these results to the conceptual framework. After a discussion of the results in Section 5, Section 6 draws upon these results to conclude and provides improvements for the subcontracting of work to prevent verification problems.

2. Research methodology

This research is based on both a literature review on verification, construction supply chain and the systems integrator concept and a case study among seventeen contractor-supplier relations. The literature review results and the case study results are respectively used for theoretical and empirical patterns. These are then analyzed using a pattern matching procedure, as described by Cao (2004) and De Graaf and Dewulf (2010). The research methodology can be split in roughly four successive parts.

First, based on the literature review, a conceptual framework was developed to categorize different types of verification problems. The framework builds upon systems engineering theory and work by Bahill and Henderson (2005). This framework allows a clear analysis of each verification problem type and the corresponding types of solutions. This framework also forms a guideline for the research, as both the theoretical and empirical patterns are matched to this framework.

Second, the framework is used for creating the theoretical patterns for the pattern matching procedure. Based on the literature review, possible expected solutions to prevent or solve verification problems are linked to the framework's verification problem types. This results in a set of theoretical patterns, that are structured as: 'In case a specific type of verification problem X occurs, it is expected that the contractor uses solution Y to solve the problem or prevent more problems.'. In the next step, these theoretical patterns are confronted with the empirical patterns from the case study.

Third, the empirical patterns follow from practice using a case study conducted at a middle sized construction contractor in the Netherlands. Context of the cases is the Dutch construction industry, which has shown the major shift in tasks and responsibilities from the client to the contractor, as described in the introduction, over the past decade. With the introduction of the Uniform Administrative Conditions for Integrated Contracts (UAC-IC, UAV-GC in Dutch) in 2005, construction projects are tendered in earlier phases of their life cycle and for a larger part of their life cycle. This results in the Dutch construction industry making a change from an owner controlled to a contractor controlled environment. The case study was conducted using the case study procedure described by R. K. Yin (2013). First, a quick scan among nine different construction projects, using the one phase screening approach described by R. K. Yin (2013), was conducted to determine the suitability of each for further analysis. Based on this quick scan, three projects were selected, with a total of seventeen significant subcontractors. These projects were selected so that the most important part of the contractor's portfolio was covered, the number of suppliers was equally distributed over the three projects and a diversity of suppliers, with different frequently required fields of expertise and varying levels of experience in verification and working within the conditions of an integrated contract, could be analyzed. The first project concerned the design and construction of a highway exit, including a highway overpass, reconstruction of parts of the local road network and landscaping. The second project selected for the case study was the design and construction of a large sash lock, that also has a water safety function, and a moveable bridge. The third project concerned the reconstruction of an urban train station area, including the reconstruction of the train station itself, redevelopment of the train station's surrounding area and the construction of two grade separated railway crossings. To further structure the case study, a case study protocol described the procedure used for gathering the data using semi-structured interviews with employees closely involved

in these projects.

Fourth and finally, the theoretical and empirical results are integrated. A case study report described the results for each individual case first and then used a pattern matching procedure to compare the theoretical patterns from the framework with the empirical patterns from the case study in a cross case analysis. Based on this comparison, the influence of different solutions on the verification of subcontracted work is determined and some recommendations for improvements are given.

3. Verification problems

Essential parts of systems engineering are verification and validation. Verification is defined as proving the compliance to the specified requirements by providing objective and explicit evidence (INCOSE, 2015). A distinction is made between design and execution verification. Design verification is providing evidence to prove that the design meets the specified requirements. Execution verification is providing evidence to prove that the built system meets the specified requirements and its design. Validation is defined as determining whether the system actually meets the expectations, demands and needs of the stakeholders (De Graaf, 2014; Department of Defense, 2001; INCOSE, 2015).

Validation is often considered at the system level and is not always possible on specific parts of the system. This research focuses on subcontracting, in which only a specific part of the system is subcontracted to a supplier. The supplier is, due to its limited scope, not always able to execute the validation process. The further down the supply chain, the more difficult it becomes to validate. This can be illustrated using an example, from the case of the moveable bridge. The client, the organization that operates the bridge, wants a system that can facilitate ships of a certain class (e.g. CEMT Va) and a certain intensity of road traffic, without causing too much delay for either type of traffic. These expectations of the client can only be validated when the system is considered at the system level (Department of Defense, 2001). Looking at only a small part of the system that is subcontracted to a specific supplier, e.g. the engine that actually drives the bridge deck, these expectations cannot be validated. The specific requirements for this specific part however, can be verified by the supplier. Also, so called *in-process validation*, in which the client's expectations, demands and needs are validated during the project, is difficult for an individual supplier, since direct communication between client and supplier is often not allowed by the contractor to prevent contradicting information or commitments from different suppliers. Finally, most problems experienced in the construction industry are related to verification and not validation. These verification problems are also the reason for this research. Therefore, validation is not included in the scope of this study. Only the verification of the specified requirements is considered.

Contractors experience problems with the verification of work that is subcontracted to suppliers, such as the verification not being executed by the supplier, the verification not being complete and not being executed to the desired level of detail, the verification executed by the supplier not matching the specified requirements, discussions about responsibilities and interfaces, detection of verification problems in a late phase of the project when changes are expensive and difficult, a lack of coercive instruments to stimulate the supplier to execute the verification and finally extra costs to solve the aforementioned problems. These verification problems in the contractor-supplier relation, have negative effects on the contractor's relation with the client. Parts of the work, contracted to suppliers but for which the contractor bears the final responsibility, cannot be verified. This obstructs acceptance of the work by the client.

Categorizing verification problems

As different types of problems require different solutions, it is useful to develop a framework to categorize verification problems, in order to find suitable solutions for the verification problems that are experienced when work is subcontracted to suppliers. To categorize system failures, Bahill and Henderson (2005) developed the System and Requirements Classification Model (SRCM). This model juxtaposes two important and interrelated concepts from the systems engineering theory: 'system verification and validation' and 'requirements development' (i.e. determining stakeholder expectations, demands and needs and process these into a (functional) requirement set). Based on these two concepts, the model categorizes system failures and (1) provides a means of categorizing systems in terms of design conformity and requirements satisfaction and (2) provides a way to study requirements not yet satisfied by any system. The SRCM model can provide a framework to categorize problems and find solutions for the verification of suppliers' work.

The SRCM model is however not directly applicable to the case of verification problems with work that is subcontracted to suppliers. Validation is an integral part of the SRCM model, as system verification and validation are considered together. The systems are either verified and validated or unverified and unvalidated. Simply leaving out the validation part, would cripple the model, as a large part of the model would no longer be possible. Directly applying the SRCM model to this study is therefore not possible.

The axes of the SRCM model on which failures or problems are categorized are, however, very useful within the scope of verification of subcontracted work. Therefore, an adapted framework using these axes is developed for categorizing verification problems that occur with subcontracted work from a supply chain perspective. The framework is based on two axes: (1) supplier compliance to the contracted verification obligations and (2) the validity of the contracted requirement set.

The first axis, the compliance, comprises three parts, while the second axis, the validity, comprises two parts:

- Supplier compliance to the contracted verification obligations.
    - A. Fully satisfied
    - B. Incompletely satisfied
    - C. Not satisfied
- Validity of the contracted requirement set.
    1. Valid requirement set
    2. Invalid requirement set (incomplete, incorrect or inconsistent)

These axes result in a union with a total of six types of verification problems. The validity axis intentionally comprises only two parts. First, adding a third group, between valid and (completely) invalid, which describes the partly valid requirements, requires an arbitrary and subjective choice whether the requirement set is completely invalid or partly valid. Since the validity of a requirement set is not a quantitative variable, deciding whether a requirement set is no longer partly valid but invalid, is an arbitrary and subjective decision. Second, a relation between contractor and supplier with a completely invalid set of requirements is impossible, since the relation is based on a contract between the two parties that at least briefly describes the contents of the work of the supplier. The compliance axis on the other hand, comprises three parts, as it is easily determined whether a supplier has provided evidence to prove the verification only partial or provided no evidence at all.

To ensure a consistent application of the framework, some assumptions have to be observed.

- Starting point of the application of the framework is the detection or identification of a (possible) verification problem. Once a problem is detected or identified, it can be analyzed according to the axes of the framework and categorized into one of the groups. Choosing the detection of a (possible) verification problem as the starting point, also prevents endless discussions about the validity of requirement sets in cases in which no problems occurred. A requirement set is never entirely complete, as specifying requirements has to stop at some level.
- The framework is considered from the viewpoint of the contract that is concluded between the contractor and supplier.
    - o The supplier compliance to the contracted verification obligations describes the degree to which the supplier fulfills the verification obligations described in the contract concluded between the contractor and the supplier. A supplier that is obliged by the contract to execute the verification for an entire object, but only completes the verification for a part of that object, is categorized in column B (partly satisfied). A supplier that is only responsible for the execution of a construction activity and not for the verification however, is categorized in column A (fully satisfied), even if the activity was not verified, because the supplier satisfied its obligations.
    - o The validity of the contracted requirement set is considered form the viewpoint of the supplier and within the context of the goal of the subcontracting procedure. For example, a requirement set that is invalid and incomplete for a highly specified contract in which the supplier only executes a specific activity, can be valid if further requirement development is described as part of the scope for the supplier.
- The framework is applied to the situation after the completion of the project and does not describe the interim status of the verification. This prevents incomparable results. For example, a supplier that has not satisfied its verification obligations after completion of the project is different from a supplier that has not yet satisfied its verification obligations but is intending to do so later on.
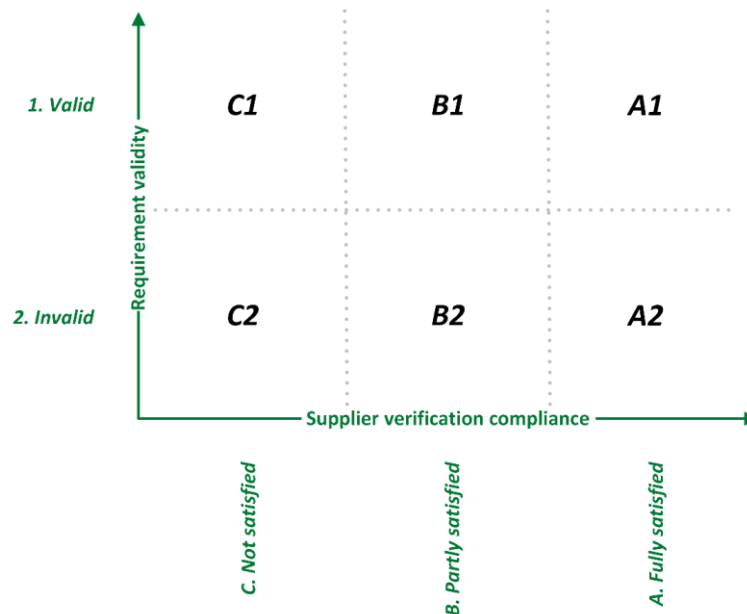
Figure 1 - Framework for categorizing supplier verification problems

