Using triangulation in lean six sigma to explain quality problems

An enterprise engineering perspective

Roland Ettema
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Cover illustration:
Suppose the goal is to understand a problem with an internal combustion engine. A constructional approach would begin with information on how an engine is constructed. Although this information is valuable, we cannot use it to explain problems, since problems are not engineered.

With a statistical approach, on the other hand, we would look at individual variables of parts of the engine, one at a time. The variables might highlight an abnormality such as a hot piston, but they would not show the relationships between the parts or the processes in a working engine.

Using triangulation, combining both approaches, we would have a model of cause and effect in a complete working engine, with each part correctly related to all the other parts, and we would have empirical data for each part in operation. We can tweak the throttle in the causal mechanism and see how that affects the fuel intake, carburettor and exhaust. We can watch the pistons pump and turn the crankshaft. We can deconstruct the engine at our leisure and look at each part in relation to the parts it affects, and is affected by.

This is the power of triangulation. Instead of getting several separate answers to discrete queries, as in a traditional statistical analysis, you get to see how those answers (like the engine parts) fit together, giving valuable context to make faster and better decisions.
The research reported in this thesis was conducted at the Institute for Computing and Information Sciences of Radboud University Nijmegen in partnership with University of Antwerp, under the auspices of the Enterprise Engineering Network. The research was partially supported by the Open University of the Netherlands.

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Using triangulation in lean six sigma to explain quality problems

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Roland Wilfred Ettema
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Promotoren:

prof. dr. H.A. Proper
prof. dr. J. Verelst

Universiteit Antwerpen, België

Copromotoren

dr. F. Russo
prof. dr. J.B.F. Mulder

Universiteit van Amsterdam
Universiteit Antwerpen, België

Manuscriptcommissie

prof. dr. M.C.J.D. van Eekelen
prof. dr. J. de Mast
prof. dr. J. Sanz

Universiteit van Amsterdam
National University of Singapore

Paranimfen

Bibi Ettema (dochter)
Noël Ettema (zoon)
Roland: En Bibi, ga je later ook promoveren?

Bibi: Neel, ik ga het in één keer goed doen.
Conventions

In this manuscript, the reader will find several text styles that distinguish between different kinds of information. Below are some examples of these styles and an explanation of their meaning.

- **New terms** and **important terms** are shown in bold.
- ‘**text in italic indicated citations** followed by a reference

<table>
<thead>
<tr>
<th>Concept</th>
<th>Concepts and their definition appear in a box like this. Underlined words in a definition refer to other concepts.</th>
</tr>
</thead>
</table>

- **P0X:** A principle appears in COURIER like this.
- A reference to a principle in the text appears in COURIER.

Specifications

In this research, we studied methodologies conforming to their specification. Since methodologies are constantly in flux – as they are subject to developments in science and praxis – we list the specifications that are used in this research. We have applied:

- For Lean Six Sigma: ‘A rational reconstruction of Six Sigma's breakthrough cookbook’ – the research results of the IBIS-UvA research institute (http://www.ibis-uva.nl).
- For ArchiMate: The ArchiMate specification 2.1 from the Open Group (http://www.opengroup.org)
- For DEMO: The DEMO 2.0. specification from the enterprise engineering institute (http://www.ee-institute.org)

Further details as to the exact documents and papers applied appear as references in the text.
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Chapter 1

Research Plan
Abstract This thesis starts from the observation that the way causality is demonstrated in the sciences is changing. Furthermore, there are problems with quality diagnostics within an organisation that could be resolved by introducing new theoretical understandings of causality and its confirmation. Starting with lean six sigma, a popular method used in organisational diagnostics when resolving quality problems, this chapter outlines a number of current issues in this field. This is followed by a discussion of our research questions and research strategy, as well as an outline of the structure of this thesis.

Figure 1 The contribution of Chapter 1.

1 This figure is explained in section 1.8 “The structure of this thesis”
1.1 Background

Quality management has long been characterised by the elaborate formalisation of industrial statistics. This is a legacy of ‘Taylorism,’ an approach to the scientific management of workflows dating from the 1880s, which emphasised manageable and measurable processes. (Taylor 1911; Nelson 1980). In this style of management, the quality of products – to be understood as including services – is continually and closely monitored using measurements. Conclusions about the business process – and the production process which is part of it – are drawn from these results (Taylor 1911). The measurement is conducted by treating particular product characteristics as quality variables and monitoring these. If the actual value of such a quality variable is observed to move beyond its defined acceptable limits, corrective measures can be taken. Where the value of one or more quality variables cannot be successfully managed, we are confronted with what is generally known in the quality assurance world as a quality problem.

The discipline that centres on explaining organisational problems (e.g. quality problems) is known as organisational diagnostics or organisational diagnosis (Alderfer 1980; Wagner 1993; Struss 1997; Harrison and Shirom 1999; Alderfer 2014). Its goal is to understand the possible causes of a quality problem by observing, analysing and explaining the measurable behaviour of selected variables. In practice, establishing a proper diagnosis is a far from trivial challenge, because there may be many possible causes of a given problem. The process owner (the person who must ensure that the process operates within acceptable limits) is thus faced with a dilemma (Alderfer 1980; 2014). On the one hand, it is desirable to obtain the required information as easily as possible: the diagnostic process should be efficient. On the other hand, one must draw the right conclusion from that information: the diagnostic process should lead to credible causal explanations, and when it does not, it should be clear why the process led to unreliable results.

Changes in the values of quality variables are by definition the result of changes in the business process. Organisational diagnosis, therefore, tries to find connections between product quality variables and process variables. A process variable is one that is conjectured to have a relationship to a quality variable. For example, the number of machine-hours (subject to mechanical defects) or man-hours (subject to employee absenteeism) may change in the course of time, affecting product quality. So far, organisational diagnosis has relied mainly on statistical analyses, such as the Six Sigma approach, the Shainin system and Taguchi’s method to study quality problems (de Mast and Bergman 2006). The lean six sigma approach is the most widely used diagnostic method for organisational diagnosis purposes (de Mast and Does 2006; de Mast 2007; de
Mast and Does 2010; Zhang and Irfan 2012). In lean six sigma, the process of identifying a cause for a quality problem is regarded as a form of scientific research (de Mast and Bisgaard 2007). Lean six sigma offers a methodology that a diagnostician uses to reach a conclusion about a possible cause for a quality problem. This embodies a step-by-step plan known as DMAIC, referring to its five phases: Define, Measure, Analyse, Implement and Control (de Koning and de Mast 2006). Each phase ends with a result that is the input for the following phase. The first step is to define the quality variables, then the quality problem is identified by measurement, and statistics are used to find correlations between quality and process variables, so that in the end conclusions support decision-making on interventions to correct the quality problem.

The Hawthorne Effect.

In a series of experiments from 1924-1932, researchers studied the worker productivity effects associated with altering the environment in the Hawthorne Works, a factory in Illinois. The changes included changing light levels, tidying up the place and moving workstations around.

Just when they thought they were on to something, they noticed a problem: The observed increases in productivity flagged almost as soon as the researchers left the Works, indicating that the workers’ knowledge of the experiment, not the researchers' changes, had fuelled the boost. Researchers still call this phenomenon the Hawthorne Effect.

Source: http://en.wikipedia.org/wiki/Hawthorne_effect

Figure 2 The Hawthorne Effect.

1.2 The problem

The conflation of causality and correlation is one of the most common logical errors in the lean six sigma method (Card 1998; Card 2006). Even seasoned
diagnosticians can fall into this trap; see the ‘Hawthorne Effect’ in Figure 2. The verification of causality, i.e. proving that one phenomenon is the result of another, is a nebulous field. We can easily understand that measurements and statistical analyses can demonstrate that variables alter in concert, yet the existence of a causal relationship between the phenomena is merely a hypothesis about reality. The lean six sigma method tells us too little about how the hypothesis of causality is produced and what requirements the hypothesis must satisfy if a causal relationship is to be demonstrated.

When we consider the lean six sigma method in detail, as we do in Chapter 3, one striking feature that emerges is that the method and tools offer no support for causal assessment (finding out what causes what) or for validating hypothesised causal explanations (elucidating how a cause produces its effect). Yet formulating and testing a causal hypothesis – or in everyday language, finding the cause – is crucial to identifying adequate measures to resolve a quality problem. This step should, in fact, be incorporated in the ‘Improve’ phase of the DMAIC sequence. But if we look at this step, as we do in Section 3.3.3, we find only brainstorming techniques which can assist in generating suggestions regarding causes, but give no further support about how a causal relationship can be proven. This makes it inevitable that the participants in a lean six sigma brainstorming session will find themselves flailing around with debatable assertions about causal relationships.

Some recent developments in philosophy regarding validity claims about causality, as these are found in the social and natural sciences, provide a starting point for evaluating lean six sigma’s methodology to produce a hypothesis and to demonstrate causality. These developments tell us that a causal mechanism must be identified before one can claim to have a theoretical explanation. The identification of a mechanism as a starting point for demonstrating causality is entirely unlike the use of statistics. The fundamental differences – as well as the advantages and disadvantages of each – are identified in this study by means of a review of the literature on causality (Russo 2008; Illari et al. 2011) in the organisational sciences and in philosophy. The results of this literature study are presented in full in Chapter 2,3 and 4, but a preview here will provide a context for our formulation of the key questions for this thesis.

Our literature study on causality, and especially causal inference, identified two essentially different types of approaches to causality: those that generate evidence of difference-making and those that generate evidence of production. The first entails collecting and analysing facts obtained through observation (measurements) and seeking variables that correlate to the target variable, which in our case is the quality variable. By measuring different populations, and/or conducting experiments, one can isolate the variables and search for evidence
that a variable makes a difference. That is, variable A is treated as the cause of changes in the value of variable B, if changes in A lead under all circumstances to changes in the value of B. The essence of difference-making is to demonstrate that variable A makes a difference to the value of B. Evidence of production – the second approach – embodies a different concept of causality: one seeks evidence as to how the system – on the basis of a cause – produces an effect. This is an ontological approach that concentrates on how and why cause and effect are linked (Illari 2011). Literature on causality (Illari and Russo 2014) distinguishes three approaches that generate evidence of production, centring respectively on process, mechanism and information. The more traditional of these regards causality as a process, in which a number of phenomena follow in sequence, leading from a cause to an effect. A more recent approach seeks to identify a mechanism. (Bunge 2004; Craver 2006; Russo 2011a; Russo 2011b). A diagnostician who takes this approach assumes that there must be an organisation in which entities within the system under consideration cooperate in such a way that they are responsible for the phenomenon. Finally, in the information approach, the diagnostician assumes that the system contains information and that this information changes as it moves from the starting state to the end state. The diagnostician examines how and why that information changes (Illari and Russo 2014). These considerations lead us to a canvas (the visual representation of a theoretical matrix) showing the essentially different strategies in causal inference. If we project the lean six sigma methodology on this canvas, it is evident that it falls entirely within the evidence of difference-making section. We therefore need to be aware of the following limitations of such an approach, which are discussed in the literature (see Section 4.2):

- Evidence of difference-making is ‘empirically empty,’ that is, explanations regarding causes are logically implied by assumptions and the validity of these assumptions is not part of the explanations.
- Evidence of difference-making incorporates a familiar kind of bad logic: *cum hoc ergo propter hoc* (Latin: “with this, therefore because of this”), meaning, ‘with A, caused by A.’ In reality, where two phenomena often occur together and exhibit a correlation, this does not necessarily mean that one causes the other.
- The credibility and validity of evidence of difference-making are affected by the population size.

These problems are inherent in statistical research. It is, therefore, interesting to study the arguments of researchers in the social and natural sciences explaining why they increasingly combine evidence of difference-making with evidence of production, in what is known as a ‘mixed method research strategy’ (Campbell
and Fiske 1959; Johnson and Onwuegbuzie 2004; Boer 2006; Holzhauser 2008; Cresswell and Clark 2010; Edwards 2010; Fielding 2012). Such researchers combine qualitative and quantitative elements in their research strategy to achieve a detailed qualitative understanding with the scope of quantitative techniques (Fielding 2012).

The exponents of a mixed method research strategy claim that a mixed approach enhances confidence in the ensuing findings. This effect is described in Campbell's papers as convergent validation (Campbell and Fiske 1959) and in developments in grounded theory (Glaser and Strauss 1967), whose “constant comparative method” involves comparing data from different sources. In this manuscript, we use the term ‘triangulation’ as a metaphor. This metaphor was coined by Smith (1975), referring to maritime navigation in which a position is determined using multiple reference points.

In the praxis of lean six sigma, we regularly find cases where the observed populations are too small to arrive at reliable statistical conclusions. Furthermore, there are cases where conducting experiments (to validate a hypothesis) is not allowed, as they would involve risks to the continuity for the business system. These situations are not ideal for drawing conclusions on the basis of evidence of difference-making; a diagnostician needs to adapt to such circumstances by changing the diagnosis strategy. By following Campbell’s use of the term “triangulation” as a means of convergent validation (Campbell and Fiske 1959) – including the distinction between evidence of difference-making and evidence of production – we think triangulation might offer a promising diagnostic strategy for those lean six sigma project situations where the conditions for drawing conclusions on the basis of evidence of difference-making are not ideal.

The above hypothesis suggests that methodological triangulation is an interesting approach that can be used to enhance the credibility of the results that lean six sigma generates. The main question here is: can methodological triangulation (further referred to as ‘triangulation’) be applied in lean six sigma?

1.3 The scientific challenge

Circumstances in many lean six sigma projects are not ideal for drawing conclusions about causality using approaches that generate evidence of difference-making. In many cases, variables can only be observed ‘as is.’ Experimentation using a control group to study a variable and find causal connections is rarely possible. Often there is insufficient time and money for such research and practical problems such as a small population may stand in the way of setting up a detailed study and reaching reliable conclusions. The addition of
Chapter 1

evidence of production may, therefore, be advisable to make causal assessment applicable under these conditions. Triangulation should give the findings greater credibility. However, we do not intend to prove that triangulation is beneficial to the lean six sigma method; that would require many lean six sigma projects, and more time than we have available. This study focuses rather on the practical feasibility of triangulation, with the idea that practicability must be studied first, before attempting experiments to evaluate whether triangulation does, in fact, improve the credibility of results based on lean six sigma.

The practicability of triangulation for lean six sigma will be examined using the causal mechanism approach to evidence of production. The process and information approaches to evidence of production will not be used (see Section 5.2). It has been argued that the process-oriented diagnostic approach is not compatible with the non-linearity of causality in social systems, and it is questionable whether the informational approach is a true causal mechanism approach. Modelling a social system as information flows, and observing how information changes in operation, is more of a marker technique to detect causality than a causal account by which a phenomenon can be explained.

Having noted that the causal mechanism approach also has its limitations, we surveyed other studies to obtain a foretaste of the challenges we could face in this study. We looked at fields in which conclusions about causal mechanisms have been drawn on the basis of statistics and in which researchers have recently switched to a triangulation approach. After considering publications from social sciences, the natural sciences and medicine, one of the most concrete examples matching these criteria was evidence-based medicine (Russo and Williamson 2011; Joffe 2011; Chakraborti et al. 2012; Clarke et al. 2013). Medical research presents the challenge of developing a general treatment plan for a medical disorder or physical limitation, using the best available evidence. Researchers have long relied on randomised controlled trials (RCT). In ‘the evidence that that evidence-based medicine omits,’ (Clarke et al. 2013), the authors study the impact of including causal mechanisms – as evidence of production – in addition to RCTs. They find that a triangulation approach can increase the reliability and reproducibility of evidence-based medicine results (Tashakkori and Teddlie 2003; Teddlie and Tashakkori 2008). However, they also note the difficulties that hinder the inclusion of causal mechanisms in the analysis, so that the potential advantages of a triangulation approach are not achieved. For each these scientific challenges are:

1. A causal mechanism is seen as a complex system whose characteristics are still unknown. It is necessary to demonstrate that the various entities constitute an organisation that is capable of producing the relevant phenomenon. The
identification of entities – and determining whether they constitute an organisation – is a ‘wicked problem’ and a circular question, since it is only after a causal mechanism has been demonstrated that the boundaries and constituents of the causal mechanism can be logically and consistently identified.

2. A causal mechanism can only be said to comprise an organisation once one knows how the interactions between its entities work. This requires a theory about interactions, which in many cases is lacking.

3. The causal mechanism should be verified through observations and measurements. However, there is a risk that in developing a hypothesis, researchers will observe what they expect to find. A methodology should include an independent check to prevent this.

4. The existence of a mechanism is more difficult to verify objectively, in comparison to statistical results. The sources of this greater subjectivity and how it may be overcome have not been discussed in evidence-based medicine research.

While the idea of an explanation based on mechanisms can help a diagnostician to avoid pitfalls about causality, it is evident from these challenges that once cannot simply restrict one’s findings to those justified by a causal mechanism. Much depends on how the concept of a causal mechanism is used. The risk is that one may get no further than anecdotes about the mechanisms at work within business processes, without theoretical precision or empirical relevance. An important prerequisite for precision and relevance is to begin with a clear theory about the actions and interactions within the business processes. Based on an action theory, as the term is used in analytic sociology, one can create a model of a causal mechanism that can be empirically validated. Conclusions from that validation can then be interpreted and processed accurately, using the same action theory until the model is a sufficiently accurate reflection of reality. This give-and-take between an action theory, the model, and empirical validation, with the aim of finding an explanation for a quality problem based on causal mechanisms, has not been studied in the field of organisational diagnostics. Any study of this dynamic will face some scientific challenges. For example, what is the theoretical basis for such a synthesis between an action theory, the model and the empirical? What issues arise if a diagnostic approach in organisational diagnosis does not incorporate an action theory? And how do the concepts used in organisational diagnosis fit within this synthesis?
1.4 Purpose of the study and associated research questions

As reported by De Leeuw, (1979; 1996), every study should stipulate what it is intended to produce. Kuypers (1984) refers to two aspects of the goal of a study: the first is internal to the study and is defined in the research questions, the second is what will be achieved by answering those questions, i.e. the purpose of the study. As for the latter, research in the field of organisational diagnosis – and within organisational diagnosis in the discipline of industrial statistics – has yielded a great deal of knowledge about quality diagnosis based on observations and evidence of difference-making, although it must be said that this understanding is rather general and not specifically applied to the lean six sigma approach (see the columns ‘observing’ and ‘analysing’ in Figure 3). However, there is a gap in our knowledge (represented with the arrow pointing to explaining in Figure 3) about approaches to causality other than ‘evidence of difference-making.’ This gap should be filled, not only to expand our understanding of causal inference within organisational diagnosis, but also to assist those using lean six sigma in practice, by providing knowledge about the ‘evidence of production’ approach, as a basis for further discussion on quality problem diagnosis (see the ‘explaining’ column in Figure 3) and of remedial measures. This study is intended to contribute to such as effort, in part by incorporating state-of-the-art philosophy on causality. The central research goal is formulated as follows:

*Acquiring knowledge about the practical applicability of applying ‘methodological triangulation’ in lean six sigma, and using ‘causal mechanism’ as a mode of explanation.*

In line with this, the following research questions have been formulated:

(a) *What are the consequences for the lean six sigma methodology if triangulation and causal mechanisms are taken as a starting point?*

(b) *What requirements must lean six sigma satisfy if triangulation with a causal mechanism is applied to ‘explain’ (identify and confirm) the cause of a quality problem?*
A literature review (see Chapters 2, 3 and 4), was used to further define some of the concepts relating to the research purpose and questions. The concepts involved in the research goal and research questions are:

- **Triangulation** (or Methodological Triangulation): this was explained above, see Section 1.2.

- A **quality problem** exists in a business process where it is no longer possible to control the value of one or more quality variables within the prescribed range. A quality variable represents a particular product characteristic whose value is regularly recorded.

- **Lean six sigma** is an organisational diagnostic method for the systematic observation, analysis and explanation of a quality problem.

- A **methodology**, in line with Seligmann’s definition, (Seligmann et al. 1989) comprises five components: a way of thinking, a way of working, a way of modelling, a way of controlling the project and way of supporting (see Figure 3). The five elements are defined as: **Way of thinking**: the theory about the kind of object systems that the method addresses; it provides the basis for integrating the other ‘ways’ **Way of modelling**: the distinct products (aspect or partial models) that together constitute the complete model of the object system, as well as the applicable representation techniques (diagrams, tables, decomposition, etc.). **Way of working**: the process (procedures etc.) of developing the models, as well as the set of techniques (analysis, interviews, etc.) for acquiring the knowledge about the object system that is needed to make the models **Way of controlling**: the organisation and the control of the project in which the methodology is applied; it applies to both the way of
modelling and way of working; **Way of supporting**: The instruments, software or other artefacts that support the methodology.

- **Consequences (in the context of this research)**, the impact of including a different conceptual starting point (way of thinking) on the other elements of a methodology. In this study, we introduce methodological triangulation as a way of thinking in the lean six sigma method, as a strategy to explain quality problems. We study the consequences of this change for the way of modelling and way of working (see the column ‘explaining’ in Figure 3). We expect that all the methodological components of lean six sigma will need to be re-aligned to establish triangulation for the purpose of proper causal assessment for lean six sigma.

- **The concept of a causal mechanism** is in literature defined in various ways (see section 5.3). We have used Russo’s definition: a causal mechanism consists of entities and activities organised in such a way that they are responsible for the phenomenon under consideration. Using this definition as synonym for explaining, we will study the impact of this new way of thinking on lean six sigma (on its way of working and way of modelling).

- **Method design requirements**: our study of the practical contents of the components of lean six sigma methodology, when the conceptual approach in the lean six sigma method has been changed, should yield clear requirements for the design of a new method. A requirement is defined as a simply documented statement of what a particular component of the lean six sigma method should achieve to establish triangulation. This would then be a starting point for further research leading towards a new methodology.

### 1.5 Scientific relevance

As noted above, this research was inspired by a growing awareness, in organisational diagnostics, that the statistical approach is insufficient to demonstrate causality. One of the ways philosophers of science have responded to this problem is to search for new principles on which diagnosis can be based (Russo 2008; Illari et al. 2011; Illari and Russo 2014). Relatively little research has been done on new approaches to causality that could be applied in organisational diagnosis, industrial statistics and the lean six sigma method. There is certainly a need for better understanding of this complex area, because current practice is considered inadequate, (Illari et al. 2011) and because quality control and the resolution of quality problems are likely to be the subject of discussion for
some time to come. The societal importance of this issue is illustrated by the fact that the IBIS-UvA Institute\textsuperscript{2} - one of the principal bodies in the field of quality management in the Netherlands - has asked for research such as the current study (de Mast 2012). The IBIS-UvA Institute conducts applied scientific research for quality management and organisational diagnosis in the financial and industrial sectors and in health care institutions. It works with partners in the field to conduct research for the government, advisory organisations and sector or industry organisations.

The scientific importance of this research is that introducing a triangulation approach in lean six sigma is expected to yield insights that will support the development of a theory of causal mechanisms in business processes. Such a theory could be used to describe and evaluate a hypothesis about causes for quality problems. Although we know more and more about the organisation of business processes, very little is known about causal connections within these processes and how they may lead to a quality problem. We see this as new knowledge, from which new theories can be developed.

Another aspect of the scientific importance of this study is that we are attempting to link philosophy, science and practice in a productive way. Philosophy encourages us to reflect on fundamental questions. While this may yield good results, all too often philosophy’s answers have little practical value for scientists and professionals working in the field. This study, in contrast, seeks to make some views about causality, found in the philosophy of science, practically accessible. By showing that the various conceptual, metaphysical and philosophical points of view are also features of the practice of lean six sigma, we can bridge the gap between the philosophy of science and scientific practice, so that the current philosophical debate about causality can bear fruit sooner. That will benefit the scientific discipline as well as organisational practice, while assisting researchers who undertake the suggested further research.

Finally, in this thesis we focus on the lean six sigma diagnostic method. This method has been scientifically validated in 2007 (de Koning and de Mast 2005; de Koning and de Mast 2006; de Koning 2007). However, that research was based on a rational reconstruction approach to lean six sigma literature, and there is little literature about causality and the principles underlying lean six sigma. Our study will extend the scientific validation of the lean six sigma approach in the context of the philosophy of science. We think that this will support the further

\textsuperscript{2} www.ibis-uva.nl
development of the lean six sigma approach by enabling new approaches to causality to be considered.

1.6 Scientific approach

Much of the research relating to lean six sigma has been descriptive in nature (Hahn et al. 2000; Nave 2002; i.e. George 2003; Koning and Mast 2005) or focuses only on the statistical or mathematical aspects of lean six sigma. Researchers have positioned lean six sigma as a research object for observation and not as a subject for redesign. The action research approach can be used to satisfy the need for scientific research to incorporate triangulation in the lean six sigma approach. The following paragraphs will present some considerations affecting the scientific approach of the present study, derived from a critical analysis of recent developments in industrial statistics and of the scientific background to this study. A key element in that background is the University of Amsterdam's (UvA) newly developed policy on research in industrial statistics (2012), which states that current research has focused too much on developing new mathematical and statistical methods:

‘Below, I will explain in what direction, in my opinion, research and teaching in industrial statistics should improve. That implies a certain critique of the status quo, especially of the dominance of mathematics in industrial statistics. The purpose of my criticism is not to discredit existing practices, but to show colleagues that there is a way for research in the field to have more impact’ –(de Mast 2012 p. 13, translated from Dutch)

The strongly mathematical character of this research has made it inaccessible to those working in the field of organisational diagnostics (de Mast 2012). It has not been able to bridge the gap between theory and solving quality problems in practice. In the new approach, industrial statistics is not regarded as a branch of mathematics, but rather as a technique for solving problems. Because of this change, UvA’s research agenda now centres on designing practice-oriented methods and techniques. Since our research results are intended to serve the discipline of organisational diagnosis, it is logical for us to attune our research to this orientation. However, we wish to express a reservation about encouraging design methods and techniques, in that this suggests a Design Science Methodology (DSM). In some research settings, DSM is impossible, at least in the first instance. For example, where the requirement of having a minimum initial specification cannot be satisfied. That requirement would constitute a minimum set of information needed to implement each step in the design and implementation process, see Figure 4. It appears to us that an experimental and exploratory setting is required to answer two issues that concern us:
(1) how the ‘way of working’ and ‘way of modelling’ components of the methodology influence how a causal mechanism appears, and

(2) how to produce a synthesis of an action theory, a model and empirical practice that will under-gird a reliable conclusion about a causal mechanism.

This research applies the strategy of testing “hypothetical” combinations of methodologies to acquire knowledge about the practical applicability of ‘methodological triangulation’ in lean six sigma, and using ‘causal mechanism’ as a mode of explanation. So, what-if scenarios for triangulation strategies need to be tested in case studies, based on informed assumptions derived from a theoretical and practical understanding of the individual methodologies and knower modes about causal mechanisms across the different sciences.

We are therefore not yet ready for research that follows a ‘standard design science process where the lean six sigma methodology is the central artefact (Hevner and Chatterjee 2004; Hevner et al. 2004a). Rather, we are venturing into what Van Aken calls the ‘fuzzy front end’ of design-oriented methodology, see Figure 4 (van Aken and Nagel 2004; van Aken and Andriessen 2011; van Aken 2013). In other words, at this stage of the design-science process we must focus on developing an explanatory theory, rather than a design theory (Varey et al. 2002). According to Van Aken, the fuzzy front end is a necessary stage in which we examine our
interests, suspicions and assumptions. This yields an explanatory theory and the first set of specifications. Only then are the requirement of a minimum specification satisfied and the first iteration of the design process can begin.

Since we expect our research to be conducted mainly in this fuzzy front end, we will discuss this phase of design-oriented research at some length. The fuzzy front end is a stage in which a problem (that the statistical approach to organisational diagnosis is inadequate) is explored or transformed, guided by a vague idea of a solution (lean six sigma with causal mechanism as the way of thinking and the triangulation approach as the way of modelling and way of working; see Figure 3), which results in a minimum specification for a new approach to the problem. The minimum specification will be formulated as triangulation design principles, classified in two directions: the methodological direction (vertical) and the stepwise direction of organisational diagnosis. These triangulation design principles are considered as the knowledge object of this study, that is, the intended product of this research. Establishing triangulation design principles requires a developmental approach, in which problem-solving requires several distinct iterations. In each iteration, a possible solution is proposed on a theoretical basis, and developed so that it can be applied and tested in practice. The key to this approach is that the knowledge object from a previous iteration is used in later iterations and develops as the number of iterations increases. (van Aken and Nagel 2004; van Aken and Andriessen 2011)

![Figure 5 Single-loop versus double-loop learning.](image)

The developmental approach does not focus on solving a client’s problems, but on increasing people’s problem-solving capacities (Boonstra and Vink 1996; van Aken and Nagel 2004; van Aken and Andriessen 2011). Only when one knows what can increase people’s problem-solving capacity is it possible properly to specify the requirements for a new approach that will impart that problem-solving capacity. Thus, the developmental approach, which we consider ideal, focuses on people’s learning processes. The learning process – in relation to
solving problems – is associated with generating new ideas to address the problem (Dülger et al. 2011).

In the developmental approach, a learning process is used in which people (such as those working in a discipline or profession) can proactively examine whether their convictions and practices contribute to maximising the outcomes of the methods they apply. If these people are able not only to participate in perfecting routines (single-loop learning), but also to continually question and debate the norms and principles themselves, this is known as double-loop learning (see Figure 5). The proposed transformation process in which we, as researchers, suggest that different fundamental assumptions and principles could be adopted within lean six sigma is an example of double-loop learning. Single-loop learning can be seen in the way we help experts with the practical application of these suggestions, by experimenting with new ways of working and ways of modelling to identify a causal mechanism. The researcher then faces the challenge of studying the effects of these interventions as objectively as possible.

To guarantee objectivity in double-loop learning, we called on a panel of experts in industrial statistics and enterprise engineering who had not played any role in the organisation involved in the project concerned. This approach shares many characteristics with what is known in the literature as a case-driven developmental approach, which is implemented through action research. Two discrete requirements emerged from this process. First, we need to conduct at least two case studies to generate reliable findings by comparing them (see ‘motivation’ in Section 5.5). Second, we need to follow the rules of action research to guarantee the scientific quality of this study. Furthermore, since the underlying assumptions in the causal model (i.e. the causal mechanism) and its characteristic aspects are known from its application in other sciences (e.g. medicine, physics, etc.) the observed findings in the case studies can be established with relatively high confidence levels. Therefore, a bottom-up approach is necessary to test a triangulation strategy in praxis in order to generate and test meaningful hypotheses for lean six sigma. A top-down approach is required to understand triangulation (based on the current body of knowledge) and to present arguments why researchers should apply triangulation/causal mechanisms in lean six sigma initiatives.

1.7 Research design

The design of this study derives from the scientific approach described above. Double-loop learning will be used to produce an explanatory theory for the subject of this research. This research design is shown schematically in Figure 6.
Our design begins with a literature review (see Figure 5) to reveal how causality is conceptualised in the lean six sigma approach. We elaborate on why it is so difficult to identify a cause for a quality problem using this approach. Our literature research also involved looking at concepts of causality in other sciences, so that we could judge whether different approaches and concepts on causal assessment could offer simpler and more reliable ways of identifying causes. In so far as they do, we can then consider whether these concepts should be applied to address the shortcomings of lean six sigma. This theoretical research yields the ‘new’ way of thinking for causal assessment, which is the knowledge object of this study (see Figure 6). This new way of thinking led us to the general research goal for this project. Based on the ‘new’ way of thinking about causal assessment – externalised in methodological design principles for triangulation – we make a proposal for the way of working and way of modelling in lean six sigma projects. The relationship between the way of thinking and the other ways to which we refer is illustrated in the link between the knowledge object and research object in Figure 6. The theoretical hypothesis is that incorporating new methodological design principles will result in a triangulation approach for lean six sigma projects that addresses causality more efficiently and more reliably than the original lean six sigma approach (see Figure 3).

The proposed research object (way of working and way of modelling) is then tested in a series of case studies. Each study consists of a documented triangulation approach and evaluation criteria to measure its success. It is
important to us that case studies are conducted in the light of the knowledge object so that they yield answers to our research questions. The most important question to be answered with the aid of a case study is whether the methodology, as proposed, has contributed to identifying a causal mechanism for a quality problem. Our research strategy requires critical reflection to validate the hypotheses in the methodological design principles, and to validate the way of working and the way of modelling of the organisational diagnosis approach that has been used. The methodological design principles may need to be modified, which then requires a new case study to test the modification, leading towards a design for an adequate triangulation approach. We will if necessary return to the literature to search for new answers.

1.8 The structure of this thesis

The fuzzy front end is more than an iterative process, it is a creative process to uncover insights and ideas from multiple disciplines and sciences, leading in our case to a new approach for organisational diagnosis. The consequence of conducting research in the fuzzy front end of design science (see Figure 4) is that the structure of this thesis is not as straightforward as a report on design science research. This introductory chapter, for example, could not have written without Chapters two, three and four, in which we identify the opportunity to change organisational diagnosis. From this obtained knowledge, we could generate ideas and could start our case studies, which are reported in the following chapters. If we position all our chapters in relation to the fuzzy front end (see Figure 4) and align them to our research design (see Figure 6), the following picture appears (see Figure 7):

Chapter 2 introduces the discipline of organisational diagnosis, its concepts and their definitions from existing body knowledge. We learn from existing literature about the objective of organisational diagnosis and take a closer look at what is meant by ‘explaining organisational problems.’ We also look at organisational control, which is the context of organisational diagnosis, to understand why explanations are important.

Chapter 3 introduces the lean six sigma methodology from an organisational diagnosis perspective. From this perspective, we note that the lean six sigma methodology is mainly an organisational analysis approach. Its methodological prescriptions excel in supporting a diagnostician in the statistical evaluation of observations. However, these prescriptions offer weak support for causal inference. This support is largely limited to brainstorming techniques to generate conclusions from the results of the analysis.
Chapter 4 outlines the idea – suggested by the literature on causality – that methodological triangulation as a diagnosis approach yields more reliable results than a single evidence approach. We will learn that lean six sigma is based mainly on evidence of difference-making. To introduce methodological triangulation in the lean six sigma approach, we need to include evidence of production in the process of drawing a causal inference. This requires an exploratory study of evidence of production, as a basis for a proposal for the new lean six sigma method. This exploratory research shows that three kinds of evidence can be positioned as evidence of production: a ‘causing process,’ a ‘causing mechanism,’ and an ‘informational account of causality.’

Chapter 5 continues the topic of evidence of production. In this chapter, we argue why we prefer a causing mechanism as evidence of production, rather than a causing process or an informational account of causality. On the basis of causal mechanisms, we present a set of triangulation design principles that represents our idea for applying triangulation in a lean six sigma project. In addition to these principles we present a methodological design for testing in our case studies.

Chapter 6 – the first analytic chapter – explores in detail how triangulation and the concept of a causal mechanism can be included in a real life lean six sigma
project. In the first case study, conducted at the pension provider Zwitserleven, the observations and statistical analyses of a lean six sigma project are combined with a functional system orientation to identify and confirm a causal mechanism for the perceived quality problem. Reflection on this led to a rethinking of our methodological design and our initial triangulation design principles.

Chapter 7 analyses a second case study, conducted at the pharmaceuticals company Merck, using a constructional system orientation to identify and confirm a causal mechanism for the perceived quality problem. We wanted to try this perspective so that we could make a recommendation as to which system perspective should be adopted to identify a causal mechanism.

Chapter 8 presents and compares the two fundamentally different system orientations (the functional and the constructional) by applying them as ‘ways of modelling’ for business processes in the tax authority case. By applying both orientations in one case study, we can judge which perspective is required for organisational diagnosis.

