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Title: Developing a Lean Value Creation Benchmark

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Introduction
Lean Manufacturing is a widely used business philosophy originating in the automotive industry. After the initial success by Toyota and the rest of the industry, it is now steadily being implemented in a wide field of other industries. Lean Manufacturing is also called the Lean Philosophy when used in a more abstract environment or just Lean to capture all associated aspects. The Lean Philosophy focusses on determining value creating activities and eliminating all non-value creating activities, also designated as waste. Many practices and techniques were and are developed to aid in the Lean process. Some examples are: Just-In-Time (JIT), Kaizen, Seven Wastes, Kanban.

Problem definition
Many companies are now in varying stages of Lean implementation and the need arises for a method of comparing their performances. With such a method, companies can monitor their relative Lean Manufacturing performance and steer their actions accordingly. A general method for measuring Lean performance does not exist, although many (partial) attempts have been made in academic literature and practice. These attempts often resulted in long lists of indicators which is unwieldy and obscures the real trends and mechanism at play. To prevent this, this research will be focusing on the value creation aspect of Lean using only quantitative measures. The benchmark method to be developed should also only use publicly available information in order to be practically useful.

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The professor,

Prof. dr. ir. G. Lodewijks
Summary

Lean Manufacturing is a widely used business philosophy originating in the automotive industry. After the initial success by Toyota and followed by the rest of the industry, it is now steadily being implemented in a wide field of other industries. Many companies are now in varying stages of Lean implementation and the need arises for a method to compare their performances. The goal of this thesis research is, subsequently, to develop a benchmark which enables comparing the Lean performance of companies from varying industries to each other. A definition of Lean was formulated, based on work by Womack and Jones (Womack and Jones, 2003), which provided constraints on the scope of this research. The Lean definition is formulated as follows: Lean is a process of eliminating waste with the goal of creating value for the customer. This definition shows the importance of value creation in a Lean company and thus the scope is narrowed to the Lean value creation aspect. The research is further constrained in using only publicly available figures (Annual Reports) in order to provide an easy to use benchmark model. It was determined through a literature study that value creation will be expressed in terms of ratio’s to turnover and profit because these two variables represent two types of value produced by a company. The nature of the indicators, being ratio’s to turnover or profit, also provides indicators which measure the Lean concept of Flow. This results from the fact that turnover and profit are measured on a yearly basis and this provides a time aspect to the measurements.

Nine Lean value creation indicators were selected from the literature (T/E, T/I, T/PPE, T/R&D and P/T, P/E, P/I, P/PPE, P/R&D) which can be grouped into five characteristics: Human Resources (T/E and P/E), Process Flow (T/I and P/I), Physical Means (T/PPE and P/PPE), Innovation Capability (T/R&D and P/R&D) and Financial Performance (P/T). The automotive industry was used as used to create the Lean Value Flow Performance Benchmark. All nine indicators were statistically analyzed using the automotive dataset and all the profit based indicators showed a very large degree of correlation to each other. This turned out to be caused by the much higher data spread exhibited by the profit variable. The other trends in the other variables are overwhelmed by the profit variable which results in the profit indicators mostly measuring just the trends of the profit variable itself. These indicators were subsequently dropped for further use in the benchmark except for the profit margin indicator (P/T). This indicator was kept because it relates to the turnover instead of company characteristic variables and provides a means of measuring the profitability of the company.

A further in depth analysis of the resulting indicators (T/E, T/I, T/PPE, T/R&D and P/T) it was found that the T/R&D indicator possibly showed divergent behavior from the other indicators. The intrinsic assumption is that a higher value for an indicator relates to a higher performance by that company. The T/R&D indicator showed constrained behavior from which it was suspected that companies actively manage the R&D expenditure rate. The result was that companies with very high values most likely did not represent strong performers but exhibit other causes that influence the company. This suspicion was further strengthened by the subsequent analysis of the benchmark scores and together with the lack of available data from the case studies it was decided to drop the indicator. The other indicators showed a consistent enough distribution with the automotive dataset to be included in the final Lean Value Flow Benchmark. The benchmark was ultimately tested using six case studies for its practical usefulness. The case studies consisted of two automotive companies (Porsche and Daimler (Mercedes-Benz)), three non-automotive manufacturing companies (SEW Eurodrive, Lely Industries and Intergas Verwarming) and one supplier to manufacturing companies of industrial MRO products (Brammer Group). The case studies showed that the automotive companies can be readily compared to the automotive benchmark dataset which shows its intra-industry application. The T/PPE indicator turns out to show vastly higher values for the non-automotive case studies than with the automotive companies. This indicator dominates the total benchmark scores for these companies which gives them a unrealistic performance score. Through an indepth analysis it was investigated if the high T/PPE scores were caused by the relatively smaller size of the non-automotive
companies or by their large growth values over the measured period. But this most likely is not the case and the indicator behavior then probably shows other characteristic values for other industries. More research with larger datasets is needed to confirm this. The P/T indicator showed to prone to outliers caused by sudden swings the amount of profit by a company. The benchmark scoring method turned out to be very sensitive to these outliers and thus rewarded these companies very high values in these cases. This distorted the performance scores for the P/T indicator and thus it is recommend to re-evaluate the scoring method or the indicator to mediate this effect. T/E and T/I turned out to show consistent results and are readily applicable for use in this benchmark.

It is concluded that the current innovation indicator T/R&D shows complex behavior and should be altered or replacement with another innovation indicator. The ratio of turnover to Property, Plant and Equipment turns out to show different behavior in non-automotive companies and could signal different characteristics in different industries. More research is recommend to investigate these results. The P/T and the profit as a whole show much larger data spread than the other indicators and a method should be developed to mediate this spread. The T/E and T/I indicators showed consistent behavior and can be readily applied using this benchmark method.
Summary (in Dutch)

Lean Manufacturing is een wijdverbreide bedrijfsfilosofie die oorspronkelijk in de auto industrie ontwikkeld is. Na het initiële succes bij Toyota werd het snel overgenomen door de rest van de industrie en wordt tegenwoordig veel verschillende typen bedrijven geïmplementeerd. Veel bedrijven bevinden zich nu in verschillende stadia van Lean implementatie en daardoor een behoefte ontstaan voor methode om de bedrijfsprestaties onderling te kunnen vergelijken. Het doel van dit onderzoek vloeit hier uit voort en wordt als volgt omschreven: Ontwikkel een benchmark methode waarmee uiteenlopende bedrijven hun Lean prestaties kunnen vergelijken. Als basis voor het definiëren wat Lean is voor dit onderzoek, is er een definitie geformuleerd gebaseerd op het werk van Womack en Jones (Womack and Jones, 2003). Deze definitie luid als volgt: Lean is een proces van het elimineren van verspilling en het creëren van waarde vanuit het oogpunt van de klant. Deze definitie heeft als effect dat het onderzoekskader vernauwt kan worden naar het specifieker onderwerp Lean waarde creatie. Het belang van waarde creatie volgt direct uit de definitie en vormt de basis voor het selecteren van indicatoren voor de benchmark. Een ander voorwaarde is dat alleen publiek beschikbare informatie (jaarverslagen) gebruikt mag worden zodat de benchmark makkelijk toe te passen en uit te breiden is. Door middel van een literatuur studie is er geconcludeerd dat waarde creatie uitgedrukt dient te worden in ratio’s (verhoudingen) van omzet en winst met andere variabelen. Doordat de omzet en de winst per jaar worden gemeten zullen de daaruit volgende indicatoren een tijdselement hebben. Hierdoor kunnen deze indicatoren ook geïnterpreteerd worden vanuit het belangrijke Lean concept genaamd Flow (Stroming). De naam van de benchmark wordt hierdoor als volgt geformuleerd: Lean Waarde Stroming prestatie benchmark.

Uit de literatuur studie worden vervolgens negen indicatoren geselecteerd die Lean waarde creatie meten. Deze indicatoren zijn T/E, T/I, T/PPE, T/R&D en P/T, P/E, P/PPE, P/R&D en kunnen onderverdeeld worden in de vijf volgende karakteristieken: Menselijk Kapitaal (T/E en P/E), Innovatie Capabeliteit (T/R&D en P/R&D), Proces Doorstroming (T/I en P/I), Fysieke Middelen (T/PPE en P/PPE) en Financiële Prestatie (P/T). The auto industrie zal dienen als de basis voor de benchmark dataset. Alle negen indicatoren zijn vervolgens statistisch geanalyseerd met behulp van deze dataset en daaruit kwam als eerste resultaat dat de winst indicatoren een zeer grote correlatie laten zien met henzelf. Dit wordt veroorzaakt door de grotere dataspreiding van de winst variabele waardoor deze de trends in de andere variabele overschaduwt. De winst indicatoren correleren dus sterk met elkaar omdat ze voornamelijk de winst zelf meten. Hierdoor zijn deze indicatoren niet bruikbaar voor deze benchmark en zullen ze verder buiten beschouwing gelaten worden. Alleen de winst marge (P/T) wordt meegenomen omdat deze gerelateerd is aan de omzet en zodoende belangrijke informatie verschaf zodat de winstgevendheid van de onderneming.

De overgebleven indicatoren (T/E, T/I, T/PPE, T/R&D en P/T) worden vervolgens onderzocht doormiddel van gerichte statistische en kwalitatieve analyses. Daaruit kwam naar voren dat de T/R&D indicator fundamenteel ander gedrag vertoont dan de andere indicatoren. The intrinsieke aanname in dit onderzoek is dat een hogere waarde van de indicator ook een hogere prestatie vertegenwoordigt van het bedrijf. Het blijkt dat in het geval van de T/R&D indicator, bedrijven waarschijnlijk actief de waarde R&D uitgaven beïnvloeden om die op hetzelfde relatieve peil te houden. Hierdoor zijn bijzonder hogere waardes eerder een oorzaak van andere invloeden op de bedrijfsvoering dan een teken van verbeterde prestaties. Deze observatie werd onderbouwd door resultaten uit de daaropvolgende analyse van de benchmark score. Omdat er ook een gebrek aan R&D cijfers voor de case studies beschikbaar was werd er besloten dat T/R&D niet verder onderzocht zou worden en ongeschikt is in zijn huidige vorm voor de benchmark.

De andere indicatoren lieten wel consistent genoeg gedrag zien in de auto industrie dataset en dus meegenomen in de uiteindelijke Lean Waarde Stroming Benchmark. De benchmark werd vervolgens getest aan de hand van zes case studies. Twee case studies bestaan twee auto bedrijven (Porsche en
Daimler(Mercedes-Benz)), drie bestaan uit niet-autofabrikanten(SEW Eurodrive, Lely Industries en Intergas Verwarming) en één case studie werd gevormd door een distributeur van werktuigbouwkundige componenten (Brammer Group). De case studie analyse liet zien dat de benchmark goed presteert in het vergelijken van de prestaties van de autofabrikanten onderling. De T/PPE indicator daarentegen liet heel verschillende gedrag zien bij autofabrikanten en niet-autofabrikanten. De niet-autofabrikanten bedrijven scoorden zeer veel hogere waarden op deze indicator dan de auto bedrijven. De scores van deze indicator domineerden dan ook de totaal scores van de niet-autofabrikanten waardoor zij onrealistisch hoge prestaties kregen toebedeeld. Met een gerichte analyse van de T/PPE indicator werd er onderzocht of deze verschillen werden veroorzaakt door de grootte van de bedrijven (de niet-autofabrikanten hebben relatief kleine omzetten) of door de grote groeicijfers van deze bedrijven. Het bleek dat beide potentiële oorzaken niet eenduidig dit verschil verklaarden en dus moet de oorzaak waarschijnlijk gezocht worden in het feit dat niet-autofabrikanten andere karakteristieken vertonen op dit gebied. Meer onderzoek met uitgebreidere datasets is nodig om deze potentiële verklaring aan te kunnen tonen. The P/T indicator liet zien dat het onderhevig is aan zogenoemde uitschieters in de dataset. Door de werking van benchmark score berekening worden deze uitschieters sterk beloond waardoor de rest van resultaten genivelleerd worden. Het wordt dus aanbevolen om of de benchmark bereken methode te herevalueren of om de P/T indicator en de andere winst indicatoren te bewerken op zo’n manier dat deze uitschieters weg gefilterd worden. De T/E en T/I indicatoren bleken wel rechtstreeks bruikbaar te zijn om bedrijven van allerlei achtergronden met elkaar te kunnen vergelijken. Deze kunnen dus zondermeer gebruikt worden in deze en andere benchmarks.