Figure 1 shows the framework for categorizing supplier verification problems. Given the two axes, the following six groups can be distinguished:

- Group A1 describes the relations in which a valid requirement set was contracted and the supplier fully satisfied its verification obligations. The supplier proved that the system fulfills the specified requirements. Also, the requirement set is considered valid for the scope of the supplier's work. In fact, group A1 describes the cases in which no real verification problem occurred.
- Group B1 also describes relations in which a valid requirement set was contracted. However, the supplier only partly satisfied its verification obligations. Although the requirements were valid, for some parts of the supplier's work it cannot be proved that the specified requirements were met. The problem has to be sought in the supplier's verification process. It can, for example, be caused by a lack of supplier competence. Additional verification can prove that the system satisfies the specified requirements.
- Group C1 describes situations in which the supplier did not satisfy its verification obligations at all. The contracted requirement set is valid, but it cannot be proved that these requirements are satisfied due to the absence of verification.
- Group A2 describes the relations in which the supplier satisfied its verification obligations. However, the contracted requirement set is considered invalid for the goal of the subcontracting procedure. It can, for example, be incomplete for the type of work of the supplier. Although the supplier has satisfied its verification obligations, i.e. fulfilled the verification of the requirements in the contract, and there is no contractual problem between contractor and supplier, not all relevant requirements are part of the contract. This may lead to verification problems for the system as a whole or validation problems later on.
- In group B2, the supplier also only partly satisfied its verification obligations, which causes a contractual problem between contractor and supplier. The requirements are not sufficient for the goal of the subcontracting process, which may lead to verification or validation problems later on. Also, it cannot be proved that the system meets these requirements.
- Finally, group C2 described the relations in which the supplier did not satisfy its verification obligations at all. In addition, the contracted requirement set is not sufficient for the goal of the subcontracting process. To solve this type of problem, improvements on both axes have to be implemented.

To clarify the application of the framework to an actual case, an example for the moveable bridge case is used. Contractor A has contracted supplier X for the design, engineering and construction of the drive mechanism for the deck of the bridge. During completion of the verification documentation, it is identified that supplier X did not verify that the system fulfills the specific requirement 001: '*The maximum time required for the opening procedure of the moveable bridge is 90 seconds*'. To apply the framework to this verification problem, it is first determined what column (compliance) this situation can be categorized in. Supplier X did not verify this specific requirement 001, but did verify the other relevant requirements. Therefore, the compliance to the verification obligations is only partly satisfied, column B. During more detailed investigation, it is determined that supplier X successfully developed requirement 001 into more detailed requirements that, together, fulfill requirement 001, as was required in the contract. Supplier X however forgot to completely execute the verification. This makes the contracted requirement set valid, thus row 1 and group B1. This problem can be solved by executing additional

verification of requirement 001. The situation then moves to group A1.

With the framework, it is now possible to classify different types of verification problems. To solve these problems, the contractor and supplier have to apply one or more solutions, which are formulated based on the literature review and described in the next section. By linking the classification of the verification problems to these solutions, it is possible to formulate expectations for applicable solutions in the case of a specific type of verification problem. This combination of verification problem type and expected solution is defined as the theoretical pattern, formulated as: 'In case a specific type of verification problem X occurs, it is expected that the contractor uses solution Y to solve the problem or prevent more problems.'. These theoretical patterns are later compared with the empirical patterns from the case study to determine whether these expected solutions are actually applied in practice.

Linking possible solutions to the framework

To help solving or preventing verification problems of work that is contracted to suppliers, the categorizing framework discussed in the previous section is linked to several possible solutions that were formulated based on verification, supply chain and systems integrator literature. The combination of verification problem types and the expected solutions, creates the theoretical patterns. Six possible solutions were found in literature. These solutions can be divided in pre-contract solutions (I, II and III) that can be applied during the contractor's procurement process before the contract with the supplier is signed, and post-contract solutions (IV, V and VI) that can be applied during the project and verification process, after the contract with the supplier is signed.

First (I), the contractor can consider the level of detail at which the work will be subcontracted to a supplier. This level determines which part of the tasks and responsibilities is allocated to the supplier. The contractor has several options for this level of detail, e.g. (1) a prescribed supply or activity (all design and engineering tasks are performed by the contractor), (2) design and execution by the supplier with verification executed by the contractor, (3) design, execution and verification by the supplier, using a prescribed verification procedure or (4) design, execution and verification by the supplier (i.e. 'completely' subcontracted) (Bemelmans et al., 2013; Gundlach & Cannon, 2009).

Second (II), the contractor can consider which supplier is selected, based on the level of detail of the contract and taking into account the competences and experience of the supplier (Davies, Brady, & Hobday, 2007; Hobday, 2005; Rutten et al., 2007; Winch, 2010).

Third (III), the contract that is conducted with the supplier should explicitly describe the parties' scope, responsibilities and expectations, especially considering the verification process and results (Elich, Schreinemakers, & Vullings, 2012).

Fourth (IV), the contractor should coordinate the requirement development and interfaces for the entire project, making sure that all requirements, developed by the suppliers or the contractor, can verify the top level requirements and that no gaps or contradictions between the developed requirements arise (Bemelmans et al., 2013; Elich et al., 2012; Erbil, Akıncıtürk, & Acar, 2013).

Fifth (V), the contractor could improve the competences and skills of the supplier, by supporting the supplier during the verification process (Gadde & Dubois, 2010; Matthews, Pellew, Phua, & Rowlinson, 2000).

Sixth (VI) and finally, the contractor can take over the verification tasks from the supplier and execute or finish them (ProRail et al., 2013; Rutten et al., 2007).

Combining the aforementioned solutions with the categorizing framework, some solutions can be expected for each type of verification problem. This is shown in Figure 2. Since group A1 describes situations in which no real verification problem occurred, no solutions are linked to this group. Group A1 is, however, interesting for further analysis to determine what solutions or measures lead to the absence of verification problems.
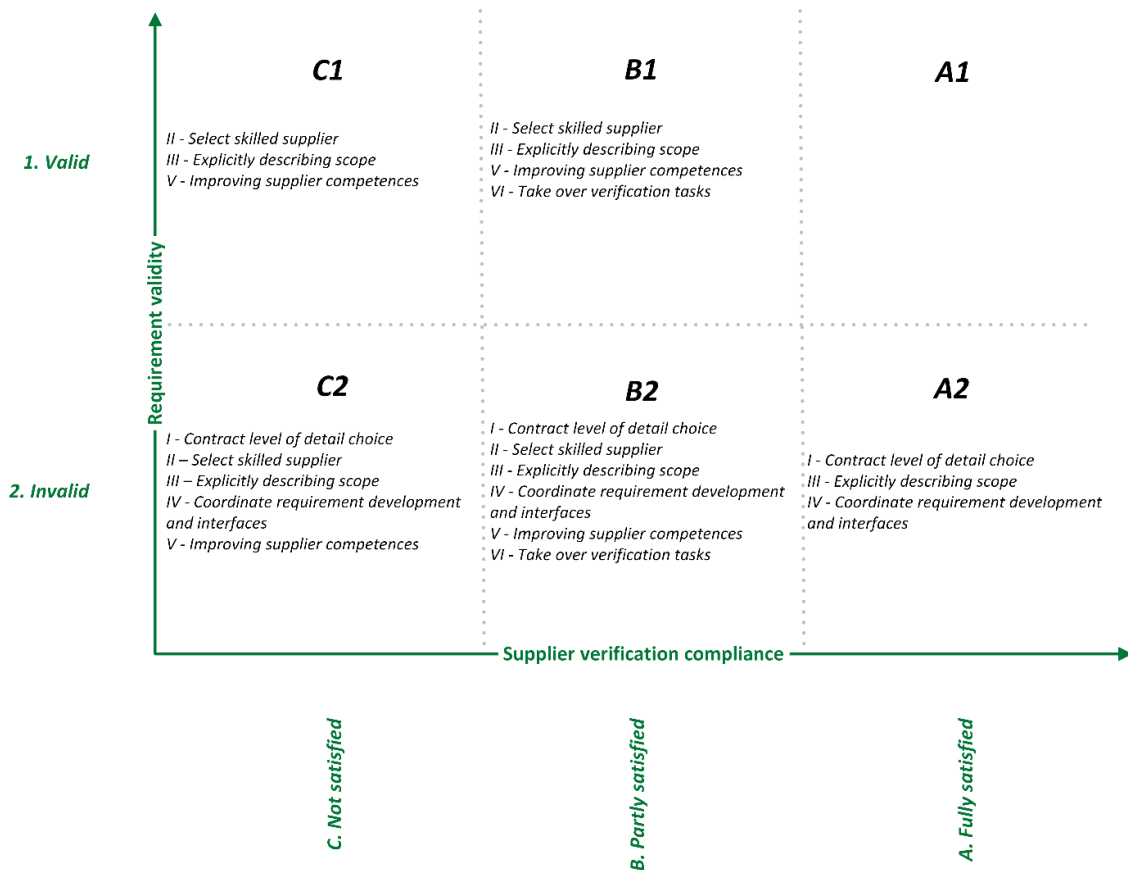
C1	*B1*	*A1*
II - Select skilled supplier	*II - Select skilled supplier*	
III - Explicitly describing scope	*III - Explicitly describing scope*	
V - Improving supplier competences	*V - Improving supplier competences*	
	VI - Take over verification tasks	