Using the insights obtained from the two case studies, Chapter 9 presents a set of requirements for a new lean six sigma method. We maintain that these are essential requirements for an organisational diagnosis approach that begins with causality. Since we have also learned something about what such a method could entail, this chapter also presents a preliminary design. This design specifies each of the five components of the methodology, resulting in a coherent method for identifying a causal mechanism for a quality problem. Chapter 9 ends with the most important conclusions from the preceding chapters and a discussion of the implications of this study.
Chapter 2

The discipline of organisational diagnosis
Abstract In this work we raise questions about the lean six sigma methodology, based on the scientific domain of organisational diagnosis. This chapter prepares the ground by presenting the theoretical basis of organisational diagnosis and pointing to inconsistencies in its literature. By drawing parallels to diagnosis in medicine, and viewing organisational diagnosis through the lens of systems theory, we can ‘repair’ these inconsistencies. As a result, we offer a model for organisational diagnosis that will serve a lens through which the lean six sigma methodology can be evaluated.
2.1 Introduction

Picture yourself visiting a medical practitioner, and imagine that the practitioner was to prescribe a medicine, before asking about the symptoms you might have. You would be flabbergasted and would not accept this, even from an expert. A medical practitioner is expected to demonstrate the link between the patient’s problem and its cause or causes before recommending a treatment. Treatments not preceded by diagnosis would in today’s world be regarded rightly as quackery or medical malpractice.

In contrast to this situation, we see how managers of organisations call in the help of business consultants and ask for team building, conflict management, or organisational redesign with absolutely no interest in, or willingness to pay for, preliminary assessment work (Lowman 2005; Vlielander 2011). In other words, managers tend to apply medicines without adequate consideration of the causes underlying the symptoms they want to be ‘treated.’ The survey of Vlielander (Vlielander 2011) confirms this view by showing that managers are more interested in treatment than accurate assessments.

This situation is in stark contrast to the opinion of the main authors from organisational diagnosis (Levinson et al. 1972; Alderfer 1980). These authors teach us that, without competent assessment, there is no assurance that suggested treatments will either address what ails the organisation or result in long-lasting change. Lowman, who studied the work of Levinson says in this respect:

‘… when a problem is more than transient, or causal, before trying to fix it, the consultant should understand what caused it and why it persists’ (Lowman 2003)

Taking the importance of a proper assessment before planning and administering a treatment, the questions arise: what is organisational diagnosis, for what purpose is it applied, and what is its methodology? In the following subsections (see Figure 8) we aim to find precise and accurate answers from organisational diagnosis literature and relevant theories to define the knowledge object of this scientific work.

2.2 Current characterisations

Since Alderfer’s publication in 1980, there have been nearly three decades of debate on the right characterisation of organisational diagnosis. The main contenders are:

‘Organisational diagnosis is a process based on behavioural science theory for publicly entering a human system, collecting valid data about human experiences
with that system, and feeding that information back to the system to promote increased understanding of the system by its members’ (Alderfer 1980)

Organisational diagnosis is an investigation that draws on concepts, models and methods from the behavioural sciences in order to examine an organisation’s current state and help clients find ways to solve problems or enhance organisational effectiveness’ (Harrison and Shirom 1999)

‘Organisation diagnosis is a process that helps organisations to improve their capacity to assess and change inefficient patterns of organisational behaviour as a basis for greater effectiveness’ (Brown and Harvey 2006)

‘Organisational diagnosis is a method used for analysing the organisation in order to identify organisational shortcomings so they would be neutralised through organisational change’ (Janičijević 2010)

Apart from some minor changes (see Alderfer’s original publication from 1980, Brown and Harvey’s 2006; Janićijević 2010; Alderfer’s 2010), these broad characterisations remain in use by their original proponents, and many others.

An important question that needs to be asked is: ‘Are these characterisations consistent in: (i) positioning organisational diagnosis; (ii) separating concerns of the activities involved in organisational diagnosis and (iii) defining concepts in organisational diagnosis?’ Unfortunately, through the lens of these sub-questions we see differences among these characterisations.

First we observe differences in the way organisational diagnosis is positioned. Alderfer states that organisational diagnosis is ‘a process.’ In his literature (Alderfer 1980; Alderfer 1987; Alderfer 2014), organisational diagnosis is presented as a generic discipline applicable to many kinds of organisational problems. Brown and Harvey support this position in (Brown and Harvey 2006). Other researchers, such as Harrison and Shirom (Harrison and Shirom 1999), emphasise the non-linearity in the way of working and position organisational diagnosis as ‘an investigation’ limited to social problems. Janićijević does not disagree; he positions organisational diagnosis as ‘a method’ to emphasise the aspect that approaches used in organisational diagnosis consist of procedures and techniques.

Second we recognise how organisational diagnosis characterisations differ in separating concerns. This is problematic since the activities in organisational diagnosis of ‘collecting data,’ ‘analysis’ and ‘changing the organisation’ refer to different kinds of scientific disciplines (e.g. social science, industrial statistics or
change management). These scientific disciplines may share general methodological concerns, including the subject of causality.

Third, these characterisations differ in scope, accompanied by differences in concepts. The contenders presented above refer to concepts such as ‘human system,’ ‘organisation’ or ‘organisational behaviour.’ One may assume that these authors refer to the same objects. However, the literature on organisational diagnosis does not provide crisp definitions for these concepts thus leaves us in the middle to which objects these concepts refer.

These inconsistencies in the literature of diagnosis are problematic for this research. If we examine the potential of causal assessment in organisational diagnosis (as we do in Chapter 3) we need to define the knowledge object for our work in a way that: (i) positions organisational diagnosis unambiguously, (ii) is precise about its function, activities and scope and (iii) provides crisp definitions for its main concepts that are subject to change in this work. In the following subsection, we reveal the strategy to cope with these inconsistencies.

2.3 Tackling inconsistencies in the characterisations

In this research, we need a consistent characterisation of organisational diagnosis. What we need is a world view (‘Weltanschauung’) on diagnosis, to understand the positions of the authors in organisational diagnosis. A worldview constitutes an overall perspective on a subject that sums up what we know about it and how we evaluate it (Craig 1992). Our strategy to deal with inconsistencies in the literature of organisational diagnosis is to study the worldview of medical diagnosis. Knowledge of the way medical diagnosis is positioned, its activities, the diagnosticians’ concerns and its main concepts may help us to frame organisational diagnosis more precisely and consistently than has thus far been the case. The following paragraphs present the relevant knowledge of this domain. We will start with a small example.

When a patient presents his or her symptoms to a medical doctor and asks for help, it is likely that the examination will start with interviewing the patient, followed by tests or procedures, leading to a diagnosis. The procedure is known as differential diagnosis, which is a scientific method used to deduce a diagnosis from the patient’s symptoms and a list of possible diseases. This diagnostic process can lead through various logical forks and dead ends. This seems a simple and straightforward process, but is diagnosing so straightforward?

The book How Doctors Think (Groopman 2008) shows that there are many diagnosis approaches in medicine. The approaches of physicians, pathologists and radiologists differ. For instance, physicians apply more ‘heuristics’ or rules of
thumb and jumps of insight compared to the formal logic or careful stepwise reasoning of pathologists and radiologists. Pathologists and radiologists study samples, entire bodies or images, (CT, MRI, etc..) using formal procedures. From this book it is clear that diagnosing a single case, in medicine, relies on multiple perspectives and methodologies. Diagnosis is an intertwined approach involving different specialised approaches.

Although Groopman noticed plurality in medical diagnosis he also noticed a pattern of activities through which each medical diagnostician (e.g. expert and physician) needs to pass. Each diagnostician observes the symptoms of the patient, analyses the relationships between symptoms, and explains the medical problem based on the analysis results and what is known about the human system. Once the cause for the problematic symptoms is explained, a doctor can determine a treatment plan (Groopman 2008). In this view, diagnosis and intervention are separate disciplines, see Figure 9.

![Figure 9 Doctor-patient model.](image)

There is broad consensus on this model (Emanuel 1992; Charles et al. 1999; For example, in Carter and Berlin 2003; Wirtz et al. 2006). This model has a high level of abstraction and therefore does not include all the specific forms of diagnosing in medicine. We think this abstract model is applicable to a study of diagnosis in other scientific domains. Furthermore, the model is easy to understand and separates the concerns of each individual activity. Therefore, we apply this model to define organisational diagnosis in more precise and consistent terms than in the characterisations presented in Section 2.2.

2.4 Characterising organisational diagnosis

In this section, we establish a characterisation for organisational diagnosis for this work by merging the systems theory of organisational control and the doctor-patient model. The incorporation of the doctor-patient model is necessary to clarify the activities on a more detailed level than we have found in the literature.
on organisational control. Furthermore, this merger allows us to clarify the main concepts of organisational diagnosis in the context of systems theory, for which we think it leads to more precise and detailed clarification (see Section 2.2). To avoid a merely abstract, theoretical, clarification, we present a short illustration from daily practice to which we will refer when clarifying organisational diagnosis on a theoretical basis.

Imagine an organisation (e.g. the Ministry of Transport and Public Works) that is responsible for the safety of transportation and utilisation of a country’s traffic infrastructure. Managers who work in this organisation are accountable for the success of this organisation. To determine whether these managers satisfy the business goals, this hypothetical organisation registers traffic accidents. Once per month they evaluate whether they meet their specified goal. If this is not the case, we are looking at a troubled organisation.

The illustration is an example of what in management science is called ‘an organisation as the object of control,’ referring to a general situation of monitoring and controlling organisational behaviour with the objective of satisfying certain business goals. The essential aspects of controlling are described in science in the so-called ‘paradigm of control,’ which is familiar from the technical sciences (Wiener 1948). Later, in 1979, the notion of control entered management science, regarding controlling in the context of an organisation (de Leeuw 1979).

2.4.1 Characterising organisational problems
Before we take the stance that organisational control is the context for organisational diagnoses, we first present the paradigm of control and introduce its core concepts. These concepts are important since they overlap the concepts of the doctor-patient model. The graphical representation of the paradigm is presented in the left side of Figure 10. This representation shows a bi-directional relationship between a supervising system and an observed system. The figure also shows a reciprocal relationship between the supervising system and the environment of the system.

The supervising system (part of the complete system, see dashed box on the left side of Figure 10) is the controlling part of the complete system. It is ‘responsible’ for observing the part of the system that acts upon the input from the environment and produces output for its environment. For example, the Ministry of Transportation is the supervising system and public infrastructure is the observed system.
The supervising system ‘controls’ the behaviour of the observed system by observing it and making changes in the observed system. The motivation for the supervising system is that it aims to adapt to the system’s environment to satisfy their expectations. For this task, the supervising systems needs to observe the environment to determine the specification for the behaviour for the observed system.

The boxes and links in the representation represent concepts which have not yet been introduced, and which must be defined to clarify organisational diagnosis and to work towards a proper definition for an organisational problem. First, we address system (see dashed box on the left side of Figure 10). The paradigm of control is a general system theory and does not address one particular system. At this point we need a clarification. Organisational diagnosis deals with organisations that by default are goal oriented (they have a function for the environment) and controlled. To denote an organisation as a system we apply in this work the term ‘enterprise system’ with the following definition:

**Enterprise system**

A designed social system that consists of individuals who work together to achieve its function.

Both the supervising system and the observed system are part of the enterprise system. So, the supervising system (i.e. the individuals in the role of management) is the part of the enterprise system that is concerned with observing and controlling the observed system. The observed system is the part of the
enterprise system (i.e. the individuals actively involved in a business process) that acts upon the input from the environment (i.e. customers and suppliers of raw materials) to produce meaningful output for the environment (i.e. services and products).

The role of the supervising system is to observe the enterprise’s environment and to reformulate expectations in terms of goals for the observed system. In terms of daily practice, management sets specifications for key variables (e.g. the expected number of traffic accidents) in which the environment is interested. If the value of a key variable threatens to go outside limits that have been defined as acceptable, corrective measures on the observed system can be taken. If the value of one or more key variable cannot be successfully managed by the supervising system, there is an organisational problem.

<table>
<thead>
<tr>
<th>Organisational Problem</th>
<th>The situation in which the value of one or more key variables cannot be successfully controlled within the specified limits.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Variable</td>
<td>A measurable characteristic which is important – for the supervising system – to satisfy a specification.</td>
</tr>
</tbody>
</table>

2.4.2 Characterising the discipline

The paradigm of control is not only helpful to characterise the concepts that are important for organisational diagnosis, it can also serve as the context for organisational diagnosis itself. In the following paragraphs, we describe how this paradigm contributes to characterising the discipline and its activities. For this purpose, we merge the doctor-patient model with the paradigm of control to establish more detail in the model. This merger is graphically presented on the right side of Figure 10.

The first contribution of the merger of the paradigm of control and the doctor-patient model is that the activities defined in the doctor-patient model link the activities of organisational diagnosis to the paradigm of control. This offers a new perspective on the scope of organisational diagnosis. For example, we can observe that organisational control includes the activities of ‘observing,’ ‘analysing,’ ‘explaining’ and ‘intervening,’ see the grey area on the right side of Figure 10. This sheds new light on organisational diagnosis since the doctor-patient model (Figure 9) positions the activity of intervening beyond the scope of diagnosing, because it is not necessarily the responsibility of the diagnostician to plan a treatment.
This conclusion can be confirmed in the literature of organisational diagnosis, which refers to a dialogue between a consultant who observes, analyses and explains a problem and the responsible manager who is responsible for changing the organisation (Levinson et al. 1972; Alderfer 1980; Alderfer 2014). We think it is therefore feasible to conclude, for this study, that the scope of organisational diagnosis ends by delivering an explanation for an experienced problem. We also conclude that the results of organisational diagnosis serve decision-making. In other words, organisational diagnosis is an action-oriented discipline, not a knowledge-oriented discipline.

Unfortunately, the model does not inform us about the distinction between analysing and explaining. A sharp demarcation could help us to isolate the explaining role further, which would help us to clarify what explaining is. However, at this we point we find clues in the literature on organisational diagnosis, we quote:

‘The key difference between organisational analysis and organisational diagnosis is their aim: the aim of organisational analysis is understanding the organisation for the purpose of its exploration, while the aim of organisational diagnosis is understanding the organisation for the purpose of changing and improving it (action). It could be said that organisational diagnosis is a specific form of organisational analysis – a form focused on the performing of organisational change for the purpose of improving organisational performance.’ (Janičijević 2010)

According to Janičijević, organisational analysis consists of the activities observing and analysing observational data for exploring the behaviour of the observed system. Analysis is a knowledge-oriented discipline in which one explores who, what, when and where. Organisational diagnosis goes one step further. The objective in organisational diagnosis is to explain an organisational problem, which is about finding answers to why and how a problematic phenomenon occurs (Brown and Harvey 2006; Alderfer 2014). Now, based on the former elaboration, we characterise organisational diagnosis and its related disciplines as:
2.5 Conclusion and contribution

The clarifications presented in the previous two paragraphs (see the definition boxes) is more precise compared to those we found in the literature (see Section 2.2) and is for this work for two reasons important. First, we clarify how different scientific disciplines (i.e. organisational analysis, organisational diagnosing and organisational control) share common methodological concerns, including the subject of causality. The literature on organisational diagnosis has not clarified the disciplines and activities in which causality is established and where not (Morgan 1976; Tuomela 1980). Our clarification positions the subject of causality in a precise way, exclusively in the activity of explaining.

Second, our clarification allows us to study how the discipline of organisational diagnosis is affected when the way of thinking about causality changes. Consistency must be guaranteed between organisational analysis, organisational diagnosing and organisational control. This allows an impact study, which is necessary when changing a methodology for organisational diagnosis. In summary, our clarifications enable us to understand organisational diagnosis better, since we have positioned it in the bigger context of controlling a system (systems theory) and have differentiated it from other related disciplines.

The clarification offers us a theoretical base for this work. What is needed now is a research object on which we may test the impact of changing the way we think about causality. We need a methodology from practice that represents the discipline of organisational diagnosis where we may test new causal approaches.

| Organisational analysis | is a knowledge-oriented discipline that consists of observing and analysing the behaviour of key variables. |
| Organisational diagnosis | is an action-oriented discipline that consists of organisational analysis and explaining the behaviour of key variables. |
| Organisational control | is the discipline that consists of organisational diagnosis and the responsibility to intervene into the observed organisation to keep the value of one or more key variables within specified limits. |
Chapter 3

Lean six sigma through the lens of organisational diagnosis
Abstract Organisational diagnosis is part of organisational control. Therefore, the results from organisational diagnosis must support decision-making. It must deliver an adequate explanation for an organisational problem. In this chapter, we examine the lean six sigma methodology by breaking down its methodology from an organisational diagnosis perspective assuming its application delivers an explanation for a quality problem. We apply the following strategy: first, we motivate our choice of lean six sigma as a research object for this study. We then present its observing, analysing and explaining capabilities and its main concepts, and compare its explaining capability with explanatory accounts as known in the literature of organisational diagnosis. Based on this assessment, we conclude that lean six sigma does not contain any explanatory account. Nor does it sufficiently prescribe a methodological approach to generate explanations.

Figure 11 The contribution of Chapter 3.
3.1 Introduction

In this chapter, we justify our decision to position the lean six sigma methodology as the research object of this work. We will examine lean six sigma through the lens of organisational diagnosis and explain why we think the lean six sigma methodology can benefit from new ways to demonstrate causality. To introduce the central problem and hence the urgency of improving the research object, we recall the situation of visiting a medical practitioner, presented in the introduction of Chapter 2. Now we consider the point at which the medical practitioner discusses treatment options with the patient to decide about a treatment. This is the moment when the diagnosis result shows its value for decision-making.

The traditional pattern of decision-making in medicine, in which doctors make decisions on behalf of their patients, is increasingly seen as outdated (Stevenson et al. 2000). A more modern pattern is the pattern of ‘informed decision-making.’ This pattern promotes the idea that a patient is actively involved in the decision-making process. Informed decision-making in medicine is highly comparable to the situation in organisational diagnosis (see the consultant dialogue, Alderfer 1980) and therefore offers relevant literature for this work. In consonance with the literature on informed decision-making, the process has four main characteristics (Murray et al. 2006). These are: (1) both the patient and the medical practitioner are involved, (2) both parties share information, (3) both parties take steps to build a consensus about the preferred treatment and (4) an agreement is reached on the treatment to be implemented (Stevenson et al. 2000; Murray et al. 2006).

Apart from the purely theoretical aspects, the contribution of lean six sigma to informed decision-making needs to be outlined. By doing so, we will reveal the arguments for our stance that it is time to change its methodology. Our elaboration (see Figure 11) begins with our reasons for selecting lean six sigma as a research object. We will learn about its importance for business and industry, its scientific grounding and its link to the discipline of organisational diagnosis. It is our strategy to break the lean six sigma methodology down into its main concepts so we can examine the observing, analysing and explaining capabilities of its methodology. This examination gives reason to doubt its explanatory capability. Since we are studying the lean six sigma methodology through the lens of organisational diagnosis, our next step is to survey the relevant literature on explaining, noting what has been said about explanatory accounts and how interaction models play an important role for causal inference. Such accounts and models – which lean six sigma lacks – are important to bridge the gap of explaining positioned between analysing a problem and solving it. We consider this lack as a problem that justifies research towards a remedy. That immediately gives rise to the question: what
explanatory account (and interaction model) is ideal for the lean six sigma approach, to establish it as a problem-solving methodology?

3.2 Motivation for selecting the domain of quality management

In this work, we choose to study organisational diagnosis in the field of quality management. There are three motivations for selecting this specific field. Firstly, quality management is a strategic subject for the management of organisations (Juran and Gryna 1988; Beecroft 1999; Hammer 2002; de Mast 2004; Brady and Allen 2006). Mainstream thinking in quality management is that manufacturing and delivery costs are reduced by increasing conformity with the requirements and needs of the customer, an aspect of the relationship between the environment and the supervising system in Figure 10 (Beecroft 1999). Although the thought of cost reduction through quality management still prevails in organisations, it is now subordinate to the notion that delivering quality is a means of ensuring an organisation's continuity. If an organisation cannot satisfy customer requirements, it is of strategic importance to start a diagnostic process to find out what causes this quality problem.

The second motivation is that quality management offers an exact meaning for organisational control, namely quality management. To control the quality of products – including services – an organisation usually selects particular product characteristics which are important to customers. These characteristics are denoted as quality variables and their values are measured regularly to monitor whether products satisfy the expectations of the customer. As noted above, if the value of a quality variable threatens to go outside limits that have been defined as acceptable, quality management can take corrective measures. Quality management matches the paradigm of control and therefore falls under the clarification of organisational diagnosis as already presented in Section 2.4. Within this quality management domain, we will apply the following concepts:

<table>
<thead>
<tr>
<th><strong>Quality problem</strong></th>
<th>A situation in which the value of one or more quality variables cannot be successfully controlled within the specified limits.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quality variable</strong></td>
<td>A measurable characteristic of a product that should satisfy a specification.</td>
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The third motivation is that the field of quality management offers a methodology for quality control, namely lean six sigma. Lean six sigma consists of
a stepwise approach ('Define,' ‘Measure,' ‘Analyse,' ‘Improve,' and ‘Control' (DMAIC)) that is consistent with the activities and scope of organisational analysis, organisational diagnosis and organisational control.

<table>
<thead>
<tr>
<th>DMA</th>
<th>Is lean six sigma's methodological approach for organisational analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMAI</td>
<td>Is lean six sigma's methodological approach for organisational diagnosis</td>
</tr>
<tr>
<td>DMAIC</td>
<td>Is lean six sigma's methodological approach for organisational control</td>
</tr>
</tbody>
</table>

This compliance to organisational diagnosis (see Chapter 2) makes lean six sigma for this research an ideal research object. Furthermore, the methodology is scientifically underpinned, see (de Koning 2007; Does et al. 2007; de Mast and Bisgaard 2007). Therefore, we do not need to put effort into tackling inconsistencies in its literature. Having justified our positioning of organisational diagnosis in the field of quality management, we will now discuss the methodological aspects of lean six sigma.

3.3 Lean six sigma's methodology and concepts

This section presents the research object of this study, based on its scientific grounding and applications in organisational diagnosis, as background to a critical review of its capability to explain. Our main source for methodology and concepts is the rational reconstruction of lean six sigma’s literature that was conducted at the Lean Six Sigma Institute of the University of Amsterdam (de Koning 2007; Does et al. 2007; de Mast and Bisgaard 2007). Normally lean six sigma is introduced and presented in terms of its stepwise DMAIC approach. But to ensure clear relationships to organisational diagnosis, which is action-oriented and oriented to decision-making, we will introduce lean six sigma in terms of the essential activities of observing, analysing and explaining presented in Chapter 2.

3.3.1 Observing

When the evolution of the quality management over the last 30 years is observed, the introduction and stability of the rationale on variation is most notable. Lean six sigma prescribes measurements of quality variables and the analysis of variations in their values within and across populations, to draw conclusions on the cause of quality problems. The premise that variation is a reliable business indicator for quality was presented in the 1980's by a Motorola engineer, Bill
Smith, in his theory of latent defect (Baum and Jitendra 1994; Dahlgaard and Dahlgaard 2002). This theory states that variation in manufacturing processes is the main culprit for defects, and eliminating variation will help eliminate defects, which in turn will eliminate the ‘wastes’ associated with defects, which saves money and increases customer satisfaction.

Smith developed his theory of latent defect after studying the correlation between a product’s field performance (customer satisfaction) and the variation and rework rate in manufacturing. Smith noticed that products produced in business processes that had a significant rework rate had higher field failure rates than those produced in processes that had low variation and minimal rework rates. Smith coined the term ‘Six Sigma’ as a target for defect-free product manufacturing. The term was derived from the idea that process capability can be described by deviations of the values of quality variables from their specification (e.g. the deviation of product weight that was specified at 50 kilogram).

**Correlation** indicates the degree to which two or more variables show a tendency to vary their values together.

The sigma value for standard deviation (σ) is a statistic that tells you how tightly all the values of a quality variable are clustered around the mean. Such values are collected when measuring the quality variables of each product during a time period or a specific volume of production. The number of products observed is called a population.

**Population** The number of products for which quality variables are measured.

When values are quite tightly bunched together (e.g. the products vary between 49.8 kilograms and 50.2 kilograms), the standard deviation is small. When the values of a quality variable are widely spread (e.g. the weight varies between 40.1 kilograms and 58.4 kilograms), one has a relatively large standard deviation. The higher the variation, in a key variable relevant to control, the less likely it is that the business process is under control.

A real lean six sigma case will illustrate how a business process is observed and how the sigma value may indicate a quality problem. This case was recorded at the Red Cross Hospital in the Netherlands by researchers from the University of Amsterdam (Bisgaard and Does 2008). This cases are included to demonstrate the
activities of observing, analysing and explaining in a lean six sigma project. Furthermore, it allows readers who are unfamiliar with lean six sigma to grasp the core ideas and concepts directly from praxis. The subject of observation within the Red Cross Hospital case was the quality variable ‘length of stay’ of patients with Chronic Obstructive Pulmonary Disease (COPD).

A population of 146 COPD patients were observed and each length of stay was recorded. If we look at a plot of these values (see Figure 12) we see that the values cluster around a central value (9.86 days, see Figure 12) with fewer observations further from this centre. This can be visualised with a histogram (see Figure 13). A histogram is a specialised type of bar chart. Individual data points are grouped together in classes, so that you can get an idea of how frequently data in each class occurs in the data set. High bars indicate more points in a class, and low bars indicate fewer points. In the histogram of the Red Cross Hospital we observe a frequency peak in the ‘six day stay’ class, where eighteen points represent a frequency of eighteen patients who had a stay of 6 days.

![Figure 12 Observations of 'length of stay' of COPD patients in the Red Cross Hospital.](image-url)
Now suppose, hypothetically, that management specified an upper level of 13 days and a lower limit of 7 days as a quality specification for the length of stay of COPD patients. We observe in the histogram many patients whose care did not fit in this 6-day window. In fact 45% of cases (66 patients) did not satisfy the hospital’s quality specification. In terms of lean six sigma the defect rate is 45%.

**Quality Specification**

The accepted range of a quality variable as defined by customers. A quality specification consists of a lower and upper limit.

**Defect**

A product for which the value of a quality variable falls outside the quality specification.

The philosophy of lean six sigma is to strive towards zero ‘defects’ since there are costs related to defects (costs of hospitalisation, repeating visits of patients, decrease in the hospital’s ranking). To express the actual situation and to compare it with the desired situation, a lean six sigma expert uses a so-called Six Sigma table that represents the sigma value based on the normal distribution in statistics, see Table 1.
Table 1 Six Sigma – DPMO table

To determine the actual sigma value, the following calculation can be made. The hospital can treat 55% (100% – 45% defects) of COPD patients within the specification. If this rate is recalculated in terms of defects per million opportunities, we see that the hospital operates below the 1 sigma level. If the Red Cross Hospital can change the processes in such a way that it operates on sigma level 2, it would only have 4.25% defects. When defect costs are included in this rationale, the hospital can significantly reduce its costs if it reduces variation in its operation.

Observing is not only about observing quality variables to explain a quality problem. Observing in lean six sigma is at the same time an activity in which one observes variables that are believed to represent changes in the business process in which products are made (e.g. changes in capacities of machines and labour). We define such variables as process variables.

| Process Variable | A variable hypothesised to correlate with a quality variable |

In the case of the Red Cross Hospital, there was a list of process variables generated that were suspected of influencing the length of stay of COPD patients. In lean six sigma each process variable is a hypothesis that, in the stepwise approach of lean six sigma, is subject to a confirmation/falsification process. Therefore, it is necessary to observe the process variables in the same population window in which the quality variables are observed. Table 2 presents the list of process variables in the Red Cross Hospital example. All recorded values of 146 COPD patients constitute the set of process and quality variables. This data is the object of analysis, which is discussed in the following section.
<table>
<thead>
<tr>
<th>Process Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient number</td>
<td>A number assigned to the patient at admission</td>
</tr>
<tr>
<td>Main diagnosis</td>
<td>Main diagnosis of patients made at admission to hospital</td>
</tr>
<tr>
<td>Length of stay (days)</td>
<td>Days for treatment or in-bed days</td>
</tr>
<tr>
<td>Pre-admission (days)</td>
<td>Number of days admitted for pre-operative research</td>
</tr>
<tr>
<td>Pre-operative research (min.)</td>
<td>Time for pre-operative research</td>
</tr>
<tr>
<td>Waiting time for tests (days)</td>
<td>Number of days a patient should wait for the results of the pre-operative tests</td>
</tr>
<tr>
<td>Research in OR (hours) Reconstruction 1 (days)</td>
<td>Research time in operating room (OR)</td>
</tr>
<tr>
<td>Doctor’s visit (minutes)</td>
<td>Number of days a patient recovers on the ward from the tests before the doctor visits the patient</td>
</tr>
<tr>
<td>Recovery 2 (days)</td>
<td>Amount of time the doctor exams the patient to see how the patient is doing</td>
</tr>
<tr>
<td>Time between discharge and departure (days)</td>
<td>Number of days a patient recovers on the ward after the visit of the doctor Number of days between the moment of discharge of the patient and the actual moment the patient leaves</td>
</tr>
<tr>
<td>Specialty</td>
<td>Specialty</td>
</tr>
<tr>
<td>Specs name</td>
<td>Name of the specialist</td>
</tr>
<tr>
<td>Department</td>
<td>Department in which the patient is being treated</td>
</tr>
<tr>
<td>Admission ward (Y/N)</td>
<td>Is the ward in which the patient is treated the same as where the patient was admitted</td>
</tr>
<tr>
<td>Discharge ward (Y/N)</td>
<td>Is the ward in which the patient is treated the same as where the patient will be discharged</td>
</tr>
<tr>
<td>Day of admission</td>
<td>Day of the week on which the patient was admitted</td>
</tr>
<tr>
<td>Hour of admission</td>
<td>Hour of the day on which the patient was admitted</td>
</tr>
<tr>
<td>Urgency</td>
<td>Whether a patient was admitted electively (planned) or urgently (urgent)</td>
</tr>
<tr>
<td>Age</td>
<td>Age of the patient</td>
</tr>
<tr>
<td>Gender</td>
<td>Gender of the patient</td>
</tr>
<tr>
<td>Day of discharge</td>
<td>Day of the week on which the patient was discharged</td>
</tr>
<tr>
<td>Year of registration</td>
<td>Year of admittance</td>
</tr>
<tr>
<td>Year &amp; day of week of discharge</td>
<td>Year of discharge and day of the week</td>
</tr>
<tr>
<td>Destination code</td>
<td>Code describing the destination to which the patient was discharged: 0 = own home; 1 = assisted living; 2 = other institution (other hospital, nursing home, etc.); 3 = deceased; 4 = left against advice</td>
</tr>
</tbody>
</table>

Table 2 List of process variables in the Red Cross Hospital.

### 3.3.2 Analysis
The observation of quality variables and process variables leads to a set of data that is measured simultaneously. This data is subject to statistical analysis to
identify statistical dependencies between variables (e.g. ‘length of stay’ and ‘day of admission’). In lean six sigma, *multivariate statistics* is a synonym for statistical analysis. Such an analysis goes further than ‘just’ detecting a statistical relationship between a quality variable and a process variable. Multivariate statistical analysis encompasses the simultaneous statistical analysis of multiple quality and process variables. The goal of multivariate statistics is to identify relevant relationships among multiple variables of a system and its environment at the same time.

Statistical analysis – based on multivariate statistics – offers a way to explore the operational behaviour of an enterprise system. Now, allow us to give meaning to *exploring* based on a publication from Rencher (2005):

> ‘We need to untangle the overlapping information provided by correlated variables and peer beneath the surface to see the underlying structure. Thus the goal of many multivariate approaches is simplification. We seek to express what is going on in terms of a reduced set of dimensions. Such multivariate techniques are exploratory; they essentially generate hypotheses rather than test them.’ (Rencher 2005).

We learn from Rencher that the application of multi-variance analysis can reduce the set of hypothesised process variables (see Table 2) to a ‘constellation’ of variables that are statistically dependent. Such *constellations* are in many cases represented by a graphical model that allows one to explore all the *associations* between the variables that play out in the observed system in the time it was observed. Analysing is an essential activity in organisational diagnosis that requires specification for:

<table>
<thead>
<tr>
<th><strong>Association</strong></th>
<th>The relationship between two variables, the values of which are statistically dependent.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Associational model</strong></td>
<td>A model that users have in mind about the associations among a set of variables.</td>
</tr>
</tbody>
</table>

To establish a relationship between practice and these concepts, we will take a closer look to the practice of statistical analysis. Lean six sigma prescribes many different analysis techniques in multivariate statistics (e.g. MANOVA[^3], CCA[^4], CVA[^5],

[^3]: MANOVA: Multivariate analysis is a statistical analysis approach to cover cases where there is more than one dependent variable to be analysed simultaneously.
or LDA\textsuperscript{6}) (de Koning and de Mast 2006). These techniques support the process of exploring an enterprise’s behaviour by allowing a diagnostician to reveal associations among variables. Since we will be confronted with these techniques in our case studies, it is worth mentioning that many of these statistical techniques are based on statistical algorithms which are automated in software tools (e.g. Minitab, Microsoft Excel). These software tools support a diagnostician in processing the observational data to multi-variance results and in applying visualisation techniques which support the diagnostician in his or her exploration.

For example, in the case description of the Red Cross Hospital (Bisgaard and Does 2008), we find several graphs that are based on multi-variance analysis. Each graph type offers a different perspective on the associations between the observed variables, see Figure 14.

\textsuperscript{4} CCA: Canonical correlation analysis or bivariate analysis is a statistical analysis approach to find linear relationships among two sets of variables.

\textsuperscript{5} CVA: Canonical variate analysis is a statistical analysis approach that aims to establish whether a set of variables can be used to distinguish between two or more groups of cases.

\textsuperscript{6} LDA: Linear discriminant analysis is a statistical analysis approach to compute a linear predictor from two sets of normally distributed data to allow for the classification of new observations.
A Pareto chart is for example a graph in which values of variables are plotted in decreasing order of relative frequency from left to right. In the Red Cross Hospital case, we see a Pareto chart (see upper part in Figure 14) that offers a cumulative perspective on the variable ‘hour of admission’ and classifies its values on the basis of its effect on the quality variable. In this case, we see that the greatest cumulative effect in the planned admissions comes mainly from those that occur at 10:00 and 14:00, whereas urgent admissions do not have any cumulative effect. Although the Pareto chart may not have a direct bearing on the issue of length of stay (the quality variable), this is useful to understand the behaviour of the process variable in the observed system.
The lower part in Figure 14 from the Red Cross Hospital case offers another perspective. This figure shows a scatter plot diagram. A scatter plot diagram is a graph constructed to study the association between two variables. The scatter plot diagram graphs pairs of numerical data, with one variable on each axis. If the variables are correlated, the points will fall along a line or curve. The better the correlation, the tighter the points will hug the line. In the scatter plot presented in the lower part of Figure 14 we see on one axis the values for the ‘length of stay’ and on the other the value for a ‘patient’s age.’ Furthermore, the pairs (‘patient’s age,’ ‘length of stay’) are plotted by different symbols. Three symbols are used: code 0 indicates that the patient was discharged to his or her own home; code 1 that the patient was discharged to an assisted-living facility; and code 2 to another institution, including nursing homes. The scatter plot diagram in Figure 14b shows that younger patients tend to be discharged earlier and go back to their own homes. Older patients generally stay longer in hospital and are more frequently discharged to assisted living, a nursing home, or another institution.