Er kan uiteindelijk geconcludeerd worden dat de huidige T/R&D indicator niet geschikt is om in zijn huidige vorm gebruikt worden in de Lean Waarde Stroming prestatie benchmark. De indicator laat fundamenteel ander gedrag zien en zal aangepast of vervangen moeten worden door een andere indicator die de innovatie capabiliteit meet. De ratio tussen omzet en PPE blijkt potentieel andere karakteristieke waarden te vertonen tussen de auto en de niet-auto industrie. Meer onderzoek met grotere datasets van andere industrieën is nodig om deze bevinding te onderbouwen en verder te onderzoeken. De P/T en andere winst indicatoren laten een (te) grote dataspreiding zien waardoor deze minder of niet bruikbaar zijn in de huidige methode. Een methode om de dataspreiding te onderdrukken zal waarschijnlijk nodig zijn om deze indicatoren bruikbaar te maken. De omzet per werknemer(T/E) en de voorraad omloop (T/I) indicatoren blijken wel goed bruikbaar om bedrijven met verschillende achtergronden te vergelijken via deze benchmark methode.
List of abbreviations

T  – Turnover or Revenues
P  – Profit or specifically the EBIT(earnings before interest and taxes)
E  – Employees, number of
I  – Inventory, the financial value of
PPE – Plant, Property and Equipment, the financial value of
T/E  – Turnover per Employee
T/I  – Turnover per Inventory also called the inventory turnover
T/PPE  – Turnover per Plant, Property and Equipment
T/R&D  – Turnover per R&D expenses
P/T  – Profit to turnover ratio, also called the profit margin
## Contents

Summary ........................................................................................................................................... 4
Summary (in Dutch) ................................................................................................................................. 6
List of abbreviations ............................................................................................................................. 8

1. Introduction ...................................................................................................................................... 11
   1.1. Problem Definition .................................................................................................................. 12
   1.2. Research Question .................................................................................................................. 13

2. Literature ......................................................................................................................................... 14
   2.1. The Lean Philosophy ............................................................................................................... 14
   2.2. Value Creation .......................................................................................................................... 15
   2.3. The Concept of Flow ................................................................................................................. 16
   2.4. Indicators .................................................................................................................................. 17
   2.5. Conclusions .............................................................................................................................. 20

3. Methodology .................................................................................................................................... 22
   3.1. Data Set ..................................................................................................................................... 22
   3.2. Variables ..................................................................................................................................... 24
   3.3. Linear Regression Analysis ........................................................................................................ 24
   3.4. Benchmark Score Calculation ................................................................................................... 25

4. Analysis ............................................................................................................................................ 26
   4.1. Bivariate Correlation Analysis ................................................................................................ 26
   4.2. Continuous Improvement: Indicator growth ............................................................................ 30

5. Indicator Analysis ............................................................................................................................ 32
   5.1. T/E ............................................................................................................................................. 33
   5.2. T/I ............................................................................................................................................. 36
   5.3. T/PPE ....................................................................................................................................... 39
   5.4. T/R&D ...................................................................................................................................... 42
   5.5. P/T ........................................................................................................................................... 45

6. Benchmark ....................................................................................................................................... 48
   6.1. Results ....................................................................................................................................... 48
   6.2. Research and Development ....................................................................................................... 51
   6.3. Conclusion ................................................................................................................................. 53

7. Case Studies ..................................................................................................................................... 54
   7.1. Introduction ............................................................................................................................... 54
   7.2. The Lean Value Flow Performance Score ................................................................................. 56
   7.3. T/E ........................................................................................................................................... 59
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.4. T/I</td>
<td>61</td>
</tr>
<tr>
<td>7.5. T/PPE</td>
<td>63</td>
</tr>
<tr>
<td>7.6. P/T</td>
<td>66</td>
</tr>
<tr>
<td>7.7. Conclusions</td>
<td>68</td>
</tr>
<tr>
<td>8. Conclusion</td>
<td>70</td>
</tr>
<tr>
<td>8.1. Conclusions</td>
<td>70</td>
</tr>
<tr>
<td>8.2. Recommendations</td>
<td>72</td>
</tr>
<tr>
<td>References</td>
<td>73</td>
</tr>
<tr>
<td>Appendix A</td>
<td>75</td>
</tr>
<tr>
<td>Appendix B</td>
<td>83</td>
</tr>
<tr>
<td>Appendix C</td>
<td>85</td>
</tr>
<tr>
<td>Appendix D</td>
<td>86</td>
</tr>
<tr>
<td>Appendix E</td>
<td>87</td>
</tr>
<tr>
<td>Appendix F</td>
<td>90</td>
</tr>
<tr>
<td>Appendix G</td>
<td>102</td>
</tr>
<tr>
<td>Appendix H</td>
<td>103</td>
</tr>
<tr>
<td>Appendix I</td>
<td>108</td>
</tr>
</tbody>
</table>
1. Introduction

This thesis research will investigate the topic of Lean performance measurement with the specific focus on Lean implementation, value creation and the Lean concept of “flow”. Through a rigorous analysis, a performance measurement benchmark model will be presented called the “Lean Value Flow Performance Benchmark”. The benchmark model will be developed from literature and theory and subsequently tested through case studies. The benchmark consists of a representative dataset of automotive companies because this industry is seen as a prime example of Lean Manufacturing. The research concludes with how well the proposed benchmark model performed and what aspects could be improved.

In this chapter, the problem definition, research goal and research questions will be covered. Chapter 2 will present a literature study on the Lean philosophy, value creation and potential indicators. At the end of the chapter the selected indicators for further research are presented. Chapter 3 covers the methodology of the statistical analysis and benchmark construction. Chapter 4 and 5 constitute the (statistical) analysis of the proposed indicators, their constituent variables and the gathered automotive benchmark dataset. Indicators which do not perform as expected, e.g. because of too much statistical noise, will be dropped and the resultant set of indicators used in the benchmark model. In Chapter 6 the benchmark will be constructed from the automotive dataset and qualitatively analyzed. The practical use and implications will be tested in Chapter 7 by means of six case studies. Two case studies comprise automotive companies, three case studies consist of non-automotive manufacturing companies and one case study figures a supplier of products to the manufacturing industry. Chapter 8 presents the final conclusions and recommendations.

This research will contribute to the field of Lean performance measurement by investigating the potential use of indicators which measure Lean value creation and presents a benchmark model with which companies can compare their performances to each other.
1.1. Problem Definition

Lean Manufacturing is a widely used business philosophy originating in the automotive industry. After the initial success by Toyota and followed by the rest of the industry, it is now steadily being implemented in a wide field of other industries. Many companies are now in varying stages of Lean implementation and the need arises for a method to compare their performances. With such a method, companies can monitor their relative Lean Manufacturing performance and steer their actions accordingly. A general method for measuring Lean performance does however not exist, although many (partial) attempts have been made in academic literature and in practice. These attempts often resulted in long lists of indicators which are unwieldy. The large amount of indicators also obscure the deeper trends and mechanisms at play. Also, many studies aim to measure the Lean performance of companies by focusing on measuring the performance and implementation of specific Lean techniques. But implementing a Lean technique in your company doesn’t necessarily mean that your company’s performance will increase. It’s only a means to achieve the goal. To guard for these problems, this research will be focusing on the specific aspect of (Lean) value creation using only quantitative measures. In this manner the Lean performance of a company can be measured more objectively. To make the benchmark model practical in use, it is required that only publicly available measures are used. This overlaps with the requirement to use variables which have a general nature in order to compare companies from varying backgrounds. In short, the subject of this research is measuring Lean value creation using general and publicly available measures.

The goal of this research can be described in the following manner:

*Develop a Lean performance benchmark model which measures the Lean performance on company level by using Lean value creation indicators found from literature and theory and is tested using real world data.*

The automotive industry, as a long time adopter of Lean Manufacturing, is chosen as the basis for the benchmark to which other companies can be compared to. The benchmark model will subsequently be tested with case studies consisting of two automotive and four non-automotive companies. The four non-automotive companies consist of three manufacturing companies and a supplier of products to the manufacturing industry. These four case studies constitute companies in a general lower size range than the automotive benchmark though some overlap exists. In this way the benchmark model can be tested with case studies which have partly different characteristics and partly the same with the automotive industry. The two automotive cases function as a test to see how it responds to the natural variance within the same industry, in other words if it’s useful to benchmark its own industry.
1.2. Research Question

Taking into account the goal and scope of this research, the following main research question can be formulated:

*How can a Lean value creation benchmark be developed to provide a means of comparing company performances to each other?*

The following sub questions have been defined to guide the research:

1. What is constitutes the Lean Philosophy from the perspective of this research?
2. What is the definition of Lean and how does it relate to value creation?
3. What is value creation and which variables measure this?
4. What indicators can be found from literature and theory which measure Lean value creation?
5. How do these indicators perform in practice?

Lean and value creation are the main topics of this research and thus a concise definition of Lean and description of value creation are needed to provide a framework to judge the potential indicators theoretically. In the following chapters the main and sub questions will answered through literature and quantitative research.
2. Literature

In this chapter, the Lean philosophy, value creation and Lean value creation indicators are discussed through a literature study. A definition of Lean is formulated to guide further interpretation and selection of indicators. More detailed descriptions of Lean performance measurement in the literature are included in Appendix A – Lean Performance Models. From the literature a selection is made of useful indicators and interpreted in the context of this research.

2.1. The Lean Philosophy

Origins of Lean
Lean Manufacturing is nowadays a widely used business philosophy, implemented to varying degrees in different companies and branches. It’s contrasted to (traditional) mass production which dominated business thinking in the larger part of the 20th century. Mass production focused on standardization and generally employed a push model in production. Mass production struggled with large inventories, long lead times and large amounts of wasted materials. In response, Lean Manufacturing focusses on waste reduction and employs a pull model in production. It is based on the Toyota Production System develop by Toyota and has incorporated elements from other methods such as Supply Chain Management and Six Sigma. As shown by Womack, Jones and Roos (Womack et al., 2007) and Womack and Jones (Womack and Jones, 2003) Lean Manufacturing has proven itself as a successful business philosophy by greatly reducing lead time and inventory and thus greatly reducing costs. Subsequently, Lean has been accepted unanimously as being beneficial for company performances (Bhamu and Sangwan, 2014). Shah and Ward (2007) presented a schematic of the development of Lean (beginning as Toyota Production System) in practice and in academics. The timeline constructed by them is listed in Appendix A – Lean Performance Models.