1. Valid

Requirement validity

C2	*B2*	*A2*
I - Contract level of detail choice	*I - Contract level of detail choice*	*I - Contract level of detail choice*
II – Select skilled supplier	*II - Select skilled supplier*	*III - Explicitly describing scope*
III – Explicitly describing scope	*III - Explicitly describing scope*	*IV - Coordinate requirement development and interfaces*
IV - Coordinate requirement development and interfaces	*IV - Coordinate requirement development and interfaces*	
V - Improving supplier competences	*V - Improving supplier competences*	
	VI - Take over verification tasks	

2. Invalid

Supplier verification compliance

C. Not satisfied *B. Partly satisfied* *A. Fully satisfied*

Figure 2 – Theoretical patterns (solutions linked to the framework for categorizing supplier verification problems)

The solutions for specific types of verification problems, as shown in Figure 2, are the theoretical patterns for the pattern matching procedure described in de results section. These are compared to the empirical patterns from the case study.

To further elaborate the linking of these six solutions to the framework, Table 1 shows for each solution why it is a solution for specific verification problems, how the solution can be implemented and why the solution is not linked to other verification problem types. From the contractor's point of view, it is suggested to first apply the pre-contract solutions (I, II and III) as early in the project as possible. The post-contract solutions (IV, V and VI) can be applied once the supplier is contracted.

Solution	Linked to verification problem type(s)	Explanation
I – Contract level of detail choice	A2, B2, C2	Indistinctness in the level of detail of the contract between contractor and supplier can cause verification problems because the division of responsibilities can be unclear. The contract level of detail determines the division of responsibilities, as it determines from which level of detail or for which tasks, such as requirement development to higher levels of detail, the supplier is responsible. By making a well-thought and clear choice for this contract level of detail, it is clear to everyone from which level of detail the supplier is responsible. This solution is important to solve or prevent verification problems of types in which the requirement set is considered invalid, i.e. A2, B2 and C2. Choosing a clear contract level of detail can help in creating a valid requirement set. In situations with verification problems of types in which the requirement set is already valid, this solution does not need to be applied. This solution can be implemented by making the choice for the contract level of detail a separate and clear step in the procurement procedure, for example by basing the contract level of detail on the goal of the procurement procedure and the knowledge present at the contractor.
II – Select skilled supplier	B1, C1, B2, C2	When a supplier is not skilled for the tasks it has to do, verification problems can arise. A supplier is considered skilled when it has the competences to successfully complete its assigned tasks. Skill is thus not an absolute scale or value, but depends on the nature of the tasks assigned to the supplier. For example, when a supplier is responsible for the verification of its own work but doesn't have the required competences for doing this, the supplier is considered to be not skilled for its tasks. However, when verification is not assigned to the supplier, it might be considered skilled for its tasks. Selecting a skilled supplier is thus based on the nature of the tasks the contractor wants to procure. An explicit and well-thought supplier selection process can prevent the allocation of tasks to a supplier that lacks the required competences and also solves the problem of contractors assuming and not actually knowing that a supplier is skilled. This solution is effective for situations in which the cause for verification problems can be found at the supplier, for

		example if the supplier does not have a good procedure for verification execution. The solution is therefore linked to verification problem groups B1, C1, B2 and C2. In the other verification problem groups, i.e. A1 and A2, the supplier fully complied to its verification obligations, so this solution is not effective in these situations. Implementing this solution can be done by an analysis during the procurement procedure in which the required competences, based on the tasks that have to be procured, and the supplier's actual competences are compared.
III – Explicitly describing scope	B1, C1, A2, B2, C2	When a supplier does not know what its responsibilities are, some of its tasks might not be done or completed or might be done twice, by both the contractor and/or suppliers. When a supplier is contracted, its scope of work, including interfaces with the contractor and other suppliers, should be explicitly described to prevent any uncertainties about each suppliers' scope. Also, explicit scope descriptions can help detect gaps or overlaps between the contractor's and/or suppliers' scope. This solution is considered useful in situations in which the cause of verification problems can be found at the contractor, i.e. B1, C1, B2 and C2. For example, if a supplier didn't complete verification because it wasn't fully aware of its responsibilities. Also, this solution can be applied in situations in which the requirements set is invalid, because it doesn't match the supplier's scope or because the supplier's scope is not clear, i.e. A2, B2 and C2. Implementing this solution can be done by making an explicit overview of each supplier's tasks and responsibilities during the procurement process. This solution also enables the contractor to check the entire project scope (the contractor's scope and the suppliers' scope together) on integrity or overlaps.
IV – Coordinate requirement development and interfaces	A2, B2, C2	When work is subcontracted to different suppliers, interfaces will arise between these suppliers. Coordination of these interfaces is important for keeping the requirement set valid. Some suppliers might, due to these interfaces or certain design choices, develop their contract requirements into more detailed (technical) requirements. These developed requirements might be conflicting with other requirements, developed by the contractor or other suppliers. Both these interfaces and the suppliers' requirement development processes have to be coordinated to prevent contradictions or gaps. A requirement set can be valid when contracted to a supplier, but can become invalid if requirement development or new interfaces create contradicting requirements. For example, if an installations supplier chooses a certain type of ventilation system, this system has to fit in the concrete structure designed and realized by another supplier. The requirement development process at the installations supplier thus also create new requirements for the concrete supplier. Therefore, these interfaces and the requirement development process have to be coordinated. This solution is useful in cases in which the requirement set is or became invalid due to new requirement development results or new interfaces, i.e. A2, B2 and C2. In the other groups, A1, B1 and C1, there is no invalid requirement set and this solution is not explicitly suggested. This solution can be implemented by actively monitoring the results of the requirement development processes, to detect possible contradicting requirements between contractor and/or suppliers, and monitoring the existing or new interfaces, to determine whether additional requirements or actions are required. This can be best done by the contractor or one of the suppliers that have an overview of the entire project, for example the main designer.
V – Improving supplier competences	B1, C1, B2, C2	When verification problems arise that are caused by a lack of competences of the supplier, this supplier should increase its competences, for example by training or hiring extra expertise. However, the contractor can also improve the supplier's competences by guiding or improving the supplier's verification process or providing training. This can also be beneficial for future work with this supplier and can contribute to a more partnership like supplier relation. This solution is considered useful in situations in which the supplier did not comply to its verification obligations, i.e. B1, C1, B2 and C2. In the other situations, A1 and A2, the supplier did comply to its verification obligations and likely possesses the required competences, so improvement is not necessary. This solution can be implemented by supporting the supplier's verification process with staff with verification expertise or by setting up training programs.
VI – Take over verification tasks	B1, B2	As a sort of a last resort when verification still doesn't go well, the contractor can take over verification tasks from the supplier during the project. If a supplier doesn't completely comply to its verification obligations, and other solutions don't work, the supplier can decide to execute the remaining verification tasks himself. However, this means that the supplier isn't kept to its contractual obligations and automatically results in extra work and costs for the contractor. Therefore, it is only suggested to apply this solution for a limited amount of verification, keeping the extra costs and work low. It is thus suggested only in situations B1 and B2, in which the supplier did not completely comply. In situations C1 and C2, the supplier did not comply at all. Taking over verification tasks in these situations would lead to large extra costs for the contractor. In situations A1 and A2, the supplier fully complied to its verification obligations and no verification tasks remain, so this solution is not necessary.

Table 1 – Solutions linked to verification problems groups

4. Results

In the case study among seventeen suppliers in three projects, seven supplier relations did not show verification problems and were thus categorized in group A1. A total of ten suppliers were categorized as having experienced verification problems (i.e. groups B1, B2, C1 and C2). Table 2 provides an overview of the cases, suppliers and corresponding verification problem groups. The case study results are analyzed in three parts.

First, an individual supplier analysis is done. Based on the theoretical patterns derived from theory and the categorizing framework, and the empirical patterns from the case study results, a pattern matching analysis is done for each supplier relation. The expected and actual patterns are described and discussed. The complete individual supplier analysis can be found in Appendix A. Second, a cross case analysis describes the specific patterns, if applicable, for each of the three cases. Third, a cross supplier analysis is done. Based on the verification problem groups from the framework, the specific patterns that are visible in each group are discussed. For each verification problem group, the general problems, the theoretical patterns and empirical patterns are described. Also, the overall patterns based on the pattern matching results for all seventeen relations, are

described. This three step analysis is then used to as input for recommendations and improvements.