The paragraphs above discussed the role of multi-variance analysis in organisational diagnosis and the concepts of associations and the associational model. Statistical analysis serves to reduce the large volume of observational data into an associational model. Simplification can be achieved by using graphical models to organise statistical dependencies, by drawing variables as nodes and arrows between them to represent the detected associations. Path diagrams and directed acyclic graphs are model types that are applied for this purpose, see for example Figure 15.

![Figure 15 Illustration of an associational model.](image)

We understand in this thesis that this artefact is the product of the analysing activity in organisational diagnosis. This artefact is the input for the explanation activity which is described in the following section.
3.3.3 Explaining
An associational model is a general model that represents the statistical dependencies (associations) between variables at the time the organisation was observed. An associational model is useful for exploring associations to learn how a system and its environment behaved (see Figure 15). In other words, it helps explore behaviour. However, an associational model is not by itself a sufficient explanation for a quality problem. This insufficiency appears when we ask ‘how’ and ‘why’ the associational model holds in the way that it does.

The lack of an explanation is not always a problem. For example, the causes of diabetes have not been understood until recently, but the effectiveness of insulin as a treatment had been established powerfully. The way of working in the current praxis of lean six sigma is similarly pragmatic. For example, problems with variability in chemical and food processes are solved by feedback controllers; this remedy does not require a full explanation of the causes of variability. One of the reasons for this pragmatism is the focus of lean six sigma on problem solving (De Mast and Lokkerbol, 2012).

In this study, we position pragmatism as the quality level at which the lean six sigma methodology currently operates. We aim to raise this quality level by introducing methodological support for establishing explanations for quality problems. So, we question ‘explaining’ in this section and apply the following definition: explanation is a hypothesis as to why one event is the result of another event.

<table>
<thead>
<tr>
<th>Causality</th>
<th>Causation</th>
</tr>
</thead>
<tbody>
<tr>
<td>indicates that one event is the result of the occurrence of another event</td>
<td></td>
</tr>
</tbody>
</table>

If analysis results in lean six sigma do not generate explanations, what does? To answer this question, we zoom into the ‘Improve step’ of lean six sigma’s cookbook. This is the step where analysis results are available and the lean six sigma expert generates a causal meaning for them. The cookbook (read Page 782-783, de Koning and de Mast 2006) presents all the tools and techniques that can be applied in this step. Based on their characteristics, we make a distinction between tools for experimentation and brainstorming (Mulder et al. 2005; Snel et al. 2011).

Experimentation and how its results are read is a topic for the following chapter. However, in advance of that discussion, we would like to explain its purpose. Through experimentation, a diagnostician applies a statistical framework to reduce the number of relevant process variables by comparing analysis results from multiple populations. Independently of the intention to solve quality
problems in lean six sigma, in experimentation a statistician aims to formalise – by applying a statistical framework – intuitions about cause and effects. This is done to make assumptions and predictions about future effects clear and explicit. So, after experimentation, we get closer to a model for making predictions about the organisation under investigation. However, this (statistical) model does not explain how the quality problem is produced.

In addition to experimentation, we find tools and techniques for brainstorming. Do brainstorming techniques such as ‘robust design’ or ‘affinity diagramming’ provide explanations? And, are they capable to provide the answer to the how-question? If we examine both tools, we find that they do not. For example, if we critically compare an ‘affinity diagram’ with an associational model we conclude that an ‘affinity diagram’ is a representation of an associational model. We have already concluded in Section 2.5.2 that such models do not explain, they are only able to represent a system’s behaviour during the time it was observed. The prescribed ‘robust design’ approach, in the cookbook Improve phase, represents a system’s structure in its desired state as a solution for the quality problem. A ‘robust design’ represents in fact the intervention (see the paradigm of control in Figure 8) which also is not an explanation for why the associational model holds true, in the way it does.

Based on our observations of the lean six sigma cookbook – which covered the analysis of the complete DMAIC sequence - we conclude that lean six sigma does not methodologically support the generation of an explanation. Lean six sigma experts can point to the daily practice of lean six sigma by stating that workers, domain experts or managers can formulate an explanation when brainstorming as described in the lean six sigma methodology (de Koning and de Mast 2006). This is true, but the outcome is chancy and the logic that generates it is in many cases based on tacit knowledge.

The following section explores the ‘logic’ or ‘methodological support’ for explaining in the discipline of organisational diagnosis. We hope to find answers and knowledge that can be beneficial for lean six sigma.

3.4 Explaining in organisational diagnosis

In this section – in contrast to explaining in lean six sigma (read section 3.3.3) – we provide the praxis and theory of explaining in organisational diagnosis. The science behind organisational diagnosis is to explain organisational behaviour regarding causality in the networks of human actors, whereas the traditional praxis of lean six sigma is analytics oriented and pragmatic in problem solving (De Mast and Lokkerbol 2012). We also demonstrate that explaining (in organisational diagnosis) offers a valuable but as yet unimplemented interpretation of lean six sigma.
Several authors have tried to describe what causality in organisational diagnosis is about. In the book *The practice of Organisational Diagnosis: Theory and Praxis* (Alderfer 2014), the author presents several ‘explanatory accounts’ such as those of Levinsson, Argyris and Schein. These accounts are explanatory as they provide a rationale that can be applied to show how and why an organisational problem can exist and maintains itself in the operations of an enterprise system. What these explanatory accounts have in common is the idea that social individuals – or workers – are responsible for managing unwanted changes in the enterprise system by conducting actions and interactions to influence their values. In the following subsection, we introduce the concepts of an explanation which are compatible with explanatory accounts in organisational diagnosis. The first step is to take notice of these explanatory accounts.

The first explanatory account that we discuss is that of Harry Levinsson (Levinson et al. 1972). Levinsson tells us to focus on ‘the ego ideal of the worker,’ meaning the extent to which workers view themselves as living up to their ideal. The main argument for non-effective interactions in this account is that misalignments between ideals lead to misunderstandings between individuals about what needs to be achieved (e.g. a manager that aims for maximal business result or a manager that through employee satisfaction aims for maximal business result). In the account of Chris Argyris – the second account - we find a rationale of how individuals respond and adapt to ‘formal organisational structures’ (Argyris and Schon 1989). Control systems and management structures, in particular, may affect social behaviour by changing the motivations of each individual. Non-effective interactions arise when an individual is confronted with problematic situations (e.g. a quality problem) and motivation is affected due to ineffective relationships that are defined in the formal organisational structures. In the third and last account, Edgar Schein identifies ‘subjective truths’ of humans as a root cause for problematic actions (Schein 2006). Schein tells us that individuals are not identical and thus they perceive, understand and behave differently. In the eyes of Schein, problematic situations may arise when the beliefs of workers become incompatible with the culture of the organisation.

From these explanatory accounts, we conceptualise the explanatory aspect by noting that individuals (as employees) in an organisation are responsible for keeping certain variables within specification. For example, a stock manager is responsible for the number of products in stock. In business operations, products are ordered and the stock decreases. The stock manager interacts with the supplier to restore stock levels. What we learn here is that the associations – detected in the analysis activity (left side of Figure 16) – may remain intact due the actions of individuals and interactions between them (right side of Figure 16). This is the basis for all three explanatory accounts. What differentiates them are
the authors’ views on why social individuals behave the way they do. Or, negatively expressed, why do individuals perform ineffective actions or interactions to keep a variable within its specification?

<table>
<thead>
<tr>
<th><strong>Interaction</strong></th>
<th>The causal relationship between two individuals in an enterprise system.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interaction model</strong></td>
<td>A model that users have in mind about the interactions between individuals in an enterprise system.</td>
</tr>
</tbody>
</table>

Now, based on the notions of interaction and an interaction model, we can take notice of the operational structure of the enterprise system. The operational structure embodies a causal assumption on how the social system functions, but not on why social individuals act or interact in this way. Why should a worker obey a manager? What guarantees the maintenance of interactions? Each account (i.e. Levinsson, Argyris or Schein) has a different rationale to answer these questions. They are helpful, but we may ask whether the answers to the why question depend on the account that is applied, and what makes one answer derived from explanatory account A better than through explanatory account B?

### 3.5 Conclusion and contribution

Compared to organisational diagnosis lean six sigma is a technical discipline, based on simple linear causal models, and its purpose is to improve products and business processes. Organizational diagnosis and improvement are much more complex. Organisations, which are networks of human actors, have a much more complex causal structure (system dynamics), and in addition, they are driven by subjectivity (humans have perceptions, interpretations, agendas and values). In the previous chapter we show that interactions maintain associations, and how
information about these associations influences human actors in their interactions. Interactions and associations are two sides on the same coin when examining a quality problem. In business schools, this is the distinction between operations management (the field of lean six sigma), which is about processes and structures, and organizational behaviour, which is about complex systems of human actors.

We have shown that association models and interaction models are two different kinds of results. Association models are useful for understanding the problematic behaviour of an enterprise system. We can draw graphical representations of statistical dependencies which increase our knowledge about the behaviour of the variables. Furthermore, when associational models are statistically underpinned and the statistical models behind them are validated, such models can be used for prediction. Interaction models created on the basis of explanatory accounts in organisational diagnosis can increase our knowledge about the social interactions in an enterprise system. They can shed new light on what causes an associational model to remain the way it is.

Where does this leave us? We aim for methodological support for explaining (read section 1.4). Can we indeed increase the explanatory capability of lean six sigma by simply adding the explanatory accounts as known in organisational diagnosis? The contribution of this chapter is that we need to respect the analysing capability of lean six sigma. We are convinced it provides strong methodological support to establish an associational model for a quality problem. However, it seriously lacks methodological support for explaining. The conceptualisation of an explanation, which is an interaction model that explains the associational model, allows us to discuss concrete artefacts that should be generated in lean six sigma to increase its support for decision-making.

The concept of interactions will be followed up further, since on the one hand interactions explain associations, and on the other hand, interactions are the right concepts for decision makers that refer to the points in the organisation on which they can intervene. The management of an enterprise system regulates interactions by making organisational decisions. An associational model, which, for example, represents a quality problem, is the result of regulation and management decisions. We learned that interaction models explain how an associational model remains intact. However, the why question (why individuals behave as they do?) depends on which explanatory account (e.g. Schein, Levinsson or Argyris) is applied.

We think that if we position the interaction model as the explanation result, we are one step closer to methodological support for explaining in lean six sigma. In
our eyes this direction answers the how question in an explanation. Further we think that methodological support for explaining in lean six sigma should be objective, and independent of the explanatory account that is applied. The explanatory accounts used in organisational diagnosis (i.e. Levinsson, Argyris or Schein) come with a high risk of tunnel vision when we address the why question in explaining, as each consists of prior assumptions (see Section 3.4).

From organisational diagnosis we discovered an artefact (the interaction model) that can be taken as a point of departure for a methodological redesign of lean six sigma in the direction of methodological support for explaining (see the arrow in Figure 3 in section 1.4). Unfortunately, the explanatory accounts available in organisational diagnosis show us that if we succeed in developing methodological support for the creation of an interaction model, this artefact can be interpreted in multiple ways. Imagine a situation in which the diagnostician is a `Levinsson believer' and the process owner an `Argyris believer,' and they need to establish a consensus about an intervention. Both can read an interaction model, but each is likely to reach different conclusions. We have made a significant step, but we do not think we have yet established a firm basis for causality on which to base a redesign of the lean six sigma methodology. We think we need to consult the literature on the philosophy on causality, which offers knowledge that has been applied in areas in which similar situations arise.
Chapter 4

Why lean six sigma can benefit from triangulation
Abstract Now that the definition of the research object is complete and the objective, to develop methodological support for explaining in lean six sigma, has been determined, we turn to the relevant philosophical environment to generate new ideas on this research subject. This chapter will focus on causal assessment, driven by the question: How can one read causality from multiple sources of evidence and achieve the identification of the interactions in the organisation that maintain the quality problem to exist? We will consult the philosophy of causality literature in relation to evidence. In addition, we will examine strategies for causal assessment and focus on the aspect of reading causality from multiple sources of evidence. The result of this literature study is the identification of a triangulation process that integrates evidence, as an approach to causal assessment. This strategy offers a promising hypothesis on methodological support for explaining in lean six sigma.
4.1 Introduction

The point of departure for this chapter (see Figure 11) is the question as to how we can think about observational data, and how it relates to knowledge, theories and hypotheses on causality. Is ‘data’ the answer to all the questions we have for an unexplained phenomenon? Does the hypothesis for explaining a problematic situation imply more than just a question that requires data? In addition, if we collect the data, do we generate an explanation and in this way support adequate decision-making?

Unfortunately, the literature on causality is vast and complex. To find answers to these questions, Section 4.2 (see Figure 11) looks at the Illari-Russo classification scheme to study those philosophies that tell us more about reading causality from observational data (Illari and Russo 2014). There are multiple reasons for selecting this literature on causality. Firstly, the work of Illari and Russo presents the topic of causality from an ‘evidence-centric’ perspective. Secondly, it offers a classification scheme for kinds of evidence. Thirdly, the work has been noticed, since many philosophers and scientists refer to it. The Illari-Russo classification scheme enables us to examine the shortcomings of the philosophies that are inherently connected to the observational approach of lean six sigma.

Working with observational data is common in many scientific fields (e.g. the social and natural sciences). They all face the dilemma that it is very difficult to deduce causality from observational data. Some authors even show how this is impossible (see e.g. Simpson’s paradox (Pearl 2013), and Smoking: The Lung Cancer controversy (Fisher 1958)).

In Section 4.3 (see Figure 11), we introduce the subject of research strategies and explain that this knowledge is of value to lean six sigma. Because working with observational data is only one way of obtaining knowledge, we also describe several other ways and compare their strengths and weaknesses. We give a brief overview of triangulation (a research strategy) to set the stage for a more extensive discussion of evidence that gives meaning to observational data.

Evidence that gives meaning to observational data is – in consonance with the Illari-Russo classification scheme – denoted as ‘evidence of production.’ Evidence in this category is important in science as it supplies the how and why meanings for observations and measurements. Section 4.4 (see Figure 11) will show that evidence in this category can be read in three ways: as a causal process; as a causal mechanism or as an exchange of information. For this research, these possible readings are relevant since the interaction model – positioned as an explanation for a quality problem in Section 3.4 – has not yet been connected to a
causal reading. The literature on organisational diagnosis does not tell us how such models should be interpreted causally.

The conclusion and contribution of this literature study (Section 4.5, see Figure 11) consist of the message that triangulation offers a promising hypothesis for explaining in lean six sigma. The Illari-Russo classification scheme provides the primary kinds of evidence (evidence of difference-making; evidence of production) for triangulation, and triangulation seems an appropriate causal assessment approach where there are doubts about the credibility of diagnosis results.

4.2 Evidence of difference-making

The conflation of causality and correlation is one of the most common logical errors in science (Card 1998; Card 2006). Even seasoned researchers can fall into this trap. (See, the Hawthorn effect, Figure 2). Causal assessment, i.e. proving that one phenomenon is the result of another, is a nebulous field. We can readily understand that measurements and statistical analyses can demonstrate that variables alter in concert, yet the existence of a causal relationship between the phenomena is merely a hypothesis about reality.

As already discussed (see Section 2.5.2), results from lean six sigma show which variables alter in concert. These statistical results are expressed in what scientists call the ‘reduced form.’ It is ‘reduced’ because based on statistics one can condense a whole complicated associational model into a (seemingly) simple formula: $Y = \beta(X) + \varepsilon$. This formula says that the effect $Y$ is a function $\beta$ of the cause $X$ plus some errors $\varepsilon$ due to imperfect measurement or to other chancy elements in the observed system. However, the reduced form hides the complicated subject of giving meaning to observational data. These complications manifest when examining the way statistical correlations can be read.

In this section, we study the possible causal readings from observational data. The reason for this study is to identify the general shortcomings related to these readings, since the lean six sigma prescribes such readings. According to the Illari-Russo classification scheme (Illari and Russo 2014), statistical results fall into the category of ‘evidence of difference-making,’ see Figure 18. The name evidence of difference-making emphasises the aspect of seeking differences in observational data (in one or more populations) that hint at the causes for a phenomenon.
Before we present, the subcategories of evidence of difference-making, the reader should keep in mind that all readings are related to lean six sigma. For example, the subcategory ‘variation in a population’ (see Figure 18) prevails as causal reading in the analysis phase of lean six sigma. The subcategory of ‘variations across populations’ (see Figure 18) prevails in the improve phase of lean six sigma. The improve phase prescribes experimentation that establishes more than one populations from which conclusions are drawn (see the lean six sigma cookbook on pages 782, 783 in de Koning and de Mast 2006). We present both subcategories in Section 4.2.1 and Section 4.2.2. In Section 4.2.3 we elaborate on the pitfalls and shortcomings of causal assessment based on observational data.

4.2.1 Reading variation in a population
To understand variation in observational data – a motivation that drives the diagnostician in the ‘Analysis phase’ to find answers - we begin with Illari and Russo’s observation (Illari and Russo 2014) that data can have three possible readings: (a) a variational reading, (b) a manipulationist reading, and (c) a counterfactual reading. All three readings can give meaning to causality. Illustrated by the reduced form: \( Y = \beta(X) + \epsilon \) and referring to the hospital case (see Chapter 3) these three different readings are:

a) The variational reading of observational data. Variations in the putative cause X are accompanied by variations in the putative effect Y. How much Y (the values of the quality variable) varies in response to the variation in X is
quantified by the parameter $\beta$. Usual tests (goodness of fit, exogeneity, invariance, etc.) will help decide whether and to what extent these joint variations are by chance ($\epsilon$) or are ‘causal’ ($\beta$).

b) **The manipulationist reading of observational data.** From the variational reading, we can derive a manipulationist reading. In experimental contexts, manipulations of $X$ make $Y$ vary. Thus, in a controlled experiment, joint variations in $X$ and $Y$ are shown to be due to manipulations on the putative cause-variable $X$.

c) **The counterfactual reading of observational data.** The counterfactual reading is also derived from the variational reading. Here, the equation says that were we to change $X$; $Y$ would accordingly change. Thus, joint variations between $X$ and $Y$ are not merely observed in the data set (non-experimental contexts), nor are they observed in response to performed manipulations (experimental settings). They are instead hypothesised, if the equation faithfully represents the causal relation between $X$ and $Y$.

The above reading types that a diagnostician can apply when interpreting observational data can be extended to those kinds of reading that span multiple data sets that represent multiple observed populations. For example, suppose the Red Cross Hospital (see Section 3.3) observes the length of stays of patients in the first quarter of a year and then in the third quarter. Observing the differences between populations may also contribute to causal assessment, this is the subject of reading variations across populations that will be discussed in the following subsection.

### 4.2.2 Reading variation across populations

The topic of ‘reading variation across populations’ is in many circumstances connected to experimenting. Experimenting plays a significant role in the ‘improve phase’ of lean six sigma (see the design of the experiment in the Lean Six Sigma cookbook on P. 782, 783 in de Koning and de Mast 2006). Experimenting in lean six sigma is an instrument which the diagnostician can use to determine the significance of some process variables for the quality variable. Multiple populations are involved in isolating such process variables. According to the Illari-Russo classification (Illari and Russo 2014) we need to take notice of four different kind of causal assessment (methods) that John Stuart Mill (1806–1873) presents in ‘A System of Logic’ (Mill 1846; Holland 1986):

a) **Method of Agreement:** In the method of agreement, one compares different instances in which the phenomenon occurs. In this approach, the diagnostician searches for the common factors of the phenomena between populations (e.g. the same month; the same department; the same age).
b) **Method of Difference:** In method of difference, one compares instances in which the phenomenon does occur with similar instances in which it does not. In this approach, the diagnostician searches for differences between populations in which the phenomena occur (e.g. different season; different department; differences in ages).

c) **Method of Residues:** In the method of residues, one subtracts from any given phenomenon all the portions which can be assigned to known causes (e.g. from scientific papers). The remainder will be the effect of the antecedents that had been overlooked or the effect of which was unknown. Based on experimenting, one may confirm this cause for this case.

d) **Method of Concomitant Variation:** this method is particularly useful when none of the previous methods (Agreement, Difference, Residues) can detect a variation of circumstances. For instance, in the presence of permanent causes or indestructible natural agents that are impossible either to exclude or to isolate, we can neither hinder them from being present nor contrive that they shall be present alone. However, in such a case, a comparison between concomitant variations will enable us to detect the causes.

These four essential approaches to analysing differences between populations contribute to reducing the number of relevant process variables based on difference-making. This is what Holland calls associational inference (Holland 1986). It is therefore not a surprise to find experimenting in lean six sigma's cookbook (de Koning and de Mast 2006). Although we are not interested in the role of evidence of difference-making for analysis and associational inference, we need to notice these methodologies as they can make contributions to causal assessment. The relevant question that is left open here is: Can we read causality from evidence of difference-making? Or, in other words: Can we read causality from observational data?

### 4.2.3 Can we read causality from observational data?

In lean six sigma, statistics is a strategy to reduce - on the basis of their importance for the variation in the quality variable - the number of suspected process variables that threaten the quality variable(s). Now suppose this process leads to a few vital variables: we still need to read causality from them. At this point, it is interesting (in contrast to our literature study in the previous two subsections) to present lean six sigma's way of reading observational data and drawing conclusions.

Explaining a quality problem and the topic of reading observational data is most logically positioned in the 'Improve' phase of the DMAIC sequence. The lean six sigma cookbook (see P. 782, 783 in de Koning and de Mast 2006), contains tools and techniques for experimentation. Experimentation in lean six sigma has many
commonalities with readings from variations across populations. However, capability analysis and the design of experiments and statistical significance tests (see p. 785 of the lean six sigma cookbook in de Koning and de Mast 2006) is not the same as explaining. In terms of the distinction between organisational analysis and organisational diagnosis (see section 2.4) we position these lean six sigma methodological elements as data exploration and validation techniques for organisational analysis. Lean six sigma’s cookbook also positions prescriptions for brainstorming in the Improve step. Apparently brainstorming is positioned as a technique for identifying an explanation. So, theoretically, brainstorming would be the lean six sigma technique that would offer the best method to fit into the explaining activity of organisational diagnosis. However, one must ask how the brainstorming techniques of ‘affinity diagram’ and ‘robust design’ provide explanations.

If we critically compare an ‘affinity diagram’ with an associational model (Section 3.3) or interaction model (Section 3.4), the ‘affinity diagram’ has the most in common with the associational model. We already concluded in Section 2.5.2 that associational models do not explain, they are only capable of representing a system’s behaviour when it was observed. The prescribed ‘robust design’ technique in the Improve phase of lean six sigma is capable of representing a system’s construction in its to-be state. In the context of organisational control (Figure 10), the ‘robust design’ is the representation of the intervention, it is not an explanation. Although both brainstorming techniques give meaning to observational data, they do not incorporate readings for variation in or across populations.

Although we can identify approaches of reading observational data in the literature related to causality, we cannot find instructions on how to read observational data in lean six sigma’s cookbook (see the lean six sigma cookbook on P. 782, 783 in de Koning and de Mast 2006). The reading instructions in the improve phase are brainstorming techniques. From this thesis perspective – applying a clear distinction between organisational analysis and organisation diagnosis (see section 2.4) – based on our elaboration we think the improve phase in lean six sigma offers several methodological techniques that belong to different disciplines. The lean six sigma techniques capability analysis, design of experiments, and statistical significance tests clearly contribute to the objective of organisational analysis. The objective of brainstorming is clearly aligned to the objective of explaining in organisational diagnosis. Although brainstorming (i.e. affinity diagramming, robust design) could help to summarise or visualise associations and could offer a basis for speculating about causal relationships, we do not recognise in the prescribed brainstorming techniques of the lean six sigma cookbook methods for causal inference where the results of organisational
analysis are included as the point of departure. We think this weak support for explaining may facilitate rash leaps – from organisational analysis results – to formulating interventions in organisational control.

4.3 The need to apply triangulation

When explaining is at stake, and researchers find that statistical data alone does not help, they are increasingly combining qualitative and quantitative methods to explain a phenomenon (Campbell and Fiske 1959; Johnson and Onwuegbuzie 2004; Holzhauser 2008; Cresswell and Clark 2010). A ‘combinatorial’ research approach has proven highly efficient and adequate, and is mentioned - in addition to qualitative and quantitative research - as the third important research strategy in science. Before we explain what this combinatorial approach is, and how a combinatorial approach may help in causal assessment and demonstrating causality, we first need to agree on a name for this strategy. It appears in the literature on research strategies under many names. Bryman for example, calls the combinatorial research approach a ‘multi-strategy approach’ (Lewis-Beck et al. 2004). The names ‘mixed methodology’ or ‘mixed methods’ can also be found (Tashakkori and Teddlie 2003; Holzhauser 2008; Cresswell and Clark 2010). In this work, we use ‘triangulation’ – a term originally introduced in Campbell’s paper (Campbell and Fiske 1959) to refer to the effect of ‘convergent validation’ (Smith 1975; Denzin 1978; Webb and Weick 1979; Jick 1979)

Triangulation is used as a metaphor from navigation (Smith 1975). In navigation, a position of a location is determined by using multiple reference points. Smith uses this metaphor to introduce the idea that multiple viewpoints allow greater accuracy. Similarly, conforming to Smith, researchers can improve the accuracy of their judgements by collecting different kinds of data related to the same phenomenon (Jick 1979).

Triangulation has much in common with the idea in mixed method research approaches of asking two independent researchers to explain the same phenomenon (Mertens and Hesse-Biber 2012). In the following paragraphs, we take a closer look at what the evolution of mixed method research strategy tells us and what research strategies can be applied to achieve triangulation when causal assessments based only on reading observational data prove to be fruitless.

Triangulation in scientific research can be traced back to 1959 under the heading ‘multiple operations’ (Campbell and Fiske 1959). Campbell states in this work: “…the convergence of findings stemming from two or more methods enhances our
beliefs that the results are valid.” Not surprisingly, many scientists apply triangulation in their research, and have supported it with arguments such as:

- The belief that combining kinds of evidence leads to greater validity.
- The notion that multiple kinds of evidence answer the research question from several perspectives.
- Various kinds of evidence can fill ‘gaps’ in the information/data that is collected.
- A triangular approach ensures that the results are less likely to be shaped by the researcher’s prior assumptions.
- Triangulation is practical when one methodology does not provide all the information required.

These arguments suggest we are heading in this research into the right direction; triangulation has the potential to increase lean six sigma’s credibility. However, we have not yet found in literature what logic in triangulation makes results more credible. To find answers to this question, we examined ‘triangulation’ more precisely, in the literature of triangulation research (Lewis-Beck et al. 2004; Teddlie and Tashakkori 2008; Holzhauser 2008; Cresswell and Clark 2010; Mertens and Hesse-Biber 2012; Jick 1979).

The logic of triangulation is in the broadest sense the logic of achieving consistency between types of evidence to explain the studied phenomena. Denzin (1978) categorises types of triangulation:

- **data triangulation**, the combination of different data types;
- **investigator triangulation**, the combination of insights from different researchers;
- **theoretical triangulation** – the combination of different theoretical perspectives;
- **methodological triangulation** – the combination of different methods.

In addition, Denzin distinguishes ‘within-method triangulation,’ i.e. combining different cases of the same method and ‘between-method triangulation,’ i.e. combining studies of various methodologies. Clearly, in relation to demonstrating causality, between-method triangulation offers a more radical confrontation between kinds of evidence than ‘within-method triangulation.’ The more radical confrontation increases the credibility of causal assessment as one kind of evidence may confirm or contradict the other. There is an analogy in medical examinations: when a physician is unsure in identifying a causal process
underlying symptoms, he or she is likely to combine physical and biomedical examinations. The data from a physical examination are compared and converge with – or diverge from – the data from the biomedical tests. The physician can confirm the suspected causal process based on the congruence and consistency between types of evidence.

Now imagine a situation in which a business manager faces a serious quality problem, while the proposed intervention will have a major impact on the organisation. In this situation, the manager would probably ask the diagnostician for more justification than simply evidence of difference-making. The manager is likely to ask for an *explanation* that demonstrates the causality in the language in which the intervention is formulated (e.g. see Section 3.1 on the patient-doctor dialogue). The diagnostician needs to show the cause of a quality problem in terms of the interactions and structure of the enterprise. In addition, for the sake of credibility, the diagnostician needs to demonstrate the consistency of difference-making. If we project this case onto the methodology of lean six sigma, this would require methodological support in which congruence and consistency between evidence of difference-making and the interaction model is a formulated strategy. This parallel between triangulation and lean six sigma is leading us towards a promising hypothesis for methodological support for explaining quality problems in lean six sigma.

The interaction model (see Figure 16 in section 3.3.3), which we suggest should be central to causal explanation in lean six sigma, has been fairly explicitly presented above under the heading of ‘evidence of production.’ Evidence of production is the second kind of evidence in the Illari-Russo classification scheme. A further study of evidence of production should give us a more precise definition of the nature of interaction models. The literature of organisational diagnosis tells us little or nothing about the philosophical underpinnings of interaction models, suggested methodologies, and actual research using this approach (see Section 3.4). So, if we wish to understand better how things work, there is an urgent need to take careful notice of ‘evidence of production.’ It may lead to new knowledge whereby triangulation can be used as a viable, practical diagnosis strategy to explaining quality problems in lean six sigma.
Chapter 4

4.4 Evidence of production

The basis of the logic of causal assessment using triangulation is the integration of available types of evidence. If we return to the evidence classification scheme of Russo we find – in addition to evidence of difference-making – a second category that is denoted as ‘evidence of production’ (see Figure 19). This type of evidence has much in common with interaction models as it provides a decomposition and regular behaviour of the elements of the system under observation. This evidence provides answers to how and why questions when interpreting measurements. Evidence of production is not an assessment of what is known about a system’s ontology or metaphysics. Evidence of production is about causal pathways that answer questions such as ‘why’ and ‘how’ associations between variables exist. It is difficult to identify evidence of production, as it is parallel to the complexity of understanding a system. Russo identified three main accounts – in the literature on causality – for evidence of production that researchers and scientists can take as points of departure for their causal inference: processes, mechanisms and information (see Figure 19). The three kinds of evidence provide substantially different ways of thinking about causal explanations, each with its own philosophy on ‘how and why’ cause and effect are connected. In the following paragraphs, we present these three kinds of evidence and discuss their characteristics for causal assessment.

![Evidence of production diagram]

Figure 19 Evidence of production.

4.4.1 Processes

The idea that causal pathways in a system constitute a ‘process’ can be traced back to several ideas about causal assessment: causal lines, the mark method, transference and conserved quantities. Causal lines (Russell 1948) are space-time trajectories that persist in isolation from other things. In agreement with this way
of thinking, when a billiard ball in a billiard system hits another ball and its direction changes, a new causal line should be introduced to identify the causal paths. The ‘mark method’ of Hans Reichenbach (1956; 1958) offers a way to improve the identification of causal lines. The main idea behind this approach is that a causal pathway that is marked in the beginning will transmit or carry this mark until its end, as it is manifested at all stages in between. For example, if we mark a billiard ball every time it moves in one direction, we will find the marks on the billiard ball when it stops.

In transference, introduced by Aronson (1996) and further developed by Fair (1979), the focus is on physical relationships that indicate the direction of causal processes. Transference is only concerned with changes that are the result of two interacting objects (e.g. two billiard balls that hit each other), not with internal changes in the objects. The core idea introduced by Aronson is that if C causes E, then before E occurs, the two bodies are in contact, and the cause object transfers a quantity such as momentum, energy, force, and such like, to the effect object during the contact. The direction of transference is the direction of the causal process. For example, in the billiard system, when a white billiard ball hits three red balls, the white ball transfers energy to the red balls. The direction of energy transfer is what ensures that the white ball moves the red balls, and not that the red balls cause something to occur in the white ball.

Close to the idea of transference is the idea of conserved quantities. This idea was introduced by Salmon (1984) and later modified by criticisms made by Dowe (1995) and Anscombe (1992). Both conceive ‘causal processes’ as world lines7 of objects possessing conserved quantities that can be transmitted to them. Conserved quantities are any quantities that are universally conserved (e.g. mass-energy, linear momentum, or charge), as described by the theory of physics. When a causal pathway intersects, objects exchange conserved quantities and change each other’s state, which in this account is called a causal interaction.

The main contribution of the idea of conserved quantities is that it distinguishes causal processes from pseudo-processes. This is an advantage where phenomena are multi-interpretable, such as the intersecting vapour trails of airplanes. A collision between airplanes would result in a change of direction (and a crash). Planes moving are real causal processes. However, when the shadows created by these airplanes on the ground cross, nothing happens. They move on undisturbed. The shadows and their movements are also physical processes, and

7 In physics, the world line of an object is the path of that object in 4-dimensional space-time, tracing the history of its location in space at each instant in time.
we can see and track the shadows as easily as we see and follow the planes. We can distinguish pseudo-processes from causal processes if we consider the transmission of quantities. In the case of shadows crossing, nothing changes due to these apparent ‘interactions.’

The theories on process tracing to detect causal pathways are attempts to say what causation in the world is, independently of how we perceive it. In different ways, they all draw on physical theory in their accounts of causation, and clearly some think that looking at physics is the way to tell what causality is. There is certainly something to this idea of causal explanations, but it not easy to apply it to organisational diagnosis in enterprise systems.

The contribution of ‘causal processes’ to identify causal pathways in a system should be considered. An essential argument (in the words of Salmon) is that the idea of ‘causal’ process puts ‘cause’ back into ‘because.’ That is, the physical process leading up to an effect explains the effect, which is what Salmon calls an ‘ontic’ explanation, rather than some description of the process explaining the effect. Another perspective on accounts of causal processes is that they attempt to describe what ‘causality’ is – independent of people’s interpretation – by turning to physical theories to find answers. It is, in a way, an objective approach, free from interpretations. However, we also need to notice the criticisms and serious problems related to such a way of thinking. For example, the problem of absence. If something is absent, the absence may create a cause, or establish a circumstance that is sufficient for a cause. Causal lines cannot be connected to something that does not exist. Another point to note is the relationship between objects and their relevant properties. We need more fine-grained information than simply knowing which object has an effect on which object. For example, in the billiard system, it is pertinent to know the density of the balls to design an intervention. If one needs to rely on the properties of the elements in the system, one needs to avoid chasing a pseudo-process; otherwise irrelevant properties may be taken as relevant in the causal assessment.

4.4.2 Mechanisms
Seeing evidence of production as causal processes – whether supported by the mark method, transference and conserved quantities – is difficult to apply to associations such as ‘smoking and heart disease.’ Biomedical scientists do not explain causality based on causal processes, rather they study mechanisms in the human body. Mechanisms are becoming a core subject in the philosophy of science, and two parallel literatures are being developed. The first, and perhaps better known, has been sparked by the recent works of Bechtel (2005), Craver (2006), Darden (2002), Glennan (1996), and Machamer (2000). These authors discuss mechanisms primarily in the context of biology, neuroscience, and
psychology. The second strand examines mechanisms in social sciences, for instance in analytical sociology, economics, or demography. Significant contributions include those of Hedström and Swedberg (2008; 2009; 2010), Demeulenaere (2011), Little (1992), Steel (2007), and Ylikoski (2010).

Below we quote the accounts of Machamer et al., Glennan, and Bechtel and Abrahamsen to illustrate the current debate on its characterisation.