Definition of Lean
No universally accepted definition of Lean is currently in use (Pettersen, 2009), (Bhamu and Sangwan, 2014) though most practitioners and researchers (in a lesser degree) agree on what constitutes Lean. Bhamu and Sangwan (Bhamu and Sangwan, 2014) performed an extensive literature study on the definition of Lean, analyzing 209 papers for their use of definition, and concluded that this ambiguity exists in part because Lean has evolved over time. In other part it exists because there is also disagreement about what Lean Manufacturing comprises (Shah and Ward, 2007). The definition thus varies between different situations and authors and, according to Pettersen (Pettersen, 2009), should be tailored to the specific situation. Murman, et al (Murman et al., 2002) described Lean as follows: “Becoming lean is a process of eliminating waste with the goal of creating value.” Womack and Jones (2003) define “creating value” more specifically as creating value from the customers perspective, thus ensuring that energy is not wasted in creating unwanted products. In the scope of this research, the following working definition can be formulated:

*Lean is a process of eliminating waste with the goal of creating value for the customer.*

Waste is defined as any (in)action or resource which is not used in creating value. Taiichi Ohno famously defined seven types of waste: Transport, Inventory, Motion, Waiting, Overproduction, Overprocessing, Defects. An eighth waste, bad design, was added by Womack and Jones (2003) to account for the waste of unwanted products. In Lean Six Sigma, another waste is commonly added: unused talent.
2.2. Value Creation

Value creation capability is an important aspect of the functioning of a company. It is also an important part of Lean Manufacturing, which states that non-value adding activities must be eliminated (Womack et al., 2007). The definition of Lean says that *creating value for the customer* while *eliminating waste* is the basis of a Lean process. Optimizing value creation is thus an inherent focus of any Lean process and is thus for this reason taken as the Lean aspect to be investigated. The value of the product or service is defined by the customer who is the one who, in the end, pays for the product (Womack and Jones, 2003). According to one definition given by (Parasuraman et al., 1985), customer value is the subjective opinion of the customer as to what extent the provided product and service package meets his/her expectations. The value the customer assigns to the product can be measured, in one way, through the revenues of a company. The assumption is here that the customer is free to choose to buy the product or not which isn’t always truly the case in every branch. Nevertheless, even if the company’s product will have a guaranteed sale, the internal efficiency of the value creation can still be measured using the turnover. In that case, the turnover will function more as a given and the other variables will put it into perspective.

From a company’s point of view, value is created when profit is made in excess of its cost (Gelei, 2007). In other words, if more value is returned through revenues than is expended in the process. Profit thus forms another way of measuring the value created.

Value Added is another way of measuring the value creation of a company. Mandal and Goswami, (Mandal and Goswami, 2008), defined it as simply the output value minus the input value. They further show, through a case study, in their research that Value Added and the Value Added Statement are useful methods of measuring the value creation performance of company. This is presented as an alternative way of measuring the performance of a company. Using Value Added as a value creation measure is an interesting way of measuring performance and fits into the concept of Lean Accounting. However, value added statements and lean accounting aren’t a standard practice in Annual Report and financial statements. Some companies, like Audi, BMW and Skoda, incorporate it into their annual reports but most companies don’t. For this reason it’s not practical, yet, for this research and thus Value Added will not be used.

Turnover and Profit are thus selected as the value creation variables for this study. Turnover and profit can be considered as the output variables of the system (the company) and other variables which measure aspects of a company can be combined to form basic ratios. In the next paragraph, a literature study will be performed to find potential Lean value creation indicators which can be used for constructing the benchmark.
2.3. The Concept of Flow

Womack and Jones in their book “Lean Thinking” (Womack and Jones, 2003) describe five steps in implementing the Lean philosophy in a Lean enterprise: Specify Value, Define the Value Stream, Flow, Pull and Perfection. According to them, Flow is an important aspect of Lean thinking which requires a wholly different mindset from the classic mass production way of thinking. *Specify Value* and *Define the Value Stream* result in a greater focus on value creation and are measured through use of value creation indicators. *Flow* entails the whole integration of all process steps in a coherent and communicating system by the means of keeping the product in constant *Flow* or movement. The idea is that a product should continuously be processed with value adding activities. Non value activities are muda(waste) and should be eliminated which includes storage, waiting and unnecessary movement and processing. Flow also entails an evenly paced and continuous process so that just-in-time deliveries and shipment of the product are achieved. It reduces the need for buffers and inventories inside the Lean enterprise and outside in the suppliers and receivers in the chain of companies. Because the yearly figures of profit and turnover are used to measure value creation, it also in some degree measures the Flow within the company. The fact the turnover and profit are year basis provides a time measure to the indicators. For example, relating the turnover to the inventory in the ratio Turnover per Inventory, gives a measure of how often the inventory is totally resupplied in a year. If the turnover is six times as large as the value of the inventory than this translates to a inventory overturn every two months or that the product resides on average two months in varying forms of inventory storage. It, shows in other words, the speed in which the products(measured in terms of value in the turnover figure) flow through the inventory. Other indicators or ratio’s can be interpreted in a similar way to deduce the degree of Flow within a company, albeit not always as directly as the previous example.

Flow is an important and often difficult concept to grasp in practice, as is shown with ample examples by Womack and Jones (Womack and Jones, 2003). Because the way the Lean value creation indicators will be constructed it also provides a measure of Flow. It consequently is justified to incorporate this concept in the name of the benchmark. Throughout this research the flow aspect of the indicators will be referenced and investigated.
2.4. Indicators

In the previous paragraph, the two value creation variables (Turnover and Profit) which will be used for this research were defined. It was established that Turnover and Profit are measures of value creation and the next step is to find indicators which relate them to other aspects of a company. A literature review has been performed on the topic of Lean performance measurement in order to find potential suitable indicators. Performance measurement can be defined as the process of quantifying the efficiency and effectiveness of action (Neely et al., 1995). Several models and benchmarks have been found in literature which aim to measure (an aspect of) Lean performance in companies and often contain several potentially useful indicators. The relevant literature is discussed in detail in Appendix A – Lean Performance Models, and the list of potential Lean value creation indicators selected from this literature is presented in Appendix B – List of Lean value creation indicators. The initial criterion of selection is the fact that an indicator relates turnover or profit to some other aspect of a company. This yielded a long list, as shown in Appendix B – List of Lean value creation indicators, of all potential indicators to be used in the Lean benchmark. In the following section, the list of potential indicators will be discussed and the resulting selection of indicators will be presented. To be selected, an indicator must comply to the Lean philosophy and the associated variables have to be retrievable from publicly available sources (annual reports). Found indicators which fail these criteria will not be selected.

Workforce

The turnover per number of employees (T/E) and profit per number of employees (P/E) are two of the three indicators used in the 3C model for measuring value leverage capability (Beelaerts van Blokland et al., 2007). T/E is a metric used to measure the Configuration dimension and P/E the Continuation dimension. Dividing the turnover and profit with the number of employees functions as a way of normalizing the turnover and profit in order to be able to compare different companies to each other. It also shows the productivity of the workforce of a company which is a Lean concept. The number of employees can be readily retrieved from annual reports and thus T/E and P/E will be selected.

Inventory

Inventory is one of the original seven wastes in Lean production (Womack, et al., 2007) and inventory reduction forms a regular part of Lean implementation projects (Womack and Jones, 2003). Swamidass (Swamidass, 2007) even went so far as to use the indicator total inventory over net sales as the sole indicator of leanness (called Toyota Production System). Using only this indicator, though, would give a too narrow view on the complex relations within the company’s processes. Other research also suggests that there is an optimum in inventory reduction related to performance increase (Eroglu and Hofer, 2011) which shows that inventory indicators have their boundaries in the Lean progression. In a follow up study (Hofer et al., 2012), it was found empirically that inventory leanness (the minimal optimum inventory level) performs a partial mediating effect between Lean production and financial performance. This partial mediating effect is shown in Figure 1.
Thus the inventory turnover (T/I) indicator is deemed a useful indicator of the leanness and process flow and will be selected for the benchmark.

Besides the total inventory value, the Work-In-Process inventory in ratio to the turnover is also suggested as an indicator by (Pakdil and Leonard, 2014). Because all forms of inventory are considered waste according to the Lean philosophy, it is decided that only the total inventory value variable will be used for the indicator.

Fixed Assets
In the paper (Beelaerts van Blokland and De Jong, 2016), a model is presented which measures Lean implementation for (aerospace) maintenance service companies. Three new indicators were presented which measure Lean Transaction Costs Efficiency and combined with other indicators to measure Lean implementation. The three new indicators are based on the fixed assets of a company and two of them also incorporated turnover (T/FA) and gross margin(GM/FA). T/FA measures the flow of value through the system and relates this to the value of the fixed assets, according to (Beelaerts van Blokland and De Jong, 2016). The fixed assets, also known as Property, Plant and Equipment (PPE), are also identified as the manufacturing assets utilization by (Maaskant, 2011) and subsequently used in the indicator T/PPE to measure the manufacturing capability of a company. Turnover and fixed assets/PPE are readily available in annual reports and thus this indicator can be added.

The gross margin to fixed assets ratio (GM/FA) is used to compare the financial indicator, gross margin, the fixed assets value. The gross margin is an often used financial indicator which measures the ratio of gross profit to turnover. The gross margin doesn’t measure value creation directly as defined earlier and thus would yield a less straightforward indicator to be interpreted. Replacing the gross margin with profit will yield an indicator which shows straightforward value creation and thus P/FA is selected as replacement of GM/FA.

Innovation Capability
Tseng et al. (Tseng et al., 2009), developed a business performance model for the high tech industry with five performance dimensions. One of these dimensions measures the innovation capability of a company through, among others, the ratio of R&D expenses to the profit (R&D/P). This indicator is called the R&D expenditure ratio, which measures the profit return on innovation expenses. Another variant of this indicator was identified through a survey of expert opinions by (van Stuyvesant Meyen, 2015) as the turnover to R&D expenses ratio (T/R&D). This indicator is proposed as a general indicator for benchmarking company performance. The innovation capability of a company is an important way of the fulfilling the continuous
improvement aspect of Lean. The R&D expenses are often listed in annual reports thus these indicators fulfill the necessary criteria for selection.

Cost of Goods Sold

In a study to benchmark the Lean performance of automotive companies, (Bayou and de Korvin, 2008), the indicator Cost of Goods Sold over Turnover (CGS/T) was introduced as a measure of long-term kaizen. Kaizen is described by in the book “The Machine That Changed The World” (Womack et al., 2007) as “…a continuous and incremental improvement in the production process” and consists of a series of events (Kaizen events) in which a team of directly related employees redesign the process to improve its performance. This is a basic Lean technique and Bayou and De Korvin(2008) use the CGS/T as a measure of the production costs against the total sales. According to them, this yields an indicator which measures the successful implementation of kaizen events when the indicator decreases; Kaizen events should decrease the production and product costs and thus the indicator should decrease accordingly. CGS is a complicated variable consisting of the costs of bought-in goods and services plus the costs directly attributable to the (production) process (Investopedia, 2015). This omits indirect costs made by the company such as R&D and administrative expenses. From the viewpoint of the author of this research, CGS obscures two important aspects of the company’s process: the bought-in costs and the costs made the company itself. This distinction is important in understanding the performance of the company’s own activities against that of the supply chain. Besides this, CGS excludes the costs made by the company on indirect activities (but the same expenses made by the suppliers are included in the bought-in costs and thus return in CGS). All costs made by the company are important in determining its Lean performance, not just the direct process activities. Cost of Goods Sold is thus concluded to be a too complicated variable to be used in benchmarking Lean value creation performance.

Lean Assessment Tool

The Lean Assessment Tool (LAT) is a model developed by (Pakdil and Leonard, 2014) which encompasses an extensive list of Lean performance indicators divided among several dimensions. Most of the indicators that are relevant for this research are related to the Costs dimension and are indicators like Total Defectives($)/Total Sales or Total Prevention Costs/ Total Sales. See for the whole list Appendix B – List of Lean value creation indicators. Other indicators constitute the “# of times that parts are transported/total sales”, for example. The data needed for all these indicators isn’t normally retrievable from annual reports and thus can’t be used in this research. Two indicators, Net Profit/Net Sales and WIP/Total Sales, are retrievable from annual reports and are discussed in the following respectively inventory sections.