Case	Supplier	Type of work	Verification problem group
Case 1 - Design and construction of a highway exit, including a highway overpass, reconstruction of parts of the local road network and landscaping.	Supplier 1-1	Integral design process.	B1
	Supplier 1-2	Engineering, production and supply of the overpass' girder work and pressure layer.	B2
	Supplier 1-3	Design and realization of vertical vegetation on the highway overpass, including the verification of the requirements.	B2
	Supplier 1-4	Design, realization and maintenance of greening.	A1
	Supplier 1-5	Engineering and realization of road markings, barriers, signage and traffic measures.	A1
	Supplier 1-6	Execution of earthworks.	A1
Case 2 - Design and construction of a large sash lock, that also has a water safety function, and a moveable bridge.	Supplier 2-1	Integral design, engineering, production, testing, supplying, assembling and completion of the steel structure of the movable bridge and the steel lock doors.	B1
	Supplier 2-2	Integral design of both the civil constructions and roadworks, supplier reviews, risk management and interface management.	A1
	Supplier 2-3	Integral design, engineering, production, testing, supplying, mounting and completion of all mechanical installations for both the moveable bridge and the lock doors.	C2
	Supplier 2-4	Execution of sheet piling, canal/lock floor protection, canal/lock bank construction, slackening structures, groundworks and some detailed design tasks.	A1
	Supplier 2-5	Design, engineering, production, testing, supplying, mounting and completion of all electrical installations (e.g. the bridge and lock door control systems).	B2
Case 3 - Reconstruction of an urban train station area, including the reconstruction of the train station itself, redevelopment of the train station's surrounding area and the construction of two grade separated railway crossings.	Supplier 3-1	Positioning of the railroad crossing's deck.	B1
	Supplier 3-2	All rail related objects in the project, such as the tracks, sleepers, ballast and electrical installations.	A1
	Supplier 3-3	Integral project design, excluding the design responsibilities of Supplier 3-5.	C1
	Supplier 3-4	Engineering and execution of all sheet piling, drainage, CSM-walls and groundworks.	A1
	Supplier 3-5	Design, engineering and execution of all installations (except the rail related installations from Supplier 3-2) and lighting.	B2
	Supplier 3-6	Design and adaptation of the station's steel roof structure, including the conservation and mounting.	B1

Table 2 – Overview of cases, suppliers and corresponding verification problem groups

Individual supplier analysis

As a start of the pattern matching procedure, the supplier relations in each case are first analyzed separately. As an example, the individual analysis for one relation is described in this section. An extensive description of the patterns in each relation can be found in Appendix A. For each supplier, a short description of the relation is given, including the type of work that was contracted and the supplier selection procedure. Then, each supplier is categorized in one of the verification problem groups. Based on this category, the theoretical patterns, i.e. expected solutions based on the verification problem group, are described. This is followed by the empirical patterns, i.e. the solutions that were actually applied. The number (I to VI) of each solution corresponds with the number in Figure 2. * indicates the application of a solution not expected based on the framework. The match between theoretical and empirical patterns is then shortly explained. In these descriptions, the 'contractor' is the main contractor at which the case study was executed.

As an example, the analysis of supplier relation 2-1, from the sash lock and moveable bridge case, is described. Supplier 2-1 was responsible for the integral design, engineering, production, testing, supplying, assembling and completion of the steel structure of the movable bridge and the steel lock doors. A letter of intent was conducted with Supplier 2-1 during the project's tendering phase.

Supplier 2-1 is categorized in verification problem group B1. In general, the verification executed by the supplier was incomplete and lacked the required detail. Therefore, the supplier only partly complied to the verification obligations. The contracted requirement set is considered valid. The entire contract between the client and contractor was subcontracted to the supplier. This was, given the integral role of Supplier 2-1 considered to be valid.

Based on the verification problem group B1, the theoretical pattern expected is the appliance of the following solutions:
-    Select skilled supplier (II)
-    Explicitly describing scope (III)
-    Improving supplier competences (V)
-    Take over verification tasks (VI)

In the case study, the following solutions were actually applied:

- Contract level of detail choice (I)
- Select skilled supplier (II)
- Explicitly describing scope (III)
- Coordination of requirement development and interfaces (IV)

The contractor decided to subcontract all steel structure related work, as the required competences and knowledge were not present at the contractor. The choice for Supplier 2-1 was therefore based on its experience with steel structures. Also, with the letter of intent during the tendering procedure, the supplier's expertise and knowledge could already be used in an early phase of the project. The supplier choice was therefore well-thought. The supplier's scope was explicitly described in an appendix to the contract. However, verification was not described in detail. Finally, the contractor coordinated the requirement development process and the interfaces between suppliers during the project, especially in the design phase.
The verification problems in this relation were mainly caused by a lack of supplier effort for the verification. This resulted in incomplete and inconsistent verification.

Cross case analysis

In the three cases, with a total of seventeen supplier relations, no case specific procurement strategies could be found. For example, in none of the cases it was decided to always subcontract verification to the supplier. However, another, less clear pattern was found in the case study.

In case 2, the sash lock and moveable bridge project, Supplier 2-2, responsible for the entire design process, had the best overview of the suppliers' interfaces, also compared to the main designer or contractor in the other projects. Coordination of requirement development and interfaces was therefore, in this case, applied to all other suppliers. This prevented many interface problems and decreased the effects of problems that did occur. However, the coordination was mainly present during the design phase and decreased during the execution phase. Therefore, not all interfaces were adequately coordinated. It is however strongly suggested to apply such coordination in every project.

Further analysis of the pattern matching results and the suggested improvements are, due to the lack of clear case specific patterns, not based on the cases but on the individual contractor-supplier relations.

Cross supplier analysis

Based on the individual supplier analysis, described earlier and in Appendix A, the results are also analyzed across all supplier relations. First, the cross supplier results are discussed based on the framework's verification problem groups. As group A2 is not present in the case study, this group will not be discussed. Both group C1 and C2 occur only once in the case study, which makes determining cross supplier patterns difficult. Therefore, the cross supplier results are analyzed for situations with a valid requirement set (i.e. groups B1 and C1) and with an invalid requirement set (i.e. groups B2 and C2). Second, some overall patterns, visible in the majority of the cases, are discussed.

The seven supplier relations categorized in group A1, actually experienced no verification problems as both the requirement set was considered valid and the supplier complied to its verification obligations. Although the framework does not predict any solutions for these situations, looking at these relations can provide useful insights in possible effective solutions. First of all, in all supplier relations in group A1, a clear choice for the contract level of detail was made. In six of the seven cases, the suppliers' scope of work was explicitly described. Both solutions prevent verification problems due to an unclear division of responsibilities and tasks. Furthermore, in three of the four relations in which the supplier was not prescribed, the choice for the contract level of detail and the choice for the supplier were strongly related. This suggests that combining these choices, or at least not considering these separately, can prevent verification problems.

In total, in five supplier relations in which verification problems occurred the requirement set was considered valid (four suppliers were categorized in verification problem group B1 and partly complied to their verification obligations and one supplier was categorized in group C1 and did not comply to its verification obligations). The verification problems in these relations were not caused by incomplete, incorrect or inconsistent requirements, but can be traced back to the supplier not complying to its verification obligations. This can be, for example, caused by a lack of supplier competences, a lack of supplier commitment or a tight schedule or phasing. Based on the verification problem groups, the theoretical pattern expected is the appliance of the following solutions: select skilled supplier (II), explicitly describing scope (III), improving supplier competences (V) and take over verification tasks (VI, except for group C1). In only one relation, Supplier 2-1, a well-thought choice was made for the selected supplier, taking into account the required competences. In the other cases, it was experienced that the supplier lacked the required competences. In three cases the suppliers' scope was explicitly described, for example using a standardized purchasing form, but verification was either not part of the description or not described in detail. This caused verification problems due to discrepancies in the contractor's and suppliers' conception of the verification tasks. An important finding is that in none of the cases the contractor took actions to improve the supplier's competences, although actions are expected based on the framework. This can be disadvantageous for future projects with these suppliers. In three of the five cases the contractor decided to take over verification tasks or complete verification.

In five situations verification problems not only occurred due to only partly or no supplier verification compliance, but also due to invalid requirements. In four of these situations, the supplier only partly complied to its verification obligations and

the relation was categorized in group B2. In one relation, the supplier did not comply at all and the relation was categorized in group C2. The verification problems in these relations were caused by both invalid (incomplete, incorrect or inconsistent) requirements and the supplier not complying to its verification obligations. An invalid requirement set was, for example, caused by a low level of requirement detail combined with the absence supplier responsibility for requirement development. As with the other verification problems, lacking supplier verification compliance can be caused by a lack of supplier competences, a lack of supplier commitment or a tight schedule or phasing. Based on the verification problem groups, the theoretical pattern expected is the appliance of the following solutions: contract level of detail choice (I), select skilled supplier (II), explicitly describing scope (III), coordination of requirement development and interfaces (IV), improving supplier competences (V) and take over verification tasks (VI, except for group C2). The empirical patterns however, do not match the theoretical patterns. The only complete match between theoretical and empirical pattern for these verification problem groups, is related to the explicit description of the suppliers' scope of work. However, although explicitly described in the contracts with the suppliers, the scope descriptions did not always contain enough detail regarding the verification. An important finding is that the theoretical patterns of the appliance of both the contract level of detail choice and the selection of a skilled supplier, are present in only one supplier relation, with Supplier 1-3. In this specific supplier relation, the verification problems were mainly caused by an invalid requirement set, combined with a supplier with limited verification experience. In the other four relations, both patterns are absent. In these relations, the verification problems can largely be traced back to unclear choices for contract level of detail and for the selected supplier. A coherent choice for these aspects also lacked. Another clear pattern, is that in only two relations, both from case 2, requirement development and interfaces are clearly coordinated. The verification problems in these cases can also be largely traced back to incompetent suppliers. In the three other cases, this coordination lacked and created interface problems. In only one relation, the contract took specific actions to improve the supplier's competences. This, however, not solved the verification problems and in three cases, the contractor decided to complete the verification himself.

Looking at all seventeen supplier relations, some overall patterns are also visible. The choice for the contract level of detail and the supplier choice are often made separately, for example in the relations with Supplier 1-1, Supplier 2-3 and Supplier 3-3. This results in a mismatch between the required supplier competences and the actual competences. In these cases, this led to the contractor taking over verification tasks and thus making extra costs. In cases where the contract level of detail was adjusted to the supplier's competences, or vice versa, this mismatch was absent and less problems occurred, for example in the relations with Supplier 1-6 and Supplier 2-4.