*Machamer et al. 2000, p3*

*Mechanisms are entities and activities organised such that they are productive of regular changes from start or setup to finish or termination conditions.*

*Glennan 2002*

*A mechanism for a behaviour is a complex system that produces that behaviour by the interaction of a number of parts, where the interactions between parts can be characterised by direct, invariant, change-relating generalizations.*

*Bechtel and Abrahamsen 2005*

*A mechanism is a structure performing a function in virtue of its parts, component operations, and their organisation. The orchestrated functioning of the mechanism is responsible for one or more phenomena.*

The account of Machamer, Darden and Craver on mechanisms is rooted in biology and emphasises that a mechanism is active. The parts of a mechanism are always busy sustaining the studied phenomenon. In agreement with these authors, the parts of a mechanism are *entities* and *activities* and they are equally important. Thus, it is not sufficient to identify what the parts do.

Glennan’s ambition is to find and account for mechanisms that cover all, or at least many, sciences. He describes a mechanism as “a complex system” to emphasise the ideas of self-organising aspects within a system, and that this organisation is responsible for some behaviour. Glennan distinguishes his work from the account of Woodward of ‘causal manipulationism.’ Causal manipulationism is not just the position wriggle X and Y wriggles, and vice versa (Strevens 2006). Alternatively, to phrase it in Glennan’s words, that the relationships between parts of a mechanism are governed by direct, invariant, change-relating generalizations.

The work of Bechtel emphasises the meaning of *function* in mechanisms. Function, conforming to Bechtel, is a role-function that emphasises the role of an entity in the mechanism. An important instrument is functional decomposition, a form of analysis aimed at understanding the role-function of each entity.

The strategy to describe what causality is based on mechanisms is not free from problems. For example, *objectivity in determining a role-function.* “See what you
believe” epitomises this pitfall. In addition, context is an important aspect when describing a function. In many cases, common background factors are overlooked. For example, legal regulations in health care, which are part of its business mechanisms, are usually forgotten although their absence would certainly affect them. Another problem is the ‘organisational relationships between different natures of entities.’ Multi-field mechanisms are increasingly important: in some circumstance, we need entities of different natures to act by the same mechanism, such as in health economics and social epidemiology.

4.4.3 Information
It is not always possible to find obvious answers on how and why questions when giving meaning to observations. For example, in the case of the avian flu, the H5N1 virus. In 2003, it was evident that most human contractions of the avian flu resulted from handling dead infected birds or contact with infected fluids. The spread of the H5N1 virus from Asia to Europe in a few of weeks surprised many. How could the H5N1 virus have been transmitted over such a distance, or so quickly? The number of possible causal links is huge, and one may ask whether there is a medium in the system that should be considered responsible for the distribution of the virus?

The question contains an assumption that there is some physical explanation. According to Anscome (1995), one should make a distinction between ‘thick’ causal linking, such as pulling, pushing, breaking and binding, and ‘thin’ causal linking. Thin causal linking refers to causes for which we do not understand the connection between cause and effect. Thick causal links are rich and informative. For example, we instinctively understand what ‘breaking’ means and know that it is a kind of causing. It is a real problem to understand what cases of ‘thin’ causal links (e.g. the spread of the H5N1 virus) share, given how diverse they are.

In 1999, John Collier (Collier 1999) tried to establish a conceptual link between causality and information that can be positioned in the ‘thin causal linking category of Anscome.’ Collier presented the following idea:

The basic idea is that causation is the transfer of a particular token of a quantity of information from one state of a system to another. (Collier 1999, p215)

Collier fills ‘thin’ causal links out by offering an account of what information is, and an account of information transfer. We will explain these in turn. First what is information in causal assessment? As reported by Collier, there are various ways of describing things informationally. For Collier, the information in a ‘thing’ is formally, and objectively, defined in terms of computational information theory. He describes the static case first, which is the case of an object that is not doing anything:
In the static case, the information in an object or property can be derived by asking a set of canonical questions that classify the object uniquely [. . .] with yes or no answers, giving a 1-1 mapping from the questions and object to the answers. This gives a string of 1s and 0s [. . .] There are standard methods to compress these strings [. . .] The compressed form is a line in a truth table, and is a generator of everything true of the thing required to classify it. There need not be a unique shortest string, but the set will be a linear space of logically equivalent propositions. The dimensionality of this space is the amount of information in the original object. (Collier in Dodig-Crnkovic and Burgin 2011, p91)

This approach for detecting an object’s information is widely applicable. Anything can be described in a series of yes/no answers. For example, a car can be described in this way. Is it a Honda? Yes (1). Is it blue? Yes (011001 (EGA Code for Blue)) Is it large? No (0). This yields a string of 10110010. Although there are various ways of choosing the questions to ask, the resulting measure, especially the compressed strings, are independent of human minds. For this reason, the measure applies easily to the physical world, which is why ideas of object information are extensively developed in physics.

Further complexities of Collier’s account can be found in his papers (Collier 1999; Collier 2011), which we set aside here to concentrate on the core idea. This comes in the move from describing a static thing informationally, to describing a flow of information, which is something dynamic, something that happens over time. Collier describes information flow in terms of identity of information:

\[ P \text{ is a causal process in system } S \text{ from time } t_0 \text{ to } t_1 \text{ if some particular part of the information of } S \text{ involved in stages of } P \text{ is identical at } t_0 \text{ and } t_1. \] (Collier, 1999, p. 222)

This is refined in more recent work drawing on the idea of information channels (Collier, 2011). In brief, for Collier an information channel is a family of infomorphisms. What Collier means by ‘infomorphism’ can be understood by supposing you have two systems. Each system consists of a set of objects, and each object has a set of attributes. For example, an object might be a switch, and its possible attributes would be on or off, and another object a bulb and its attributes also on or off. If knowing the attributes of the first system, the switch, tells you about the attributes of the second system, the bulb, there is an infomorphism. Note that knowing the attributes of the switch might not tell one everything about the state of the bulb, as information might be lost. For example, a torch consists of a bulb, battery, a switch and case. Conforming to the information channel theory, the torch is a system consisting of a series of infomorphisms (connecting switch to the bulb via battery and case). Collier states:
\( P \) is a causal connection in a system from time \( t_0 \) to \( t_1 \) if and only if there is a channel between \( s_0 \) and \( s_1 \) from \( t_0 \) to \( t_1 \) that preserves some part of the information in the first state. (Collier 2011, P10-11).

So, for Collier, the causal connection is an informational link. In his most recent theory, informational connection is still fundamentally identity, and information flow is given in terms of the identity of information at various stages in the information channel (Collier 2011, P11-12). So for Collier the devices we use every day, such as mobile phones, are information channels through which we can track identity of information at the various stages. It is this that supports users and the reason we make use of them.

Collier claims that a primary virtue of his theory is its generality. He has provided a perspective that “applies to all forms of causation but requires a specific interpretation of information for each category of substance (assuming there is more than one).” (Collier 1999, p215-216) The claim is that he has given a very broad outline, which can also be used to capture differences in diverse scientific domains, where we can specify kinds of constraints on informational connections, such as constraints we discover empirically relating to particular domains. Collier also claims that his view subsumes other theories of causality, most notably the conserved quantities view, simply by delimiting the kind of informational connection we find in that domain. However, Collier avoids the problem that some physical processes cannot be marked—they can all be described informationally.

4.4 Conclusion and contribution

In this chapter, we consulted the literature on causal philosophies based on the Illari-Russo classification scheme for evidences to demonstrate causality. The grounding of the Illari-Russo classification scheme is a profound literature study on causality and kinds of evidence, which was conducted to allow the scientific community to make reflections based on philosophical accounts of causality in scientific practices.

This chapter has presented philosophical reflections on organisational diagnosis too by positioning statistical evidence – as generated in lean six sigma, see the left side of Figure 20 – as evidence of difference-making. From the studied literature on causality (see section 4.2), we have seen which causal readings are associated with observational data and experimentation. Although causal readings from observational data may be possible in some circumstances, extensive observational data and experimentation are rarely available in organisational diagnosis.
In the last decade, more and more researchers have combined qualitative and quantitative methods in causal assessment. This combinatorial research approach, positioned as triangulation, has received notable attention from researchers and has proven itself as highly efficient and adequate. The strategy behind triangulation (see Figure 20) is to establish consistency between different kinds of evidence. To us, the triangulation approach, combining evidence of difference-making and evidence of production, is like asking for a second opinion from somebody who looks at the same phenomena from a completely different perspective. When the evidence found by two different diagnosticians is mutually consistent, then - in the eyes of the decision maker – causality is demonstrated and perceived as a credible result.

This study of lean six sigma aims to find ways of raising the credibility of its methodology. So, the idea of establishing consistency between kinds of evidence when diagnosing is a promising hypothesis. This led us to look at the Illari-Russo classification scheme and to recognise that evidence of production, in addition to evidence of difference-making, offers a promising window on causality (see the right side of Figure 20)

Evidence of production, in relation to causal assessment, is about reasoning how one or more events may cause other events and together bring about the phenomenon under investigation. The way of reasoning that generates such
Chapter 4

types of evidence requires observing the operation of the system as either a process, a mechanism or an information flow. For organisational diagnosis, it is important to apply the language of social interactions (see Section 3.4) when identifying a process, mechanism or information as evidence of production for a quality problem.

On the basis of our reflection from philosophy on the scientific practice of organisational diagnosis and more particularly on the methodology of lean six sigma, we think that triangulation is a feasible strategy and methodological support for explaining in lean six sigma. Triangulation, to be understood as combining evidence of difference-making and evidence of production to confirm causality, shows the potential to increase the credibility of diagnostic results. In addition, the feasibility of integrating evidence of difference-making and evidence of production has been demonstrated in other sciences with promising results (e.g. in evidence-based medicine).

We have no reason to think that such a strategy cannot be applied in organisational diagnosis. As we proceed to study the feasibility of triangulation for lean six sigma, this chapter provides us with a clear starting point. This consists of the lean six sigma methodology, which already offers methodological support for organisational analysis in which evidence of difference-making plays a central role (see the key to Figure 20). What is needed, if the method is to provide methodological support for organisational diagnosis, is to incorporate support for generating evidence of production and for the strategy of triangulation which integrates the two types of evidence.

In the next chapter, we will continue to explore – on a theoretical basis – the feasibility of integrating evidence of production in a triangulation strategy for lean six sigma. We think this is feasible since evidence of production comprises all the elements that are necessary for generating an explanation, without excluding the interaction model which was positioned as an artefact in the explanation phase of organisational diagnosis. However, there are three kinds of evidence of production, each with its promising aspects (see the right side of Figure 20). So, this immediately raises the following questions: ‘Which evidence of production is a good candidate for use in lean six sigma? Which evidence of production is feasible for establishing triangulation?’ and ‘Are there practical approaches to generate this kind of evidence?’ All these questions should lead to answers that help us to prepare a first draft of methodological support in explaining quality problems.
Chapter 5

Triangulation design principles
**Abstract** This chapter presents the first version of our knowledge object. This knowledge object organises the knowledge from: ‘the organisational diagnosis discipline’ (Chapter 2); ‘lean six sigma methodology’ (Chapter 3); and ‘philosophies on causal assessment (Chapter 4) as a set of triangulation design principles. This form, a predetermined set of methodological design principles, helps us to get a grip on the body of knowledge that spans multiple chapters. Furthermore, it enables access to a structured way of thinking for explaining quality problems, from which we can design a triangulation strategy (way of working and way of modelling) for a lean six sigma project.

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**Figure 21 The contribution of Chapter 5.**
5.1 Introduction

In this chapter, we establish in direct relation to scientific and practical work on methodological triangulation (see Chapter 4), the knowledge object of this work. We present our knowledge object (way of thinking) as a set of principles for situational methodological design (Winter et al. 2009). Situational methodological design fits the features of this research since design principles can adapt to new knowledge (e.g. enabling double-loop learning, see Section 1.7). Once we have established a theoretical set of principles in this chapter, we can use them in our first case study and adapt them in the light of the knowledge obtained in the reflections. Once the set of design principles offers proper guidance for real world situations, it will be possible to leave the “fuzzy front end” of design science (see Section 1.6).

This chapter is structured as follows (see also Figure 20). Section 5.2. presents our justification for positioning ‘causal mechanisms’ in the centre of our knowledge object (way of thinking). Our justification centres on the essential points and characteristics of causal mechanisms for causal assessment and for demonstrating causality. This discussion is followed by a brief examination of relevant literature to characterise causal mechanisms and to position a conceptual model for their application as evidence of production in a triangulation strategy (in Section 5.3). Section 5.4 presents the first draft of triangulation design principles as a way of thinking to be used in the case studies. Section 5.5 is concerned with specific design considerations for the research object (way of working and way of modelling) that are coherent with the knowledge object (way of thinking).

5.2 Why centring triangulation on causal mechanisms?

Some recent developments in philosophy regarding validity claims about causality in the social and natural sciences tell us that a causal mechanism must be identified before one can claim to have a theoretical explanation. The identification of a mechanism is entirely unlike the use of statistics as a starting point for demonstrating causality. The differences, and the advantages and disadvantages of each, are identified in this study from a review of the literature on causality, and expressed as the contrast between evidence of difference-making and evidence of production, presented in Chap 4.

Our study in Chapter 4 shows two fundamentally different approaches in causal inference, based on evidence of difference-making and evidence of production, respectively. Since both kinds of evidence are fallible – all evidence is fallible – triangulation should be applied in causal assessment to achieve more reliable
results. Since lean six sigma embodies only an evidence of difference-making strategy, the question arises: What kind of evidence of production (i.e. process, mechanism or information) should we apply in lean six sigma projects to establish a triangulation strategy to increase the reliability of the diagnosis results?

To answer this question, we first need to understand the role of evidence of production in triangulation. Evidence of production – in contrast to evidence of difference-making – embodies a concept of causality: one seeks evidence as to how the system – based on a cause – produces an effect. So, evidence of production is an ontological approach that concentrates on how and why cause and effect are linked (Russo 2009). In Section 4.4 we noticed three approaches to evidence of production, centring respectively on process, mechanism and information. This information is input for our study of the options for a feasible triangulation approach. The first option is to apply a traditional ontological perspective (approach) to causality, in which one perceives causality as a process where several phenomena follow in sequence from cause to effect. The second option is a more recent approach in which one aims to identify a mechanism. (Bunge 2004; Craver 2006a; Russo 2009; Russo 2011a) A diagnostician who takes this approach assumes that there must be an organisation in which the entities of the system cooperate in such a way that they are responsible for the phenomenon. The last option is to apply the information approach, in which the diagnostician assumes that the system contains information and there is a driver to change this information, which moves the system from a starting state to an end state. The diagnostician examines how and why the information driver is causal (Illari and Russo 2014). This last option is a very recent account of causality and is still the subject of debate and development.

Inspired by the trend in social science, and, in particular, analytical sociology, to put causal mechanisms at the centre of causal assessment, we advocate a causal mechanism centred triangulation approach for lean six sigma. This justification, to follow the trend in social science, is not the only argument. When we compare the three different approaches in evidence of production, we see that the characteristics of some are a better fit with lean six sigma than others. For example, we find in the literature (Illari et al. 2011) an argument that the characteristics of the process-oriented diagnosing approach are not a good match for the non-linearity of causality in social systems since behaviour in organisations is more emergent than process oriented (Hoogervorst 2009). It would be practically impossible to trace causal pathways in sociology with the help of the techniques mentioned in Section 3.4.1. The characteristics of the informational-oriented diagnosing approach also point to shortcomings. First we can question whether the informational approach is a causal account. Expressing a system as information and observing the way information changes is more a
marker technique to detect causality than an account by which a phenomenon can be explained. Furthermore, if we study the number of publications and the programmes of conferences on causality, we must conclude that the informational-oriented approach is too immature for application in this work.

Having explained why we prefer a causal mechanism approach for triangulation in lean six sigma, the question is what makes it practicable for our purposes. From researchers in social sciences and natural sciences we learn that they have adopted the idea that a causal mechanism must exist in the system and that this causal mechanism explains the observed phenomena by means of the observed associations between variables (Russo 2008; Russo 2011b). This mechanism should be identified if one is to speak of a theoretical explanation of causal relationships behind the observed associations. Causal mechanisms have some distinctive features, as compared to other approaches, that contribute to causal assessment.

The first feature of a mechanism centric approach in explaining is that the identification of a causal mechanism is more than a decomposition of the observed system into its parts. The causal mechanism approach requires the identification of the system's executive functions. For this purpose, scientists create models, or representations, that represent the system and help us to understand how the system and its parts operate. Now, imagine a continuum of models by which causal mechanisms are demonstrated, ranging from possible models to factual models. Such a continuum is found in natural science, for example in relation to planetary orbits. The model of Copernicus is relatively speculative as compared to Kepler's model. Kepler could decrease the speculative element in his model as he could apply more accurate techniques to make observations, and falsified his theory several times based on new measurements and observations. The more accurate the identification of the executive functions of a system, involved in the hypothesised causal mechanism, the more a causal mechanism can be accepted as a credible diagnosis result (Russo 2011b).

The second feature of a mechanism centric approach in explaining are that they offer 'methodological' support to the process of explaining. Thagard (1998) noticed three cohesive aspects of the causal mechanism approach that contribute to the process of causal inference. The first methodological aspect to which Thagard points us is that a causal mechanism may confirm presumed causal relationships that are assumed to exist based on observations. The causal mechanism approach functions to affirm that the process of causal reasoning based on observations may stop.
Chapter 5

The second methodological aspect to which Thagard points us is that causal mechanisms can alert diagnosticians to possible erroneous causal conclusions from observations and analysis. A causal mechanism may falsify presumed causal relationships that supposed to be based on observations. In such cases, the causal mechanism approach functions as a falsification instrument to stimulate new observations. The third methodological aspect to which Thagard points us is that the causal mechanism approach can indicate possible causes that can be confirmed or denied based on background knowledge of the system. In such cases the causal mechanism functions as a heuristic instrument to generate hypotheses that then can be tested.

In consonance with Thagard, the last aspect is a conclusion from the first two. Summarising Thagard’s take away message in our own words, we can say that the causal mechanism approach allows one to apply background knowledge about the system under observation in the process of causal assessment. In contrast, evidence of difference-making is a fact-driven approach, it admits only observations and measurements as content for statistical analysis. Finding an explanation for a quality problem would require many measurements and observations, which may involve a significant investment for the organisation. The methodological aspects of the causal mechanism approach can offer a more pragmatic approach without losing the benefits of integration with evidence of difference-making, at least when both ‘causal mechanisms’ and ‘statistics’ are combined, as the methodological triangulation strategy suggests.

The paragraphs above have presented the main features of a mechanism centric approach in explaining and our arguments for testing the causal mechanism approach as way of thinking for a triangulation strategy in lean six sigma projects. The section below will examine the characteristics of a causal mechanism. This characterisation is necessary to define the core concepts for the way of thinking, way of working and way of modelling, since we require that triangulation should lead to a credible explanation for a perceived quality problem. Furthermore, the explanation, in the form of a causal mechanism, should be clear and expressed in such a way that it can support decision-making on measures to be taken in the organisation to correct the quality problem. The concept of a causal mechanism needs to be understood and correctly defined to avoid misinterpretations and inadequate decision-making as a result.

5.3 Characterising causal mechanisms

After three decades, the debate on the correct characterisation of a causal mechanism, based on Bechtel and Richardson's book (1993), has once again been intensified by Machamer, Darden and Craver’s thought-provoking paper (2000). In this study, we will adopt a recent definition presented by Illari et al. (2011), which
aims to provide an understanding of what is common to causal mechanisms across several fields:

**Causal Mechanism**

‘A mechanism for a phenomenon consists of entities and activities organised in such a way that they are responsible for the phenomenon.’ (Illari et al. 2011, p.120)

This definition, when applied, provides an intelligible answer to the question of why something happened and, even more importantly, how things work and how outcomes come about. All in all, the prospects for explanations based on causal mechanisms appear to be promising. In the following paragraphs, we present the three elements of this definition and their meanings: ‘responsible for the phenomenon,’ ‘entities and activities,’ and ‘organisation.’

First, the expression ‘responsible for a phenomenon’ contains three aspects. The first aspect is indication; to explain a phenomenon we need to collect the indications that the mechanism is the cause of the phenomenon. A shared difficulty across the sciences is that different causal mechanisms may cause a phenomenon. The second aspect is diversity. ‘Responsible for a phenomenon’ refers to the diversity of things that causal mechanisms do, i.e. a single causal mechanism can cause different phenomena. ‘Diversity’ refers for example to the behaviour of a standard roulette wheel. The wheel does not have different causal mechanisms for distributing the ball to pockets 16 and 17; rather the same causal mechanism produces all 37 outcomes. The third aspect is that causal mechanisms carry out activities, such as regulation or control, exhibit behaviours, such as growth, and maintain stable states. Therefore, the expression ‘responsible for a phenomenon’ for causal assessment means that one regards the importance, diversity and various forms of the stability of the system containing the mechanism.

Second, a causal mechanism consists of entities and activities. Each functional component in a causal mechanism has a ‘preferred’ role in the production of a outcome. In this sense, the function of entities is tied to the role they play in the overall organisation of the causal mechanism. A causal mechanism consists of a combination of the elements that jointly activate a mechanism, which, as an organisation, produces the outcome or thing. Craver (Craver 2001) presented this statement in a simplified form, as shown in Figure 22a: where M stands for ‘mechanism’ and Φ (Phi) stands for ‘phenomenon.’ An entity that efficaciously engages in a productive activity acts as a cause (thus it is a difference maker), and a causal mechanism's activity to produce something, Φ, is explained by decomposing and analysing how its components, that is entities (C₁, C₂, …, Cₙ),
acting in a particular way, $\lambda_1, \lambda_2, ..., \lambda_n$, are relevant to the outcome of $\Phi$. A causal mechanism should show that a component cannot be isolated from the other components; rather, its contribution to the causal mechanism for $\Phi$ comes from its mode of operation, its size and force as well as its relation to the other components. The same functional component, for example, may have a different effect when it occurs in combination with other components.

![Figure 22: Causal Mechanism adapted from Craver (2001).](image)

Third, a causal mechanism that produces a particular outcome in the social sciences rarely has a linear or stable structure, see Figure 22b. (Craver 2001) Often the outcome is produced by a complex system of functional components activating the causal mechanism to produce the outcome. This complexity imposes operational conditions and restrictions for the identification and postulation of causal mechanisms. Operational conditions must be detected since domain-specific laws and entities explain nothing until initial conditions have been specified. For example, Newton’s laws do not tell us the movements of the planets until their initial positions and velocities are determined. This seems an abstract discussion. However, in relation to organisational diagnosis one needs to realise that the employees of an organisation apply implicit or explicit business rules (laws) in their activities. We cannot tell anything about how activities evolve if we do not know anything about their current state. For example, in a hospital, the intake before a medical surgery is prescribed in a protocol (e.g. check a person’s identity, the surgery request and the current medical status).

The aim of the previous discussion was to show how causal mechanisms can provide new insights for an account of explanation. By identifying the entities, the activities, and their organisation, we focus on the ‘functioning’ of the causal mechanism. The articulation of its functioning provides the basis for a successful explanation. It is worth noting that causal mechanism-based explanation assumes that what we describe is the functioning of ‘worldly’ causal mechanisms out there. The idea of decomposing the black box - figuring out the functioning of
the causal mechanism - presupposes a mild form of realism according to which the authors on causal mechanism think (i) that there is a box, and (ii) that it can be decomposed in smaller boxes. We follow the ideas of authors (Sankey 2004; Craver 2006; Mouchart and Russo 2011; Illari 2011a) that causal mechanisms should be central in explanatory accounts.

The idea of explaining phenomena by causal mechanisms can be fruitfully applied to organisational diagnosis and lean six sigma. Simply put, a business process is composed of entities (departments or people) performing various activities. Their organisation gives rise to the phenomenon we are interested in, be it the typical behaviour of the enterprise or some dysfunction of it. For example, the organisation of a flower shop can be interpreted in mechanistic terms. In a flower shop, different people (entities) may be working together and performing different roles (activities) in the management of the shop. When a dysfunction in the behaviour of an organisation is observed, we need to diagnose its origin or cause by means of explaining it. Therefore, when diagnosing we need to identify:

(i) the phenomenon to explain;
(ii) the entities and activities involved; and
(iii) a causal mechanism's organisation and operation (the role-functions of the entities to produce the phenomenon).

In the following section, we seek for a format for the knowledge object that can be applied in the case studies. In this attempt, we integrate the established knowledge of: (a) the discipline of organisational diagnosis (Chapter 2); (b) the lean six sigma methodology (Chapter 3); and (c) philosophies relating to causal assessment (Chapter 4), to provide principles (a way of thinking) for designing a triangulation strategy in a lean six sigma project.

5.4 Way of thinking: triangulation design principles

In this section, we aim to combine all the knowledge obtained in Chapters 2, 3 and 4 in a practical format for our case studies. We present the knowledge object of this work as a set of triangulation design principles that integrate the knowledge obtained in these chapters. The principles will provide a pre-specified and pre-programmed way of thinking, from which we can design a triangulation strategy (way of working and way of modelling) for causal assessment in lean six sigma projects.

The triangulation design principles presented in the following paragraphs represent the outcome of the previous discussions of organisational diagnosis and the topic of causal mechanisms. Each principle is a meta-element in our
knowledge object and will be highlighted in Courier New font, so the reader will note when the knowledge object is discussed or changed in this research.

We think that establishing triangulation design principles requires a systematic approach. For this purpose, we introduce a meta-triangulation design principle that represents the primary philosophy (way of thinking) behind all other principles. If – because of the case studies – this way of thinking needs to be changed, we will be able to study the consequences for all other principles. For the knowledge object of this work, which centres on explaining quality problems in lean six sigma projects, we apply the following meta-triangulation design principle:

P01: A plausible explanation for a quality problem is a confirmed causal mechanism.

This meta-principle ensures that a causal mechanism is the goal orientation for the explaining activity. Furthermore, P01 implies that finding a mechanism is not a goal in itself, the mechanism needs to be confirmed by integration of types of evidence. This requires a triangulation strategy in which an associational model and interaction model are involved.

Establishing an explanation, in the context of organisational diagnosis, cannot be an objective. It is an essential link in organisational control, where the identification of a causal mechanism for a quality problem is the starting point for the process of informed decision-making. So, identifying a causal mechanism is not an end it supports the process of informed decision-making. P01 must, therefore, entail P02 that:

P02: A confirmed causal mechanism supports decision-making for a quality problem.

Quality problems are perceived differently over the course of time. The same observations (quality variables and process variables), recorded at different times, do not lead to one and the same associational model (problem representation). In contrast, interaction models represent social interactions, they are ideally stable and can be observed at any time during the operation of the enterprise system. To respect this aspect in organisational diagnosis we advocate:

P03: An associational model confirms a quality problem, is temporary, adequate and time-dependent.
The second main aspect of P03, time-dependence, means that associational models need to be interpreted in the context of their creation time and in relationship with the population that was observed. Still it has become clear in the discussion about interaction models, and in relation to causal mechanisms, that the interaction model needs to reveal the entities and activities of the observed enterprise system, see Section 5.3. From this, it follows:

P04: An interaction model confirms the entities and activities of the causal mechanism in the enterprise.

The activity of constructing an interaction model must centre on causality. An interaction model should be helpful in explaining the cause for a quality problem, without aiming to present a solution or prevention plan. This seems a straightforward requirement. However, we also require that an interaction model should not bias our observations. For example, the explanatory accounts in organisational diagnosis (see Section 3.4) each have a strong presumption on how to observe the organisation (e.g. Argyris advocates looking for troubles in the formal structures of the organisation and assumes that repairing problems is a matter of changing the formal structure of the organisation). To avoid the problem that an interaction model influences causal assessments, we have a methodological principle:

P05: Interaction models are decoupled from any solution paradigm.

This brings us to the next point. Decoupling interaction models from solution paradigms - as stated by P05 - is not enough to ensure an objective way of working. Lean six sigma uses a gradual approach that leads to the selection of the most significant variables. This process has a lot in common with Ockham's razor, the principle that among competing hypotheses, the one with the fewest assumptions should be selected. We need Ockham's razor also when identifying the essential entities and activities of the causal mechanism for the interaction model. For example, a diagnostician may model an organisation on the level of its departments, but then decide to lower the abstraction level, to the level of individuals. Lowering abstraction can blur the view of the entities and activities suspected to be involved in the causing mechanism, since many non-significant details and assumptions will enter the model. To avoid this, and to stay focused in modelling, we propose the following principle.

P06: Demonstrating the essence of the identified causal mechanism requires Ockham’s razor on both sides of the triangulation. Diagnosing is a dynamic process that involves gradually
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eliminating assumptions and non-significant details.

This principle emphasises the process of gradual clarification on both sides of the triangulation. We also want to make a statement about the integration itself. The quality of integration determines the level of confirmation. Confirmation is an important aspect in our meta-principle P01. To provide guidance for integration, and therefore confirmation, the diagnostician needs to respect the following principle:

P07: The quality of confirmation depends on the degree of conciseness, comprehensiveness, coherence and consistency in the integration of types of evidence.

The principles above represent the knowledge object, in its first version, based on the theoretical insights of Chapters 2, 3 and 4. We believe, at this point, that these triangulation design principles offer guidance to any diagnostician who wants to incorporate a triangulation strategy in a lean six sigma project (see Figure 3). Methodologically, this knowledge object, is the way of thinking which influences the way of working and way of modelling that should be designed for the situation in each case study. Before we jump into a situational design, the following section presents the interpretation of triangulation design principles on the level of a way of working and way of modelling.

5.5 Way of working and way of modelling

In the previous sections, we have explained and positioned the causal mechanism as a candidate for evidence of production. We define a causal mechanism as ‘entities and activities that are organised in such a way that it produces a quality problem.’ We also positioned the concept of causal mechanisms at the centre of our first triangulation design principles, the knowledge object of this work. In this section, we discuss how to maximise the expressiveness of causal mechanisms in lean six sigma projects. To obtain expressiveness – by producing an artefact – the following paragraphs present our ideas on the level of the research object. That is, our ideas on how to establish artefacts in the suggested way of working and the way of modelling.

The point of departure is the simple requirement that a diagnostician must invest in creating an artefact on the evidence of production side of triangulation. This artefact must present information on how individuals have organised themselves and conduct social interactions in such a way that this organisation constitutes a mechanism that can be held responsible for the quality problem. Additionally, we
require information on why these social interactions continue and the quality problem remains. Such an artefact, which we call an organisational model, can be established using organisational modelling frameworks and languages. The available organisational modelling frameworks and languages (e.g. BPMN, ArchiMate, UML, etc.) embody distinct approaches: e.g. agent-based modelling approaches; structural modelling approaches; or a social influence modelling approach. Each has different characteristics that may or may not be helpful for reading causal mechanisms from the organisational model.

Allow us to hypothesise – inspired by viewpoints in enterprise architecture (Iacob et al. 2006; Buckl et al. 2007; Buckl et al. 2009) – briefly the implications of these different approaches for establishing evidence of production. Agent-based models aggregate the results of individual-level actions of individuals in the organisation to give macro-level outcomes. The agent-based approach can be beneficial for identifying the entities and activities involved in the causal mechanism and allows access to information about causal trajectories in the organisation. Structural models attempt to demonstrate the effects of given social structures or institutions (e.g. the department structure) on social outcomes (e.g. quality level). This approach can be beneficial to address the fact that an enterprise is a designed system; the approach puts the design at the centre of the investigation and allows a diagnostician to reason about the causal trajectories along pathways in this design. Social influence models attempt to identify the factors that work behind the backs of individuals to influence their choices. Such approaches emphasise the why question in causal assessment, which tell us more about the continuation of the quality problem.

The different approaches used in organisational modelling do not make it easy to establish a theoretical design for the research object to be used in the first case study. However, given the primary objective of this research ‘Acquiring knowledge about the practical applicability of ‘methodological triangulation’ in lean six sigma’ (see Section 1.4), we do not intend to test all approaches in organisational modelling. That would be a time-consuming and would go beyond our objective and the time available for this research. Therefore, we apply the research strategy of contrasting approaches (Orlikowski and Baroudi 1991). This entails selecting fundamentally different modelling approaches to create as much contrast as possible in the case study results. The contrast will probably identify the extremes of the spectrum of organisational modelling approaches for diagnosing. Based on this strategy, we hope to see strong contrasts showing the modelling aspects that contribute, or do not contribute, to the identification of a causal mechanism.

Seeking contrast, by selecting fundamental different modelling approaches in our case studies, is an important element in this study. Contrast-seeking has been
used in enterprise engineering, the discipline that develops organisational modelling approaches and addresses the differences among them (Dietz et al. 2013). See for example the manifesto of the Enterprise Engineering research community (2011) or its positioning paper (Dietz et al. 2013). This discipline has a focus on organisational modelling. Enterprise engineering therefore offers a body of knowledge on organisational modelling that fits the evidence of production side of triangulation and in which we find the contrast necessary for our research strategy.

Enterprise engineering recognises two distinct abstraction levels for organisational modelling. The lowest is the level at which modelling approaches address all the implementation details of the organisation. For example, models that represent business processes, the actors who are involved, the associated information technology and the infrastructure. This abstraction level and corresponding modelling approaches are known as enterprise architecture. The highest abstraction level is enterprise ontology. This level of modelling is abstracted from any implementation details. At this level the models and representations consist only of the indispensible elements of the organisation that collectively represent the essence of the organisation. Both abstraction levels can offer the necessary contrast to make a statement on the recognition of causal mechanisms when triangulating in lean six sigma.

Enterprise engineering offers two candidate modelling approaches, matching the abstraction levels of enterprise architecture and enterprise ontology. The first is ArchiMate, an organisational modelling language for enterprise architecture. The second is DEMO (Design and Engineering Methodology for Organisations), an organisational modelling approach for enterprise ontology. Based on ArchiMate and DEMO we can test the triangulation design principles on both abstraction levels and explore the support that these organisational modelling approaches can offer in identifying a causal mechanism.