Financial Indicators

Sales growth rate ($T$) and profit margin ($P/T$) are two financial indicators mentioned in the literature. These two use the turnover and profit variables but do not relate them to a specific aspect of the company other than the sales and profit. Pakdil and Leonard (Pakdil and Leonard, 2014), describe the indicator Net Profit over Total Sales as an indicator for the Costs dimension of the LAT model. The difference with the profit margin($P/T$) is the use of the net profit, which is the profit after interests and taxes instead of the EBIT or operating income. This thus includes financial aspects which aren’t directly related to the Lean performance of the company, though they do serve as a general (financial) performance indicator. In this research indicators are sought which relate some company characteristic to the turnover or the profit. The balance between these two variables in the form of the indicator $P/T$ provides useful insight to the general performance of the company which complement the characteristics based indicators. A steady performing company will show a steady ratio between profit and turnover. The $P/T$ indicator will thus be selected for this research.
**Value Velocity**

Value Velocity is in theory a useful indicator for this research because it measures the value addition rate (value creation rate) of a company. The indicator uses Profit (EBIT) and number of inventory days to be calculated. Inventory days are generally not listed in annual reports or other publicly available source and thus the indicator cannot be calculated in this manner. The number of inventory days could be approximated by using the inventory turnover ratio (expressed in days) but this implicitly says that every part of the turnover went through inventory. This is in practice not true because the turnover also contains non product related costs such as wages, administrative expenses etc. These expenses are part of the cost build-up of the product which is sold and thus the turnover represents more than the physical product that could go through inventory. The Value Velocity thus cannot be used in this research.

2.5. Conclusions

A set of Lean value creation indicators were selected from the literature in the previous paragraph which complied with the set criteria. The Turnover and the Profit (EBIT) were identified as the variables to measure value creation and indirectly Flow. Subsequently a literature study was conducted to find indicators which include these variables to measure Lean performance and value creation. The resulting set of indicators is listed in Table 1 with references. Turnover and profit will be considered as the output variables of the system (the company) and thus the indicators are inverted (if necessary) to reflect this. In order to judge if value is created efficiently and effectively, the turnover and profit must be related to important aspects of the value creating system (the company). Through the found indicators, five important aspects were identified in the functioning of the (manufacturing) company: Human Resources (Employees), Process Flow (Inventory), Physical Means (Fixed Assets), Innovation (R&D expenses) and Financial Performance (Profit margin). To measure the value creation performance related to these aspects, the associated variables are combined with the value creation variables to create ratio’s. Only one of the eight resulting ratios was not attested in literate, Profit/Inventory, and is subsequently added by the author of this thesis. The aspects are further illustrated in the next section. The combination of these indicators into a benchmarking model will called the Lean Value Flow Performance Benchmark. This name captures the focus concepts of Lean, Value Creation and the derivative concept of Flow.

**Table 1 List of selected indicators**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Aspect</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>T/E</td>
<td>Human Resources</td>
<td>(Beelaerts van Blokland et al., 2007, Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>T/FA</td>
<td>Physical Means</td>
<td>(Beelaerts van Blokland and De Jong, 2016, Maaskant, 2011)</td>
</tr>
<tr>
<td>T/R&amp;D</td>
<td>Innovation</td>
<td>(Maaskant, 2011)</td>
</tr>
<tr>
<td>P/E</td>
<td>Human Resources</td>
<td>(Beelaerts van Blokland et al., 2007, Tseng et al., 2009)</td>
</tr>
<tr>
<td>P/I</td>
<td>Process Flow</td>
<td>Added by the author</td>
</tr>
<tr>
<td>P/FA</td>
<td>Physical Means</td>
<td>(Beelaerts van Blokland and De Jong, 2016)</td>
</tr>
<tr>
<td>P/R&amp;D</td>
<td>Innovation</td>
<td>(Tseng et al., 2009, Beelaerts van Blokland et al., 2010)</td>
</tr>
</tbody>
</table>
**Characterizing a company**

Employees constitute an important aspect of the functioning of a company. They are the ones that ultimately perform and control the processes within the company and effective utilization of the workforce is a prime subject of Lean Manufacturing.

Inventory is the amount of materials and products that are within the system boundaries of the company. The amount of inventory compared to the turnover shows the flow of the process, which is an important part of Lean. Lean emphasizes the constant flow of the products through the process and thus inventory should be minimized to prevent products from not flowing. It is thus in one way a process indicator.

The fixed assets (also called Property, Plant and Equipment)\(^1\) are the means by which the process is performed and constitutes the buildings, equipment etc of a company. According to lean theory, non- or wrongly utilized resources are a source of waste and thus should be eliminated. Thus using too many fixed assets to perform the process is not lean and the ratio turnover to fixed assets should thus be minimized.

R&D expenses are important for the long term survival of the company because it needs to continuously improve its products to fit the needs of the customer. R&D expenses represent the basic innovation capability and is one way of contributing to the continuous improvement aspect of Lean.

The financial performance of company is in one way characterized by the steady positive ratio between profit and turnover. Wild swings in the profit margin shows a company which less control over its processes. A steady state ratio between profit and turnover is thus an indicator the right balance between costs and revenues. In other words, it shows the ratio of extra value added by the company(Profit) to the total value created (Turnover).

---

\(^1\) PPE is preferred by the International Financial Reporting Standards (IFRS 2005. IAS 16 — Property, Plant and Equipment.)
3. Methodology

Eight indicators have been selected from literate and theory to form the basis of the Lean value creation benchmark. In this chapter, the method of constructing the benchmark is described. The automotive industry will provide the data for the benchmark.

3.1. Data Set

The automotive industry will be used as the industry to construct the benchmark from. This industry is chosen because of its long history of Lean implementation and a relative straightforward industry focus: building cars. Other industries could have a more mixed set of focus products which makes comparing the companies to each other more complicated. The chosen time period is from 2003 to 2014 because of practical reasons. The necessary data from before 2003 could not be acquired for every company. The data is extracted from the annual reports and other financial statements of the companies. The automotive industry lists the specific value of its physical means called the Plant, Property and Equipment (PPE). This value is chosen to replace the more general Fixed Assets because it measures the physical means more adequately.

For companies to be selected for the benchmark, they need to satisfy several criteria to ensure they form a representative group. Selected companies are the companies from which the necessary figures could be gathered from the annual reports and are comparable to itself over the time period. Daimler and Fiat for example aren’t comparable to itself because Chrysler demerged from Daimler and then was subsequently acquired by Fiat. Another criterion is that the companies must be longstanding (20+ years) international car producers to make sure they all compete in the same (international) market. Competing in the international market means competing with manufacturers with long traditions of Lean and thus high degrees of Lean implementation. An international competing company thus either also has Lean implemented or otherwise is able to match the performance of Lean Manufacturing. Most Chinese companies for example operate almost solely in China and thus can’t be viewed as international.

Table 2 shows the ranking according to OICA (Organisation Internationale des Constructeurs d’Automobiles) of automotive manufacturers with the greatest number of produced vehicles in 2014. To create a representative set of automotive companies for this research, it is important to include at least one Chinese car manufacturer. The first manufacturer which can reasonably be considered operating on the international market is Great Wall Motors. This company has a presence in the European market since 2006 (Dyer, 2006) and achieved a peak value of 8% of total revenues from overseas sales. It also has a high focus on Lean Manufacturing according to its 2014 Annual Report. The selection of the OICA ranking listed in Table 2 thus encompasses all companies up until Great Wall Motors (23rd place). All companies in this selection were systematically tested using the criteria established above before they are selected for further analysis. Reasons for rejection are given in the same table under “notes”; bold printed names are the companies accepted to the research dataset. An additional three companies were added to the list to boost the statistical significance. These aren’t listed in the OICA ranking because they are subsidiaries of other automotive companies but otherwise meet all criteria. These companies are: Audi, Daihatsu and Skoda. The last column of Table 2 shows the final selection resulting in a data set of 17 companies. Together, these automotive produced 72% of the total vehicle production in 2014 (65.6 million out of a total of 90.7 million) or 78% of the total when only looking at personal cars (55.9 million out of 72.1 million).
Table 2 OICA World Ranking of Automotive manufacturers according to number of produced vehicles in 2014. Reasons for rejection are listed in the Notes column. The last column shows the final selection of 17 companies for the dataset.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Company</th>
<th># vehicles in 2014 (millions)</th>
<th>Notes</th>
<th>Final Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TOYOTA</td>
<td>10.475</td>
<td></td>
<td>TOYOTA</td>
</tr>
<tr>
<td>2</td>
<td>VOLKSWAGEN</td>
<td>9.895</td>
<td></td>
<td>VOLKSWAGEN</td>
</tr>
<tr>
<td>3</td>
<td>GM</td>
<td>9.609</td>
<td></td>
<td>GM</td>
</tr>
<tr>
<td>4</td>
<td>HYUNDAI</td>
<td>8.009</td>
<td></td>
<td>HYUNDAI</td>
</tr>
<tr>
<td>5</td>
<td>FORD</td>
<td>5.970</td>
<td></td>
<td>FORD</td>
</tr>
<tr>
<td>6</td>
<td>NISSAN</td>
<td>5.098</td>
<td></td>
<td>NISSAN</td>
</tr>
<tr>
<td>7</td>
<td>FIAT</td>
<td>4.866</td>
<td>Inconsistent</td>
<td>HONDA</td>
</tr>
<tr>
<td>8</td>
<td>HONDA</td>
<td>4.513</td>
<td></td>
<td>PSA</td>
</tr>
<tr>
<td>9</td>
<td>SUZUKI</td>
<td>3.017</td>
<td>Insufficient data available</td>
<td>RENAULT</td>
</tr>
<tr>
<td>10</td>
<td>PSA</td>
<td>2.917</td>
<td></td>
<td>BMW</td>
</tr>
<tr>
<td>11</td>
<td>RENAULT</td>
<td>2.762</td>
<td></td>
<td>MAZDA</td>
</tr>
<tr>
<td>12</td>
<td>BMW</td>
<td>2.166</td>
<td></td>
<td>MITSUBISHI</td>
</tr>
<tr>
<td>13</td>
<td>SAIC</td>
<td>2.088</td>
<td>Insufficient data available</td>
<td>FHI (Subaru)</td>
</tr>
<tr>
<td>14</td>
<td>DAIMLER</td>
<td>1.973</td>
<td>Inconsistent</td>
<td>GREAT WALL MOTORS</td>
</tr>
<tr>
<td>15</td>
<td>CHANGAN</td>
<td>1.447</td>
<td>Fails international criterion</td>
<td>SKODA</td>
</tr>
<tr>
<td>16</td>
<td>MAZDA</td>
<td>1.328</td>
<td></td>
<td>AUDI</td>
</tr>
<tr>
<td>17</td>
<td>DONFENG</td>
<td>1.302</td>
<td>Insufficient data available</td>
<td>DAIHATSU</td>
</tr>
<tr>
<td>18</td>
<td>MITSUBISHI</td>
<td>1.262</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>BAIC</td>
<td>1.116</td>
<td>Insufficient data available</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>TATA</td>
<td>945</td>
<td>Insufficient data available</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>GEELY</td>
<td>891</td>
<td>Fails international criterion</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>FHI</td>
<td>889</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>GREAT WALL</td>
<td>731</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Case studies