Although the scope was explicitly described in most supplier relations, verification lacked as an explicit part of this description. Also, the scope description did mostly not include a description of the actual expectations of the verification process and results. This resulted in mismatches between the contractor's and the suppliers' conception of the verification process and verification responsibilities. Solving this problem required additional scope descriptions or scope changes during the project. In cases where verification and expectations were described, for example in the relations with Supplier 1-6 and Supplier 2-4, no discussions about verification occurred.

Overall coordination of requirement development and interfaces, for the entire project, mostly lacked. If coordination was done, it mostly only focused on parts of the project. In none of the projects, a total overview of the requirement development and interfaces for all project phases was present. Most notable exception was the design phase in case 2, in which Supplier 2-2 had an almost complete overview.

In only one relation, with Supplier 2-3, the contractor took actions to improve the supplier's competences, although this was expected in nine relations. Instead of improving competences, which could be useful for future projects with the supplier and can contribute to moving towards a more partnership like relation, supplier verification tasks were more often taken over by the contractor. This had mostly no negative results for the supplier, e.g. by withholding payments, but did have negative financial effects for the contractor, as extra effort was required.

These problems, can be partly traced back to a lack of time spent to these aspects, for example caused by a tight schedule or limited budgets. The tight schedule for the contractor can be caused by an already tight client schedule, an aspect outside the scope of this research. However, it can also be caused by the contractor paying too little attention to or not recognizing the importance of procurement and verification. The same holds for the budget for procurement and verification, which can be limited due to a tight overall project budget. It can also be caused by the contractor reserving insufficient budget for procurement and verification.

Improvements

Based on the results of the pattern matching procedure, possible improvements are suggested and shortly described. The most important improvements are described in more detail in the recommendations section. The improvements are grouped in pre-contract and post-contract.

First, the improvements suggested for the pre-contractual phase are discussed. First of all, it is recommended to (1) choose a suitable level of detail for the contract with the supplier, and (2) link this decision to the choice of the supplier. This enables a match between the required competences and the supplier's actual competences. Another pre-contract improvement is (3) the more explicit description of the scope of each party involved, especially regarding verification. This also enables an integrality check.

On the post-contract side, some other improvements are recommended: (4) continuous coordination, identification, management and monitoring of interfaces, (5) explicitly discussing and describing the expectations and conceptions of the scope for each party involved and (6) improving the supplier's competences. The most important recommendations are described in more detail in de recommendations section.

Overall, it is recommended to reserve sufficient time and budget for the procurement process and verification during all phases of the project. The most important improvements described here, are further elaborated in the recommendations section.

5. Discussion

This research shows that a contractor faces numerous problems with verification when subcontracting work to suppliers. These problems are analyzed using a conceptual framework, based on Bahill and Henderson (2005), which is used to both categorize the verification problems and link possible solutions. The framework proved to be very useful as an approach for finding suitable solutions for problems with the verification of subcontracted work. This research integrates previous work on verification, construction supply chain and systems engineering with the results of a case study. As most previous research focuses on the relation between client and contractor, the specific focus on verification within the scope of subcontracted work both contributes to literature and helps contractors to improve their procurement processes.

An important lesson in this research, is that problems with the verification of subcontracted work, can be caused and solved in both the procurement process and the verification process. Verification problems are not always caused by the supplier, but can also originate from choices made by the contractor in early stages of the project. One should therefore not only focus on the verification process executed by the supplier, but also on how the contractor procures work to suppliers and the integration of the entire system, as also noted by Elich et al. (2012) and Segerstedt and Olofsson (2010).

One of the core problems with the verification of subcontracted work caused in the procurement process, is the mismatch between the contract level of detail and the selected supplier's competences. In most projects that showed verification problems, the expected patterns for making the choice for the contract level of detail and the choice for the supplier did not occur. These choices were often made separately. Although the contract level of detail (Bemelmans et al., 2013; Gundlach & Cannon, 2009) and the supplier choice (Elich et al., 2012) have been described separately, the explicit coupling of these choices in relation to the verification of work subcontracted to suppliers has not been described before. Coupling these choices has a major positive effect on the verification of subcontracted work.

Another core problem on the procurement process side, is the lack of explicit descriptions of the scope regarding verification. As expected from literature (Elich et al., 2012) and seemingly obvious, an explicit scope description was present in all but one of the supplier relations that did not experience verification problems. However, in all but two of the supplier relations that did experience verification problems, the scope was also explicitly described. A clear link between the presence of an explicit scope description and specific verification problem groups cannot be made. Important to note is that in only two supplier relations, the scope described the supplier's verification tasks in detail. This lack of a detailed description of the verification tasks leads to misconceptions or discrepancies in the contractor's and suppliers' conception and can ultimately lead to verification problems.

A striking determination on the verification process side, is the absence of the integral coordination of interfaces and requirement development during all project phases. Although in one project, case 2, the interfaces were coordinated during the design phase, coordination during the execution phase lacked. This does not match the expectations from Bemelmans et al. (2013), Elich et al. (2012) and Segerstedt and Olofsson (2010).

A final important finding on the verification process side, is that in only one supplier relation, the one in group C2, the contractor took specific actions to improve the supplier's competences. Although expected, based on the framework, in ten supplier relations, this pattern was almost completely absent. This contradicts the expected patterns when moving towards more partnership like supplier relations (Gadde & Dubois, 2010; Matthews et al., 2000).

An overall source of the problems described above, seems to be a lack of both time and budget reserved for and spent on the procurement and verification processes. In all cases studied it seemed that, in retrospect, the contractor did not recognize the full importance of the procurement and verification processes and reserved and spent too little time and budget on these processes.

However, some problems in applying the framework were discovered. First, not all solutions expected from the framework, were actually effective in practice. For example, the suppliers' scope was described explicitly in most of the project, even the projects in which verification problems did occur. This was most likely caused by the fact that the solution was applied, but not to the extent needed to actually solve the problem. Verification, for example, was often not part of the scope description. Second, some additional solutions that were actually applied by the contractor to prevent or solve problems, were not expected in the framework. This is most likely caused by the absence of descriptions of these solutions in literature and these solutions were thus not included in the framework. Further research, in which more solutions and improvements are described and linked to the framework's verification problem types, can improve the framework.

6. Conclusion and recommendations

This research shows which problems a contractor faces when subcontracting parts of a construction project to suppliers, with a focus on the verification of the work done by these suppliers. Due to a shift in tasks and responsibilities in the construction industry from client to contractor, the tasks and responsibilities in the relation between contractor and supplier also change. This shift has caused problems with the verification of subcontracted work.

This research introduces a conceptual framework, based on the SRCM-model described by Bahill and Henderson (2005), to categorize different types of verification problems that occur when subcontracting work to suppliers. The framework is based on two axes: (1) the supplier compliance to the contracted verification obligations and (2) the validity of the contracted requirement set. Solving these verification problems requires solutions that match the actual causes of the problems. In this paper, the results of a literature and case study are integrated and both problems and solutions are linked to the framework. The categorizing framework helps analyzing the verification problems and provides useful suggestions for solutions. The research can thus help contractors to adjust their procurement procedures, to prevent verification problems or to solve problems when they do occur.

Compared to other available literature, this research contributes by integrating two important aspects of the construction industry: supply chain and verification. Since the specific characteristics of the supply chain play an important role in construction projects, due to fragmentation and a geographical focus, it is useful to consider the supply chain effect on the verification process.

Recommendations for successful verification of subcontracted work

Based on the case study and literature review, this paper finishes with three improvements for the subcontracting process, to prevent verification problems of work that is subcontracted to suppliers.

First, a contractor should always consider the combination of contract level of detail and supplier selection as a whole. Considering these choices separately, may result in a contract level of detail that does not match the supplier's competences, or vice versa. These choices have reciprocal effects. A certain contract level of detail, for example, has a direct effect on the competences the supplier needs to satisfy the contract requirements. Therefore, it is suggested to first determine the goal of the procurement procedure (e.g. do we want to subcontract an entire moveable bridge, including all operation and control elements, and including the verification of the entire object? Or do we want a supplier to just produce the steel structure of the bridge deck?). Once this goal is clear and the contract level of detail is known, the possible suppliers should be selected based on the required competences. Third, once a supplier is contracted, the contractor should verify that the supplier's competences match the contract level of detail.

The second improvement is to explicitly describe the scope and expectations of each party, including the verification process and results, and adjust the information supplied with the contract accordingly. By explicitly describing verification scope and expectations, such as the required detail level of the verification, the verification methods used, the moments in time on which verification should be executed, problems of verification not matching the contractor's expectations can be prevented. By adjusting the information that is supplied with the contract according to the scope and the contract level of detail, an information overload due to irrelevant information for the supplier can be prevented. The effectiveness of the information can be further increased by providing this information in a more intelligent system, e.g. by geographically or according to the systems engineering structure displaying information, instead of hiding information in numerous documents.

The third and final improvement that is suggested, is the continuous coordination of interfaces and monitoring of the integrity of the entire system. Interfaces should be continuously coordinated (i.e. identified, described, allocated, managed and checked) during the entire project. As interfaces can arise during a project, for example due to certain design choices, identifying interfaces only once will not suffice. Interface coordination is therefore a continuous task. In addition to the interface coordination, it is suggested to also regularly check the integrity of the entire system. Are all interfaces identified and managed? Are certain interfaces likely to arise? Does the scope of the contractor and all suppliers together cover the entire scope of the project? By regularly or continuously checking the system for integrity, verification problems due to parts falling between two stools can be prevented.

Finally, it is important to note that an important part of the solutions require 'soft skills' and trust between contractor and supplier, as Gundlach and Cannon (2009) already stated. Such competences cannot always be implemented in project management systems and require specific personal characteristics of the project team members.