5.6 Triangulation design for the case studies

In the following chapters, we present our cases studies and discuss both organisational modelling approaches in more detail. What remains for this chapter is to transform all the knowledge obtained thus far into a first triangulation design for the methodological approach that we are going to test in the case study. We propose the following design, which shows the intended consistency between the way of thinking, way of working and way of modelling:
### Step 1. Identify the phenomenon (quality problem) to explain

<table>
<thead>
<tr>
<th>Way of thinking</th>
<th>Way of working</th>
<th>Way of modelling:</th>
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| **P03:** An associational model confirms a quality problem, is temporary, adequate and time-dependent. |  ● Follow lean six sigma DMAI phases.  
● Use body of knowledge of lean six sigma and industrial statistics |  ● Establish an associational model of process variables and quality variables (see Figure 15)  
● Use the CTQ flowdown to establish a CTQ tree.  
● Associate the quality variables and the process variables based on statistical analysis in lean six sigma DMAI phases. |

### Step 2. Identify the entities and activities involved in the enterprise system.

<table>
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<tr>
<th>Way of thinking</th>
<th>Way of working</th>
<th>Way of modelling:</th>
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| **P05:** Interaction models are decoupled from any solution paradigm. |  ● Follow the modelling approach of ArchiMate or DEMO.  
● Use the body of knowledge of enterprise engineering |  ● Establish an interaction model (see Figure 16).  
● Case 1: Apply ArchiMate modelling language and establish process diagrams  
● Case 2: Apply PSI-theory and establish DEMO aspect models |

### Step 3. Identify the entities and activities involved in the causal mechanism.

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<th>Way of thinking</th>
<th>Way of working</th>
<th>Way of modelling:</th>
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| **P04:** The integration of models (types of evidence) confirms the entities and activities involved in the causal mechanism. |  ● Map the variables (based on the responsibilities of the social individuals in the organisation) on the interaction model.  
● Use the body of knowledge of organisational diagnosis (explanatory accounts) |  ● Establish an integration model: integrate the interaction model and the associational model.  
● Case 1: Map variables in ArchiMate model  
● Case 2: Map variables in DEMO aspect models |
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**Step 4. Identify the organisation and operation (the role-functions of the entities to produce the phenomenon) of the causal mechanism that is responsible for the quality problem.**

<table>
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<tr>
<th>Way of thinking</th>
<th>Way of working</th>
<th>Way of modelling</th>
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<tbody>
<tr>
<td><strong>P06:</strong> Demonstrating the essence of the causal mechanism requires Ockham’s razor on both sides of triangulation.</td>
<td>• Use the body of knowledge of causal mechanisms in social sciences.</td>
<td>• Read causal mechanism from interaction model.</td>
</tr>
<tr>
<td><strong>P07:</strong> The quality of confirmation depends on the degree of conciseness, comprehensiveness, coherence and consistency in the integration of types of evidence.</td>
<td></td>
<td>• Case 1: Identify a causal mechanism along the pathways of ArchiMate modelling concepts and their relationships</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Case 2: Identify a causal mechanism along the pathways of the DEMO modelling concepts and their relationships</td>
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</table>

The contribution of this methodological design for this research project is its format. The four-step format allows us to conduct all our case studies in the same way. Furthermore, we can use the format to compare the case studies and to focus on the supportive function of the organisational modelling approach (ArchiMate versus DEMO). In addition to the format, we apply the strategy of identifying a causal mechanism at two different levels of abstraction, those of enterprise architecture and enterprise ontology. Both, the strategy and the format, will help us to achieve maximum research results. It allows us to: a) compare the effectiveness of each approach side by side; b) understand which modelling aspects are responsible for the result and; c) understand the effects when diagnosing takes place on different abstraction levels.
Chapter 6

Case Study - Triangulation at the level of enterprise architecture
Abstract The previous chapter focused on the triangulation design principles (the knowledge object). We also presented a theoretical design for triangulation by means of a way of working and a way of modelling in a lean six sigma project. In this theoretical design, we identified two distinct abstraction levels for diagnosing quality problems: enterprise architecture and enterprise ontology. In the following case study, we examine the feasibility of this theoretical result in a real-life case in a large insurance company in the Netherlands. We applied ArchiMate as a way of working and modelling to support the process of discovering a causal mechanism for the experienced quality problem. Using ArchiMate entails diagnosing the organisation on the level of enterprise architecture. We will illustrate that identifying a causal mechanism at this level of abstraction is a far from trivial problem in practice. Firstly, models created with ArchiMate cannot explain, since this modelling language consists of only functional concepts that does not contain any causal information. Secondly we report, on the abstraction level of enterprise architecture, challenges with the current version of our triangulation design principles.
6.1 Introduction

The methodological design for triangulation in a lean six sigma project (see Section 5.5) is a theoretical hypothesis, subject to falsification and reflection. In this chapter we test our design on the enterprise architecture abstraction level for organisational modelling. Consistent with this abstraction level, we test the following way of working and way of modelling: first we rely on the way of working and way of modelling prescribed in the lean six sigma DMA phases as this offers guidance to establish evidence of difference-making. Then we apply the ArchiMate framework and modelling language for organisational modelling, since we think that organisational modelling offers support to articulate and express evidence of production in an organisational model. The integration of the two types of evidence, in the form of an associational model and interaction model, should lead to the identification of a causal mechanism.

We tested this approach in a real world lean six sigma project in the Zwitserleven organisation. Zwitserleven is a pension provider in the Netherlands. It reaches contribution agreements with employees of other organisations in the form of a pension plan that stipulates how much premium will be available for the pension. Zwitserleven invests the contributions, after deducting its purchase costs. The value of these investments becomes the pension capital for the pension holder. The amount of the capital depends on the investment results. Due to the risks involved in this process, pension holders ask Zwitserleven about the status of their capital or pose other pension-related questions. Our lean six sigma project focused on improving the response time to these questions. Our text aimed at explaining the quality problems in the organisation of information request handling.

The current chapter is a report on this project and presents the results of falsification and reflection for this design. The following research questions will be addressed:

- Are the claims (expectations and beliefs of guidance and support) in the above triangulation design (see 5.6) valid?
- Is the approach feasible in practice?
- What parts of the design (i.e. ArchiMate) are useful or even indispensable for that?
- How are both types of evidence (lean six sigma results and ArchiMate results) integrated, including the use of the triangulation design principles for identifying a causal mechanism?
This chapter consists of five sections, see Figure 23. Section 6.2 is a short presentation of the ArchiMate framework and modelling language, since ArchiMate is proposed as organisational modelling approach on the evidence of production side of triangulation. Section 6.3 presents the triangulation approach used at Zwitserleven at the enterprise architecture level. This section contains the results that we delivered to the management of Zwitserleven including the integration of the types of evidence and reading the integrated evidence. After the presentation of the case study, Section 6.4 presents the outcome of the triangulation approach by evaluating the case study results. Finally, in Section 6.5 we reflect on the case study results in relation to the triangulation design principles and draw conclusions about these principles.

6.2 Decomposing organisations with ArchiMate

In this case study, we test the feasibility of triangulation in a lean six sigma project on the level of enterprise architecture. We selected the ArchiMate approach as the way of modelling for this initiative. ArchiMate is based on the descriptive notion of architecture (Hoogervorst and Dietz 2008), which means that an enterprise architecture in ArchiMate corresponds to a functional model of the business processes in an enterprise. In this section, we briefly explain the ArchiMate approach and discuss its framework and its modelling notation based on its specification (Opengroup 2012). The actual application of ArchiMate in our case study is presented in the next section, where we will put ArchiMate in the context of triangulation to remain focused on its role in identifying a causal mechanism.

ArchiMate is a language for modelling enterprise architectures in accordance with a meta-model and a conceptual framework of modelling concepts, called the ArchiMate framework. The ArchiMate framework is presented in Figure 24. Three architectural layers are distinguished: the business layer, the application layer, and the technology layer. The idea is that the application layer provides services to the business layer, while the technology layer provides services to the application layer. Moreover, the business layer is said to provide business services to the environment of the enterprise.
On the horizontal axis, three major aspects are distinguished, called the active structure, behaviour, and passive structure. The first two refer to generic system aspects, as identified for example by Weinberg (Losty and Weinberg 1976). The third aspect is related to the discipline of information system engineering (Hoogervorst and Dietz 2008). ArchiMate’s perspective on organisations (read Lankhorst et al. 2010) is strongly influenced by this discipline. The meta-model of the language and its concepts (see Figure 25) is structured in conformity with the framework of Figure 24.

Each layer has its own meta-model: the business layer meta-model (Section 3.1 in Open Group 2012) presented in Figure 25; the application layer meta-model (Section 4.1 in Open Group 2012) and the technology layer meta-model (Section 5.1 in Open Group 2012). Each meta-model explains the core modelling concepts and the relationships between them. Each modelling concept belongs exclusively to one of the three aspects (i.e. passive, behaviour or active). The modeller chooses which system aspect prevails when representing a business process.

The meta-model for the business layer therefore consists of active structural elements, of behavioural elements and of passive structural elements. The concepts on the right-hand side in Figure 25 refer to the active structure aspect. The concepts in the centre relate to the behavioural or dynamic aspect, and the concepts on the left-hand side relate to the passive aspect. For the way of working with ArchiMate, this means that the modeller must look for objects and artefacts in the organisation that designate instances of the meta-model concepts as presented in Figure 25. Furthermore, the modeller needs to position the identified entities within the ArchiMate framework and define the relationships that exist conforming to the ArchiMate meta model. This way of working was
conducted in the following case study on triangulation on the enterprise architecture level, for both the business and application layer, see Section 6.3.

![Figure 25 ArchiMate Meta Model of the business layer.](image)

6.3 Case study: Triangulation at Zwitserleven

Thus far, we have focused on concepts of a causal mechanism, but have not emphasised how causal mechanisms are discovered in the practice of organisational diagnosis. In the following case study, we attempt to discover a causal mechanism. We illustrate that discovering a causal mechanism for a quality problem in a business process turns out in practice to be a far from trivial problem, and we present the challenges in the current state of organisational diagnosis. The case study took place in the pension fund Zwitserleven, responsible for managing the pension arrangements of all its pension holders. In 2007, Zwitserleven decided to invest in a lean six sigma project to improve the information request handling business process. Management’s goal was to reduce costs and increase customer satisfaction. From the causal mechanism perspective advocated in the triangulation design principles, we can reformulate this challenge as follows:

‘What is the causal mechanism that is responsible for the high costs and low customer satisfaction in the business process of information request handling?’
The following subsections report on the approach, based on our initial triangulation design (Section 5.6), while we also discuss the extent to which the triangulation strategy succeeded in identifying a causal mechanism.

**6.3.1 Identifying the phenomenon to explain**

In this case, Zwitserleven applied the lean six sigma approach, whose elements are virtually all tools and techniques developed in industrial statistics (de Koning 2007). The lean six sigma approach was introduced as a methodology in organisational diagnosis in chapter 3. Initially, lean six sigma requires a more specific description of the quality problem by means of functional decomposition⁸ (de Koning 2007). The CTQ flowdown is the activity in the define phase where the CTQ Tree is generated as a point of departure to improve quality (de Koning and de Mast 2007). In such a tree, the quality focus (i.e. customer satisfaction) is specified by measurable quality variables which, in lean six sigma jargon, are denoted as Critical to Quality variables (CTQs), see Figure 26.

In this case, customer satisfaction was specified by the quality variables: ‘CTQ2: Throughput’ and ‘CTQ3: Rework.’ The CTQ tree template (read p. 47-p.48 de Koning 2007) requires additional information on the quality variables, e.g. its unit, its measurement protocol, its null measurement, and its targeted value. This additional information is required to operationalise the measurement of the variable. The result of the CTQ flowdown for Zwitserleven is presented in Figure 26.

The CTQ tree of this case (see Figure 26) provides the necessary information to conduct the null measurement, required for an understanding of the current situation. In this case, the data of the null measurement consisted of 15295 information requests which represents the workload (CTQ1) between June 2006 and June 2007. This workload was subject to statistical evaluation to understand the behaviour (variation) in the business process of information request handling. To understand this behaviour, a classification of 13 types of information requests was used to conduct a Pareto analysis. The analysis results showed that 6 out of the 13 identified types created 80% of the workload (CTQ1), and furthermore, that the average throughput (CTQ2) was 6 days with a highly diverse distribution over all types. A histogram on CTQ2 showed that 29% of the information request were handled in one day, 20% in two days and 51% in three days or over. Rework (CTQ3) in this period (i.e. the percentage of information requests which were

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⁸ The meaning of a functional decomposition in lean six sigma is consistent with the meaning given in enterprise engineering. A functional decomposition here, and in enterprise engineering, is a technique to reveal detail in a conceptual model from the eye of a stakeholder. It does address inherent system properties that are constructional aspects.
caused by a former information request) was 15%. A histogram on CTQ3 showed that 80% of this rework arose from four information request categories. This kind of analysis demarcates the problematic behaviour of business processes, but not the problematic phenomenon to be explained.

This analysis result led to a management decision to improve information request handling in one department (CPA3). In the null measurement, CPA3 was responsible for handling 7956 information requests. For the duration of four months the project team was asked to assess the quality level of CPA3 and report monthly. In the first month, the improvement cycle was set up, followed by three one-month improvement cycles. This period was sufficiently long to provide a reasonable conclusion whether the estimated savings could be achieved.

The improvement cycle started with a brainstorming based on an Ishikawa / fishbone diagram, asking: ‘which process variables might possibly affect the quality variables?’ (de Koning 2007). The brainstorming identified thirty process variables (i.e. ‘availability of employees,’ ‘new promotion activities,’ ‘changes in regulations’). It was decided to observe eighteen process variables, by registering their values (including the values of the quality variables) each time an information request was received. The correlation strengths between all eighteen process variables and the three quality variables were determined by statistical
software. The process variables with the most influence were filtered based on their strength of correlation, and presented in a table, see Table 3.

<table>
<thead>
<tr>
<th>No.</th>
<th>Variable</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>qv1</td>
<td>workload</td>
<td>effect ctq1</td>
</tr>
<tr>
<td>pv1.1</td>
<td>channel_type</td>
<td>change 1.5</td>
</tr>
<tr>
<td>pv1.2</td>
<td>File_type</td>
<td>change 1.6</td>
</tr>
<tr>
<td>pv1.3</td>
<td>category</td>
<td>change 1.3</td>
</tr>
<tr>
<td>qv2</td>
<td>throughput</td>
<td>effect ctq2</td>
</tr>
<tr>
<td>pv2.1</td>
<td>digital_format</td>
<td>change 1.7</td>
</tr>
<tr>
<td>pv2.2</td>
<td>clarity</td>
<td>change 1.4</td>
</tr>
<tr>
<td>qv3</td>
<td>rework</td>
<td>effect ctq3</td>
</tr>
<tr>
<td>pv3.1</td>
<td>correct_policy</td>
<td>change 1.4</td>
</tr>
<tr>
<td>pv3.2</td>
<td>correct_IR</td>
<td>change 1.7</td>
</tr>
</tbody>
</table>

Table 3 Associational model of information request handling.

All entries of the Table 3 should be read as a tuple (e.g. <qv1, pv1.1>) of variables representing an association between a quality variable (qv) and a process variable (pv).

The lean six sigma team used the associations (e.g. <qv1, pv1.1>) as input for asking employees for suggestions to improve the values of the quality variables. The idea was to identify changes in the organisation that would reduce the association strength between the process variable and quality variable. To illustrate how a change proposal leads to an experiment, the archetypical approach to follow up on statistical analysis, we highlight one example.

The example which we are going to highlight is a pilot (an experiment) in which customers were called outside office hours (pv2.2) to reduce the throughput time (qv2). The result of this experiment showed that more information request was handled within the targeted two days of throughput. Furthermore, the statistical results on qv2 (CTQ2) showed that customer satisfaction increased in November and December. However, the positive effect on qv2 (CTQ2) could not be implemented as a durable solution since calling pension holders outside office hours created high costs and inefficiencies within the organisation. The pilot was terminated.
To avoid such problems, it was suggested that we study the problem of information request handling more fundamentally by reframing the identified associations as phenomena that need to be explained. This was an opportunity to apply a triangulation approach in which the logical following step is to identify the entities and activities involved in these associations.

### 6.3.2 Identifying entities and activities involved

Causal mechanism theory (as discussed in Section 5.3) suggests that the following step – after identification of the phenomena – is to identify all entities and activities involved in the detected associations. The assumption here is that the phenomenon is mechanically produced, which is not a logical assumption for social systems. In response to this criticism, the causal mechanism theory states that one should adopt the fallible, explanatory heuristics (as opposed to algorithms) of *decomposition* and *localisation* to identify entities and activities (Bechtel and Richardson 1993). In this theory, decomposition refers to taking apart or dis-integrating a causal mechanism into either component parts or component operations, and localisation refers to mapping the component operations onto component parts. At this point in the lean six sigma project we envisioned that the ArchiMate framework and its modelling language would help us with localisation and decomposing the business process under investigation.

We proceeded as follows. Decomposition with ArchiMate means looking for objects and artefacts of information request handling that designate instances of the meta-model concepts (i.e. the business layer see Figure 25), then positioning the identified entities within the ArchiMate framework and identifying relationships conforming to the ArchiMate meta-model. This procedure was followed in this case for both the business and the application layer. The result is a decomposition – from a functional perspective – of information request handling. Due to space limitations, the ArchiMate model presented in Figure 27 is a reduced version of the real model.

The reduction of the ArchiMate model can be observed in the following way. The business objects involved in information request handling are multiple data objects stored in multiple databases. For example, the *business object* 'information request' was implemented in 15 *data objects* that can be assigned to six *application components*. We did not include all these data objects in the graphical representation, rather we gave them the label <<15 DO>> (see Figure 27). Furthermore, we reduced the graphical representation on the application layer. In reality, the information request handling process used forty-two information systems. In Figure 27 we presented only the three main information systems. Although not all information systems are modelled they have to be taken into account.
account since employees in information request handling may be confronted with these systems.

![Figure 27 ArchiMate model augmented with associations.](image)

Based on the functional decomposition of the business process of information request handling (the ArchiMate model in Figure 27), team members conducted a localisation step. The exercise - as described in the theory of causal mechanism, see (Bechtel and Richardson 1993) - is one of mapping. Activities and entities are paired based on the relationship: '<Variable> is an aspect of <ArchiMate Modelling Concept>' The results are shown in Table 4. The table has been enhanced with information on the value range of the variables, information which was helpful for understanding the bandwidth of the behaviour studied. In the next phase, the information captured in Table 4 was used to augment the ArchiMate model. The result of this augmentation is shown as the red associations on the canvas of the ArchiMate model, see Figure 27.
Table 4 Mapping table (associational model and organisational model).

### 6.3.3 Identifying the operation of the mechanism

Since a causal mechanism is more than an aggregate of its parts, we must understand how entities and activities are organised to produce the quality problem (see Section 5.3). The system that produces the quality problem is being composed of entities and activities. In diagnosing the quality problem, it is important to distinguish the involvement of each part in the phenomenon. Inspired by causal loop diagramming (Russo 2009), the project team decided to integrate the established types of evidence by augmenting the ArchiMate model with the detected associations. The necessary information was already available from the previous phase, see Table 4 and the ArchiMate model in Figure 27.

The team expected to be able to use the augmented organisational model to understand the organisation of the entities and activities involved and how they operate in producing the quality problem at Zwitserleven. To satisfy this expectation, we followed the following procedure. In the augmented ArchiMate model, we see the tuples \(<qv, pv>\) as endpoints of the association. This association should be explained by reasoning based on the ArchiMate concepts that are traversed by the association (e.g. the ArchiMate concepts that ‘connect’ \(qv1\) and \(pv1.1\)). The relationships between the 'ArchiMate' entities and activities would then explain the operation of the causal mechanism.

In this case, the causal assessment from the associations and the organisational model was fruitless. No plausible causal mechanism could be identified from the ArchiMate model that connected, for example, the rework of information request
and its cause (e.g. \textless qv3, pv3.2\textgreater ). It was not plausible to state that rework is explained by an interaction between the activities of 'completing registration' and 'completing request' (see Figure 27). Firstly, the relationship of 'one activity triggers the other' is a descriptive relationship, that does not provide us with any information on how and why the operation of a business process works. Secondly, ArchiMate does not recognise causality in its framework since it does not provide us with any theory on the \textit{interactions} between active elements and \textit{how} these interactions cause change. Such an explanatory account or theory, like the accounts of Levinsson, Argyris and Schein in organisational diagnosis (see Section 3.3.3), would provide a rationale to generate answers to the questions of how and why interactions occur.

One may argue that information request handling was not modelled in active elements (e.g. see Section 2.6 of TheOpenGroup 2012). We agree with this point. The process could be modelled using concepts other than those we chose. However, even if the information request handling was modelled with active elements of the meta-model of the business layer (see Section 3.1 of TheOpenGroup 2012), we would be confronted with descriptive relationships (e.g. a \textless role\textgreater is assigned to an \textless actor\textgreater ), not with causal relationships. Such relationships (i.e. 'is assigned to') do not represent interactions between active elements, nor do these graphical expressions explain how an 'is assigned to' relationships lead to (state) changes in information request handling.

Although we recognised these shortcomings in the ArchiMate approach, we tried to formulate an ArchiMate-based explanation for a causal mechanism. We confronted interviewees with our reading, based on the augmented ArchiMate model. This reading was incompatible with the situational causal knowledge of the interviewees. The reading was perceived as to functional and structural and lacks of information on how thing works. So, there seemed to be a gap between the descriptive model and the causal knowledge of the employees involved. This gap made our causal assessment fruitless.

6.4 Reflection

In this section, we reflect on the way triangulation was performed in the case study using the theory of causal mechanisms. This reflection is based on the fact that, in organisational diagnosis, a diagnostician attempts to describe the functioning (and dysfunctioning) of an organisation in causal terms. Such a causal description must be compared to any correlations identified. It should be noted, however, that the initial phases of the case study focused merely on identifying correlations (i.e. the correlations in Table 3). Though these correlations are useful to isolate the areas that are related to the phenomenon to be diagnosed, they are not sufficient to provide a causal description of the phenomenon. What is
needed, in fact, is an understanding of the organisational components that are to be changed to remedy a problematic phenomenon. As discussed in sections on the theoretical design for a triangulation approach (see Section 5.5), the identification of a causal mechanism helps with this task. In the case study, an ArchiMate model was used precisely for this purpose. In this section, we will reflect on the ability of the triangulation approach supported by ArchiMate to detect a causal mechanism.

To identify a mechanism, the underlying entities, activities and organisation should be uncovered, as discussed in Section 5.3. In an organisational diagnosis context, sufficient entities and activities related to the organisational phenomenon must be identified by means of a decomposition technique. Then we should consider the organisation of the entities and activities that produces the phenomenon. For this, two different perspectives can be used in agreement with enterprise engineering: the functional perspective and the constructional perspective (Dietz 2011). The functional perspective describes how the system is used by a certain stakeholder. A functional model (or black-box model) is by its very nature subjective: the model can differ for each stakeholder. In other words, function is not a system property but a relationship between a system and a stakeholder. In contrast, the constructional perspective describes what a system is, in its ontological sense. A system is understood by its construction and operation, irrespective of how the system is used by stakeholders. A constructional model (or white-box model), therefore, can always be validated from the actual construction and thus its nature is objective.

To design a constructional model, enterprise engineering requires a description of the composition, environment, boundary and activity of the system, based on the generic definition of a system (Reporport 1980). The composition refers to the set of elements the system consists of (i.e. the elements required in the causal mechanism definition). The activity refers to the state changes caused by the system (i.e. the activities required in the causal mechanism definition). The structure refers to the way the elements of the system influence each other (i.e. the organisation required in the causal mechanism definition). Consequently, only a constructional (and not a functional) perspective is adequate to uncover the relevant entities, activities and their organisation for describing a causal mechanism. Based on the case study in this paper, we argue that such a perspective is currently lacking in organisational diagnosis. Three observations in the case study support this argument.

A first observation is that only functional decomposition is typically used in organisational diagnosis. We refer to the explanatory accounts of Levinsson, Argyris and Schein (see Section 3.4). A functional perspective is, in enterprise engineering, a systems perspective through the eyes of a stakeholder in which
the stakeholder expects to find a function (Dietz 2006). Levinsson, Argyris and Schein apply only the functional perspective, even in their decompositions. This only leads to more fine-grained models from the functional perspective (e.g. a management structure, an organisational structure or a cultural value model). A fine-grained functional decomposition is not the same as creating a constructional model, since this perspective requires the elements described in the previous paragraph (i.e. composition, environment, boundary and activity). Therefore, functional decomposition does not allow us to identify causal mechanisms since we are in search for the executive elements and the organisation. Indeed, enterprise engineering argues that a functional perspective is sufficient to control the behaviour of a system, but not to change the system itself (Dietz and Hoogervorst 2012).

Similarly, causal mechanism authors describe how causal loop diagramming can be used to specify associations between variables (Russo 2009), but also that such approaches are only able to explore the behaviour of organisations, and not to explain the observed phenomenon (Craver 2006). Moreover, Woodward argues that such approaches may even fall short when used for predicting behaviour: ‘without constructional knowledge, it is not possible to foresee the conditions under which those relations might change or fail to hold altogether’ (Woodward 2005). The Zwitserleven case study shows that current organisational diagnosis approaches rely heavily on functional decomposition. As an example, we mention the CTQ tree, which decomposes goals into finer-grained elements, but does not attempt to define the organisational components needed to fulfil the goals. These approaches are insufficient to identify a causal mechanism.

A second observation is that no clear modelling concepts (i.e. entities and activities) are used when elaborating on functional decomposition models such as the CTQ tree. In the case study, an ArchiMate model was used for this purpose. While an explicit meta-model is presented in ArchiMate (e.g. the business layer meta-model Page 14 TheOpenGroup 2012), it was clear in the case study that this tends to ‘blur’ reality with ‘fictional’ modelling concepts. Many ArchiMate modelling concepts and relationships are conceptual and not observable (see Page 14 Opengroup 2012), do not correspond to real entities and activities, or are too abstract to be useful for causal inference. For example, modelling ‘Customer File Management’ as an [application service] in Figure 27 makes it very difficult to establish a direct relationship with observations, as such a service does not exist. Instead, many applications perform this service. Other examples are relationships such as ‘triggers,’ ‘realises,’ and ‘assigned to’ which are used to indicate a kind of activity without providing any details on how that activity is carried out. Additional problems occur when the provisional status of the modelling concepts and relationships is lost sight of. Both examples show to what extent a functional
model can be detached from reality, and can lead to an incorrect diagnosis. Adding such modelling concepts can easily result in 'an illusion of understanding' (Craver 2006). What is required instead is a meta-model that describes the entities and activities adequate to produce the phenomenon under diagnosis. This meta-model is adequate if it relies on an (inter)action theory, with the activities of entities in a business process as its subject matter.

A third observation is that the use of inadequate modelling concepts idealises reality, instead of adequately describing it. This obstructs the correct identification of a causal mechanism.

When modelling a business process in the ArchiMate language one implicitly assumes that a business process is a sequence of activities. This presupposition is embedded in the meta-model of ArchiMate (see the business layer meta-model Page 14 TheOpengroup 2012), and must be accepted implicitly by any modeller. Another presupposition of ArchiMate is that every employee is allocated to some activity. Both presuppositions force the diagnostician to see a business process as a properly organised system, while in reality, employees communicate and conduct activities outside the organisation as well. Again, this shows that diagnosticians require a meta-model both to adequately describe the system producing the phenomenon and to empirically validate the phenomenon. If not, what is modelled is an idealised reality omitting important causal information. From the analysis of the organisation of the system, therefore, it must be evident which entities and activities are to be included or excluded in a certain meta-model. Otherwise, a diagnostician cannot judge whether a model allows the detection of the causal mechanism for a certain phenomenon.

Based on these observations, we argue that a constructional perspective with a clearly defined meta-model must be integrated in organisational diagnosis approaches. Approaches such as enterprise engineering, which explicitly incorporate a constructional perspective and separate it from behavioural observations, do not offer any practical support on how to use both perspectives to find a causal mechanism. However, the hypothetico-deductive (hypothesis-and-deduction) methodology of causal models does provide a way to integrate both perspectives. It involves three stages: (1) hypothesising, (2) building the model, and (3) drawing conclusions on the empirical validity or invalidity of the model (Russo 2009). In this methodology, the behavioural measurements belong to a ‘factual world,’ while the constructional model belongs to an ‘interpretative world’. The potential gap between them is important for this reflection. Similarly, enterprise engineering argues that all behaviour is engendered by the construction of a system (Dietz and Hoogervorst 2012). Therefore, the behaviour of a system as a causal mechanism can only be understood through an alternation between the functional and constructional perspectives. Based on our
reflection, and supported by theories on causal mechanism and enterprise engineering, we conclude that alternating between function and construction is crucial for identifying the causal mechanism responsible for a certain phenomenon. The next step in this research will, therefore, focus on the construction of a method to detect a causal mechanism which enables such an alternation and adheres to the principles of enterprise engineering.

### 6.5 Conclusions

In this chapter, we set out to open new paths for professionals in organisational diagnosis and researchers in science. We recognise that the integration of concepts coming from different fields may be difficult and take time, but we think it will be a beneficial exercise for both enterprise engineering and the sciences related to organisational diagnosis. On the one hand, the use of causal mechanisms can improve organisational diagnosis. On the other hand, the ‘causality in the sciences’ literature has not investigated the field of enterprise engineering, so fruitful exchanges can be foreseen in this direction. Nevertheless, one should note that within enterprise engineering, a school from information and organisation science (Dietz 2011) has developed a theory to capture the ontology of a business process. Causal mechanism can be revealed from such an ontology. However, it has not been used for diagnosis, since enterprise engineering is focused on designing and engineering business processes. This theory on the ontology of business processes has been operationalised in the DEMO approach, which includes a modelling language. Effort should be devoted to studying the use of DEMO in a meaningful, evidence-based way for organisational diagnosis. Most importantly, organisational diagnosis professionals must begin the process of organizing and sharing what they know to inform and expand the knowledge that will move organisational diagnosis towards an approach aimed at explaining by causal mechanisms. This need has motivated us to conduct a second case study, which will be presented in the next chapter.
Chapter 7

Case Study - Triangulation at the level of enterprise ontology
Abstract The previous chapter showed that discovering a causal mechanism on the abstraction level of enterprise architecture turns out in practice to be a far from trivial task. The triangulation design principles we used showed deficiencies when applied on the abstraction level of enterprise architecture. We will therefore apply the proposed triangulation strategy to a quality problem in a large pharmaceutical company, but using DEMO as a way of working and modelling to support the process of discovering a causal mechanism for a quality problem. We will show that it is possible to discover a causal mechanism on the abstraction level of enterprise ontology, due its distinct characteristics as compared to enterprise architecture.

Figure 28 The contribution of Chapter 7.
7.1 Introduction

The case study in Chapter 6 shows that lean six sigma starts with a functional decomposition that results in a CTQ tree (see Section 6.4). A functional decomposition is not enough to detect a causal mechanism. Introducing ArchiMate as an organisational modelling approach to decompose the structure of the organisation from a functional perspective did not lead to the successful identification of a causal mechanism for the perceived quality problem. The inadequate modelling concepts of ArchiMate idealise reality too much and force the diagnostician to see a business process as a properly organised system. The reality is that employees also communicate and act outside such idealised views. Therefore, functional models or idealised models are not useful for diagnosing purposes. This Chapter presents a triangulation strategy on the abstraction level of enterprise ontology. We will follow the same organisational diagnosis procedure as within the case of Zwitserleven. However, this time we will apply DEMO. This choice shifts the triangulation approach to the abstraction level of enterprise ontology. Furthermore, in terms of enterprise engineering, we will shift from interpretative modelling (linked to the functional perspective) to evidence-based modelling (linked to the ontological perspective) (van Reijswoud and Dietz 1999). This shift offers an attractive contrast with the former case study, which should provide interesting insights for organisational diagnosis.

In this case study, we included DEMO in a triangulation strategy in a real lean six sigma project. The study was conducted in the Merck organisation, a worldwide pharmaceutical company with a research lab and production plant for birth control pills in the Netherlands. The case study was conducted at this site and was intended to explain perceived “order reliability” problems. The current chapter is a report on this project and presents the results of falsification, and our reflection on the choice for DEMO. The following research questions will be addressed:

- Are the claims (expectations and beliefs regarding guidance and support) made in the DEMO literature true in practice?

- Is the approach feasible in practice?

- What parts of the design (i.e. DEMO) are useful or even indispensable for that purpose? and

- How are both results (lean six sigma results and DEMO results) integrated, including the use of the triangulation design principles for identifying a causal mechanism?

This chapter consists of five sections, see Figure 28. Section 7.2 provides a summary of the DEMO method and its theory to outline the way of working and
way of modelling on the evidence of production side of triangulation. Section 7.3 presents the triangulation approach on an enterprise ontology level in action. This section contains the results that we delivered to the management of Merck, including a presentation on our triangulation strategy, the integration of kinds of evidence, and the reading of these types of evidence. Section 7.4 then presents the fruits of our triangulation approach by evaluating the case study results. Finally, in Section 7.5 we reflect on the case study results about the triangulation design principles and draw the consequences for them.

7.2 Decomposing organisations with DEMO

In this case study, we aim to test the feasibility of triangulation in a lean six sigma project on the level of enterprise ontology. We selected DEMO for this initiative. DEMO relies fully on the Ψ'-theory (PSI'-theory) (Dietz 2006). In this theory, an enterprise (organisation) is a system in the category of social systems (Repoport 1980). The distinctive property of social systems is that the active elements are human beings or subjects. These subjects perform two kinds of acts: production acts (P-acts for short) and coordination acts (C-acts for short). By performing P-acts, the subjects contribute to the goods or services that are delivered to the environment. By performing C-acts, subjects enter and comply with commitments towards each other regarding the performance of P-acts. Examples of C-acts are ‘request’, ‘promise’ and ‘decline.’ The effect of performing a C-act is that both the performer and the addressee of the act become involved in commitments regarding the occurrence of the corresponding P-act.

C-acts and P-acts occur as steps in a generic coordination pattern, called transaction. Figure 29 presents the ‘basic transaction pattern,’ as the elaboration and formalisation of the workflow loop as proposed in (Denning 1995). A transaction evolves in three phases: the order phase (O-phase for short), the execution phase (E-phase for short), and the result phase (R-phase for short). In the order phase, the initiator and the executor negotiate to reach consensus about the P-fact (production fact) that the executor is going to bring about. The main C-acts in the O-phase are the request and the promise. In the execution phase, the P-fact is brought about by the executor. In the result phase, the initiator and the executor negotiate for achieving consensus about the P-fact that is produced (which may differ from the requested one). The main C-acts in the R-phase are stating and the corresponding accepting. The terms ‘initiator’ and ‘executor’ replace the more colloquial terms ‘customer’ and ‘producer.’ These

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9 Performance on Social Interactions
authors also refer to ‘actor roles’ instead of subjects. An actor role is defined as the authority and responsibility to be the executor of a transaction type. Actor roles are fulfilled by subjects, such that an actor role may be fulfilled by several subjects and a subject may fulfil several actor roles.

The actual course of a transaction may be much more extensive than the basic pattern in Figure 29. This is accommodated in the $\Psi$-theory by appropriate extensions of the basic pattern. The ‘Atomic Building Blocks’ in Figure 29 shows a compact notation of the basic transaction pattern. A C-act and its resulting C-fact are represented by one, composite, symbol; the same holds for the P-act and the P-fact. At the lower left side, the complete transaction pattern is represented by only one symbol, called the transaction symbol; it consists of a diamond (representing production) embedded in a circle (representing coordination). Transaction types and actor roles are the molecular building blocks of business processes and organisations, the transaction steps being the atomic building blocks.
Another important component of the the Ψ-theory is the distinction between three human abilities, which are exerted in both C-acts and in P-acts: the forma, the informa, and the performa ability. Regarding coordination, the forma ability concerns uttering and perceiving written or spoken sentences, the informa ability concerns formulating thoughts and educing them from perceived sentences, and the performa ability concerns getting engaged in commitments. On the production side, the forma ability concerns datalogical production (storing, transmitting, copying etc. of data), the informa ability concerns infological production (computing, reasoning), and the performa ability concerns bringing about original new facts (deciding, judging, creating). We, therefore, call it ontological production.

The distinction between the three human capabilities on the production side gives rise to the distinction of three layered aspect organisations, as depicted in Figure 30. The ontological model of an enterprise is the model (conforming to the Ψ-theory) of its B-organisation. DEMO helps in ‘discovering’ an enterprise’s ontological model, basically by re-engineering from its implementation, for example as contained in a narrative description. The complete ontological model of an enterprise consists of four aspect models (see Figure 30):

1. The Construction Model contains the actor roles and transaction kinds.
2. The Process Model contains the business processes and business events.
3. The State Model contains the business objects and business facts.
7.3 Case study: Triangulation at Merck

This section presents a case study in which we test the feasibility of DEMO in triangulation. The case study took place in Merck, an organisation that produces, manufactures and packages injection fluids, tablets, capsules and other dosage forms of medicines. The Merck organisation can be considered to have a high maturity in lean six sigma. The lean six sigma council of this organisation produces quality reports and is part of higher management responsible for quality management. From one of these quality reports, it became apparent that the ‘order reliability’ was under pressure. This observation was attributed to market turbulence due to the ongoing financial crisis. In normal circumstances, market demand is a stable fact and can be met based on stable sales forecasts. However, the economic crisis had reduced confidence in this market, and the sales forecasts had become unreliable. The ambition of management – despite the market situation – was to reduce the problems in order fulfilment to a specified level. Despite three earlier lean six sigma initiatives this level had not yet been achieved. We tested the triangulation approach in a fourth initiative, in which the objective was defined as:

*Find the causal mechanism that is responsible for the reliability problems in order delivery which affect the business processes of order fulfilment.*

In the following subsections, we report on our approach and discuss the extent to which the analysis we performed met the challenge in our formulation.