The case studies consisted of two automotive companies (Porsche and Daimler(Mercedes-Benz)), three non-automotive manufacturing companies (SEW Eurodrive, Lely Industries and Intergas Verwarming) and one supplier to manufacturing companies of industrial MRO products(Brammer Group). These case studies were arbitrarily selected from within the manufacturing related industry to test the benchmark.
3.2. Variables
The values for the variables are extracted from the annual reports for the selected companies and the specific figures that are used are listed in Table 3. All figures will be converted to euro’s and the historic exchange rates are listed in Appendix C – Historic currency exchange rates. The data is gathered for the years 2003 through 2014. The variables form the basis of the eight selected indicators: T/E, T/I, T/PPE, T/R&D, P/E, P/I, P/PPE, P/R&D

Table 3 List of the used variables with associated symbol and the specific figures used.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Variable</th>
<th>Specific figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>Turnover</td>
<td>The consolidated (group) revenues or sales income</td>
</tr>
<tr>
<td>P</td>
<td>Profit</td>
<td>The consolidated (group) operating income or EBIT</td>
</tr>
<tr>
<td>C</td>
<td>Number of Employees</td>
<td>Number of employees at years end of the total group</td>
</tr>
<tr>
<td>I</td>
<td>Inventory</td>
<td>Total value of all inventories in the balance sheet</td>
</tr>
<tr>
<td>PPE(FA)</td>
<td>Plant, Property and Equipment (or Fixed Assets)</td>
<td>Consists of the total value listed on the consolidated group balance sheet. PPE and Fixed Assets are basically synonymous with the term PPE being preferred by the International Financial Reporting Standards (IFRS, 2005).</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>R&amp;D expenses</td>
<td>The Research and Development expenses by the consolidated group.</td>
</tr>
</tbody>
</table>

3.3. Linear Regression Analysis
In this research simple linear regression is used to investigate potential correlation relations between different variables and indicators. Pearson’s product-moment correlation coefficient will provide the means of assessing the degree of significance of the analyzed data with Table 4 listing the used critical values associated to the size of the datasets. The critical values are color coded and this color code will be used in subsequent correlation coefficient tables to show the degree of correlation significance. N=12 is used for the amount of years, N=17 for when comparing companies and N=204 for the total data set. Pearson’s correlation is used because it’s a relative straightforward and often used test and it takes into account the absolute distance between data points. This is in contrast to for example Spearman’s Rank Correlation Coefficient (which only takes the relative rank of each data point into consideration) and ensures that only simple linear relations are measured.

Table 4 List of the often used critical values for Pearson’s correlation coefficients.

<table>
<thead>
<tr>
<th>Pearson’s R (two tailed)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>N df=n-2</td>
<td>95%</td>
</tr>
<tr>
<td>12 10</td>
<td>0,576</td>
</tr>
<tr>
<td>17 15</td>
<td>0,482</td>
</tr>
<tr>
<td>102 100</td>
<td>0,195</td>
</tr>
<tr>
<td>204 202</td>
<td>0,137</td>
</tr>
</tbody>
</table>

The number of years
The number of companies in the benchmark
The size of the dataset for the pre- and post-crisis period
The total size of the dataset
3.4. Benchmark Score Calculation
In this analysis each automotive company is given a benchmarking score relative to each other which is based on the Lean Dynamic Model introduced by Kinik, et al. (Kinik et al.). The basic method was used to rank a set of companies on their performance on the three indicators of the 3C model. This ranking method provides a straightforward way of comparing the performance of different companies and several indicators to each other.

Per parameter the companies receive a score value according to their performance relative to the other companies. The company with the highest parameter value receives 10 points and the lowest receives 1 point and this will set the score range. The scores for every parameter are then summed to give the total score. Equation 1 shows how the grid size of every benchmarking parameter is calculated. The grid size is then used in Equation 2 to calculate the Value Leverage Capability score of the respective parameter per company.

\[
\Delta s = \frac{\text{max}P - \text{min}P}{N}
\]

*Equation 1*

In which:
- maxP = maximum value of parameter in dataset
- minP = minimum value of parameter in dataset
- N = scale
- \(\Delta s\) = grid size

Every parameter receives a score between 1 and 10 so the scale N is 9 in this analysis. Equation 2 shows how the total score per company is calculated. Equation 1 and the equation between brackets in Equation 2 are repeated for every parameter and then summarized to obtain the total score. The \(\Sigma\) sign symbolizes the summation of the individual parameter scores.

\[
\text{Total Score} = \sum \left[ \frac{x - \text{min}P}{\Delta s} + 1 \right]
\]

*Equation 2*

In which:
- x = the parameter
- \(\Delta s\) = grid size
- minP = minimum value of parameter in dataset

In the original method (Kinik et al.), the grid size \(\Delta s\) was separately calculated for every year measured and the scores were converted to a ranking. To be able to compare the scores of different years to each other, the grid size in this analysis is calculated using the whole dataset at once. MaxP and minP are the maximum and minimum values achieved by any company in any year. In this way the ranking method provides a way to also compare the relative performance of the companies over the years. With this ranking method a benchmark will be constructed from the automotive data set which was selected earlier. Other companies can then be compared to this benchmark by calculating their ranking scores. Their data will not be included in determining the grid size of the original ranking so that they will be able to score more than points or less than 1 point. This is done in order to not disturb the original benchmark created from the automotive data set and keep ensure that all ranking scores are comparable to each other.
4. Analysis

4.1. Bivariate Correlation Analysis

Table 5: Bivariate Correlation Analysis with Pearson’s r of all variables for all datapoints (204). All variables correlate significantly (99% confidence interval) with each other.

<table>
<thead>
<tr>
<th></th>
<th>T</th>
<th>P</th>
<th>E</th>
<th>I</th>
<th>PPE</th>
<th>R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>0.308</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.924</td>
<td>0.250</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>0.874</td>
<td>0.346</td>
<td>0.931</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>0.867</td>
<td>0.353</td>
<td>0.799</td>
<td>0.789</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PPE</td>
<td>0.964</td>
<td>0.300</td>
<td>0.911</td>
<td>0.885</td>
<td>0.810</td>
<td></td>
</tr>
<tr>
<td>R&amp;D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The correlation coefficients between the absolute values of all the variables are shown in Table 5. All variables correlate significantly within a 99% confidence interval with each other. This probably reflects the size effect of the companies; larger companies have in general more employees, more turnover, more PPE etc. By combining all data points of all companies, the dominating factor for correlation becomes the size of the company. So Table 5 only shows the obvious fact that all variables scale with the size of a company. One exception is the profit variable which does correlate in the 99% interval but has a clearly lower range of correlation coefficients than the other variables: 0.250 – 0.353 range for profit compared to 0.789 – 0.964 range for the other variables. This indicates, as with the other variables, that the profit is highly significant to size but also shows a much higher data spread compared to the other variables.

The variance of the variables can be further investigated by using boxplots. The boxplots of the datasets of each variable are shown in Figure 2. The datasets were indexed on the mean value of each dataset in order to better compare the spread of data points. Indexing on the median value (assigning the median a value of 100) results in aligning all the box plots and at the same time retaining the relative positions of data points of each. In this manner all datasets are scaled to the same scale so their spread can be compared easily. The y-axis of the graph is constrained between +1000 and -1000 in order to keep the graph readable. Only some of the outliers of the profit variable are outside the graph in this manner. Table 6 lists the value for the quartiles of the variable its box plots shown in Figure 2. From the graph it can be noted that the spread of the profit variable is much larger than other variables and Table 6 shows that the 75% quartile of the profit variable does indeed significantly exceed the values of the other variables. Boxplots are centered on the median of the dataset and thus the same amount of datapoints are above and below the median (50% quartile) line. Also all datasets of the variables have the same number of datapoints so it can be concluded that the profit variable has a much higher spread than the other variables when we compare the 75% quartile values. The same amount of datapoints (25%) are spread over a larger distance, 350-100=250 points in the case of profit and 87.5 points in the case of employees (C) for example. This larger spread of the profit variable could explain the lower correlation coefficient values in Table 5.
Figure 2 Boxplots of all the data points of each variable. The data is indexed on the mean value of each variables dataset. Y-axis is constrained between +1000 and -1000.

Table 6 Values of the quartiles per variable for the boxplots shown in Figure 2. Figures a normalized on the median value.

<table>
<thead>
<tr>
<th>Quartiles</th>
<th>T</th>
<th>P</th>
<th>E</th>
<th>I</th>
<th>PPE</th>
<th>R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
<td>30,94</td>
<td>24,42</td>
<td>35,60</td>
<td>39,14</td>
<td>33,14</td>
<td>18,70</td>
</tr>
<tr>
<td>50%</td>
<td>100,00</td>
<td>100,00</td>
<td>100,00</td>
<td>100,00</td>
<td>100,00</td>
<td>100,00</td>
</tr>
<tr>
<td>75%</td>
<td>169,95</td>
<td>349,80</td>
<td>187,50</td>
<td>184,20</td>
<td>171,29</td>
<td>205,37</td>
</tr>
</tbody>
</table>

In Table 8, the bivariate correlation analysis of the value creation indicators is shown. The profit based indicators show strong positive correlations among each other in the 99% confidence interval. P/E, P/I, P/PPE and P/T have correlation coefficients with each other between 0.775 and 0.897. This is suspiciously high for such a large dataset of 204 data points. P/R&D shows some lower correlation coefficients (0.444 - 0.796) but this is still substantially higher than the rest of the correlation matrix. The average correlation coefficient for different selection of indicators is shown in Table 7. This table clearly shows that the profit indicators form a group of very high correlating indicators. The other indicator groupings, Turnover vs profit indicators and turnover versus turnover indicators, do sometimes show significant correlations but on average have a very low correlation coefficient. They thus do not show general trends in contrast to the profit group.

Table 7 Average correlation coefficients for different groupings of indicators.

<table>
<thead>
<tr>
<th>Groupings</th>
<th>Average R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profit vs Profit Indicators</td>
<td>0,765</td>
</tr>
<tr>
<td>Turnover vs Profit Indicators</td>
<td>0,143</td>
</tr>
<tr>
<td>Turnover vs Turnover Indicators</td>
<td>0,096</td>
</tr>
</tbody>
</table>
Table 8 Value creation indicators compared to each other by bivariate correlation analysis.

<table>
<thead>
<tr>
<th></th>
<th>T/E</th>
<th>T/I</th>
<th>T/PPE</th>
<th>T/R&amp;D</th>
<th>P/E</th>
<th>P/I</th>
<th>P/PPE</th>
<th>P/R&amp;D</th>
<th>P/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>T/E</td>
<td>0,117</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T/I</td>
<td>0,293</td>
<td>0,462</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T/PPE</td>
<td>-0,206</td>
<td>0,001</td>
<td>-0,089</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T/R&amp;D</td>
<td>0,132</td>
<td>-0,426</td>
<td>0,033</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/E</td>
<td>0,455</td>
<td>0,082</td>
<td>0,192</td>
<td>-0,020</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/I</td>
<td>-0,009</td>
<td>0,352</td>
<td>0,187</td>
<td>0,164</td>
<td>0,775</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/PPE</td>
<td>0,052</td>
<td>0,125</td>
<td>0,399</td>
<td>0,192</td>
<td>0,766</td>
<td>0,854</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/R&amp;D</td>
<td>-0,239</td>
<td>0,001</td>
<td>0,081</td>
<td>0,592</td>
<td>0,444</td>
<td>0,668</td>
<td>0,778</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/T</td>
<td>-0,068</td>
<td>0,032</td>
<td>0,084</td>
<td>0,204</td>
<td>0,781</td>
<td>0,897</td>
<td>0,896</td>
<td>0,796</td>
<td></td>
</tr>
</tbody>
</table>

Table 9 shows the correlation coefficients between the value creation indicators and the turnover and profit. Again the profit based indicators and profit margin systematically have high correlations with profit. On the other hand, the turnover based indicators have poor correlations with any general performance indicator. Turnover(T) does show some significant correlations with the indicators but these are mostly negative, especially with all profit indicators.