Limitations and suggestions for future research

This research is based on a fairly limited amount of supplier relations, and can thus contribute only in a qualitative way. To further improve the framework, to suggest more or better improvements and to contribute in a quantitative or statistic way, larger scale research is needed. Findings of such research can further improve the applicability of the framework and the procurement processes at contractors.

The case study is based on construction projects in the Netherlands, based on the Dutch UAC-IC set of conditions. Further research, for example in other countries or in cases using other types of contracts, can test whether the results can also be applied in a broader context.

Important aspects of the construction industry that are not considered in this research, are the relation and contracts

between client and contractor, since the contractor does not have a direct influence on these aspects once a project is contracted. However, since these relations and contracts determine the conditions within which the contractor subcontracts work, they can have an important effect on the contractor-supplier relation. Further research on the effects of changes in de client-contractor relation on the contractor-supplier relation is therefore suggested.

Finally, this research intentionally only focuses on verification. Research on integrating validation into a similar framework, to further improve procurement strategies, and on subcontracting validation tasks to suppliers as well, is therefore suggested.

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Appendix A.   Individual supplier analysis

This appendix describes the analysis of each supplier relation separately. For each supplier, a short description of the relationship is given, including the type of work that was contracted and the supplier selection procedure. Then, each supplier is categorized in one of the verification problem groups. Based on this category, the theoretical patterns, i.e. expected solutions based on the verification problem group, are described. This is followed by the empirical patterns, i.e. the solutions that were actually applied. The number (I to VI) of each solution corresponds with the number in Figure 2. * indicates the application of a solution not expected based on the framework. The match between theoretical and empirical patterns is then shortly explained. In these descriptions, the 'contractor' is the main contractor at which the case study was executed.

Case 1

This project concerned the design and construction of a highway exit, including a highway overpass, reconstruction of parts of the local road network and landscaping. The main client was a municipality, together with Rijkswaterstaat, the Dutch agency for the execution of public works and water management. The project was procured as a Design & Construct contract. The contractor was responsible for the roadworks (asphalt) and project coordination. Other tasks were subcontracted to suppliers, of which six were further analyzed in the case study.

Supplier 1-1

Supplier relation: Supplier 1-1 was as the main designer responsible for the entire design process during the project. The contractor assumed that verification was a part of this design process. Supplier 1-1 was selected based on the contractor's previous positive experiences with this organization.

Verification problem group: Supplier 1-1 is categorized in verification problem group B1. As the main designer, Supplier 1-1 did not fully comply to its verification obligations. The design made by Supplier 1-1, was not fully verified in relation to the requirements in the contract. Most technical requirements were verified on element or subsystem level, but verification on system or concept level lacked. Supplier 1-1 therefore only partly complied to the verification obligation.

The requirement set contracted to Supplier 1-1, was considered to be valid. The entire contract between the client and the contractor, was contracted to Supplier 1-1, which made verification also a responsibility of Supplier 1-1. Although this requirement set was not completely specified to the element level of detail by the client or contractor, it is considered valid since Supplier 1-1 was also responsible for further requirement development and the verification problems were not caused by invalid requirements.

Theoretical patterns (expected solutions): Based on the verification problem group B1, the theoretical pattern expected is the appliance of the following solutions:
-   Select skilled supplier (II)
-   Explicitly describing scope (III)
-   Improving supplier competences (V)
-   Take over verification tasks (VI)

Empirical patterns (applied solutions)
-   Take over verification tasks (VI)

Explanation: In the selection procedure that preceded the final choice for a supplier, only some earlier experiences with Supplier 1-1 were used to decide. No specific analysis of the required competences was done, the contractor simply assumed that Supplier 1-1 was capable. However, the previous experiences were related to another project team at Supplier 1-1.

In the contract concluded with Supplier 1-1, no explicit scope was described. Supplier 1-1 was simply made responsible for the entire contract. Verification was not explicitly described, but was assumed to be part of the design responsibility. During the project, no specific actions to improve the supplier's competences were taken. The contractor only urged Supplier 1-1 to complete the verification and later took over the verification tasks.

In the case study, only the last solution was actually applied. Verification problems arose after the supplier made a switch between design principles. After verification problems in the design were detected, Supplier 1-1 was urged to complete the verification. Verification was, however, not completed. The contractor then decided to execute the supplier's verification tasks.

In general, the theoretical patterns and empirical patterns in this relationship do not match. This is mainly caused by the lack of a clear goal of the procurement procedure. No well-thought choice for a supplier was made and the supplier's scope was not explicitly described.

Supplier 1-2

Supplier relation: Supplier 1-2 was responsible for the engineering, production and supply of the overpass' girder work and pressure layer and was selected based on the lowest price in a competitive tendering procedure with four other suppliers. Verification was also considered to be part of the supplier's scope.

Verification problem group: Supplier 1-2 is categorized in verification problem group B2. Supplier 1-2 only partly complied to the verification obligations. Technical quality was verified using standardized company checks, but no explicit verification in relation the contract requirements was done.

Due to a switch between design principles, the requirement set contracted to Supplier 1-2 did not match the design that was actually realized. The verification problems that occurred can thus be traced back to incorrect requirements. The requirement

set is therefore considered invalid.

Theoretical patterns (expected solutions): Based on the verification problem group B2, the theoretical pattern expected is the appliance of the following solutions:

- Contract level of detail choice (I)
- Select skilled supplier (II)
- Explicitly describing scope (III)
- Coordinate requirement development and interfaces (IV)
- Improving supplier competences (V)
- Take over verification tasks (VI)

Empirical patterns (applied solutions)

- Explicitly describing scope (III)
- Take over verification tasks (VI)

Explanation: Although it is expected from theory that the contractor selects an appropriate contract level of detail, a clear explanation for this choice lacks. Also, no analysis of the effect of the chosen level of detail on the required competences was done. In the selection of Supplier 1-2, no specific analysis of the required competences, given the level of detail, was done. The contractor did explicitly describe the scope of Supplier 1-2, using a standardized purchasing form. However, verification is not an explicit part of this form. Coordination of the requirement development, for example how to prove the contract requirements with the quality checks that were done, and the interfaces with other suppliers was not explicitly done by the contractor. After verification problems arose, no explicit actions were taken to improve the supplier's competences. For example, no guidance on how to verify the requirements (and not only the technical quality using standard checks) was given. The contractor did take over verification tasks from Supplier 1-2, and completed the requirement verification based on the technical standardized documents and check from Supplier 1-2. The theoretical and empirical patterns in this relation thus match only partly.

Supplier 1-3

Supplier relation: Supplier 1-3 was responsible for design and realization of vertical vegetation on the highway overpass, including the verification of the requirements. The vertical vegetation set-up used, was not tested in practice before and can be considered as an innovation.

Verification problem group: Supplier 1-3 is categorized in verification problem group B2. Supplier 1-3 only partly complied to the verification obligations, as not all requirements were verified. However, the requirement set contracted to Supplier 1-3, did not provide room for the 'creative process' required for the application of the new set-up. The verification problems can be traced to inconsistent requirements, which required an innovative solution on the one hand, but limited room for the creative process required on the other hand. The requirement set is therefore considered invalid.

Theoretical patterns (expected solutions): Based on the verification problem group B2, the theoretical pattern expected is the appliance of the following solutions:

- Contract level of detail choice (I)
- Select skilled supplier (II)
- Explicitly describing scope (III)
- Coordinate requirement development and interfaces (IV)
- Improving supplier competences (V)
- Take over verification tasks (VI)

Empirical patterns (applied solutions)

- Contract level of detail choice (I)
- Select skilled supplier (II)
- Explicitly describing scope (III)
- Take over verification tasks (VI)
- Formal notice of default (*)

Explanation: The decision for the contract level of detail, i.e. subcontracting the entire vertical vegetation, was made based on the fact that the contractor did not have the required knowledge and competences. The contractor selected Supplier 1-3 based on experience with innovative vegetation. The supplier is considered an expert in this field of work. The scope for Supplier 1-3 was explicitly described in the contract and in the standard purchasing form. The contractor did not coordinate requirement development and the interfaces. In fact, no requirements were developed to the element level at all. After verification problems arose, the contractor did not take any specific actions to improve the supplier's skills regarding verification. The contractor completed the supplier's verification tasks and verified the requirements, based on design documents produced by Supplier 1-3, so verification tasks were taken over from the supplier. Another solution applied in this relation was the issuing of a formal notice of default, in order to urge the supplier to complete the verification. However, no successive actions were taken.

The theoretical and empirical patterns partly match in this relation. Although the choice for Supplier 1-3 was made based on specific expertise, the responsibilities allocated to Supplier 1-3 did not completely match the supplier's competences.

Supplier 1-4

Supplier relation: Supplier 1-4 was responsible for the design, realization and maintenance of greening. Supplier 1-4 was

selected on lowest price and Social Return On Investment (SROI) score in a competitive tendering procedure.

Verification problem group: Supplier 1-4 is categorized in verification problem group A1. No specific verification problems occurred.

Theoretical patterns (expected solutions): Based on the verification problem group A1, no specific theoretical patterns are predicted.

Empirical patterns (applied solutions)
- Contract level of detail choice (I)
- Explicitly describing scope (III)
- Explicitly describing expectations (*)
- Coordinate requirement development and interfaces (IV)

Explanation: First of all, the contractor chose to subcontract all greening related parts of the project, as the contractor does not have the specific knowledge and competences. The supplier's scope was explicitly and extensively described in the contract. This left no room for discussions about responsibilities and was important in preventing verification problems. Also, the expectations of the verification process and results of both the contractor and the supplier were described, also leaving no room for discussions. Finally, the contractor actively coordinated the requirement development.

In this relation, no real verification problems occurred. This is mainly caused by the explicit and extensive scope and expectation descriptions.