7.3.1 Identifying the phenomenon to explain

While the general cause of low order reliability was known, it remained unclear why the organisation at Merck had difficulties in adapting to the market turbulence. The ‘traditional’ lean six sigma methodology had already been applied in three initiatives, which failed to restore reliability in order fulfilment. The CTQ tree from the previous initiatives was made available to us as a suggested starting point for a fourth initiative.
In this CTQ tree, the strategic focal point (i.e. order reliability) was already specified by measurable variables. In this case, order reliability was specified by the delivery of the correct ‘amount’ on the agreed ‘delivery date,’ see layer 1,2,3 and 4 in Figure 31. Also, the acceptable deviations for these quality variables existed when we started this initiative, see layer 5 in Figure 31. Based on the information in the CTQ tree, we could define the lean six sigma concept of a ‘defect’ for this initiative. A defect is an order, for which the actual amount of product delivered and/or the actual delivery date fell outside the specified deviation. In a stable market, Merck achieves an ‘order reliability’ above ninety-five percent, which corresponds to 3.2 sigma. In the current turbulent market, Merck achieved a quality level that was no higher than seventy-two percent, which corresponds to 2.1 sigma. The sigma value adds extra valuable information on the level of defects. The sigma value expresses how tightly all the values of a quality variable are clustered around the mean (see Section 3.3.1). In the case of Merck, one can say the spread of the values of the quality variable in a stable market situation was more tightly clustered around the mean than in the unstable market. Or, in terms of lean six sigma, in the old situation the Merck company was more in control than in the present situation.

We interviewed the lean six sigma project members from the previous initiatives to learn from the choices made in these initiatives. They reported difficulties in identifying appropriate cause and effect relationships. They referred to the difficulty of identifying a ‘stable’ set of process variables, which meant that they could not identify a limited set of the most significant and influential process...
variables. After statistical analysis, they said they were confronted with a large set of process variables that could not be reduced any further. The process of working towards a critical set of process variables was fruitless. To avoid this problem in the fourth iteration, we made a classification scheme (see Table 5) containing ten 'reason codes' representing kinds of reason. This was used during the observation phase to classify the defect orders.

With the help of the reason code system, we observed the order fulfilment organisation for three months. We noted each defect order (deviance of +/-10% in the order amount and/or +/- 30 days from the agreed delivery date), and we recorded their reason, which was classified using the reason code scheme (see Table 5). We also recorded, in a free format, what happened with the order. This supplementary information was used later to learn more about the details of a situation.

<table>
<thead>
<tr>
<th>Code</th>
<th>reason</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>rc1</td>
<td>Manufacturing</td>
<td>Failure of equipment and/or processes related to manufacturing. Includes manufacturing related rework and investigations.</td>
</tr>
<tr>
<td>rc2</td>
<td>Resource Capacity</td>
<td>Conflict in equipment or personnel availability in any part of the process or site, including, but not limited to, manufacturing, lab testing, batch review and release, or investigation resolution.</td>
</tr>
<tr>
<td>rc3</td>
<td>Laboratory / Testing</td>
<td>Failure of equipment and/or processes related to the laboratory. Includes lab related re-testing and investigations.</td>
</tr>
<tr>
<td>rc4</td>
<td>Validation / Site change control</td>
<td>Process validation issues PV, PQ, Cleaning Validation, etc. Includes any change that is fully within site approval control or any CA or ICA that is delayed due to issues at the site.</td>
</tr>
<tr>
<td>rc5</td>
<td>Materials / Components (Outside Vendor)</td>
<td>Lack of available materials (raw material, bulk, semi-finished, or packaging components), or quality issues surrounding these materials</td>
</tr>
<tr>
<td>rc6</td>
<td>Materials / Components (Other SP Site)</td>
<td>Lack of available materials (raw material, bulk, semi-finished, or packaging components), or quality issues surrounding these materials</td>
</tr>
<tr>
<td>rc7</td>
<td>Regulatory / Off-site change control</td>
<td>Government Health Authority requirements, approvals, or labelling issues, etc. impeding product manufacture, release or availability. Includes CAs and ICAs that are delayed due to off-site approval, as well as art work delays. This could also include Import / Export paperwork requirements.</td>
</tr>
</tbody>
</table>
### Code reason Description

<table>
<thead>
<tr>
<th>Code</th>
<th>reason</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>rc8</td>
<td>Expedited Order</td>
<td>Any missed order that was the direct result of a request by the customer for a delivery within the normal lead-time. Each site should evaluate such requests and aggressively pursue a &quot;Promise Date&quot; as close to the Customer's Request Date as possible. Performance will be evaluated against this Promise Date.</td>
</tr>
<tr>
<td>rc9</td>
<td>Off-Site / Third Party Testing Requirements</td>
<td>Any external testing done off-site that are required prior to shipment. This could be Government Health Authority requirements, Market Customers, or another SP manufacturing site requirements.</td>
</tr>
<tr>
<td>rc10</td>
<td>Business Efficiency Considerations</td>
<td>Any increases or advances in shipments or deliveries made to enhance value or avoid costs that do NOT impact the customer's operations. This could be, but is not limited to, shipment consolidation or production efficiencies. Late shipments or deliveries under 90% are not eligible for this reason code.</td>
</tr>
</tbody>
</table>

Table 5 Classification scheme of process variables in the Merck project.

After observation, and with the help of statistical analysis, we determined the process variables (kinds of reason) that have had the most influence on the quality variables, based on their correlation strength. These correlations are presented in Table 6. All entries in Table 6 should be read as a tuple of variables (e.g. <qv1, pv1.1>) representing an association between a quality variable (qv) and a process variable (pv). A reader may not directly recognise the relationship between the quality variables, process variables and the classification system. This is due to the extra step of 'data preparation' between the organisational diagnosis steps of 'observing' and 'analysis.' In our activity of 'data preparation,' we processed the 'supplementary information' that was also recorded for each registered defect. We took the reports of the observer and isolated a set of defects (e.g. orders with an incorrect amount of products, see qv1 in Table 6). From this set, we took the defects that were clustered to, or assigned to, a reason code (e.g. 'rc1 Manufacturing'). We then studied the supplementary information and extracted from this information the process variables (e.g. within manufacturing, all defects related to planning errors). Table 5 reflects this procedure. The process variable name reflects two things: (1) the reason code and (2) the extracted process variable from the supplementary information. For example, pv1 in Table 6 has the name: rc1_ planning_error. Based on this 'data preparation,' we could reduce the number of process variables to those that were significant. Unlike the three previous lean six sigma initiatives, this initiative was not overwhelmed by a huge number of kinds of process variable. This procedure was perceived as a step forward in organisational analysis.
Now, if we return to our triangulation approach, we require an associational model (see step 2 in the triangulation design in Section 5.6). Our triangulation design states that a graphical representation of the variables and their statistical associations should be made, but in this case, we did not do so due our experience in the Zwitserleven case. In the Zwitserleven case (see Section 6.3) we mapped the quality variables and process variables on the canvas of an organisational model. We did not create a graphical associational model, only the information about the associations is required to establish an augmented organisational model.

### 7.3.2 Identifying entities and activities involved

To expose the interactions and mechanisms that facilitate the detected associations (e.g. \((v_1, v_1.1)\) in Table 6), we sought support in organisational modelling, as per the triangulation design principles. In this case, we developed a DEMO model. DEMO proposes a clear way of working for creating a constructional model of the organisation under consideration at the ontological level. Guided by the \(\Psi\)-theory in DEMO, we identified the transactions that are the elements of the ‘order fulfilment’ organisation. We created an organisational construction diagram (OCD) (Figure 32) and its corresponding transaction result table (TRT) (Table 7).
Figure 32 OCD of Merck 'Order Delivery.'

<table>
<thead>
<tr>
<th>Transaction</th>
<th>Transaction Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>T01 sales order completion</td>
<td>P01 sales order SO has been completed</td>
</tr>
<tr>
<td>T02 production management</td>
<td>P02 production management for period P has been done</td>
</tr>
<tr>
<td>T03 batch order production</td>
<td>P03 batch order BO has been produced</td>
</tr>
<tr>
<td>T04 packaging management</td>
<td>P04 packaging management for period P has been done</td>
</tr>
<tr>
<td>T05 package order completion</td>
<td>P05 package order PO has been completed</td>
</tr>
<tr>
<td>T06 production quality inspection</td>
<td>P06 the quality of batch order BO has been inspected</td>
</tr>
<tr>
<td>T07 packaging quality inspection</td>
<td>P07 the quality packaging order BO has been inspected</td>
</tr>
<tr>
<td>T08 material quality inspection</td>
<td>P08 the quality of Supplier Order SUPO has been inspected</td>
</tr>
<tr>
<td>T09 supply order completion</td>
<td>P09 supply order SUPO has been delivered</td>
</tr>
<tr>
<td>T10 shipping management</td>
<td>P10 shipping management for period P has been done</td>
</tr>
<tr>
<td>T11 shipping completion</td>
<td>R11 sales order SO has been shipped</td>
</tr>
</tbody>
</table>

Table 7 TRT of Merck 'Order Delivery.'

In accordance with the triangulation design principles (see Section 5.4) we want to find support from organisational modelling to identify the ‘executive’ elements (see Section 5.2) that are part of the causal mechanism that creates the reliability problem. Our triangulation design (see Section 5.6) prescribes augmenting the organisational model with an associational model. In this case the observations (the associational model, represented in Table 6) need to be mapped and plotted in the OCD and TRT (see Figure 32 and Table 7) to study the causal inference support of DEMO. From the Zwitserleven case study, we learned that such
mapping needs to be based on a rationale. The rationale behind the mapping in this case was to identify those transactions or actors who – in our eyes – control the values of the quality variables and process variables during run-time of organisation. Figure 33 shows the result of this procedure.

![Figure 33 Augmented OCD of Merck 'Order Delivery'.](image)

<table>
<thead>
<tr>
<th>RC</th>
<th>Causes</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>Release delay (PI capacity or artwork related).</td>
<td>42%</td>
</tr>
<tr>
<td>1B</td>
<td>Planning error, packaging material shortage, bulk shortage, order rework</td>
<td>30%</td>
</tr>
<tr>
<td>1C</td>
<td>Production delays. technical problems</td>
<td>21%</td>
</tr>
<tr>
<td>7A</td>
<td>Artwork changes (folding carton, leaflets) not on time, artwork approvals delayed, or artwork discussions on release. Optimization of the artwork change / COP planning processes</td>
<td>45%</td>
</tr>
<tr>
<td>7B</td>
<td>Import/Export documents on time (L/C; Import Licence; HUB Invoices)</td>
<td>25%</td>
</tr>
<tr>
<td>7C</td>
<td>Waiting for approval of the customer for shipment</td>
<td>20%</td>
</tr>
</tbody>
</table>

Table 8 Augmentation details of Merck ‘Order Delivery.’

Allow us to explain the mapping procedure in more detail. Both reasons (RC1 and RC7) can be attributed to different process variables (e.g. planning errors, artwork changes) and assigned to various transactions/actors (e.g. T11 or A02). This situation was for us an indication that, even with respect to a single observed reason (i.e. manufacturing delays), there may be diverse underlying causes. For
example, a manufacturing delay can be caused by actor A03, A04 or A06. Knowledge about the practice gained in the observation phase is crucial to identify the exact constructional component. However, this is not enough. We need to map variables on actors using objective criteria. Otherwise the mapping would be arbitrary, unguided and not reproducible. We agreed on three mapping rules. The first states: “a variable is managed; one actor is responsible for its values.” The second states: “a variable is a subject within a transaction: the initiator and executor are only successful when they agree on the variable’s value.” The third rule states: “a variable is mapped once.” This constrained mapping led to an augmented OCD (see Figure 33) and corresponding mapping table. This augmented OCD shows – in our eyes – all the entities and activities that are involved in the causal mechanism. It sets the stage for the third step in identifying a causal mechanism, namely to identify its organisation and operation.

### 7.3.3 Identifying the operation of the mechanism

In the previous step, we combined two kinds of evidence: statistics and organisational modelling. The latter was guided by the Ψ-theory, its application resulted in an ontological model of the organisation. When applying the Ψ-theory, and, more specifically, the operation axiom (Dietz 2006), we learn that not all transactions follow a straightforward sequence. Self-activating actors may be responsible for creating new ‘facts.’ For example, the self-activating actors (i.e. A02, A04 and A10) are responsible for determining a plan and according this plan initiating new requests in transactions with other actors to achieve the scheduled dates.

Especially in Merck’s situation, we find multiple self-activating actors. They are not driven directly by other transactions, but use the available information to determine something, such as an optimal delivery deadline. The information available to actors in the OCD is represented by interstriction links, see the dashed lines in the OCD of Figure 32. If we take a closer look to these interstrictions to understand the operation of Merck, we see how actors rely heavily on information from the production banks. To understand the operation of the causal mechanism - using the information about the entities and activities that are involved in this mechanism (see Figure 33) - we asked: ‘are the self-initiating actors informed about the values of the process variables?’ This question was raised when an employee expressed doubts about the availability of such information and suggested that informed decision-making might be at risk.

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10 The history of all production facts produced in the runtime of the enterprise
To answer the question, we studied the planning methodologies of actors A02 and A04. We drew the planning methodologies in the augmented OCD, see Figure 34. In Figure 34 we see that the self-activating actor ‘A02 production management completer’ establishes a one-year production plan. This production plan is based mainly on information from ‘CPB001 sales order forecast.’ Furthermore, we see that the self-activating actor ‘A04 packaging management completer’ creates a 12-week plan for packaging, based on information from ‘T01 sales order completion.’ In addition to the evaluation of the planning methodologies, we evaluated the information systems landscape, see Figure 35. From this assessment, it became apparent that three different information systems were in place. The first system supports the actors A01 and A08. The second system supports actors A02, A03, A04 and A05, and the third system supports actor A06.

Consequently, it can be concluded that actor A01 has no access to relevant information, which causes issues for order reliability, since A01 is restricted to the information available in his information system. More specifically, information concerning stock values, planning, and information concerning production delays are not available for A01. It is vital that this information should be available, to ensure that the delivery date and volume in T01 are feasible. This analysis is the final point of organisational diagnosis: a clear insight is provided into the constructional causes of the observed business performance issues. This case illustrates how DEMO provides support for the use of a constructional perspective in organisational diagnosis to gain such insight. Resolving the identified issues is a task for subsequent projects.
7.4 Reflection

In this section, we reflect on how the organisational diagnosis was performed in the case study. This reflection is based on the fact that, in organisational diagnosis, a diagnostician attempts to explain the functioning (and dysfunctioning) of an organisation in causal terms. Such a causal explanation must be contrasted to any correlations identified. It should be noted that the initial phases of the case study focus merely on identifying correlations (i.e. the associations in Table 6). The focus on correlations is useful to isolate and to demarcate the phenomenon to be diagnosed. However, correlations are not sufficient to support a causal description for the phenomenon to be explained. What is needed after the identification of the associational model is an understanding and identification of the organisational entities that should be changed to remedy a problematic phenomenon. As discussed in Chapter five, the adoption of ‘causal mechanism’ as the conceptualisation for a cause helps with this task. In the case study at Merck, a DEMO model was used precisely for this purpose. In this section, we will reflect on the feasibility of using DEMO for detecting a causal mechanism in lean six sigma, with a focus on the steps of the identification of the associational model. In the scope of this reflection, we address two aspects that, according Mouchart and Russo (2011), are related to feasible mechanism-based approaches: ‘flexibility in explaining' and ‘validation in explaining.’

The first aspect that we address is the experienced flexibility in explaining the quality problem. We highlight three different aspects of flexibility we found in the case study, by asking three critical questions:
Case Study - Triangulation at the level of enterprise ontology

i. can we handle mechanisms in which different types of variables interact?

ii. if the available data and background knowledge do not allow us to identify a causal mechanism responsible for the phenomenon, can we deliver some explanation on other grounds? and

iii. does the diagnosis approach allow a reciprocal connection in the way of thinking between existing (general) theories on causal mechanisms and establishing a (specific) causal theory for the enterprise under investigation?

The first question addressed the flexibility of the presented approach. We detected no types of variable that could not be included in this diagnosing approach. For instance, one of Merck's first iterations of the lean six sigma on order reliability examined how environmental variables (e.g. temperature) affect delivery times and vice versa. In this case, the diagnostician observed the temperature in the production facility (a 'physical' process variable). In the same study, the diagnostician also observed 'day of the week' as a 'social' process variable. These variables are of different kinds. The statistical method of lean six sigma allows us to characterise a mechanism by associations broad enough to include both 'physical' and 'non-physical' process variables (see Table 5 and Table 6). DEMO gives associations, even between variables of different kinds, a causal meaning. For example, measuring 'temperature in production' is only 'relevant' in the execution step of T03 for which A03 is responsible. The location of this physical variable in the OCD was in this case specified by the question 'Who controls it?' Furthermore, 'day of the week' only matters for A04. The diagnostician concluded that this 'global variable' is only 'relevant' for A04, since interviews had shown that there are staffing problems on particular days. The location of this global variable in the OCD was in this case specified by its relevance.

In the case study, the researcher / diagnostician did not have the same background information as the employees of Merck. A DEMO analysis allows a diagnostician to raise critical questions about the construction of the organisation. These questions lead to a profound understanding of what is essentially going on in the situation described. For example, the dependence of the self-activating actors (i.e. A02, A04 and A10) on information from information banks (see Section 5.3.3) cannot be inferred from statistical results. A DEMO analysis offers a diagnostician a way to deal with the lack of background information and draw conclusions. In this case, we have shown (related to question ii) that background information, information from the DEMO model and statistical analysis results can lead to an explanation. As for question (iii), we notice that understanding the operation of a causal mechanism is close to ‘establishing a ‘theory.’ The approach applied in the case study shows a reciprocation between the theory of DEMO (the Ψ-theory) and establishing a
‘theory’ about the planning mechanisms in a production environment. On one hand, the generated theory – the causal mechanism being the misalignment between the planning philosophies of the self-activating actors – is only applicable for Merck. On the other hand, the experience with the Ψ'-theory helps us to adapt it for application in new lean six sigma initiatives.

The paragraphs above have explained the flexibility of interpreting associations in DEMO aspect models. This flexibility allows a diagnostician to adapt to the situational circumstances wherever different kinds of variables are observed. This flexibility raises questions about the validation, i.e. which methodological aspect in our approach offers the necessary validation when explaining?

Mouchart and Russo (2011) discuss the topic of validation based on three interrelated aspects: (i) statistical, (ii) epistemic, and (iii) ontological. We will use this distinction as we reflect on our experiences in the Merck case. The first aspect, statistical evaluation, is included in our triangulation approach. The DMA steps in lean six sigma offer the necessary support to guide the process of organisational analysis. The associational model is the result of organisational analyses. Its reliability can be increased by considering the relevant aspects when reading variation in a population or between populations, see Section 4.2. We conclude that nothing prevents a diagnostician re-evaluating the associational model by conducting new measurements, and that statistical evaluation exists in our approach. We also observe (ii) epistemic evaluation in our case study. Epistemic evaluation is validation based on asking whether the associations correspond to employees’ background knowledge. In the case study, we showed the associational model (see Table 6) to the employees, and they recognised the findings. However, we can suggest improvements to our procedure. One suggestion is to also show the involved employees the weaker associations and allow them to suggest variables that should be included in the final associational model. We cannot exclude mistakes in the statistical evaluation, and some variables may mask other variables that would be more significant than the selected variable (e.g. the variable day_of_the_week can hide the variable staffing_level). On the other side of triangulation, the DEMO analysis (see OCD; Figure 32 and TRT in Table 7) approach was subject to epistemic evaluation. In fact, epistemic evaluation is part of the DEMO analysis (see, Ettema and Dietz 2009) since background information from the involved employees is the material from which DEMO aspect models are build. On this side of the triangulation, the modelling is an epistemic evaluation.

Statistical evaluation (i), and epistemic evaluation (ii) existed in both case studies (Zwitserleven and Merck). in methodological terms, the DMA sequence and achieving coherence between background information from employees and the organisational model existed in both case studies. But in the case of ontological
evaluation (iii), we see differences. DEMO is an ontological approach due its prescriptive approach to processing information about the organisation using the ψ'-theory and its axioms (Dietz 2006). It is claimed that correctly applying the ψ'-theory and its axioms will ensure that the organisational modeller achieves objectivity and only captures the essence of the organisation free from any implementation details (e.g. which information systems are used). Thus, a DEMO model is not an interpretation of the modeller, it represents the construction of the organisation in its most essential form. We experienced this support in the Merck case. Ontological validation can be achieved when another DEMO expert is invited to process the captured background information. We are convinced that if the ψ'-theory and its axioms is applied on the same background information about the organisation, it will lead to the same DEMO aspect models. Our belief is also borne out by our experiences with other DEMO case studies, and by reports from other DEMO experts (Albani and Dietz 2006; Barjis 2008; Op ‘t Land et al. 2009).

If we consider the topic of ontological evaluation in step 3 of our approach, ‘the integration of models’ (see Section 5.6) we found ontological homogeneity between the variables acting in mechanisms. We positioned each variable in an ontological context when mapping them into the DEMO aspect models. This ontological homogeneity between the concepts of DEMO and the variables is a combination of ontological validation with epistemic evaluation (asking which elementary actor is responsible for controlling its value). A serious weakness of this approach is that the reliability of this mapping depends on the procedure that is followed to obtain mapping information. However, in our experience it is only in rare cases that a mapping leads to a discussion. Constraining the mapping technique with the help of three mapping rules (see 7.3.2) seems to contribute to a reproducible and relevant augmented organisational model.

Summarising our reflection, we experienced the following. The approach of combining lean six sigma and DEMO was in this case not blocked by the kinds of variable involved or the characteristics of modelling concepts. The two evidence-gathering processes on the two sides of triangulation (the organisational analysis part of lean six sigma and the DEMO analysis) can be conducted in parallel and independently. We observed that validation processes occur on both sides of the triangulation and in every step of the suggested approach. The explanations in this diagnosis approach are subject to statistical, epistemic, and ontological evaluation. All three evaluations were present in this case, respectively from using the lean six sigma approach, from the DEMO approach (and its ψ'-theory), and from the coherence between the types of evidence obtained (the associational and interaction models).
7.5 Conclusions

Organisational diagnosis is a subfield in enterprise engineering which focuses on finding effective procedures for the identification of dysfunctions in organisations and for interventions to improve organisation performance. While the common practice of organisational diagnosis presents some standard methods, such as lean six sigma, we argue that these can be significantly improved if they are integrated with concepts drawn from enterprise ontology. DEMO and its $\Psi$-theory can enhance diagnostic procedure as it provides essential information on the construction and operation of an organisation. We justified our proposal and general assumptions for positioning DEMO as an organisational modelling approach on the abstraction level of enterprise ontology in an exploratory case study. In this case study, we applied triangulation with the lean six sigma approach for organisational analysis on one side and DEMO on the other side. This combination proved, in this case, to be ideal for incorporating the explanatory power of a causal mechanism in an organisational diagnosis. Furthermore, we conclude that the proposed approach provides enough validation for the findings. The conclusions from this case need to be evaluated to see whether the triangulation design principles (see Section 5.4) and triangulation design (see Section 5.6) needs to be changed. We think this would inspire other researchers to choose these triangulation design principles as starting points for their designs and so formalise this approach as a methodology. Such a methodology would be a desirable development in lean six sigma and the evolution in enterprise engineering.

We recognise that the integration of concepts from DEMO and lean six sigma may be difficult and will take time, but we think that both case studies have helped us to make progress. Before we present suggestions for future development of the triangulation approach (in Chapter 9), we first want to explore the difference between enterprise architecture and enterprise ontology for organisational diagnosis. The case studies show that two distinct decomposition perspectives can be applied: the functional perspective related to enterprise architecture and the constructional perspective associated with enterprise ontology. At the beginning of an organisational diagnosis initiative, both are unknown to the diagnostician. Establishing a decomposition is a crucial activity for the triangulation approach and, we suggest, for achieving more reliable results in an organisational diagnosis. In the next chapter (Chapter 8), we take a closer look at the difference between functional and constructional de-composition for diagnosing. We think that a theoretical investigation brings to light addition arguments to support our suggestion for the best organisational modelling framework (i.e. ArchiMate or DEMO) for organisational diagnosis.
Chapter 8

Explaining through business transactions
Abstract The previous chapter, on the case study at Merck, reports a positive result in explaining a quality problem by using triangulation and causal mechanism as the mode of explanation. It is surmised that DEMO contributed to this success. Having suggested that the characteristics of DEMO contributed to this positive result, how valid is the idea of explaining quality problems through business transactions? This is an important question for those diagnosticians who want to make a rational decision about applying DEMO in future lean six sigma projects. This chapter presents two challenges for explaining, and argues why a focus on business transactions is a valid causal approach and why implementation details (i.e. computer systems, protocols) are unnecessary. To demonstrate this, we will highlight our arguments in a theoretical case study. Furthermore, we want to avoid tunnel vision, so we include ArchiMate in this case study to compare both tools' capabilities to yield evidence of production.
8.1 Introduction

So far, two factors have been identified as being potentially important to increase the plausibility of lean six sigma results: the approach of triangulation and causal mechanism as a mode of explanation. This chapter will argue that there is a third factor, namely explaining through business communication. This third factor was observed in the second case study. What appeared as a modelling approach in step two to identify the entities and activities that are involved in a causal mechanism is an analysis approach for organisational constructions.

This chapter reports on the research we have conducted for the sake of articulating and elucidating the differences between ArchiMate and DEMO analyses, to support our statement about this third factor.

Our observation is not new. We briefly addressed it in our reflection of the Merck Case (see Section 7.4). We stated: “Thus a DEMO model is not an interpretation of the modeller; it represents the construction of the organisation in its most essential form.” Furthermore, to achieve such a model we stated: “DEMO is an ontological approach due its prescriptive approach to process information about the organisation using the $Ψ$-theory and its axioms.” Our thinking on this third factor drives us to compare the analysis approaches of ArchiMate and DEMO to support this claim. We have done this in the context of Enterprise Engineering, to which we referred in Section 5.5. Although this discipline is certainly not fully established, its main characteristics are becoming clear (Hoogervorst and Dietz 2008). They are summarised in the Enterprise Engineering Manifesto (Dietz 2011) and its positioning paper (Dietz et al. 2013).\footnote{See http://ciaonetwork.org/}

The remainder of the chapter is organised as follows. Section 8.2 summarises the histories of the two approaches. The reader will notice evolutionary differences between them. We also introduce a case description (Car Import) as a basis for the theoretical and practical comparative evaluation of ArchiMate and DEMO. Section 8.3 summarises the analysis of the Car Import case with ArchiMate, while Section 8.4 presents the DEMO analysis of the case. In Section 8.5, we compare the two approaches, both theoretically and based on the two analyses of the Car Import case. Section 8.6 contains some salient conclusions regarding the differences as well as the conclusions for organisational diagnosis.

\footnote{See http://ciaonetwork.org/}
8.2 Business communication, the third wave

We selected DEMO and ArchiMate (see Section 5.5) from Enterprise Engineering for investigation and assessment of their role in establishing evidence of production in a triangulation strategy for lean six sigma. The rationale of this choice was that the two approaches are fundamentally different and therefore offer an opportunity to compare their approaches and the support they offer to identifying the causal mechanism that is responsible for a perceived quality problem. This subsection highlights the contrast between the approaches from a historical and evolutionary perspective. This knowledge is necessary to understand why the focus on business communication emerges and why it is promising for enterprise engineers and organisational diagnosticians.

One of the characteristics of Enterprise Engineering is that it results from the merging of the current state of the art in Information Systems Sciences and in Organisation Sciences. Within the former, three phases or waves can be distinguished in the understanding of the application of Information and Communication Technology (ICT) to enterprises. The first wave started with the introduction of computers in the 1960's, and ended in the 1970's. The few approaches available at that time focused on the form of information. Applying ICT basically meant replacing a paper document with its electronic equivalent. During the seventies, a ‘revolution’ took place, pioneered by Langefors (Langefors 1977), who suggested focusing on the content of information before bothering about its form. Applying ICT began to mean automating information (i.e. content) needs, regardless of the form in which the information is stored or presented. This marks the beginning of the second wave. Around 2000 another ‘revolution’ started, pioneered by people from the Language-Action Perspective community (Weigand 2006). This marks the beginning of the third wave. Basing their insights on language philosophy (White et al. 1963; Langefors 1977; Habermas 1981), they suggested recognising the intention of information in addition to its content, and focusing on this aspect first, before considering the content and form. Examples of intentions are: request, promise, state, and accept. Because the informational notion of intention is closely related to the organisational notions of commitment and responsibility, a ‘natural’ merging became possible between information system sciences and organisational sciences, to form the discipline of enterprise engineering. Since ArchiMate is based on the descriptive concept of architecture (Dietz 2008), we can safely equate the architecture of an enterprise with a conceptual model of its business processes and objects. From the description of ArchiMate (see Section 6.2), it becomes clear that it is a second wave approach, meaning that it ignores the intentional aspect of communication and information. DEMO is a third wave approach, yet its scientific foundation is
broader. In addition to language philosophy, it includes system ontology (Repoport 1980) and world ontology (Wittgenstein 1922).

Another main characteristic of Enterprise Engineering is a profound understanding of the process of the development of a system of any kind, thus including enterprises. When changing an enterprise to support its operational activities with ICT applications, one needs to have an appropriate understanding of the stable essence of an enterprise. From the engineering sciences in general, it is known that if one wants to change a system, something of it must remain the same. For example, if one wants to redesign a meeting room, it is important that it remains a meeting room. As another example, if one wants to support or even replace the employees in an accounting department with an automated accounting system, the accounting process must essentially remain untouched. In general, one needs to understand the thing to be changed, at a level just above the level at which the changes take place. If this understanding is lacking, one cannot even evaluate a change sensibly. For a correct understanding of the process of system development, DEMO relies on the Generic System Development Process (Dietz 2008). We did not find anything similar in ArchiMate. This reinforces the observation made earlier, that ArchiMate is only a modelling language, not a methodology.

In addition to the theoretical investigation of ArchiMate and DEMO, we make a practical comparison by applying both to the Car Import case, taken from the ArchiMate project deliverable D3.5.1b (Iacob and Jonkers 2004). Below is the original narrative description:

In the Netherlands any imported car is subjected to a special kind of taxation called BPM. The business architecture supporting the whole collection process and the interaction of the Dutch Tax Department (Belastingdienst) with the importers and a number of other parties is described below. The importer (private person or car dealer/importer) must announce himself at the customer counter in any of the 30 Customs units in the Netherlands with the imported vehicle, its (provenance) documents, the approval proof of its technical inspection, and possibly with cash for the payment of the BPM tax. The public servant will handle the tax declaration as follows: first he will check all the documents, then he will fill in all the data into a client BPM application (running on a local server) and will calculate the due BPM tax value (using the BPM application and the catalogue value for that particular car). One copy of the BPM form (BPM17 ex1) will be issued and sent to the administration. Another copy of this form is handed to the importer (BPM17 ex3), together with either the evidence of a cash payment (if the importer is able to pay the BPM amount in cash), or with a bill (“acceptgiro”) issued for the due amount (in case the importer is not able to pay in cash).
At each Customs unit there will be public servants assigned to handle the additional administrative operations regarding all the incoming BPM statements. Once a day, this person will collect all the incoming BPM17 forms. For ones, which were paid in cash, he will issue and authorise another copy of the BPM form (BPM17 ex2). This copy will be sent to RDW (“Rijksdienst voor het Wegverkeer” - the Netherlands Road Transport Department), which keeps the evidence of all registered vehicles in The Netherlands. The first copy of BPM 17 will be then sent to the archive. The forms which are not yet paid, are kept “on hold” until they are paid. The payment administration and the notification service for all incoming payments for these BPM forms is done by a separate department of the Belastingdienst, namely the Tax Collection Department (“Inning”), which is responsible for the collection of all payments via bank. Once such a notification is received (via the BPM server application) the administration will prepare, authorise and send the copy of BPM17 ex.2 to RDW, and will permanently archive the ex1 of the BPM17.

8.3 Case study: Analysis of Car Import with ArchiMate

The narrative description of the Car Import case constitutes the starting point for the modelling activity with ArchiMate. The first methodological step is to identify text elements that can be recognised as ArchiMate concepts. The second step is to position these elements within the framework and to determine the relationships between them. The source from which we take the ArchiMate analysis of the case (Iacob and Jonkers 2004; Iacob and Jonkers 2006) does not provide further details about the modelling activity that led to the result exhibited in Figure 37. It merely presents this result.
Explaining through business transactions

Figure 37 ArchiMate model of the Car Import case.
8.4 Case study: Analysis of Car Import with DEMO

Every experienced DEMO analyst has his or her own way of working to produce the DEMO models of a case, being fully guided by the $\Psi$-theory. For novice DEMO analysts, however, a six-step method has been developed (Dietz 2006). Applying the first steps of this method to the narrative description of the case Car Import produces the following result:

In the Netherlands any [imported car] is subjected to a special kind of taxation called BPM. The business architecture supporting the whole collection process and the interaction of the [Dutch Tax Department (Belastingdienst)] with the importers and a number of other parties is described below. The [importer] (private person or car dealer/importer) must announce himself at the customer counter in any of the 30 Customs units in the Netherlands with the <imported vehicle>, its (<provenance>) documents, the <approval proof of its technical inspection>, and possibly with cash for the payment of the BPM tax. The public servant will handle the tax declaration as follows: first he will check all the documents, then he will fill in all the data into a client BPM application (running on a local server) and will calculate the due BPM tax value (using the BPM application and the catalogue value for that particular car). One copy of the BPM form (BPM17 ex 1) will be issued and sent to the administration. Another copy of this form is handed to the importer (BPM17 ex3), together with either the (evidence of a cash payment) (if the importer is able to pay the BPM amount in cash), or with (a bill (‘acceptgiro’) issued for the due amount (in case the importer is not able to pay in cash).

At each Customs unit there will be [public servants] assigned to handle the additional administrative operations regarding all the incoming (BPM statements). Once a day, this person will collect all the incoming BPM17 forms. For ones, which were <paid> in cash, he will issue and <authorise> another copy of the BPM form (BPM17 ex2). This copy will be sent to RDW (‘Rijksdienst voor het Wegverkeer’ – the Netherlands Road Transport Department), which keeps the evidence of <all registered vehicles> in the Netherlands. The first copy of BPM 17 will be then sent to the archive. The forms which are not yet paid, are kept ‘on hold’ until they are paid. The payment administration and the notification service for (all incoming payments) for these BPM forms is done by a separate department of the Belastingdienst, namely the Tax Collection Department (‘[Inning]’), which is responsible for the collection of all <payments> via bank. Once such (a notification is received) (via the BPM server application) the administration will prepare, <authorise> and send the copy of BPM17 ex.2 to [RDW], and will permanently archive the ex1 of the BPM17.
All ontological things are underlined. In addition, actors are indicated by placing their name between ‘[‘ and ‘]’, P-acts and P-facts are indicated by placing their name between ‘<’ and ‘>’, and C-acts and C-facts are indicated by placing their name between ‘(‘ and ‘)’. Next, we put the transaction pattern ‘over’ the ontological things. This results in the identification of three transaction kinds: T01 – the import of a car, T03 – the admission of a car to the Dutch road network, and T04 – the payment of the BPM tax.