Table 9 Value creation Indicators versus Turnover and Profit.

<table>
<thead>
<tr>
<th></th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>T/E</td>
<td>0,279</td>
<td>0,219</td>
</tr>
<tr>
<td>T/I</td>
<td>-0,004</td>
<td>-0,031</td>
</tr>
<tr>
<td>T/PPE</td>
<td>0,132</td>
<td>0,033</td>
</tr>
<tr>
<td>T/R&amp;D</td>
<td>-0,426</td>
<td>-0,124</td>
</tr>
<tr>
<td>P/E</td>
<td>-0,039</td>
<td>0,774</td>
</tr>
<tr>
<td>P/I</td>
<td>-0,228</td>
<td>0,633</td>
</tr>
<tr>
<td>P/PPE</td>
<td>-0,187</td>
<td>0,575</td>
</tr>
<tr>
<td>P/R&amp;D</td>
<td>-0,288</td>
<td>0,322</td>
</tr>
<tr>
<td>P/T</td>
<td>-0,207</td>
<td>0,667</td>
</tr>
</tbody>
</table>

Subconclusions
The profit variable showed a significantly higher spread of data points than the other variables which explains the substantially lower correlation coefficients compared to the other variables in the bivariate analysis. Its associated indicators (P/E, P/I, P/PPE and P/R&D) showed substantially higher correlation coefficients among each other than the other combinations of indicators. This could be taken as a sign that they constitute a natural model. But when the high data spread and relative low correlation coefficients of the profit variable are taken into account, it becomes more likely that the profit variable overwhelms the other variables E, I, PPE and R&D. The high variance of the profit variable obscures the trends in the other variables which reduces them to effectively a constant. Subsequently, when correlating the profit indicators with each other, you are effectively correlating profit to profit. This explains the high correlation coefficients of the indicators and the relatively low correlation coefficients of the profit variable. Table 9 clearly shows this effect were the profit indicators show an exceptional degree of correlation with the plain profit variable. The same effect of the profit variable again becomes apparent in the equally high correlation coefficients.
with the indicator P/T. This makes the profit indicators unfit for use in the benchmark and thus they are discarded.

The turnover indicators on the other hand didn’t show any obvious trend or natural model. This can be explained by realizing that a company can improve its performance by reducing costs while the turnover stays the same. This essentially means that the turnover doesn’t need to change when the internal performance increases and thus isn’t a straightforward performance indicator. Of course when the turnover decreases it is not a good sign but a truly Lean enterprise and supply chain should be able to adapt to this. In practice, relatively small drops in turnover can be accommodated with, but with larger drops the productivity of fixed assets and employees will start to decrease because they can’t be easily be disposed off. Table 10 shows that the turnover indicators also don’t have significant correlations over time except for T/E. This indicates that the other indicators are not showing any general trend to increase or decrease over time which could show that the automotive industry is revolving around some fixed value. The fact that T/E is significantly increasing over time could be the effect of currency inflation. It is, evidently, the only indicator which is not a pure ratio because it has the unit €/employee.

Thus, it can be concluded that the dataset is in a mature phase of lean implementation according to the lean value creation indicators because there is a lack of trends and correlations among the turnover indicators. The turnover indicators (and the dataset) are thus suitable for use in the benchmark.

*Table 10 Value creation indicators correlated over time. The dataset constitutes 204 data points over a time period from 2003 to 2014.*

<table>
<thead>
<tr>
<th></th>
<th>T/E</th>
<th>T/I</th>
<th>T/PPE</th>
<th>T/R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>0.231</td>
<td>0.098</td>
<td>0.123</td>
<td>0.002</td>
</tr>
</tbody>
</table>
4.2. Continuous Improvement: Indicator growth

Another important aspect of Lean Manufacturing is continuous improvement. Lean is all about reducing waste and increasing value which is performed in a never ending iterative process. Lean is a process of continually improving with the ultimate goal of perfection being like a mathematical limit which practically can’t be reached (Womack and Jones, 2003). Thus an important aspect in measuring lean is the continuous improvement of the (Lean) performance. This can be translated to measuring the growth of the value creation indicators. In determining if a company “is lean” the absolute value of the indicators is as important as the relative growth of the indicator. The relative growth versions of the indicators represented by adding a “d” in the indicator name which stands for delta. The growth indicators are calculated by indexing the values of every company in the year 2003 on the value 100.

If a company shows no growth this means the company has stopped improving on this indicator. This is subsequently interpreted as a sign of stagnating or decreasing Lean performance. Table 11 shows the correlations of the value creation growth indicators versus the general performance indicators. Again the turnover based indicators correlate poorly with Turnover and Profit. Strong and positive correlations are found for dT/dC and dT/dl with dT and dP, but dT/dPPE and dT/dR&D correlate negatively to dT and none at all with dP. This indicates that the growth of T/E and T/I is positively correlated with the growth of the turnover on an industry level. In contrast to this, T/PPE and T/R&D show a negative growth when the turnover grows. The profit based growth indicators show the same strong correlations to P, P/T and dP as their absolute value counterparts show in the previous paragraph in Table 9.

Table 12 lists the correlation coefficients between all the value creation growth indicators. Strong correlations (99% interval) are shown by dT/dC with dT/dl and dT/dPPE. And also by dT/dR&D with dT/dPPE. Growth between these indicators thus seems to be correlated. The profit based growth indicators again show very strong correlations with each other as is expected by the previous results. The conclusions of the previous paragraph are upheld by these results and the profit indicators will not be incorporated in the following benchmark model.

Table 11 Correlation coefficients: Value creation growth indicators versus general performance variables.

<table>
<thead>
<tr>
<th></th>
<th>T</th>
<th>P</th>
<th>P/T</th>
<th>dT</th>
<th>dP</th>
</tr>
</thead>
<tbody>
<tr>
<td>dT/dC</td>
<td>0.025</td>
<td>0.030</td>
<td>0.085</td>
<td>0.407</td>
<td>0.080</td>
</tr>
<tr>
<td>dT/dI</td>
<td>-0.228</td>
<td>-0.089</td>
<td>0.073</td>
<td>0.686</td>
<td>0.055</td>
</tr>
<tr>
<td>dT/dPPE</td>
<td>0.044</td>
<td>0.108</td>
<td>0.023</td>
<td>-0.261</td>
<td>0.097</td>
</tr>
<tr>
<td>dT/dR&amp;D</td>
<td>-0.091</td>
<td>-0.033</td>
<td>-0.132</td>
<td>-0.304</td>
<td>0.003</td>
</tr>
<tr>
<td>dP/dC</td>
<td>-0.012</td>
<td>0.762</td>
<td>0.791</td>
<td>0.014</td>
<td>0.629</td>
</tr>
<tr>
<td>dP/dI</td>
<td>-0.021</td>
<td>0.759</td>
<td>0.802</td>
<td>0.028</td>
<td>0.636</td>
</tr>
<tr>
<td>dP/dPPE</td>
<td>0.009</td>
<td>0.758</td>
<td>0.797</td>
<td>-0.020</td>
<td>0.612</td>
</tr>
<tr>
<td>dP/dR&amp;D</td>
<td>-0.020</td>
<td>0.731</td>
<td>0.764</td>
<td>-0.015</td>
<td>0.608</td>
</tr>
</tbody>
</table>
Table 12: Correlation coefficient matrix of the value creation growth indicators.

<table>
<thead>
<tr>
<th></th>
<th>dT/dC</th>
<th>dT/dI</th>
<th>dT/dPPE</th>
<th>dT/dR&amp;D</th>
<th>dP/dC</th>
<th>dP/dI</th>
<th>dP/dPPE</th>
<th>dP/dR&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>dT/dC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dT/dI</td>
<td>0.318</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dT/dPPE</td>
<td>0.541</td>
<td>-0.054</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dT/dR&amp;D</td>
<td>0.059</td>
<td>-0.061</td>
<td>0.560</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dP/dC</td>
<td>0.037</td>
<td>-0.065</td>
<td>0.152</td>
<td>-0.059</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dP/dI</td>
<td>-0.013</td>
<td>-0.016</td>
<td>0.115</td>
<td>-0.053</td>
<td>0.993</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dP/dPPE</td>
<td>-0.020</td>
<td>-0.087</td>
<td>0.133</td>
<td>-0.066</td>
<td>0.979</td>
<td>0.985</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dP/dR&amp;D</td>
<td>-0.010</td>
<td>-0.060</td>
<td>0.159</td>
<td>0.006</td>
<td>0.988</td>
<td>0.990</td>
<td>0.973</td>
<td></td>
</tr>
</tbody>
</table>
5. Indicator Analysis

This chapter presents an in-depth look at the five resulting Lean value creation indicators: turnover per employee (T/E), turnover per inventory (T/I), turnover per plant, property and equipment (T/PPE), turnover per R&D expenses (T/R&D) and the profit to turnover ratio (P/T). Every indicator will be statistically and qualitatively analyzed to gain insight in its applicability as an indicator and subsequently provides a reference framework for interpreting the benchmark. The automotive industry forms the basis of the benchmark’s dataset and thus general trends in this industry as well as more specific trends on company level shall be searched for. Knowing this information will provide the necessary reference framework to interpret the results from the case studies. For this reason the indicators will not only be analyzed for general trends in the dataset but also for specific trends on company level and between the pre- and post-financial crisis periods. The financial crisis started in the year 2008 and had major implications for several automotive manufacturers like General Motors. Thus it is assumed that the period preceding had different trends and characteristics from the following period. The measured time period is thus divided in two equal parts: pre-crisis years 2003 till 2008 and post-crisis years 2009 – 2014.

Figure 3 and Table 13 show the relative data spread for every indicator to provide an overview of the indicators. The data is indexed on the median value of each indicator to be able to compare the data spread. The P/T indicator shows a considerably greater spread than the other indicators which is to be expected from earlier results. The profit variable showed in previous analyses and increased data spread compared to the other variables.

![Boxplots of the five indicators](image)

**Figure 3** Boxplots of the five indicators with the axis constrained at +400 and -200. The data was indexed on the median value for every indicator to compare the data spread of the indicators.

**Table 13** List of the quartile values of the boxplots shown in Figure 3 and the standard deviation. The data was indexed on the median value with 100 points.

<table>
<thead>
<tr>
<th>Quartiles</th>
<th>T/E</th>
<th>T/I</th>
<th>T/PPE</th>
<th>T/R&amp;D</th>
<th>P/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
<td>73,72</td>
<td>78,06</td>
<td>77,61</td>
<td>81,28</td>
<td>48,75</td>
</tr>
<tr>
<td>50%</td>
<td>100,00</td>
<td>100,00</td>
<td>100,00</td>
<td>100,00</td>
<td>100,00</td>
</tr>
<tr>
<td>75%</td>
<td>122,06</td>
<td>139,84</td>
<td>130,12</td>
<td>132,06</td>
<td>159,13</td>
</tr>
<tr>
<td>STDEV</td>
<td>35,08</td>
<td>44,01</td>
<td>44,10</td>
<td>47,30</td>
<td>129,70</td>
</tr>
</tbody>
</table>

32
5.1. T/E

The turnover per employee represents the value creating capacity per employee on a company scale. Figure 4 shows the turnover versus the number of employees for the entire dataset of 204 data points. Some spread of the data can be seen but, as was shown in the previous chapter, the turnover and employees are highly correlated, showing the relationship of company size.