Supplier 1-5

Supplier relation: Supplier 1-5 was responsible for the engineering and realization of road markings, barriers, signage and traffic measures. Supplier 1-5 was a prescribed supplier, so no selection procedure was executed.

Verification problem group: Supplier 1-5 is categorized in verification problem group A1. No specific verification problems occurred.

Theoretical patterns (expected solutions): Based on the verification problem group A1, no specific theoretical patterns are predicted.

Empirical patterns (applied solutions)
- Contract level of detail choice (I)
- Explicitly describing scope (III)
- Payments only after completed verification (*)

Explanation: The contractor chose to subcontract all marking, signing and traffic parts of the project, because the contractor does not have the required competences. Also, the supplier was prescribed, since it is part of the same organization as the contractor. The supplier's scope was explicitly and extensively described in the contract and left no room for discussions about responsibilities. The supplier completed these tasks properly. Also, supplier payments were only done after completion of the verification of the relevant parts.

In this relationship, the explicit scope description is considered to be the most important factor in preventing verification problems.

Supplier 1-6

Supplier relation: Supplier 1-6 was responsible for the execution of earthworks and selected based on the lowest price in a competitive tendering procedure.

Verification problem group: Supplier 1-6 is categorized in verification problem group A1. No specific verification problems occurred.

Theoretical patterns (expected solutions): Based on the verification problem group A1, no specific theoretical patterns are predicted.

Empirical patterns (applied solutions)
- Contract level of detail choice (I)
- Explicitly describing scope (III)
- Matching contract level of detail to supplier competences (*)

Explanation: The contractor chose the contract on a high level of detail, as all knowledge and competences required to specify at this level were present at the contractor. The supplier's scope was explicitly and extensively described in the contract (detailed specification of all tasks that had to be executed). Based on the supplier's competences, the supplier had no experience with verification, it was decided that the contractor executed all verification tasks. This was explicitly described and prevented discussions. This way, the supplier only had responsibilities that it could actually comply to. By matching the contract level of detail, i.e. only the execution was the supplier's responsibility, to the supplier's competences, verification problems were prevented.

Case 2

This case concerned the design and construction of a large sash lock, that also has a water safety function, and a moveable bridge. For this project, Rijkswaterstaat is the client and operator of both the bridge and the lock. The project was procured as a Design & Construct contract. Currently, a floodgate with only one set of doors is used at this location to prevent high water

levels in a certain area. However, when the floodgate is closed, no ships can pass. Therefore, the floodgate is converted into a sash lock with two doors, so ships can be raised and lowered. The contractor, in combination with another large contractor, is responsible for the roadworks, concrete structures and the project management. Important parts, such as the lock doors, steel structures, electrical and mechanical installations, sheet piling and foundation work were subcontracted to suppliers. For this case, five suppliers were analyzed.

Supplier 2-1

Supplier relation: Supplier 2-1 was responsible for the integral design, engineering, production, testing, supplying, assembling and completion of the steel structure of the movable bridge and the steel lock doors. A letter of intent was conducted with Supplier 2-1 during the project's tendering phase.

Verification problem group: Supplier 2-1 is categorized in verification problem group B1. In general, the verification executed by the supplier was incomplete and lacked the required detail. Therefore, the supplier only partly complied to the verification obligations. The contracted requirement set is considered valid. The entire contract between the client and contractor was subcontracted to the supplier. The verification problems that occurred in this relations, cannot be traced back to invalid requirements and the requirement set is, given the integral role of Supplier 2-1, considered to be valid.

Theoretical patterns (expected solutions): Based on the verification problem group B1, the theoretical pattern expected is the appliance of the following solutions:

- Select skilled supplier (II)
- Explicitly describing scope (III)
- Improving supplier competences (V)
- Take over verification tasks (VI)

Empirical patterns (applied solutions)

- Contract level of detail choice (I)
- Select skilled supplier (II)
- Explicitly describing scope (III)
- Coordination of requirement development and interfaces (IV)

Explanation: The contractor decided to subcontract all steel structure related work, as the required competences and knowledge were not present at the contractor. The choice for Supplier 2-1 was therefore based on its experience with steel structures. Also, with the letter of intent during the tendering procedure, the supplier's expertise and knowledge could already be used in an early phase of the project. The supplier choice was therefore well-thought. The supplier's scope was explicitly described in an appendix to the contract. However, verification was not described in detail. Finally, the contractor coordinated the requirement development process and the interfaces between suppliers during the project, especially in the design phase.

The verification problems in this relation were mainly caused by a lack of supplier effort for the verification. This resulted in incomplete and inconsistent verification.

Supplier 2-2

Supplier relation: Supplier 2-2 was responsible for the integral design of both the civil constructions and roadworks. Also, the supplier reviewed the other suppliers' designs, executed the project risk management and managed the project's interfaces. Supplier 2-2 was a prescribed supplier.

Verification problem group: Supplier 2-2 is categorized in verification problem group A1. No specific verification problems occurred.

Theoretical patterns (expected solutions): Based on the verification problem group A1, no specific theoretical patterns are predicted.

Empirical patterns (applied solutions): Contract level of detail (I)

Explanation: The contractor decided to subcontract the design responsibility in its entirety, as the required competences for the management of the design of such a complex project were not present at the contractor. In general, no verification problems occurred and no other specific solutions were applied, except from the very close involvement of Supplier 2-2 during the entire project, which may have prevented the occurrence of verification problems.

Supplier 2-3

Supplier relation: Integral design, engineering, production, testing, supplying, mounting and completion of all mechanical installations for both the moveable bridge and the lock doors. Supplier 2-3 was selected on the lowest price in a competitive tendering procedure.

Verification problem group: Supplier 2-3 is categorized in verification problem group C2. During the entire project, verification executed by the supplier was untraceable and incomplete. Verifying the system's requirement compliance was not possible. Therefore, the supplier did not comply to its verification obligations. However, the requirement set contracted to the supplier is considered invalid. The mechanical installations have numerous interfaces with other suppliers, for example the steel structures and the electrical installations. The identification of and responsibility for these interfaces were not allocated correctly. This created large gaps in the requirement set which caused verification problems for the contractor.

Theoretical patterns (expected solutions): Based on the verification problem group C2, the theoretical pattern expected is the appliance of the following solutions:

- Contract level of detail choice (I)
- Select skilled supplier (II)
- Explicitly describing scope (III)
- Coordination of requirement development and interfaces (IV)
- Improving supplier competences (V)

Empirical patterns (applied solutions):
- Explicitly describing scope (III)
- Coordination of requirement development and interfaces (IV)
- Improving supplier competences (V)
- Take over verification tasks (VI)

Explanation: The contract level of detail for this supplier wasn't clearly chosen. In retrospect, splitting the mechanical from the electrical installations, created many interfaces. Also, the supplier selected in this case, did not have the required competences regarding design processes and verification and is therefore considered to be not skilled. After verification problems occurred, the supplier's scope and tasks were described explicitly and in detail. Also the contractor intensively coordinated the requirement development and the interfaces, especially between the mechanical and electrical installations. During the project, the contractor tried to improve the supplier's competences, by explaining how the requirements should be verified and further developed. However, this did not completely solve to verification problems, so the contractor took over some verification tasks to complete the verification.

Supplier 2-4

Supplier relation: Execution of sheet piling, canal/lock floor protection, canal/lock bank construction, slackening structures, groundworks and some detailed design tasks. A letter of intent was conducted with Supplier 2-4 in the project's tendering phase.

Verification problem group: Supplier 2-4 is categorized in verification problem group A1. No specific verification problems occurred.

Theoretical patterns (expected solutions): Based on the verification problem group A1, no specific theoretical patterns are predicted.

Empirical patterns (applied solutions):
- Contract level of detail choice (I)
- Select skilled supplier (II)
- Explicitly describing scope (III)
- Explicitly describing expectations (*)
- Coordination of requirement development and interfaces (IV)

Explanation: The contractor decided to subcontract the work at a high level of detail, as the required knowledge to specify at this level was present at the contractor. A clear choice for the contract level of detail (the supplier's requirements and tasks were described to a high level of detail) was made, adapted to the supplier's competences and experience. With the high level of detail, the scope was explicitly described, which left no room for discussions about responsibilities and expectations. This enabled the supplier to easily verify its requirements, as these were al known and clear. Finally, the contractor coordinated and executed the requirement development, which led to the detailed scope description, and interfaces with other suppliers.

Supplier 2-5

Supplier relation: Design, engineering, production, testing, supplying, mounting and completion of all electrical installations (e.g. the bridge and lock door control system). Supplier 2-5 was a prescribed supplier.

Verification problem group: Supplier 2-5 is categorized in verification problem group B2. Verification was only executed using the supplier's standardized quality assurance system and forms. The contract requirements were not explicitly verified. Supplier 2-5 only partly complied to its verification obligations. The requirement set contracted to Supplier 2-5, is considered invalid, as the interfaces, especially with the mechanical installations, were not adequately allocated and managed. This caused verification problems on these interfaces.

Theoretical patterns (expected solutions): Based on the verification problem group B2, the theoretical pattern expected is the appliance of the following solutions:
- Contract level of detail choice (I)
- Select skilled supplier (II)
- Explicitly describing scope (III)
- Coordinate requirement development and interfaces (IV)
- Improving supplier competences (V)
- Take over verification tasks (VI)

Empirical patterns (applied solutions):
- Explicitly describing scope (III)
- Coordinate requirement development and interfaces (IV)
- Take over verification tasks (VI)

Explanation: The contract level of detail was not considered correctly. Due to the large number of interfaces between the mechanical and electrical installations, these should have been contracted at a lower level of detail, preventing the separation of these fields. Supplier 2-5 was prescribed, so no real choice for this supplier, based on its competences, was made. Although the supplier claimed to have experience with verification, it lacked the required competences. An empirical pattern that did match, was the explicit description of the scope. The supplier's responsibilities were described to a high level of detail. Also, coordination of the requirement development and interfaces was coordinated by the contractor (actually executed by Supplier 2-2, on behalf of the contractor). No specific actions were taken by the contractor to improve these competences. Finally, the contractor finished some of the verification tasks of Supplier 2-5.