T01 is outside the scope of the case, but we will include it in our model since it clarifies the whole process from importing a car through to admitting it to the road network, and since paying BPM tax will turn out to be disconnected from importing a car, although the case description suggests otherwise. T03 is only slightly mentioned, namely in the last sentence: ... the administration will prepare, authorise and send the copy of BPM17 ex.2 to RDW ... This sentence, in particular the term ‘authorise,’ suggests that sending the copy counts as requesting admission to the road network. However, this cannot be the case from an ontological point of view: only a car owner is authorised to request that a car be admitted to the road network, just as only a car owner is authorised to request authorisation to import the car.

Another, related, sentence that is ontologically puzzling, is the third one: The importer (private person or dealer/importer) must announce himself at the customer counter in any of the Customs units... The question is, who is requesting the importer to pay the BPM tax? A candidate actor role is the one who decides on the import of a car. However, although the case description suggests that paying the BPM tax is connected to importing a car, this is not true, as further investigation has shown. The tax to be paid as a prerequisite for importing a car is the VAT. We have included this transaction for completeness sake (T02). However, importing a car is distinct from getting it admitted to the road network! One could do the first and omit the second. So, there must be another actor role, the one who requests that the BPM tax should be paid. Since paying this tax is a prerequisite for getting the car admitted to the road network, it is obvious (and institutionally quite correct) that RDW requests the car owner to pay the BPM tax after the car owner has requested the RDW to admit the car to the road network. Thus, we finally arrive at the Actor Transaction Diagram in Figure 38. The corresponding Transaction Result Table is shown in Table 9. Together they constitute the Construction Model (Figure 30).

As said before, the left part of Figure 38 was only included for the sake of explaining clearly the distinction between importing a car (including paying the VAT) and admitting a car to the road network (including paying the BPM tax). Figure 38 clearly shows that the two processes are disconnected. Therefore, we
only produce the Process Model for the right part, T03 and T04 (see Figure 39). As a help in understanding it, we have added to each step the person or organisational unit or institution that performs the step. For the sake of simplicity, we have chosen CA03 and CA04 to be performed by a private person. Obviously, RDW is the authorised institution for fulfilling actor role A02 (road network admittner). However, for performing T04/ac it has apparently delegated its authority to the Tax Office (Belastingdienst). The dashed arrow from T04/ac to T03/ex means that RDW must delay admitting a car to the road network until the BPM tax has been paid. From the case description, we derive that the current way the Tax Office informs the RDW about this payment is by sending the copy of BPM17 ex.2.

![Diagram of the Car Import case](image)

Figure 38 Actor Transaction Diagram (ATD) of the Car Import case.

<table>
<thead>
<tr>
<th>Transaction</th>
<th>Transaction Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>T01 importing</td>
<td>R01 Import I has been performed</td>
</tr>
<tr>
<td>T02 import vat payment</td>
<td>P02 import vat for Import I has been paid</td>
</tr>
<tr>
<td>T03 admitting</td>
<td>P03 Admission A has been started</td>
</tr>
<tr>
<td>T04 bpm tax payment</td>
<td>P04 BPM Tax for admission A has been paid</td>
</tr>
</tbody>
</table>

Table 9 TRT of the case Car Import.
8.5 Reflection and comparison

8.5.1 Theoretical comparison

By the theoretical comparison of ArchiMate and DEMO, we mean the comparative evaluation of the Way of Thinking as well as the Way of Modelling of each, in accordance with the evaluation framework for methodologies known as the 5-way model (Seligmann et al. 1989). Our definition of a methodology in Section 1.4 is also relevant.

The Way of Thinking of an approach is its theoretical foundation, in particular the basic understanding of the object of analysis, in our case the enterprise. At first sight, the business layer in ArchiMate seems to correspond to the B-organisation in DEMO. However, this proves not to be true. To clarify the difference, in Figure 40 we present the relationship between an organisation and its supporting ICT systems as conceived in DEMO.
Apparently, the business layer in ArchiMate corresponds to the three organisation layers in DEMO (B-, I- and D-) collectively. Most probably, the application layer in ArchiMate corresponds to the B-application and the I-application layer in DEMO, while the technology layer in ArchiMate corresponds to the D-application and the hardware layer in DEMO. However, since we have focused on the business layer, there is no evidence to verify or falsify this hypothesis. Next, the $\Psi$-theory underlying DEMO provides for an appropriate and rigorous foundation. ArchiMate lacks such a foundation. Consequently, the semantics of the meta-model (cf. Figure 24) are undefined, which may easily lead to misinterpretations.

The Way of Modelling of an approach refers to the definition of the distinct models of an enterprise, their representations, and the derivation of the models from a case description. The way of modelling in ArchiMate is to look for terms in the case description that designate instances of meta-model concepts. In this manner, the model represented in Figure 37 is produced. This way of modelling resembles very much one used in several modelling techniques from the 1970's, of which the ER model is probably the best known. This advocated looking for nouns and verbs in a text. Nouns were taken as names of entity types, and verbs as names of relationship types.
Although ArchiMate's way of modelling (and meta model) is widely used, it has serious drawbacks. One is that irrelevant concepts are included in the model, just because there was a term in the description. Another is that relevant concepts are missing because references in the description were overlooked. A third is that different analysts produce different models, since the meta-model is multi-interpretable.

In contrast, since the four aspect models of DEMO (cf. Figure 30) are grounded in the $\Psi$-theory, the ontological model of an enterprise is guaranteed to be coherent, consistent, comprehensive, and concise. Moreover, it only shows the essence of the enterprise, completely independent of any implementation issue. This holds not only for the B-organisation (the essence of the enterprise) but also for the I-organisation and the D-organisation. Therefore, it the ideal starting point for the redesign and re-engineering of enterprises (Dietz 2008). Lastly, different analysts will produce the same ontological model, because every enterprise has only one such model.

### 8.5.2 Comparing the analysis results

As one will have observed, the results of applying ArchiMate and DEMO to the Car Import case, presented and discussed in Sections 8.2 and 8.3 above, differ very much. This is due to the differences between the Way of Thinking and the Way of Modelling of the two approaches. Obviously, ArchiMate takes the case description literally; that is its Way of Modelling. The DEMO analysis evoked critical questions which led to a profound understanding of what is essentially going on in the described situation.

First, importing a car and getting a car admitted to the Dutch road network are distinct and disconnected processes. Only the latter requires that the BPM tax should have been paid.

Second, it is not true that the Tax Office authorises the RDW to admit a car to the road network; rather the car owner requests admission. The Tax Office only has a delegated authority to accept the results of transaction T04 (BPM tax payment). It then informs the RDW that the payment has been received. We have a strong suspicion that the Tax Office and the RDW are not aware of these essential relationships. It is in any case certain that this ignorance causes a lot of confusion and many failures in attempts to make the processes more efficient, e.g. by applying modern ICT.

### 8.6 Conclusions

We have carried out a comparative evaluation of ArchiMate and DEMO, both theoretically and practically, i.e. by analysing the same case using each approach.
Space limitations prohibit us from giving a full and detailed account of our research. Only the most noticeable issues could be presented and discussed. In addition, a thorough assessment of the strengths and weaknesses of ArchiMate and DEMO can only be performed based on multiple real-life and real-size cases, taken from different fields. Nevertheless, some conclusions can certainly be justified now.

The first conclusion is that ArchiMate and DEMO are hardly comparable, for several reasons. One is that ArchiMate is a second wave approach, whereas DEMO is a third wave approach, as discussed in Section 8.2. Another reason is that DEMO is founded on a rigorous and appropriate causal theory, whereas ArchiMate lacks such a foundation. Therefore, its semantics are basically undefined, which unavoidably leads to miscommunication when using it in causal inference. One would expect that a rigorous semantic definition would be a prerequisite for an open standard.

A second conclusion relates to the abstraction layers distinguished by ArchiMate and DEMO. DEMO (in fact the Ψ-theory) makes a well-defined distinction between three abstraction layers: the B-organisation, the I-organisation, and the D-organisation. New production facts (deciding, judging, manufacturing etc.), by which the enterprise world is changed, are brought about only in the B-organisation. Therefore, for diagnosis purposes, we consider the B-organisation as the world in which causality occurs. In the I-organisation one computes, calculates, reasons; this does change the world indirectly through the B-organisation. In the D-organisation one stores, copies, transports etc., documents. Although ArchiMate belongs to the second wave, it does not make a distinction between infological and datalogical issues in the business layer. As an illustration of the point, the model in Figure 37 includes actions such as archiving and sorting, in addition to calculation. Although this seems not to be an issue of concern for ArchiMate, we think ArchiMate could profit from solidly incorporating this distinction. It would make ArchiMate to some extent suitable for diagnosis too. However, the lack of a rigorous semantic definition remains a major obstacle for doing this.

We conclude that applying the Ψ-theory is essentially an analysis approach for organisational constructions. The product of this analysis approach is a constructional model that represents the business organisation in its most essential form. Moreover, the Ψ-theory and its axioms represent a causal theory for social systems. Therefore, as regards organisational diagnosis – see Section 3.4 - the Ψ-theory is a causal account, which is what we need to explain behavioural phenomena in organisations. Neither triangulation – which is a diagnosing strategy – nor causal mechanisms – which offer format and guidance to establish
explanations – constitute a causal account. However, a causal account is crucial, since every claim (i.e. a causal mechanism for a quality problem) embodies certain presumed knowledge, and therefore implies a validity claim. A claim is, therefore, criticisable and should be grounded (Habermas 1981,p.25 ff.). A diagnostician needs to show that a claim is warranted, i.e. that the knowledge on which it is based is true. This is where the Ψ'-theory and its axioms fit in. The Ψ'-theory and its axioms offer grounding for organisational diagnosis, which makes all the actions rational and, therefore, criticisable. Such criticism should not be seen as negative, but as an opportunity to improve our actions. So, a claim grounded in the Ψ'-theory and its axioms is closely related to learning, making it possible to increase the reliability of the claim in each iteration. Therefore, we position the Ψ'-theory and its axioms, in addition to triangulation and the causal mechanism approach, as the third fundamental element for organisational diagnosis.
Chapter 9

Conclusions and recommendations
Abstract Our research demonstrates the feasibility of a new approach to explaining quality problems in lean six sigma projects. The proposed approach consists of three techniques. First, methodological triangulation offers a diagnosing strategy to identify and confirm a causal hypothesis. Second, a causal mechanism approach provides a mode of explaining, and guides the formulation of an explanation. Third, business communication (the Ψ-theory and its axioms) offers a rational grounding for explanations. The feasibility of applying these three elements has been theoretically and practically demonstrated. To build on the strength of this approach in order to achieve more reliable results and to overcome practical challenges in future lean six sigma projects, we propose a research agenda to redesign lean six sigma to deliver faster and more reliable diagnosis results, to test the diagnosis strategy more thoroughly, and to clarify the mutual dependency between evidence of difference-making and evidence of production.
9.1 Introduction

This study is a response to common logical errors due to the conflation of causality and correlation in lean six sigma projects. The incidence of non-sustainable results from lean six sigma projects indicates the serious consequences of drawing conclusions based only on statistical analysis. At the beginning of this study, we were curious to know whether new ways of demonstrating causality could be applied in lean six sigma projects. We suspected that more reliable results would be obtained when the lean six sigma diagnosing strategy incorporated causal mechanisms as the mode of explanation, and methodological triangulation as the diagnosis strategy. However, the general theoretical literature on causal mechanisms, and specifically literature on organisational diagnosis, is inconclusive on several vital questions that emerge in the discourse on causality. We realised that we first needed to conduct an exploratory study at the fuzzy front end of design science first, as illustrated in Figure 4. We sought answers to the following questions:

(a) What are the consequences for the lean six sigma methodology if triangulation and causal mechanisms are taken as a starting point?

(b) What requirements must lean six sigma satisfy if triangulation with a causal mechanism is applied to 'explain' (identify and confirm) the cause of a quality problem?

In Chapter 1 we present our main assumptions and choices, based on a literature study on organisational diagnosis (Chapter 2); the lean six sigma methodology (Chapter 3); methodological triangulation (Chapter 4); and causal mechanisms (Chapter 5). We have argued that a knowledge of modes of explaining is necessary to make better decisions when diagnosing quality problems in lean six sigma initiatives. We then state that the lean six sigma methodology lacks a causal account, and that some recent developments in philosophy regarding validity claims about causality provide a promising starting point to produce a causal hypothesis, and to demonstrate causality. We make a reasonable theoretical case that introducing causal mechanisms as a mode of explaining, and methodological triangulation as a diagnosing strategy, would allow the lean six sigma methodology to shift from an analysis approach in the direction of an organisational diagnosis approach that generates plausible explanations. Finally, we apply action research to study the feasibility of this diagnostic strategy at two levels of abstraction: enterprise architecture and enterprise ontology. In a comparative analysis, we conclude that our proposed diagnostic approach (methodological triangulation and a causal mechanism strategy) needs a third element, namely a causal account of social systems, in which one can ground a
causal claim. The $\Psi$-theory and its axioms in enterprise ontology are identified as a candidate in Chapter 8.

The remainder of this chapter is structured as follows. Section 9.2 summarises the conclusions from our research. We present a new way of thinking for diagnosing quality problems in lean six sigma initiatives and explain the place of these three elements in the way of thinking. Section 9.3 then presents a proposal for organisational diagnosis to generate reliable explanations. Section 9.4 answers our research question based on this proposal, and notes the limitations of our research in two respects: what answers we are still not able to give at all, and how far our conclusions relating to lean six sigma may be extended to the intended domain – the diagnosis of organisational problems in general. Finally, Section 9.5 makes recommendations for future research.

9.2 Contribution

In this thesis, we investigate organisational diagnosis, in which the task is to determine, by observational data, all the failures and states in a social system that explain a given quality problem. We focus on lean six sigma initiatives and aim to improve its diagnostic strategy. The main challenge is to deal with the large number of possible explanations for a quality problem. A diagnostician in a lean six sigma initiative cannot expect support from the current lean six sigma methodology, since it does not offer methodological prescriptions or guidance for the causal inference process. The lack of support for causal inference results either in a very inconsistent explanation or, where a statistical analysis is the only evidence available, an explanation incorporating a large set of presuppositions. This threatens the reliability of the explanations generated with the current lean six sigma approach. Our ambition, then, was to propose a diagnosing strategy for lean six sigma initiatives that offers support when generating reliable, plausible explanations. We address the shortcomings of current lean six sigma methodology with two interventions. First, we introduce the ‘causal mechanism’ mode of explanation. This is a mental model for explanations in general, which allows us to define properly what an explanation is. A good definition of an explanation provides a clear goal orientation for the lean six sigma methodology, and offers a format for the result that is to be generated. Second, we propose using methodological triangulation as a diagnosing strategy to identify and confirm a causal mechanism. This strategy entails both subjecting the observational data to statistical evaluation and interpreting this data in a compositional model of the organisation in question.

To determine which decomposition approach is best suited for our diagnosing strategy, we tested two approaches. First we tested functional decomposition at
the level of enterprise architecture. A functional decomposition is helpful to demonstrate that some part of the organisation (e.g. a department or an ICT system) persists because of its benefits for its environment. This research demonstrated that a functional decomposition does not allow us to interpret observational data causally. A functional model consists mainly of information about what establishes and preserves functional relationships. It does not supply causal information since the model can only show that some part of the organisation is beneficial for other parts. For example, we cannot use the ArchiMate model in Figure 27 to show that cause [on time t] leads to benefit delivery from a part of the organisation [at some later time t*]. Another impediment to deriving causal information from an ArchiMate model is the conceptual nature of its modelling concepts. Many ArchiMate modelling concepts are conceptual and abstract, which is useful to express a function. However, what is needed to draw a causal inference is information about the current states of real entities and the activities of the organisation and what moves them from one state to another.

As a contrast to the functional decomposition approach in the first case study, we tested a constructional decomposition approach at the level of enterprise ontology in a second case study. This entails the diagnostician observing the operation of the organisation through the lens of business communication. Since business communication consists of a structure – a transactional pattern – a diagnostician can construct a discrete state model of the organisation. Our second case study demonstrated how the enterprise ontology allows a diagnostician to reconstruct a state in business communication from observational data; to understand how these states transit to another state; and how these transitions are able to continue in the operation of the organisation. In contrast to a functional perspective on organisations, a constructional perspective generates the necessary causal information required for organisational diagnosis. Furthermore, a constructional model allows the causal interpretation of observational data, which is an essential requirement for methodological triangulation since it requires the convergence of types of evidence.

The last contribution from this study is the identification of the analysis potential in Ψ-theory. A comparative evaluation of ArchiMate and DEMO enabled us to demonstrate the difference between mapping and processing an observation. Mapping conceals risks related to subjective evaluation that may lead to different results (e.g. different modellers can map the same observation in relation to various modelling concepts). This risk is minimised in DEMO, which processes observations through the Ψ-theory and its axioms. In DEMO, an observation is subjected to a stringent analysis. This processing may have the unexpected result
of providing deeper insight into problematic organisational issues, such that informed decision-making is possible without further steps in methodological triangulation. In the domain of constructional analysis, a DEMO analysis is as robust as statistical analysis is in the quantitative domain.

Our contributions to the field from this research are three observations for organisational diagnosis. First, methodological triangulation offers a feasible diagnostic strategy for identifying and confirming a causal hypothesis. It generates more reliable results than the single evidence approach of lean six sigma. Second, a causal mechanism mode of explaining offers a format and guide for formulating an explanation. The current version of lean six sigma provides no guidance or format for explanations, so a causal mechanism approach can improve on the current prescriptions for explaining. Third, business communication (the $\Psi$-theory and its axioms) offers a causal account of social systems. The introduction of a causal account would ensure that explanations comply with the laws of the domain.

All three observations have the potential to increase the reliability of the results achieved in lean six sigma initiatives. These elements have not been presented as a methodology at this point, but the next section presents a methodological proposal. At the beginning of this research, such a proposal was only a vision (see Figure 3). This methodological proposal may help future scientists to develop a formal methodology.

What are the consequences for the lean six sigma methodology if triangulation and causal mechanism is taken as a starting point?

The biggest consequence for lean six sigma’s methodology is that its way of thinking should incorporate a ‘causal account.’ Triangulation applies two perspectives to the same problem, and in this thesis, the causal account provides the second perspective. In practical terms, a diagnostician develops a ‘causal story’ (evidence of production) which is tested against the facts of statistical dependencies between the variables of interest (evidence of difference-making). However, if the ‘story’ is not grounded in a causal account which models causality in the wider environment, it can be questioned and its validity can be questioned, even if the facts are consistent with the causal story. Causal mechanisms as a mode of explanation also require a theoretical grounding. The available theories of causal mechanisms offer a general format and guidance for validating a causal story. Ideally the diagnostician will use more specific guidance and procedures to ground a claim about causality in a theory suited to the domain in which diagnosis occurs.
9.3 A proposal for organisational diagnosis

Building on a sound understanding of organisational diagnosis, Section 9.2 introduced the three techniques required for a feasible organisational diagnosis approach in lean six sigma projects. The causal mechanism as a mode of explanation, methodological triangulation as a diagnosing strategy and the $\Psi$-theory and its axioms as a causal account of social systems provide the methodological elements for a methodological proposal. In this chapter, we summarise the requirements for organisational diagnosis and present a methodological proposal that meets these requirements.

9.3.1 Proposed requirements

Our study of organisational diagnosis (Chapter 2) and of the lean six sigma methodology in the light of this perspective (Chapter 3) lead to the conclusion that there is a gap between organisational analysis and organisational diagnosis. The current version of the lean six sigma methodology requires a new understanding of organisations and of quality problems to close this gap. This new understanding involves concepts and a methodological understanding. Before we enter the requirements for a new methodology we first present the purpose of the methodology and the concepts involved in the methodology, as the first part of an answer to the second research question.

**What requirements must lean six sigma satisfy if triangulation with a causal mechanism is applied to 'explain' (i.e. identify and confirm) the cause of a quality problem?**

*(Answer part A)*

To develop lean six sigma for organisational diagnosis, the purpose of lean six sigma must be reformulated. We propose:

- The purpose of lean six sigma is to generate an explanation of a quality problem for informed decision-making in organisational control.

The involved concepts in this understanding are:

- an explanation is an identified and confirmed causal mechanism
- a causal mechanism is an organisation in a system that contains the perceived quality problem.
- An organisation is a social system that consists of individuals and their interactions.
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- A quality problem is a situation in which the value of one or more quality variables cannot be successfully controlled within the specified limits.
- A quality variable is a measurable characteristic of a product or service that should satisfy a specification.

In this research, we have tested triangulation and causal mechanism in two lean six sigma initiatives. The results (Section 9.2) allow us to formulate the operational mode of the methodology and to generate clear requirements for a methodological proposal.

The operational mode which we want to achieve is to understand a quality problem in an organisation in terms of causal mechanisms. Using a constructional approach, offered by DEMO, we generate all the information on how an organisation is constructed. Quality problems cannot be read from this information, as they exist only in the operation of an organisation and need to be measured to emerge as a problem. A statistical approach, such as lean six sigma, enables us to look at individual variables, for which parts the organisation are responsible, in isolation. We see one part and its variables at a time. This leaves us to attempt to understand the relationships (or associations) between the parts and how the parts fit together in an operating organisation.

Using both approaches in a triangulating diagnosing strategy gives access to the causal mechanism in the operating organisation, with each part in its correct relationship to all the other parts and in harmony with the empirical data. Since DEMO offers us access to the causal structure of business communication, we can tweak the communication between sales and production units, and see how that affects packaging and shipping in the organisation. We can watch market demand affecting sales and simulate business communication between the individuals who are affected. We can deconstruct the organisation at our leisure and look at each part in relation to the parts it affects and is affected by.

This is the envisioned operational mode in lean six sigma projects. Instead of getting several separate answers to discrete queries, as in the traditional statistical analysis approach in lean six sigma, one could see how those answers fit together, providing valuable context to identify the causal mechanism that is responsible for the quality problem.

This operational mode reflects our new understanding of organisational diagnosis, which we present as a vision due to the exploratory nature of research. Now, if we abstract requirements from this new understanding, as the second part of an answer to the second research question, they are:
What requirements must lean six sigma satisfy if triangulation with a causal mechanism is applied to 'explain' (i.e. identify and confirm) the cause of a quality problem?

(Answer part B)

- A way of thinking for identifying and confirming (by evidence of difference-making and evidence of production) a claim about a causal mechanism.
- A way of working focusing on obtaining evidence of difference-making.
- A way of modelling focusing on obtaining evidence of production.
- A way of controlling that applies triangulation design principles to guide and control methodological triangulation in lean six sigma.
- A way of supporting that offers the necessary tools to support the activities of observing, analysing and explaining in organisational diagnosis.

The involved concepts in these requirements are:

- **Evidence of difference-making** is information about significant statistical dependencies between two or more variables of the observed system and its environment.
- **Evidence of production** is information about the construction of the observed system, grounded in a causal theory for the domain to which the system belongs.

9.3.2 Proposed methodology

From the answers to the research question, and the knowledge and practical experience gained during the research, we can present a defensible proposal for a new methodology for organisational diagnosis. Figure 42 shows the same five-way canvas as in Figure 3 (see Chapter 1), but now with the content necessary to achieve the envisioned operational mode for organisational diagnosis (see Section 9.3.1).

Figure 41 shows a methodological canvas for organisational diagnosis in two dimensions. Horizontally we see the main activities of organisational diagnosis: defining, observing, analysing and explaining. Each has its own

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12 From this point, we refer in courier style to the exact location in the canvas represented in Figure 42
concern, and generates output that is input for the next activity. Due this sequential structure we call this the diagnosing process.

Figure 42 Methodology for organisational diagnosis.

In the next subsection, we will continue with the way of thinking in the organisational diagnosis framework. This way of thinking comprises all the elements in the diagnosis strategy that are necessary to identify and confirm an explanation for a quality problem and that were introduced and discussed in this Chapter.

Way of Thinking
During the research, we were inspired to see how the causal mechanism as a mode of explaining stimulates the curiosity of scientists in diverse fields. Two cases can serve as examples: 'Hypotheses for mechanisms linking shift work and cancer' (Fritschi et al. 2011) and 'A social mechanism of reputation management in electronic communities' (Yu and Singh 2000). Both have in common that the causal mechanism way of explaining shapes drives the authors' way of thinking as they seek to know more about their subject. Such curiosity is needed to explain quality problems in lean six sigma projects. Although curiosity is a necessary attitude for a diagnostician, it will be not enough to explain a quality problem. What is needed is a consistent way of thinking that connects the three techniques of methodological triangulation, the causal mechanism approach and the Ψ-theory in a consistent way. For the way of thinking (row 2) we advocate methodological triangulation as a diagnostic strategy to identify and confirm a
causal mechanism (D2). The main philosophy behind this strategy is that the convergence of two different kinds of evidence yields more reliable results than a strategy using one type of evidence. The triangulation strategy has consequences for the way of thinking in each activity, which becomes clear if we reason backwards, from explaining to observing. In the explaining activity (D2), methodological triangulation requires the availability of two different kinds of evidence. Each instance of evidence needs to be generated in the analysing activity (C2). We advocate a focus on evidence of difference-making and evidence of production (C2). These two types of evidence allow convergence and mutual confirmation, which is what triangulation requires.

The way of thinking in organisational analysis is twofold, which has consequences for this row in the canvas. We split the cells for observing (B2) and analysis (C2) to represent the parallelism in the way of thinking. For difference-making evidence (C2-upper), the diagnostician needs to observe the organisation from a functional perspective (B2-upper). Here a functional perspective means that a diagnostician observes those quality variables that have a specific function (e.g. its value represents order reliability). At the same time, the diagnostician needs to observe the organisation from a constructional perspective (B2-bottom) to generate evidence of production for the analysis (C2-bottom). In the figure, all the upper parts of the cells (B2, C2, B6, C6) are related to each other, and the same for the lower parts. So, the upper and bottom parts each represent each one side of the coin in methodological triangulation.

Having emphasised the parallel ways of thinking that apply in observing and analysing, we switch to the way of thinking that applies in explaining (D2). In general, taking methodological triangulation approaches, the philosophy is to compare two different items of types of evidence to confirm a hypothesis from two distinct perspectives. In this methodology, we do not compare evidence; rather we combine items of types of evidence in search of mutual consistency that points to a causal mechanism. This can be achieved with a hypothesis-and-deduction way of thinking (D2) that offers a mode of thinking which can integrate perspectives and items of types of evidence to confirm a claim. This also allows a diagnostician to stop whenever an acceptable level of confirmation and consistency is achieved (see Figure 43). For our methodology, we advocate oscillating between the ‘factual world’ of measurements and the ‘Lawful world’ of social interactions, and stopping when a causal mechanism is consistent in both ‘worlds’ (see Figure 43).
The oscillation process in this way of thinking is presented in Figure 43. Now suppose the way of thinking starts in the factual world. The diagnostician hypothesises associations between quality variables and process variables. Here, the process variable is a variable that is thought (hypothesised) to correlate with a quality variable. Next the diagnostician measures these variables and conducts statistical analyses to find evidence of difference-making. The diagnostician now has all the information about the associations and aims to identify a causal mechanism. At this point a constructional is needed to interpret this information, so the diagnostician needs to switch to the lawful world to build a law-based constructional model (evidence of production). When this is achieved, the diagnostician wants to confirm whether a causal mechanism is responsible for the associations between the variables. If the lawful world cannot confirm this, the diagnostician should obtain new evidence of difference-making (factual world) which can in turn be interpreted in the lawful world.

In the oscillation space – the space between both worlds – the diagnostician draws conclusions on the empirical validity or lack of validity of the evidence of difference-making considering the evidence of production, and vice versa. It must be remembered that the format for an explanation is a causal mechanism. So, identification and confirmation should lead in the direction of a causal mechanism. The oscillation stops when the diagnostician reaches an acceptable level of confirmation. A good representation for the level of confirmation is the consistency between types of evidence from both worlds. A causal mechanism should be a causal story that is supported by facts and laws (see grey circles in Figure 43).

The hypothesis-and-deduction way of thinking is not new in the world of lean six sigma (de Mast and Bergman 2006; de Mast and Bisgaard 2007). It was originally introduced as a general model for hypothesis generation and confirmation. The contribution of this study is the inclusion of the argument from enterprise engineering, that all organisational behaviour is engendered by the construction of an organisation (Dietz and Hoogervorst 2012). So, we now have a model for the
way of thinking in organisational diagnosis that retains the original philosophy of alternating between theories and observations, but in the case of this domain advocates alternating between function and construction to identify and confirm a causal mechanism for a quality problem.

**Way of Organising**

The parallelism in the way of thinking \((B_2, C_2)\) has consequences for all other methodological components. We noticed in our case studies that the process of generating evidence of difference-making was dominated by prescriptions for a way of working with the lean six sigma methodology. Furthermore, we noticed that the process of generating evidence of production is dominated by prescriptions for a way of modelling from DEMO. Although we experienced grey areas between the way of working and way of modelling we think a clear distinction should be drawn between these two ways, as each should have its own goal orientation. Therefore, we propose projecting the parallelism in the way of thinking to yield a way of working – with the goal of generating evidence of difference-making – and a way of modelling that has an evidence of production goal orientation. Therefore, the upper parts of the cells in the way of thinking row \((B_2, C_2)\) are linked exclusively to the way of working \((row 4)\) and the bottom part of the cells in the way of thinking \((B_2, C_2)\) are linked exclusively to the way of working \((row 4)\).

The way of working and way of modelling are distinct processes in the framework with their own goal orientations, and they converge in explaining \((D_3, 4)\). The cells for the way of working \((B_3, C_3)\) are reserved for describing the process that leads to evidence of difference-making. The cells for the way of modelling \((B_4, C_4)\) are reserved for describing the process that leads to evidence of production. To avoid a lengthy elaboration, we will focus only on the essential methodological elements from lean six sigma and DEMO that are necessary to achieve these goals. The content which we position in the five-ways canvas (see Figure 42) is explained in the following paragraphs.

When observing \((B_1)\) the organisation in the way of working, a diagnostician measures \((B_3)\) the quality variable(s) and process variable(s) and generates operational data as output. In parallel, the diagnostician describes \((B_4)\) the operation of the relevant business process in the way of modelling and generates an operational description of the organisation. When analysing \((C_1)\) the observations in the way of working \((C_3)\), the diagnostician conducts a statistical analysis of the operational data to identify associations between the observed variables. The output of this activity is an associational model as evidence of difference-making. In parallel, in the way of modelling \((C_4)\), the diagnostician processes the operational description of the organisation through the \(\Psi\)-theory and generates an organisational construction diagram and corresponding
transaction result table. This leads to the output of a constructional model as evidence of production.

At the point of explaining \((D1)\) the quality problem, the way of working and way of modelling converge \((D3,4)\) in a hypothesis-and-deduction way of thinking. Both kinds of evidence need to be available. Since we chose the causal mechanism mode of explaining, we need to incorporate the causal mechanism in what needs to happen in the way of working and way of modelling. Causal mechanisms as a mode of explaining guide the diagnostician to three essential steps. Firstly, identify the phenomenon to be explained; Secondly, identify the entities and activities involved. Thirdly, identify the operation of the mechanism. All three steps need to be conducted in the context of the hypothesis-and-deduction way of thinking, which means that all three steps need to find answers in the factual world and in the lawful world that are consistent with each other. For example, if we recognise order reliability as a quality problem in the factual world and not in the lawful world we cannot proceed to identify and confirm a causal mechanism for this problem.

**Way of Controlling**

What is needed to control a project that applies the framework in Figure 42 are guiding principles for the diagnostician. For this framework, these will be methodological triangulation principles. The methodological triangulation design principles given in Section 5.4 must be updated now, since we have used them in two case studies (see Chapters 6 and 7) but have not yet included what was learned from the studies, or from our comparative analysis of DEMO and ArchiMate in Chapter 8. For the next iteration of the triangulation design principles we assume:

- Awareness of the old principles (Section 5.4).
- Acceptance of the conclusion that triangulation offers a feasible diagnostic strategy for lean six sigma projects.
- Acceptance of the conclusion that the causal mechanism mode of explaining meets the requirements of decision makers in business.
- Acceptance of lean six sigma as a feasible way of working to produce evidence of difference-making.
- Acceptance of the \(\Psi\)-theory as a feasible way of modelling to generate evidence of production.

The set of triangulation design principles is a systematic set of principles for organisational diagnosis. It is systematic in the sense that the first principle is a
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meta-principle for triangulation design which expresses the primary philosophy (way of thinking) behind all the other principles. A second principle (P02) is added as a controlling mechanism to pose critical questions about compliance with (P01).

The set of triangulation-design principles is a systematic set of guiding principles for organisational diagnosis. This set is systematic since the first principle is a meta-triangulation-design-principle that represents the primary philosophy (way of thinking) behind all other principles. A second principle (P02) is added as a controlling mechanism to ask critical questions about compliance to (P01)

P01: A plausible explanation for a quality problem is a confirmed causal mechanism.

P02: Confirmation is an internally consistent claim that complies with causal laws and is corroborated by facts.

A quality problem is a functional problem and not a constructional problem. Quality issues can be perceived differently over the course of time. Measurements of the quality variables and process variables may vary over time. So, measurements and analysis at different times lead to different associational models. Therefore:

P03: An associational model represents a quality problem, and is a temporarily adequate representation and time-dependent.

The consequence is that a quality problem is connected to the time the population was observed. So, a diagnostician needs to ensure that the causal model represents the construction of the organisation in the same period. If this is achieved, then:

P04: A causal model that represents the social system of the organisation allows a causal interpretation of the associational model.

Now, considering the reflections on the Merck case study (Chapter 5) and the comparative analysis between DEMO and ArchiMate (Chapter 8) we realise that a causal interpretation of the associations between the variables of interest requires a fifth principle.
P05: An organisation is only diagnosable when each variable under consideration is the responsibility of one social individual.

The rationale of this fifth principle is that if an organisation has not assigned an employee to manage the values of the variables of interest with specified limits there is a lack of formal responsibility in the organisation. In such a situation, the diagnostician has reason to initiate a dialogue with management regarding the quality of the organisation.

The five triangulation design principles are sufficient to control an organisational diagnosis project in line with the way of thinking presented here. These five principles leave a diagnostician free to design his or her own way of working, way of modelling and way of supporting. We realise that each initiative has its own situational aspects (e.g. difficulties in measuring variables, varying possibilities of experimentation in an operating business), and a method must take these into account. Furthermore, we felt that principles 5, 6 and 7 in the first set make this set over complete and could cause overlap in the values that each principle represents. We think that the new set of five principles is complete for controlling a lean six sigma initiative in which the triangulation framework is applied, without the risk of overlap.

**Way of Supporting**

The framework for organisational diagnosis in Figure 42 is feasible for use where the diagnostician can rely on tools that support the diagnostic process. These tools should support the diagnostician in both sides of the triangulation, and should facilitate the convergence of different kinds of types of evidence. In the case of evidence of difference-making, diagnosticians should apply CTQ flowdown from the lean six sigma methodology to generate a CTQ tree \(^{(B6)}\). The CTQ flowdown (de Koning and de Mast 2007) is a model to define the quality problem (the phenomenon to explain) up to the measurement plan stage. CTQ flowdown was applied in each case study, see the CTQ Trees in Figure 26 and Figure 31.