![Turnover vs Employees Chart](image)

*Figure 4 Scatterplot of the whole dataset showing Turnover versus number of Employees*

Figure 5 shows the histogram of the whole dataset of the T/E indicator. Almost all datapoints are spread between 250,000 and 750,000 euro/employee with only a small group of datapoints clustered in the lower than 100,000 euro/employee bin. This small group are the datapoints associated with Great Wall Motors and are clearly separated from the rest of the dataset. This separation by GWM is also visible in Figure 6 where GWM is positioned in the lower left corner. Figure 6 shows the development of the indicator per company from the pre-crisis period (2003-2008) to the post-crisis period(2009-2014). The average of the indicator per period is plotted for each company with the pre-crisis period plotted on the x-axis and the post-crisis period plotted on the y-axis. The diagonal line represents all points were there was no development between the periods. Above that line is positive development and below the line is negative development. Most companies are positioned above the line, including the average of all companies(Automotive AVG). This shows that the industry in general increased the turnover per employee. As mentioned GWM forms an outlier in the lower left corner, besides that two clusters can be seen in this diagram. Skoda, Daihatsu, VW, Renault and PSA form a cluster in the center and the rest of companies are more loosely grouped to the top right. The gap between the clusters is visible in the histogram as a small dip. The gap is not as pronounced in the histogram as in Figure 6 because this effect is only apparent in the pre-crisis period. In the post-crisis period, the companies developed in such a way as to close this gap. Table 14 lists the average values and the increase or decrease(Δ) between the periods.
Figure 5 Histogram of the whole dataset (204 points) for the indicator T/E. x-axis in euro’s.

Figure 6 T/E development per company for the pre- and post-crisis periods. On the x-axis are the average values for each company plotted for the pre-crisis (’03-’08) and the equivalent averages of the post-crisis period (’09-’14) are plotted on the y-axis. The diagonal line represents the boundary between positive and negative development.
Table 14 List of the average values of the T/E indicator per company for the pre-crisis (‘03-’08) and post-crisis (‘09-’14) periods. Also listed is the increase or decrease between the periods (Δ). The table is sorted from highest to lowest pre-crisis values.

<table>
<thead>
<tr>
<th>T/E</th>
<th>2003-2008</th>
<th>2009-2014</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>HYUNDAI</td>
<td>€ 633.959</td>
<td>€ 611.782</td>
<td>-€ 22.177</td>
</tr>
<tr>
<td>MAZDA</td>
<td>€ 555.343</td>
<td>€ 488.450</td>
<td>-€ 66.893</td>
</tr>
<tr>
<td>AUDI</td>
<td>€ 538.290</td>
<td>€ 654.769</td>
<td>€ 116.479</td>
</tr>
<tr>
<td>TOYOTA</td>
<td>€ 486.803</td>
<td>€ 500.696</td>
<td>€ 13.892</td>
</tr>
<tr>
<td>GM</td>
<td>€ 479.554</td>
<td>€ 510.305</td>
<td>€ 30.750</td>
</tr>
<tr>
<td>BMW</td>
<td>€ 461.625</td>
<td>€ 658.785</td>
<td>€ 197.160</td>
</tr>
<tr>
<td>FORD</td>
<td>€ 449.970</td>
<td>€ 617.060</td>
<td>€ 167.090</td>
</tr>
<tr>
<td>MITSUBISHI</td>
<td>€ 448.472</td>
<td>€ 492.260</td>
<td>€ 43.789</td>
</tr>
<tr>
<td>HONDA</td>
<td>€ 447.306</td>
<td>€ 420.845</td>
<td>-€ 26.461</td>
</tr>
<tr>
<td>NISSAN</td>
<td>€ 414.651</td>
<td>€ 503.234</td>
<td>€ 88.582</td>
</tr>
<tr>
<td>Automotive AVG</td>
<td>€ 397.951</td>
<td>€ 455.196</td>
<td>€ 57.245</td>
</tr>
<tr>
<td>FHI (SUBARU)</td>
<td>€ 390.454</td>
<td>€ 554.846</td>
<td>€ 164.392</td>
</tr>
<tr>
<td>RENAULT</td>
<td>€ 311.438</td>
<td>€ 322.157</td>
<td>€ 10.719</td>
</tr>
<tr>
<td>DAIHATSU</td>
<td>€ 292.258</td>
<td>€ 340.516</td>
<td>€ 48.258</td>
</tr>
<tr>
<td>VOLKSWAGEN</td>
<td>€ 291.051</td>
<td>€ 326.103</td>
<td>€ 35.052</td>
</tr>
<tr>
<td>PSA</td>
<td>€ 272.081</td>
<td>€ 278.807</td>
<td>€ 6.726</td>
</tr>
<tr>
<td>SKODA</td>
<td>€ 245.300</td>
<td>€ 371.545</td>
<td>€ 126.245</td>
</tr>
<tr>
<td>GWM</td>
<td>€ 46.608</td>
<td>€ 86.168</td>
<td>€ 39.560</td>
</tr>
</tbody>
</table>

See Appendix F – Indicator Analysis Extended, section T/E for an extended analysis.
5.2. T/I

The next value creation indicator is the turnover per inventory. Figure 7 shows all data points in the data set with a trend line and correlation coefficient inserted in the diagram to show correlation between the variables found in Table 5 in the previous chapter. Again the correlation coefficient only shows a general relation between company size (turnover) and inventory size.

![Figure 7 Turnover versus Inventory in millions of euro’s. All 204 data points are plotted in this diagram with a trend line drawn to show the correlation between the variables.](image)

The T/I indicator is subsequently constructed from the variables Turnover and inventory and Figure 8 shows the histogram of the resulting T/I dataset. More than 60% (125 points) of all the datapoints lie within the values 7,0 and 13,0 and an extended “tail” upwards to 23,0 can be noticed. These higher values of the inventory turnover indicator represent higher Lean value creation performance and improved product flow in a company and thus this upwards group is associated with higher company performance. Using Figure 9, this high performance group can be identified with a group of companies. Figure 9 shows the average indicator value of a company in the pre- and post-crisis periods. Four companies (Daihatsu, Ford, BMW and Skoda) form a group of generally higher indicator values and thus can be identified as the upwards group of Figure 8. These four companies clearly form a separate group from the rest of the companies in Figure 9. Of the main group, the low performers show a tendency of improvement from pre-crisis to post-crisis while the medium performers showed in general a deterioration in the post-crisis period. The high performance group went from already high values to even higher values, continuing their frontrunner role. Only Skoda from this group decreased in its T/I value. Table 15 shows that GWM achieves the largest increase (6,95) in inventory turnover and GM shows the largest decrease with a value of -3,06. (see Appendix F – Indicator Analysis Extended, section T/I for an extended analysis).
Figure 8 Histogram of the whole dataset (204 datapoints) concerning the T/I indicator.

Figure 9 Average values of the T/I indicator per company for pre- and post-crisis periods. Pre-crisis period (‘03-’08) is plotted on the x-axis, post-crisis period (‘09-’14) is plotted on the y-axis. The diagonal line represents the points of no development.
Table 15 List of the average values of the T/I indicator per company for the pre-crisis (’03-’08) and post-crisis (’09-’14) periods. Also listed is the increase or decrease between the periods (Δ). The table is sorted from highest to lowest pre-crisis values.

<table>
<thead>
<tr>
<th>T/I</th>
<th>2003-2008</th>
<th>2009-2014</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMW</td>
<td>18,0</td>
<td>19,5</td>
<td>1,56</td>
</tr>
<tr>
<td>SKODA</td>
<td>17,9</td>
<td>16,7</td>
<td>-1,13</td>
</tr>
<tr>
<td>DAIHATSU</td>
<td>17,8</td>
<td>22,5</td>
<td>4,65</td>
</tr>
<tr>
<td>FORD</td>
<td>16,5</td>
<td>21,4</td>
<td>4,95</td>
</tr>
<tr>
<td>GM</td>
<td>13,9</td>
<td>10,8</td>
<td>-3,06</td>
</tr>
<tr>
<td>TOYOTA</td>
<td>13,4</td>
<td>12,1</td>
<td>-1,35</td>
</tr>
<tr>
<td>AUDI</td>
<td>12,8</td>
<td>10,9</td>
<td>-1,95</td>
</tr>
<tr>
<td>NISSAN</td>
<td>11,5</td>
<td>9,0</td>
<td>-2,54</td>
</tr>
<tr>
<td>Automotive AVG</td>
<td>11,5</td>
<td>12,4</td>
<td>0,95</td>
</tr>
<tr>
<td>MAZDA</td>
<td>11,4</td>
<td>9,3</td>
<td>-2,03</td>
</tr>
<tr>
<td>HONDA</td>
<td>9,6</td>
<td>8,7</td>
<td>-0,88</td>
</tr>
<tr>
<td>MITSUBISHI</td>
<td>8,7</td>
<td>9,4</td>
<td>0,74</td>
</tr>
<tr>
<td>PSA</td>
<td>8,1</td>
<td>9,8</td>
<td>1,69</td>
</tr>
<tr>
<td>VOLKSWAGEN</td>
<td>7,5</td>
<td>6,7</td>
<td>-0,76</td>
</tr>
<tr>
<td>RENAULT</td>
<td>7,4</td>
<td>10,4</td>
<td>3,00</td>
</tr>
<tr>
<td>GWM</td>
<td>7,1</td>
<td>14,1</td>
<td>6,95</td>
</tr>
<tr>
<td>FHI (SUBARU)</td>
<td>6,9</td>
<td>8,5</td>
<td>1,64</td>
</tr>
<tr>
<td>HYUNDAI</td>
<td>6,8</td>
<td>11,6</td>
<td>4,75</td>
</tr>
</tbody>
</table>
5.3. T/PPE

The turnover per Plant, Property and Equipment measures the value creation in proportion to the value of the physical means of a company. The complete dataset is plotted in Figure 10, showing the significant correlation between the turnover and the PPE and thus indicating the company size relationship.

![Figure 10 Turnover versus Property, Plant, Equipment in millions of euros. All 204 data points of the dataset are plotted together with the trend line and correlation coefficient.](image)

Figure 11 shows the histogram of the T/PPE dataset. The dataset has a rather normal distribution with an asymmetrical tail to the higher values. Over 80% of the dataset lies within the values 2.0 and 6.0 which forms the classic bell shape in the histogram. The remainder primarily resides in the upwards tail of the distribution. When comparing the pre- and post-crisis periods with each other company as in Figure 12, the same pattern can be noticed. The bulk of the companies reside in the middle of the graph with a couple of companies spreading out to the top right corner. Most companies reside quite closely to the diagonal line and this indicates that only slight changes of the average T/PPE indicator occurred between pre- and post-crisis periods. Ford has shown the greatest increase in T/PPE with 2.12 points (see Table 16), bringing it closer to BMW. BMW has by far the largest average value in the years 2003-2008; 8.95 with the second highest being Ford with 6.16. This gap is bridged only by Ford in the 2009-2014 period because of its high increase. Before the financial crisis, Ford was struggling with its general performance and is apparently restructuring its Plant, Property and Equipment assets in order to increase its performance (see Appendix F – Indicator Analysis Extended, section T/PPE for an extended analysis).
Figure 11 Histogram showing the whole dataset (204 datapoints) for the indicator T/PPE.