Case 3

The third project concerned the reconstruction of an urban train station area, including the reconstruction of the train station itself, redevelopment of the train station's surrounding area and the construction of two grade separated railway crossings. The main clients were the local municipality and ProRail, the Dutch organization responsible for the national railway network. The project was procured as a Design & Construct contract. The contractor was responsible for the construction work (concrete), roadworks (asphalt) and project management. Large parts of the project were subcontracted to suppliers, such as the design, all rail related objects, the positioning of the railway crossing's deck, groundworks, CSM-walls, sheet piling, installations and the steel station roof. For this case, six suppliers were analyzed.

Supplier 3-1

Supplier relation: Supplier 3-1 was responsible for the positioning of the railroad crossing's deck. This deck was produced by the contractor at the project location, and pushed into place in its entirety. Supplier 3-1 was prescribed, so no selection procedure took place. However, the supplier is considered to be an expert in this field of work.

Verification problem group: Supplier 3-1 is categorized in verification problem group B1. In general, the verification of the requirements executed by the supplier was incomplete, which led to many remarks from the client and revisions of verification documents. Technical quality was, however, secured using the supplier's standardized quality system. Since complete verification of the requirements lacked, the supplier only partly complied to the verification obligations. The contracted requirement set is considered valid as all relevant requirements were contracted to the supplier. The contract between client and contractor did not prescribe which execution method should be used. Deciding which method was used, was up to the contractor and supplier.

Theoretical patterns (expected solutions): Based on the verification problem group B1, the theoretical pattern expected is the appliance of the following solutions:
- Select skilled supplier (II)
- Explicitly describing scope (III)
- Improving supplier competences (V)
- Take over verification tasks (VI)

Empirical patterns (applied solutions):
- Contract level of detail choice (I)
- Explicitly describing scope (III)
- Enforce verification by supplier (*)

Explanation: The contractor chose to subcontract the entire positioning of the railroad crossing's deck, as the contractor had no knowledge and experienced in this specialized field. The supplier choice was not made based on an analysis of the required competences, as Supplier 3-1 was prescribed. The contract with Supplier 3-1 did explicitly describe the scope, which was however limited to the positioning procedure, which was an execution method that was not prescribed. Also, the contractor did not take any actions to improve the supplier's verification, as a lack of competences was not so much the cause of the verification problems. The contractor did not take over any verification tasks from Supplier 3-1, but enforced completion of the verification by the supplier, as this was part of their contractual obligations.

Supplier 3-2

Supplier relation: Supplier 3-2 was responsible for all rail related objects in the project, such as the tracks, sleepers, ballast and electrical installations. Supplier 3-2 was prescribed, so no selection procedure took place.

Verification problem group: Supplier 3-2 is categorized in verification problem group A1. No specific verification problems occurred.

Theoretical patterns (expected solutions): Based on the verification problem group A1, no specific theoretical patterns are predicted.

Empirical patterns (applied solutions):
- Contract level of detail choice (I)
- Explicitly describing scope (III)

Explanation: The contractor chose to subcontract all rail related work because of a lack of this specific knowledge. Also, ProRail only allows certified organizations to execute these works. The contractor is not certified, Supplier 3-2 is. In this relation, verification problems were mainly prevented by an explicit description of the supplier's scope. As, for railroad works,

most technical requirements are prescribed in design regulations from ProRail. Supplier 3-2 is used to work with and comply to these design regulations, so no verification problems occurred.

Supplier 3-3

Supplier relation: Supplier 3-3 was responsible for the integral project design, excluding the design responsibilities of Supplier 3-5. Supplier 3-3 was selected based on lowest price in a competitive tendering procedure.

Verification problem group: Supplier 3-3 is categorized in verification problem group C1. Verification was not executed by the supplier, as the contract described, but by the contractor. The contracted requirement set is considered valid. The entire requirement set from the contract between client and contractor was subcontracted to Supplier 3-3. Given the integral responsibility for the design, this is valid.

Theoretical patterns (expected solutions): Based on the verification problem group C1, the theoretical pattern expected is the appliance of the following solutions:
- Select skilled supplier (II)
- Explicitly describing scope (III)
- Improving supplier competences (V)

Empirical patterns (applied solutions):
- Take over verification tasks (VI)

Explanation: The supplier choice was not made based on an analysis of the required competences, but on lowest price. This resulted in a very low price and a supplier project team with no experience with verification. During the project, the contractor did not take any actions to improve the supplier competences. Also, the supplier's scope was only vaguely described in the contract, which led to discrepancy between the contractor's and supplier's expectations of tasks and responsibilities. In fact, none of the theoretical patterns were present in the case study. After verification by the supplier failed, the contractor took over verification tasks and completed the verification. In this relation, the problems were mainly caused by a lack of experience and willingness to verify.

Supplier 3-4

Supplier relation: Supplier 3-4 was responsible for the engineering and execution of all sheet piling, drainage, CSM-walls and groundworks. Supplier 3-4 was selected based on the best price/performance ratio in a competitive tendering procedure. After selection, additional meetings were held to integrate the supplier's knowledge in the project design.

Verification problem group: Supplier 3-4 is categorized in verification problem group A1. No specific verification problems occurred.

Theoretical patterns (expected solutions): Based on the verification problem group A1, no specific theoretical patterns are predicted.

Empirical patterns (applied solutions):
- Contract level of detail choice (I)
- Select skilled supplier (II)
- Explicitly describing scope (III)

Explanation: The contractor wanted to select a specialist in this field of work, as the contractor did not have the required knowledge. It was therefore decided to subcontract all sheet piling, drainage, CSM-walls and groundworks. Supplier 3-4 is considered to be an expert in its field of work. This lead to the best price/performance ratio in the competitive tendering procedure. By contracting an experienced supplier, verification problems were prevented. Also, in the meetings after the selection procedure, the scope for Supplier 3-4 was described explicitly and expectations from both the contractor and supplier were aligned.

Supplier 3-5

Supplier relation: Supplier 3-5 was responsible for the design, engineering and execution of all installations (except the rail related installations from Supplier 3-2) and lighting. Supplier 3-5 was also responsible for providing input for the design process done by Supplier 3-3. Supplier 3-5 was selected based on the lowest price in a competitive tendering procedure.

Verification problem group: Supplier 3-5 is categorized in verification problem group B2. Verification was often incomplete or too late, causing problems in the design process done by Supplier 3-3 and in interfaces with other suppliers. However, the coordination of these interfaces, by either the contractor or Supplier 3-3, was also incomplete. This caused gaps in the requirement set for Supplier 3-5. The contracted requirement set is considered invalid.

Theoretical patterns (expected solutions): Based on the verification problem group B2, the theoretical pattern expected is the appliance of the following solutions:
- Contract level of detail choice (I)
- Select skilled supplier (II)
- Explicitly describing scope (III)
- Coordinate requirement development and interfaces (IV)
- Improving supplier competences (V)
- Take over verification tasks (VI)

Empirical patterns (applied solutions):

- Explicitly describing scope (II)

Explanation: The contract level of detail, separating the installations design from the overall design, resulted in many interface problems and was not chosen correctly and was not soundly argued. The supplier choice was not based on an analysis of the required competences to complete verification. The supplier was selected on lowest price in a competitive tendering procedure in which no specific requirements regarding verification were present. The only empirical pattern in this relation, is the explicit description of the supplier's scope. In the contract conducted between the contractor and Supplier 3-5, the scope was described in detail which prevented discussions. Due to the supplier's lack of experience with verification, verification was incomplete and often too late. This lead to several interface issues and required design revisions. After these verification problems were detected, the contractor did not take any actions to improve the lacking competences. In the end, the verification was completed by the supplier and the need to take over verification tasks decreased. Finally, a lot of problems were caused by a lack of coordination of requirement development and interfaces, especially in relation to the design of Supplier 3-3. This lack of coordination was, together with the lack of competences, the main cause for verification problems.

Supplier 3-6

Supplier relation: Supplier 3-6 was responsible for the design and adaptation of the station's steel roof structure, including the conservation and mounting. Supplier 3-6 was selected based on the lowest price in a competitive tendering procedure. The supplier is, however, considered as an expert in its field of work, although experience with verification is relatively limited.

Verification problem group: Supplier 3-6 is categorized in verification problem group B1. The verification executed by the supplier was mainly based on its own standardized quality system and documents. This secured technical quality, but verification of the specific contract requirements largely lacked. The supplier only partly complied to its verification obligations. The contracted requirement set, the entire project contract, contained all necessary information and requirements for the station's steel roof structure and is considered valid.

Theoretical patterns (expected solutions): Based on the verification problem group B1, the theoretical pattern expected is the appliance of the following solutions:
- Select skilled supplier (II)
- Explicitly describing scope (III)
- Improving supplier competences (V)
- Take over verification tasks (VI)

Empirical patterns (applied solutions):
- Contract level of detail choice (I)
- Explicitly describing scope (III)
- Take over verification tasks (VI)

Explanation: As the contractor did not have the required knowledge regarding steel structures, it was decided to subcontract this specific work in its entirety. In the selection procedure, the competences of the supplier, although considered to be an expert in its field of work, did not play an important role. Selection was based on the lowest price. After verification problems arose, caused by a mismatch between the requirements and the supplier's standardized quality documents, the contractor did not take any actions to improve the supplier's competences. Instead, the contractor completed the supplier's verification tasks, based on the quality documents. Another matching empirical pattern was the explicit description of the supplier's scope. However, this scope mainly covered technical requirements and lacked the required detail regarding verification results and expectations.