The presented framework for organisational diagnosis (Figure 42) is practically feasible when a diagnostician can expect tool support. These tools should support the diagnostician on both sides of triangulation, and, should facilitate the convergence of types of evidence. In the case of evidence of difference-making, diagnosticians should apply CTQ flowdown from the lean six sigma methodology to generate a CTQ tree \(^{(B6)}\). The CTQ flowdown (de Koning and de Mast 2007) is a model to define the quality problem (the phenomenon to explain) until the level of a measurement plan. CTQ flowdown was applied in each case study, see the CTQ Trees in Figure 26 and Figure 31.
A CTQ Tree provides the necessary information about quality variables and how to measure them. Before we start observing we need to define the process variables that are thought to be critical to quality, and how to measure them. In our case studies, we obtained this information from interviews with staff, but it could also be obtained by brainstorming and from earlier lean six sigma initiatives. When this measurement plan is applied in observing, the diagnostician needs tools to identify statistical relationships between the variables. A plethora of statistical software is available, ranging from commercial tools such as Microsoft Excel and SPSS to open source tools such as the R or GNU-S project. In our case studies, we used commercial software from Minitab, since we had experience with this tool and a licence was available. Minitab (like other tools) includes many statistical features (algorithms and calculations) to evaluate statistical dependencies between variables. To find evidence of difference-making we relied on DEMO, due its causal underpinning. In using DEMO, it is advisable to start with a transcript that describes the relevant operations in the organisation. Two things can help to avoid creating a non-relevant transcript. First, a diagnostician should draft a SIPOC diagram before interviewing employees. A SIPOC diagram is a high-level view of a business process. It stands for Suppliers, Inputs, Process, Outputs, and Customers. Second, the diagnostician should test whether the SIPOC diagram allows the inclusion of the required quality variables and process variables. Based on this information, a diagnostician can decide which employees should be interviewed. Transcripts of these interviews should resemble the transcript in Section 8.2.

The procedure for transforming a transcript into a DEMO model (OCD and TRT) is described in a six-step method (Dietz 2006). Section 8.4 contains an example. This modelling activity can be supported in software ranging from general drawing tools to a dedicated DEMO modelling environment (e.g. XEMOD van MPRISE; http://www.modelworld.nl; http://www.demoworld.nl). We strongly advise using a dedicated DEMO modelling facility. A dedicated modelling facility forces a modeller to comply with DEMO’s meta-model, although it cannot ensure the correct application of the $\Psi$-theory.

We used Visio - a generic drawing tool in the Microsoft Office Suite – for DEMO modelling, because it allows the user to draw in layers, and we wanted Figure 33 to draw a DEMO model on one layer and position the quality variables, process variables and the associations between them, from the DEMO model, on another layer. Additional layers can be used to include other organisational aspects such as information about information systems (e.g. Figure 35). We did not find a dedicated modelling facility for DEMO that allows such layering. We see a future for this feature for diagnosis, since an extended meta-model for mapping
variables would help to ensure the correct mapping required by triangulation design principle P05.

9.4 Validation and Limitations

This thesis includes a design proposal for paradigm-neutral methodological support for explaining quality problems in lean six sigma projects. The study was undertaken to develop a new theoretical foundation for organisational diagnosis, learning from diagnostic approaches in other sciences. We have answered questions and evoked new ones, which is common for an exploratory study. We want to highlight three open questions, namely (1) the robustness of our contribution, (2) the relationship between model and facts when generating a hypothesis, and (3) the notion of stochastic behaviour of social systems. As for (1), the robustness of our contribution, we have not conducted many case studies for two reasons. First, this is an exploratory study of the feasibility of an idea for organisational diagnosis. We cannot guarantee that our methodological approach to identify and confirm a causal mechanism will work in another lean six sigma initiative. What we can say is that our methodology is theoretically underpinned, that we found the necessary concepts that comprise the methodology (see Figure 42) in the literature, and that its application was successful in at least one case. We can claim success because we had the opportunity to discuss the intervention management made, based on the information we provided about the causal mechanism. However, we cannot confirm that the way we have augmented the DEMO model was the correct way to identify the causal mechanism. On a more detailed level, did we map the responsibilities for the variables to the correct actors in the organisational construction diagram? It is fair to question the robustness of our contribution? This can only encourage the further development of organisational diagnosis. However, we are convinced that our contributions will lead to more ideas on how to organise organisational diagnosis. The differences between Figure 3 and Figure 42 are a good indicator of the advances that are possible. The second open question regards the relationship between model and facts when generating a hypothesis. We see a paradox: does a model enable us to collect facts more efficiently, or limit us in defining the facts we need for diagnosis? In both case studies, we found that model-based reasoning is a highly systematic and powerful way of deriving plausible hypotheses as to the causes of abnormal organisational behaviour. We also noticed that having a model affects the patterns of selection of the variables of interest in the CTQ flowdown. We are not sure whether a model (e.g. an organisational construction diagram) threatens the ‘out of the box’ drill down pattern in the CTQ flowdown.

Finally, we look at (3) the notion of the stochastic behaviour of social systems. In our research, we have shown mainly how to identify and confirm a causal mechanism.
How would one go about demonstrating causal mechanisms if one included the stochastic behaviour of the individuals that are represented as actors in a discrete event model? And how could simulations of interventions contribute to the methodology? Can we conduct what-if analyses to see how interventions affect the variables of interest?

9.5 Recommendation for future research

In our opinion, organisational diagnosis is one of the most exciting fields to be in right now. It hit its stride when enterprise engineering made its debut a few years ago. Significant advances have already been made in our understanding of enterprise architecture and enterprise ontology. Studies have elucidated the impact of information technology on organisations, at levels ranging from the functional understanding of ICT (Iacob et al. 2002) to the 'atoms molecules and fibres' of organisations (Dietz 2003). Together this large body of work provides a picture of how enterprise architecture and ontology can be engineered.

The new picture of the engineered enterprise is an argument for a stronger focus on the organisational diagnosis of defectively engineered enterprises. This may seem to be an abstract issue, but in the praxis of lean six sigma we may also observe poorly designed business processes. In this praxis, it is no exception that experts design – without first making a full causal analysis – a new business process and then show afterwards that it works satisfactorily. Enterprise engineering can help us to build on the strengths of the proposed organisational diagnosis approach and at the same time to improve on a trial-and-error approach when confronted with poorly designed business processes. The motto should be: diagnose before redesign. We propose a research agenda which can meet the following challenges: (1) to formalise organisational diagnosis as a methodology, (2) to explore and design solutions for specific steps in the diagnosis methodology, (3) to test the proposed methodology more thoroughly in other lean six sigma initiatives and (4) to clarify the mutual dependency between the functional and constructional perspective in diagnosis.

We hope that our research will open new paths to formalise organisational diagnosis as a methodology. We recognise that the integration of concepts coming from different fields may be difficult and will take time, but we think it will be a beneficial exercise, for both communities – enterprise engineering and organisational diagnosis. On the one hand, the use of causal mechanisms can improve organisational diagnosis. On the other, the literature on causality in the sciences has not investigated enterprise engineering, so fruitful exchanges can also be foreseen in that direction.
To extend this research in the direction of formalisation, we recommend focusing on solutions for specific steps in the diagnosis methodology. For example, triangulation design principle five requires a diagnostician to identify which actor is responsible for managing a variable’s value. We need heuristics, or even a theory, for detecting these responsibilities. Furthermore, we need instruction to augment DEMO aspect models with this information, since this is a promising way of identifying causal mechanisms. Also, the procedure to identify a causal mechanism from a DEMO model deserves further research. Here we see a promising parallel in the scientific work on diagnosing discrete event systems. A parallel exists because a DEMO model is technically a stochastic discrete event system and offers a discrete state space to determine plausible explanations for unwanted behaviour. Therefore, we can learn from abstract work on diagnosing stochastic discrete event systems such as: the efficient diagnosis of large scale discrete event systems (Schumann 2007); diagnosing coordination faults in multi-agent systems (Kalech and Kaminka 2005; Kalech 2009) and; the diagnosability of stochastic discrete-event systems (Thorsley and Teneketzis 2005; Zimmermann 2008).

To improve the reliability of organisational diagnosis, extended and thorough testing of the proposed methodology in more lean six sigma initiatives is needed. Existing case studies could be used, or closed case studies where a researcher in retrospect has access to information to create a DEMO model. The cases would show to what extent the methodology allows the identification and confirmation of a causal mechanism. Such research could be abductive, such as observing the contribution of triangulation by introducing a DEMO model for augmentation, and comparing the results before and after an intervention. Other future research could be exploratory, answering questions such as “How does an available DEMO model affect the formulation of quality problems in the define phase?” or “would revealing the activation philosophies of the self-activating actors speed up the identification of causal mechanisms?”. Attention could also be given to the usability of the methodological prescriptions. At issue is the richness of the descriptive model. A 'good' method describes a wide variety of situations and solutions, and a 'bad' method has a limited expressive and explanatory capacity. An all-encompassing formal description seems a solution, but at the risk of requiring complex and nuanced language. This aspect should be monitored and tested in future case studies.

Nothing in this research has taken more time than clarifying the mutual dependency between the functional and constructive perspectives when diagnosing. The problem is the lack of a specification or ontology that is common to the various disciples involved in this research. Functionality, in enterprise engineering, is a perspective from ‘the eye of the beholder.’ Objects are referred to
by stating their function (e.g. this is a washing machine). In the debate on causality, we find statements such as “the role of this part is ….” Can we consider a function? And, if this is not complex enough, is the CTQ flowdown for specifying the variables of interest in lean six sigma projects also a functional perspective? We have treated the CTQ flowdown as an exclusively functional perspective and business communication as an exclusively constructional view, but this is only a temporary solution. In the long term the risk of not specifying what is functional and what is constructional will undermine the expressive and explanatory capacity of a prescriptive diagnostic methodology. To address this problem, we recommend looking at the results of the Dual Nature of Technical Artefacts’ research program (2000-2005), in which researchers analysed technical artefacts as having both structural and intentional natures, with functions playing an important role in linking these natures (Houkes and Vermaas 2002; Houkes and Meijers 2006; Houkes and Vermaas 2010). In our opinion, the deliverables in this research programme are not influenced by enterprise engineering, organisational diagnosis or lean six sigma, and therefore offer a neutral stance for future research on this subject.

To the extent that adopting a causal mechanism-driven organisational diagnosis approach – for its greater explanatory power – represents a significant change in management science and practice, we propose that the change requires that both philosophers of causality and management scientists must be convinced that current diagnostic practices in management science are not working (discrepancy); that evidence-based diagnosis on the basis of both statistics and laws is the correct path (appropriateness); that intelligible explanation requires a constructional perspective (efficacy); that leaders in both fields should be committed to the change (principal support); and that the change should be beneficial to themselves (valence). We hope to encourage a change in practice by acknowledging the issues above and by shedding some light on both the appropriateness and efficacy of explaining by using causal mechanisms.
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Organisations increasingly apply organisational diagnosis to cope with volatile markets and fast-changing customer preferences. Organisational diagnosis is concerned with finding causal explanations for organisational problems. Without an adequate understanding of the root causes of a problem, decision makers cannot efficiently correct it. The main challenge for organisational diagnosticians is to deal with many possible explanations and the many ways to demonstrate causality. Since interventions in organisations can have major consequences, diagnostician will seek methodologies to avoid mistakes in drawing conclusions that might lead to unwanted results for decision makers.

Reason for this research

The identification and demonstration of causality in the sciences is changing. New developments in philosophy regarding validity claims about causality provide a starting point to question existing methodologies in organisational diagnosis. One of the developments in the sciences tells us to identify a causal mechanism (as a mode of explanation) before one can claim to have a theoretical explanation. Another development in the sciences is to apply mixed method research strategies to increase the reliability of the research result. We think that the justifications for these approaches also hold for organisational diagnosis. However, we did not find many studies of the potential of these approaches, proven in other sciences, for the field of organisational diagnosis.

We posit that a well-known methodology in organisational diagnosis, lean six sigma, could benefit from ‘new’ causal approaches developed in the sciences. Lean six sigma is statistically driven: it involves seeking correlations between quality variables and process variables, and on that basis drawing conclusions about quality problems. In the current version of the lean six sigma methodology, there is no methodological support for identifying and demonstrating the cause of a quality problem. Causal mechanisms provide a mode of understanding that has already shown its value in the sciences. Furthermore, we expect that the single evidence approach in lean six sigma will prove less reliable than the mixed method we have termed methodological triangulation. We therefore expect to demonstrate a potential to improve lean six sigma by strengthening its explanatory power and making its results more reliable.
Approach and contribution

We conducted action research in ‘fuzzy front end’ of design science to develop the lean six sigma methodology, beginning with a theoretical basis in organisational diagnosis, mixed methods research strategies and insights into causality gleaned from philosophy. The research was guided by two questions, and yielded the following findings:

1. What are the consequences for the lean six sigma methodology if triangulation and causal mechanism is taken as a starting point?

   The biggest consequence for lean six sigma’s methodology is that its way of thinking should incorporate a ‘causal account.’ Triangulation applies two perspectives to the same problem, and in this thesis, the causal account provides the second perspective. In practical terms, a diagnostician develops a 'causal story' (evidence of production) which is tested against the facts of statistical dependencies between the variables of interest (evidence of difference-making). However, if the 'story' is not grounded in a causal account which models causality in the wider environment, it can be questioned and its validity can be questioned, even if the facts are consistent with the causal story. Causal mechanisms as a mode of explanation also require a theoretical grounding. The available theories of causal mechanisms offer a general format and guidance for validating a causal story. Ideally the diagnostician will use more specific guidance and procedures to ground a claim about causality in a theory suited to the domain in which diagnosis occurs.

   This leads to the second research question:

2. What requirements must lean six sigma satisfy if triangulation with a causal mechanism is applied to 'explain' (i.e. identify and confirm) the cause of a quality problem?

   To develop lean six sigma for organisational diagnosis, the purpose of lean six sigma must be reformulated. We propose:

   • The purpose of lean six sigma is to generate an explanation for a quality problem for informed decision-making in organisational control.

   The involved concepts in this understanding are:

   • an explanation is an identified and confirmed causal mechanism
   • a causal mechanism is an organisation in a system that contains the perceived quality problem.
   • An organisation is a social system that consists of individuals and their interactions.
• A **quality problem** is a situation in which the value of one or more quality variables cannot be successfully controlled within the specified limits.

• A **quality variable** is a measurable characteristic of a product or service that should satisfy a specification.

Based on this new understanding, we tested triangulation with a causal mechanism in two lean six sigma initiatives. Although the number of case studies was limited, we saw significant differences. In the first case study we did not include a causal law; instead we applied the functional modelling approach of ArchiMate to develop evidence of production. In the second case we included the causal account of social systems provided by the Ψ-theory and its axioms from DEMO (Design & Engineering Methodology for Organisations). Triangulation with a causal mechanism led to a grounded explanation that could be confirmed by facts. Because of accepting the Ψ-theory (PSI-theory) and its axioms from DEMO as a causal account on performance in social interactions, we require from a lean six sigma methodology:

• A way of thinking for identifying and confirming (by evidence of difference-making and evidence of production) a claim about a causal mechanism.

• A way of working focusing on obtaining **evidence of difference-making**.

• A way of modelling focusing on obtaining **evidence of production**.

• A way of controlling that applies **triangulation** design principles to guide and control methodological triangulation in lean six sigma.

• A way of supporting that offers the necessary tools to support the activities of observing, analysing and explaining in organisational diagnosis.

The involved concepts in these requirements are:

• **Evidence of difference-making** is information about significant statistical dependencies between two or more variables of the observed system and its environment.

• **Evidence of production** is information about the construction of the observed system, grounded in a causal theory for the domain to which the system belongs.

• **Triangulation** is the convergence of two different kinds of evidence to yield more reliable results than a strategy using one type of evidence.
Methodological proposal and future research

For future research, we present a methodological proposal based on the consequences and requirements we have identified. In this proposal, the three building blocks of triangulation, the causal mechanism and the $\Psi$-theory to provide a theoretical grounding when diagnosing are attuned to one another in such a way that the methodology can satisfy the identified requirements. To build on the strength of this proposal and overcome its limitations, we also present a research agenda: (a) to formalise organisational diagnosis as a methodology; (b) to explore and design solutions for specific steps in the proposed diagnosis methodology; (c) to test the proposed methodology more thoroughly in other lean six sigma initiatives and (d) to clarify more profoundly the mutual dependency between the functional and constructional perspectives. We think this research is urgently needed to enable faster adaptation to changing customer preferences, more reliable explanations for quality problems and efficient decision-making where quality must be restored.

Roland
Samenvatting

Binnen de organisatie diagnostiek houden experts zich bezig met het vinden van causale verklaringen voor organisatorische problemen. Een goede diagnose levert inzicht op in de diepere oorzaken van een probleem waardoor de kans toeneemt dat men succes boekt met de juiste interventies. De grootste uitdaging hierbij is dat er ontzettend veel oorzaken aangewezen kunnen worden en dat de wijzen waarop de causaliteit tussen oorzaak en gevolg op legio manieren voor het voetlicht kunnen worden gebracht. Omdat interventies binnen organisaties grote gevolgen kunnen hebben is het dus noodzakelijk dat een diagnosticus gebruik maakt van een methodologie om op een zorgvuldige wijze een oorzaak en gevolg relatie voor een organisatorisch probleem vast te stellen.

Reden voor dit onderzoek

Met name enkele recente ontwikkelingen binnen de filosofie aangaande geldigheidsaanspraken voor causaliteit, die o.a. worden toegepast binnen de sociale wetenschappen en de natuurwetenschappen, vormen een bruikbare basis voor het onderzoek van dit proefschrift. Deze geldigheidsaanspraken stellen dat er een veroorzakend mechanisme aangeduid moet kunnen worden om van een theoretische verklaring van een oorzakelijke verband tussen variabelen te kunnen spreken. Een andere ontwikkeling is de trend in onder wetenschappers om twee of meer verschillende onderzoeksstrategieën parallel aan elkaar uit te voeren om vervolgens de resultaten onderling te vergelijken. Op deze wijze kan de betrouwbaarheid van een onderzoeksresultaat worden verhoogd. Deze aanpak staat in de literatuur bekend als triangulatie.

Binnen dit onderzoek bestuderen wij de toepasbaarheid van deze ‘nieuwe’ benaderingen aangaande geldigheidsaanspraken voor causaliteit voor de lean six sigma methodiek. Lean six sigma is een statistiek gedreven aanpak, het zoekt naar correlaties tussen kwaliteitsvariabelen en procesvariabelen, en poogt daaruit conclusies te trekken m.b.t. kwaliteitsproblemen. In de huidige versie van de lean six sigma methodiek worden deze ‘nieuwe’ benaderingen nog niet toegepast ondanks hun potentieel. Zo heeft veroorzakend mechanisme haar waarde als format voor een causale geldigheidsaanspraak binnen diverse wetenschapsgebieden laten blijken. Triangulatie laat zien dat het een adequate onderzoeksstrategie is waarmee de betrouwbaarheid van een onderzoek kan worden...

13 Deze samenvatting is uitgebreider dan de ‘Summary’
verhoogd. We verwachten daarom dat dit potentieel ook verzilverd kan worden binnen de lean six sigma aanpak.

**Aanpak en bijdrage**

Dit onderzoek vond plaats als actiegericht onderzoek (action research) binnen het ‘fuzzy front end’ van een ontwerpgericht onderzoek aanpak (design science). In de ‘fuzzy front end’ vind – volgens van Aken - verkennend onderzoek plaats dat gedaan wordt voordat een ontwerpgericht onderzoek kan plaatsvinden. Dit onderzoek heeft als doel om het speelveld van organisatie diagnostiek minder (fuzzy) te maken waardoor vervolgonderzoek op basis van een ontwerpgericht onderzoeksaanpak kan plaatsvinden. We richten ons op het definiëren van een theoretische basis voor organisatorische diagnostiek, combinatorische onderzoeksmethodes en geldigheidsaanspraken voor causaliteit.

Het onderzoek werd geleid door twee onderzoeksvragen, en leverde de volgende bevindingen:

1. **Wat zijn de consequenties voor de lean six sigma methodologie als triangulatie en het veroorzakend mechanisme als methodisch uitgangspunten wordt aangenomen?**

De grootste consequentie voor de lean six sigma methode heeft de introductie van het veroorzakend mechanisme als format voor causaliteit. Hoewel het idee van een mechanistische verklaring een diagnosticus kan helpen om valkuilen omtrent causaliteit te vermijden volstaat het niet om zich louter mechanistisch uit te drukken. Veel hangt af van hoe het concept veroorzakend mechanisme wordt gebruikt, anders eindigt men met louter verhalen over mechanismen binnen bedrijfsprocessen waarin theoretische precisie en empirische relevantie ontbreken. Een belangrijke voorwaarde om precisie en relevantie te bereiken is dat er gewerkt wordt vanuit een duidelijke causale theorie over acties en interacties binnen bedrijfsprocessen. Op basis van een actie-theorie, zoals die wordt begrepen in de analytische sociologie, kan een model van een veroorzakend mechanisme worden gemaakt dat empirisch kan worden gevalideerd. Conclusies uit die validatie kunnen dan weer via dezelfde actie-theorie nauwkeurig worden geïnterpreteerd en verwerkt totdat het model in voldoende mate overeenstemt met de werkelijkheid. Dit samenspel tussen actie-theorie, model en empirische validatie - met als doel om een mechanistische verklaring voor een kwaliteitsprobleem te vinden – vraagt om meer precisie en duidelijkheid over de wijze van werken en modeleren.

Dit leidt tot de tweede onderzoeksvraag:
2. Aan welke eisen moet de lean six sigma methodologie voldoen als triangulatie wordt toegepast om een veroorzakend mechanisme voor een kwaliteits-probleem vast te stellen?

Om een lean six sigma methodologie voor organisatie diagnostiek te ontwikkelen is het nodig om de doelstelling van de methodiek te herformuleren. Wij stellen voor:

- De doelstelling van de lean six sigma methodologie is het genereren van een verklaring voor een kwaliteitsprobleem voor geïnformeerde besluitvorming in de besturing van een organisatie.

De concepten in deze doelstelling zijn:

- Een **verklaring** is een geïdentificeerd en bevestigd veroorzakend mechanisme.
- Een **veroorzakend mechanisme** is een organisatie dat het kwaliteitsprobleem voortbrengt.
- Een **organisatie** is een sociaal systeem dat uit individuen en hun interacties bestaat.
- Een **kwaliteitsprobleem** is een situatie waarin de waarde van een of meer kwaliteitsvariabilen niet met succes kan worden gecontroleerd binnen de gestelde grenswaarden.
- Een **kwaliteitsvariabele** is een meetbaar kenmerk van een product of dienst die moet voldoen aan een specificatie.

Op basis van deze nieuwe doelstelling en concepten is triangulatie getest in twee lean six sigma initiatieven. Hoewel het aantal casestudies beperkt is zien we significante verschillen.

In de eerste casus (Zwitserleven - Pensioenfonds) hebben we vastgesteld dat triangulatie met de daarin toegepaste onderzoeksmethoden (lean six sigma en ArchiMate) het doel, namelijk het vaststellen van een veroorzakend mechanisme voor een kwaliteitsprobleem, niet kan worden bereikt. De eerste reden is dat lean six sigma zich beperkt tot het vaststellen van correlaties en het concept causaliteit niet kent. De tweede reden is dat functionele modellen – in dit geval een ArchiMate model van het onderzochte productiesysteem – niet geschikt is om een veroorzakend mechanisme te vinden. Een functioneel model is namelijk een weergave van een opvatting over functies van een productiesysteem. Daarmee is een functioneel model geen objectief middel om een veroorzakend mechanisme te identificeren omdat iedere stakeholder een functionele opvatting over het bestudeerde sociale systeem kan hebben.
Deze tekortkomingen werden gekaderd in de ontologische systeemtheorie. Uit deze theorie komt naar voren dat gedrag alleen kan voortkomen uit de constructie van een systeem. Een constructie is de compositie (de verzameling componenten) en de structuur (de interactie tussen die componenten) van een systeem. In de constructie ligt de werking van het systeem, dat is de inwendige manifestatie van het systeem-in-operatie, dus wat er inwendig gebeurt als het systeem in bedrijf is, besloten. De systeemtheorie stelt verder dat er maar één constructie van een systeem kan zijn maar dat een systeem meerdere functies kan hebben. Deze stellingname in de systeemtheorie betekent dat er een antwoord is voor de in de eerste casus vastgestelde tekortkomingen namelijk het toepassen van een constructionele systeem oriëntatie op een productiesysteem.

Een constructionele systeem oriëntatie op een productiesysteem is mogelijk door toepassing van de $\Psi$-Theorie (PSI-Theorie), deze theorie over performantie in sociale interacties ligt ten grondslag aan de notie van Enterprise Ontologie. Deze theorie is praktisch toepasbaar via de DEMO-aanpak. Met behulp van de DEMO-aanpak kan een constructiemodel van een productiesysteem op objectieve wijze worden vastgesteld. Om een uitspraak te kunnen doen of DEMO geschikt is om een oorzaak van een kwaliteitsprobleem vast te stellen is gekozen om dit in de praktijk middels een tweede casus (Merck) vast te stellen. In de tweede casus is triangulatie toegepast op basis van de onderzoeksmethoden lean six sigma en DEMO. In de praktijk binnen de tweede casus hebben we kunnen vaststellen dat door toepassing van een constructieve systeem oriëntatie een oorzaak voor een kwaliteitsprobleem – in de vorm van een veroorzakend mechanisme - kan worden gevonden.

In de reflectie op de tweede casus is vastgesteld dat beide methoden (lean six sigma en DEMO) een eigen rol vervullen bij het vaststellen van een veroorzakend mechanisme. Lean six sigma levert informatie over correlaties tussen procesvariabelen en kwaliteitsvariabelen. Door deze informatie eenduidige op te nemen in een DEMO-constructiemodel van het productiesysteem is het niet alleen mogelijk om een oorzaak voor een kwaliteitsprobleem te vinden maar men kan de gevonden oorzaak ook op geldigheid controleren. Een controle op de geldigheidsaanspraak is mogelijk doordat de onderzoeksaanpak van casus twee drie evaluaties op een hypothese voor een oorzaak van een kwaliteitsprobleem toelaat namelijk: (1) een statistische evaluatie; (2) een epistemische evaluatie en (3) een ontologische evaluatie. In casus een bleek dit niet uitvoerbaar, we leggen het verschil in de volgende paragraaf uit.

In beide casussen was een statistische evaluatie mogelijk omdat de resultaten van metingen gevalideerd kunnen worden door nieuwe metingen en nieuwe analyses. Echter, alleen in casus twee was epistemische evaluatie op een hypothese over een
veroorzakend mechanisme mogelijk door toepassing van de PSI-Theorie. Met behulp van de PSI-Theorie is het mogelijk om te controleren of het mechanisme consistent is met een theorie over sociale interacties. Dit is in casus 1 onmogelijk vanwege het ontbreken van een actie-theorie en de subjectiviteit van functionele modellering. Daarnaast bleek in casus twee een ontologische evaluatie op het mechanisme mogelijk namelijk door te bepalen of oorzaak en gevolg binnen het mechanisme door de constructie is bepaald en niet door aannames. De drie evaluaties zijn in onze ogen belangrijke onderzoeksresultaten die we meenemen een ontwerp voor een nieuwe aanpak waarin het vinden van een veroorzakend mechanisme voor een kwaliteitsprobleem centraal staat.

Op basis van de acceptatie van de PSI-theorie (incl. axioma’s) als causale theorie over sociale interacties stellen wij in dit proefschrift een diagnose aanpak voor op basis van de volgende requirements:

- Een wijze van denken voor het identificeren en bevestigen van een veroorzakend mechanisme voor een kwaliteitsprobleem op basis van statistische evaluatie en ontologische evaluatie.
- Een wijze van werken gericht op een statistische evaluatie van het kwaliteitsprobleem.
- Een wijze van modeleren gericht op een ontologische evaluatie van het kwaliteitsprobleem.
- Een wijze van controleren o.b.v. triangulatie-ontwerpprincipe waardoor triangulatie op de juiste wijze binnen lean six sigma kan worden toegepast.
- Een wijze van ondersteuning dat instrumentarium aanlevert voor de activiteiten van het observeren, het analyseren en het verklaren.

De concepten in deze requirements zijn:

- **Statistische evaluatie** (verwijzend naar ‘evidence of difference-making’) is informatie over significante statistische verbanden tussen twee of meer variabelen in het geobserveerde systeem.
- **Ontologische evaluatie** (verwijzend naar ‘evidence of production’) is informatie over de constructie van het geobserveerde systeem gebaseerd op een causale theorie voor het domein waartoe het geobserveerde systeem behoord.
- **Triangulatie** is de convergentie van twee verschillende soorten bewijsmateriaal om een betrouwbare onderzoeksresultaat te bereiken t.o.v. een onderzoeksresultaat op basis van enkelvoudig bewijsmateriaal.
Toekomstig onderzoek

Voor toekomstig onderzoek is in het manuscript een methodologisch voorstel gedaan dat is gebaseerd op de consequenties en eisen die wij hebben vastgesteld. In dit voorstel, zijn drie bouwstenen (triangulatie, het veroorzaken mechanisme en de PSI-theorie) zo op elkaar afgestemd dat een kwaliteitsprobleem op een methodologische manier kan worden onderzocht en wel zodanig dat het voldoet aan alle requirements die we hebben verzameld. Om voort te bouwen op dit methodologisch voorstel stellen wij een onderzoek agenda voor om: (a) het verkennend onderzoek uit te breiden met nieuwe casestudies; (b) middels ontwerpgericht onderzoek het ontwerp verder te formaliseren; (c) specifieke stappen in de aanpak te onderzoeken en (d) de relatie tussen de statistische- en ontologische evaluatie verder te specificeren. Wij zijn ervan overtuigd dat dit onderzoek dringend nodig is om onderbouwde en vlotte afwegingen in besluitvorming bij kwaliteitsproblemen mogelijk te maken. Daarnaast vinden we het noodzakelijk dat binnen het vakgebied van de organisatiediagnostiek en specifiek lean six sigma continu gezocht moet worden naar manieren om de betrouwbaarheid van de methodes te verhogen, een oriëntatie naar moderne onderzoeksmethodieken is daarbij cruciaal.

Roland
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Susanne thank you for being my wife. Your unconditional love allows me to enjoy life and to be happy. You supported me so well; it was hard, I will never forget.

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I would like to express my special appreciation and thanks to Hans Mulder, you have been a tremendous mentor for me. I would like to thank you for encouraging my research, helping me in difficult times and for allowing me to grow as a research scientist. Your advice on handling complex academical debates as well as on paradoxes in my professional career have been priceless.

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The case studies discussed in this dissertation would not have been possible without the support of ex-colleagues from Logica Management Consulting (now CGI) and the customer organisations of Zwitserleven (now SNS Reaal) and Schering-Plough (now Merck). I have appreciated their collaboration and the impressive enterprise architecture skills of individuals like Wouter Paul Trienekens, Laurens van Beurden and the lean six sigma skills of Bart Haerkens and Peter Kesseler.

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Finally, I would like to thank my parents. Mom I miss you, I know you would be proud today. Thank you both, for all the opportunities you have given me.

Roland W. Ettema
Roland Ettema (1971) received his Masters degree in E-Technology at the University of Middlesex in 1996 and started working for GET B.V. From 1997 he worked at Atos Origin for two years, three years as an independent contractor, and more than eight years for Logica Management Consulting. He joined the Open University in 2011, where he works today as the information manager and quality manager at the university office.

Roland is specialised in reshaping organizations, business processes and information technology. In more recent years Roland has specialised himself in the topic of organisational diagnosis, quality improvement and change management. In addition to his professional career Roland invested time in the development of several disciplines. For example, he worked with the founders of ArchiMate, which achieved a formal status in the OpenGroup as enterprise architecture modelling standard. Worked as an external Ph.D. candidate on the development of DEMO and started successfully a special interest group in LogicaCMG for lean six sigma.

Roland is married with Susanne Ettema-Jacobs and has two children, Bibi and Noël.
Enterprise Engineering Network

Background
The Enterprise Engineering Network (EE Network, www.ee-network.eu) is a research and training network targeting PhD candidates and research fellows. Next to the supervision of PhD candidates and research fellows, the main activities of the network involve:

- Research seminars;
- Events targeting interaction with practitioners;
- Events targeting interaction with M.Sc. students;
- Development of a joint curriculum for EE Network researchers and associated courses;
- Co-organisation of scientific events.

The hosts of the network are also concerned with formulating and conducting joint research projects. Yet, the EE Network itself focuses on the actual training activities. The history of the EE Network, and its direct predecessors, can be traced back to 2001. It is currently hosted at five locations:

1. **Headquarters:** IT for Innovation Services department of the Luxembourg Institute of Science and Technology, Belval, Luxembourg;

2. Model Based System Development department of the Institute for Computing and Information Sciences of Radboud University, Nijmegen, the Netherlands;

3. HAN University of Applied Science, Arnhem, the Netherlands;

4. Information Systems Architecture group of Utrecht University of Applied Science, Utrecht, the Netherlands;

5. Individual and Collective Reasoning and Model Driven Engineering groups of University of Luxembourg, Luxembourg, Luxembourg.
To enable a practical operation of the training activities, in particular in for the research seminars, the EE Network has a traditional geographical focus on the Rhine-Scheldt-Meuse-Moselle basin, which includes the Low Countries (Belgium, Netherlands and Luxembourg), the Rhineland in Germany, as well as Lorraine in France.

**Finished dissertations**
Dissertations produced in the EE Network, and its direct predecessors, include:


**2015-2**  L.J. Pruijt, *Instruments to Evaluate and Improve IT Architecture Work*, University of Utrecht, Utrecht, the Netherlands, November 25, 2015.

**2015-1**  D.J.T. van der Linden, *Personal semantics of meta/concepts in conceptual modeling languages*, Radboud University Nijmegen, Nijmegen, the Netherlands, February 13, 2015.


**2014-1**  F. Tulinayo, *Combining System Dynamics with a Domain Modeling Method*, Radboud University Nijmegen, Nijmegen, the Netherlands, January 27, 2014.


**2013-1**  R. Wagter, *Enterprise Coherence*, Radboud University Nijmegen, Nijmegen, the Netherlands, November 19, 2013.


**2009-2**  S. Overbeek, *Bridging Supply and Demand for Knowledge Intensive Tasks*, Radboud University Nijmegen, Nijmegen, the Netherlands, April 24, 2009.


This study is a response to common logical errors due to the conflation of causality and correlation in lean six sigma projects. The incidence of non-sustainable results from lean six sigma projects indicates the serious consequences of drawing conclusions based only on statistical analysis. To avoid these problems we need a methodological approach to reading causality from observational data.

Inspired by the trend in social science, and, in particular, analytical sociology, to put causal mechanisms at the centre of causal assessment, we advocate a causal mechanisms centred triangulation approach for lean six sigma. Lean six sigma can benefit if it triangulates (combines) its statistical approach with organisational modelling to identify and demonstrate a causal mechanism for the studied quality problem. Based on triangulation we may achieve more credible causal readings from observational data.

To experiment with triangulation with new ways to demonstrate causality from the sciences, we applied action research in real-life lean six sigma projects in which enterprise architecture and enterprise ontology are used. The goal orientation of identifying a causal mechanism as an explanation for a quality problem, the experiences with triangulation, and the hypothetico deductive way of thinking when combining evidences are valuable insights that offer future scientists arguments to improve the lean six sigma approach towards methodological support for explaining quality problems.

Roland Ettema (1971) works as quality manager and information manager at the university office of the Open University. He conducts research and is involved in education at several academic institutions.