Figure 12 Average values of the T/PPE indicator per company for pre- and post-crisis periods. Pre-crisis period (’03-’08) is plotted on the x-axis, post-crisis period (’09-’14) is plotted on the y-axis. The diagonal line represents the points of no development.
<table>
<thead>
<tr>
<th>Company</th>
<th>2003-2008</th>
<th>2009-2014</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>FORD</td>
<td>6,16</td>
<td>8,28</td>
<td>2,12</td>
</tr>
<tr>
<td>GM</td>
<td>4,58</td>
<td>6,19</td>
<td>1,61</td>
</tr>
<tr>
<td>FHI (SUBARU)</td>
<td>2,84</td>
<td>4,25</td>
<td>1,42</td>
</tr>
<tr>
<td>HYUNDAI</td>
<td>2,70</td>
<td>3,82</td>
<td>1,11</td>
</tr>
<tr>
<td>AUDI</td>
<td>5,41</td>
<td>5,95</td>
<td>0,55</td>
</tr>
<tr>
<td>DAIHATSU</td>
<td>3,32</td>
<td>3,82</td>
<td>0,50</td>
</tr>
<tr>
<td>PSA</td>
<td>3,95</td>
<td>4,38</td>
<td>0,44</td>
</tr>
<tr>
<td>Automotive AVG</td>
<td>4,29</td>
<td>4,69</td>
<td>0,40</td>
</tr>
<tr>
<td>MITSUBISHI</td>
<td>4,40</td>
<td>4,73</td>
<td>0,33</td>
</tr>
<tr>
<td>SKODA</td>
<td>4,45</td>
<td>4,75</td>
<td>0,30</td>
</tr>
<tr>
<td>BMW</td>
<td>8,95</td>
<td>9,21</td>
<td>0,26</td>
</tr>
<tr>
<td>RENAULT</td>
<td>3,26</td>
<td>3,50</td>
<td>0,24</td>
</tr>
<tr>
<td>VOLKSWAGEN</td>
<td>4,52</td>
<td>4,69</td>
<td>0,17</td>
</tr>
<tr>
<td>NISSAN</td>
<td>2,15</td>
<td>2,24</td>
<td>0,09</td>
</tr>
<tr>
<td>TOYOTA</td>
<td>2,95</td>
<td>2,88</td>
<td>-0,07</td>
</tr>
<tr>
<td>GWM</td>
<td>4,44</td>
<td>3,95</td>
<td>-0,50</td>
</tr>
<tr>
<td>MAZDA</td>
<td>3,51</td>
<td>2,88</td>
<td>-0,62</td>
</tr>
<tr>
<td>HONDA</td>
<td>5,35</td>
<td>4,14</td>
<td>-1,21</td>
</tr>
</tbody>
</table>

Table 16 List of the average values of the T/PPE indicator per company for the pre-crisis ('03-'08) and post-crisis ('09-'14) periods. Also listed is the increase or decrease between the periods (Δ). The table is sorted from highest to lowest change in value(Δ).
5.4 T/R&D

Figure 13 shows the relationship between turnover and R&D expenses in the dataset. As was shown in chapter 4.1 a very high correlation exists between turnover and R&D expenses. This was explained by the effect of size overwhelming other trends.

Figure 13 Turnover versus R&D Expenses in millions euros. Plotted are all data points of the dataset over the period 2003 - 2014. Also plotted are the trend line and correlation coefficient ($R^2$).

Another potential relationship could be that a fixed percentage of the turnover is used for R&D Expenses by a company. Figure 14 and Figure 15 respectively show the distributions of the indicator T/R&D and the R&D expenditure percentage. The indicator T/R&D shows a continuous distribution with a long tail to the higher end of the spectrum. When we invert the indicator to show the R&D expenditure percentage it becomes apparent that there indeed is something like a upper limit. The histogram in Figure 15, shows a continuous distribution from 1% to 5.5% followed by a hard cutoff at that point. This discontinuity could mean that companies actively try to keep their R&D expenses below this 5.5% mark. This effect is not clearly visible in the histogram of Figure 14 and shows that the T/R&D indicator obscures this effect. Figure 16 also shows that most companies show little development of T/R&D between pre-crisis and post-crisis periods with 10 out of 17 companies show negative growth of the indicator (see Table 17).

See Appendix F – Indicator Analysis Extended, section T/R&D for a more indepth analysis of the R&D expenditure percentage.
Figure 14 Histogram of the whole dataset for the indicator T/R&D.

Figure 15 Histogram of the percentage of turnover that is spend on R&D. The whole dataset (204 data points) is used spanning the time period from 2003 - 2014.
**Figure 16** Average values of the T/R&D indicator per company for pre- and post-crisis periods. Pre-crisis period (’03-’08) is plotted on the x-axis, post-crisis period (’09-’14) is plotted on the y-axis. The diagonal line represents the points of no development.

**Table 17** List of the average values of the T/R&D indicator per company for the pre-crisis (’03-’08) and post-crisis (’09-’14) periods. Also listed is the increase or decrease between the periods (Δ). The table is sorted from highest to lowest change in value (Δ).

<table>
<thead>
<tr>
<th>Company</th>
<th>2003-2008</th>
<th>2009-2014</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>HYUNDAI</td>
<td>33,2</td>
<td>47,3</td>
<td>14,14</td>
</tr>
<tr>
<td>DAIHATSU</td>
<td>32,9</td>
<td>42,6</td>
<td>9,78</td>
</tr>
<tr>
<td>MITSUBISHI</td>
<td>48,1</td>
<td>56,6</td>
<td>8,51</td>
</tr>
<tr>
<td>FHI (SUBARU)</td>
<td>29,5</td>
<td>36,7</td>
<td>7,17</td>
</tr>
<tr>
<td>FORD</td>
<td>22,2</td>
<td>25,4</td>
<td>3,20</td>
</tr>
<tr>
<td>TOYOTA</td>
<td>24,2</td>
<td>24,9</td>
<td>0,72</td>
</tr>
<tr>
<td>Automotive AVG</td>
<td>28,4</td>
<td>29,0</td>
<td>0,51</td>
</tr>
<tr>
<td>BMW</td>
<td>19,1</td>
<td>19,2</td>
<td>0,15</td>
</tr>
<tr>
<td>NISSAN</td>
<td>21,4</td>
<td>21,2</td>
<td>-0,15</td>
</tr>
<tr>
<td>RENAULT</td>
<td>22,9</td>
<td>22,0</td>
<td>-0,89</td>
</tr>
<tr>
<td>HONDA</td>
<td>19,1</td>
<td>17,9</td>
<td>-1,14</td>
</tr>
<tr>
<td>PSA</td>
<td>28,2</td>
<td>27,0</td>
<td>-1,22</td>
</tr>
<tr>
<td>AUDI</td>
<td>17,5</td>
<td>15,3</td>
<td>-2,14</td>
</tr>
<tr>
<td>VOLKSWAGEN</td>
<td>22,5</td>
<td>19,8</td>
<td>-2,75</td>
</tr>
<tr>
<td>MAZDA</td>
<td>29,5</td>
<td>25,5</td>
<td>-4,05</td>
</tr>
<tr>
<td>GM</td>
<td>26,7</td>
<td>19,8</td>
<td>-6,95</td>
</tr>
<tr>
<td>GWM</td>
<td>47,0</td>
<td>40,0</td>
<td>-7,04</td>
</tr>
<tr>
<td>SKODA</td>
<td>39,6</td>
<td>31,0</td>
<td>-8,58</td>
</tr>
</tbody>
</table>
5.5. P/T

The P/T indicator measures the ratio of profit to turnover of a company, also called the profit margin. It is selected to represent the profit aspect of a company’s performance.

![Figure 17 Profit versus Turnover in millions of euros. Plotted are all data points of the dataset over the period 2003 - 2014. Also plotted are the trend line and correlation coefficient ($R^2$).](image)

Figure 17 shows all data points from the automotive dataset. In contrast to the turnover indicators (T/E, T/I, T/PPE and T/RD) this indicator does achieve negative values because the profit can be negative (loss). This results in a larger data spread and subsequently produces a lower, but still significant, correlation coefficient of $R=0.308$ (99% confidence interval) compared to the turnover indicators. This correlation shows a link between the size of a company (the Turnover) and the amount of profit, albeit less strongly because of the larger data spread of the profit variable. The histogram of the P/T indicator, shown in Figure 18, shows that over half of the datapoints lie between 2 and 8 percent. This reflects the behavior that companies try to manage the profit margin to a certain percentage. For this industry the “preferred” range apparently lies roughly between 2% and 8%, with more outliers to higher values than lower values. Low or negative values are detrimental to companies financial health. High values on the other hand are often a result of exceptional high profit gains which isn’t detrimental in itself. These are often not sustained by a company for various reasons (for example by investing the extra profit gains or lowering the product prices to increase the market share).
Figure 18 Histogram of the complete data set (204 datapoints) of the Profit/Turnover indicator. P/T is expressed in percentage.

Figure 19 P/T development per company for the pre- and post-crisis periods. On the x-axis are the average values for each company plotted for the pre-crisis (’03-’08) and the equivalent averages of the post-crisis period (’09-’14) are plotted on the y-axis. The diagonal represents all the points of no development.
Figure 19 shows the development of the average profit margin for each company between the pre-(2003-2008) and post-crisis(2009-2014) periods. The diagonal line represents the boundary between negative and positive growth of the average value; above the line is positive growth and below is negative. About an equal amount of companies show a positive (9 companies) and negative (8 companies) growth of the P/T indicator. Ford, GM and Mitsubishi had a negative average profit margin before the crisis and all three managed to greatly increase this in the post-crisis period. GM achieved the greatest increase of all companies with a growth of 8,4 percent point which brings them to average post-crisis value of -0,2%, as is shown in Table 18. This still means they averaged a zero profit margin between 2009 and 2014 which is not a healthy value. The low average is caused by the very low P/T value in 2009, a result of the bankruptcy of the company that year. All subsequent years GM achieved positive P/T values. PSA had a post crisis period average of -1,5% which is the lowest profit margin average of all companies in this period. The average of all companies went from 3,9% to 5,4%, showing a general performance improvement in the industry after the crisis. Great Wall Motors (GWM) forms an outlier in this diagram by achieving 17,6% and 13,6% for the pre- and post-crisis periods respectively. The company had a more than 20 fold increase of its turnover over the whole time period and thus these large P/T percentages probably reflect this very large growth.

Table 18 List of the average P/T values per company, expressed in percentage, for the pre(‘03-’08) and post(‘09-’14) crisis periods. The difference between each period is shown in the right most column and the whole table is sorted from highest to lowest difference.

<table>
<thead>
<tr>
<th>Company</th>
<th>2003-2008</th>
<th>2009-2014</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM</td>
<td>-8,6%</td>
<td>-0,2%</td>
<td>8,4%</td>
</tr>
<tr>
<td>FORD</td>
<td>-3,9%</td>
<td>2,8%</td>
<td>6,7%</td>
</tr>
<tr>
<td>FHI (SUBARU)</td>
<td>2,7%</td>
<td>7,4%</td>
<td>4,8%</td>
</tr>
<tr>
<td>HYUNDAI</td>
<td>4,2%</td>
<td>8,9%</td>
<td>4,7%</td>
</tr>
<tr>
<td>MITSUBISHI</td>
<td>-0,6%</td>
<td>3,8%</td>
<td>4,3%</td>
</tr>
<tr>
<td>AUDI</td>
<td>6,4%</td>
<td>10,7%</td>
<td>4,3%</td>
</tr>
<tr>
<td>DAIHATSU</td>
<td>3,2%</td>
<td>6,3%</td>
<td>3,0%</td>
</tr>
<tr>
<td>VOLKSWAGEN</td>
<td>3,3%</td>
<td>5,4%</td>
<td>2,2%</td>
</tr>
<tr>
<td>BMW</td>
<td>6,5%</td>
<td>8,5%</td>
<td>2,0%</td>
</tr>
<tr>
<td>Automotive AVG</td>
<td>3,9%</td>
<td>5,4%</td>
<td>1,4%</td>
</tr>
<tr>
<td>SKODA</td>
<td>6,0%</td>
<td>5,8%</td>
<td>-0,3%</td>
</tr>
<tr>
<td>MAZDA</td>
<td>3,0%</td>
<td>2,6%</td>
<td>-0,4%</td>
</tr>
<tr>
<td>HONDA</td>
<td>6,8%</td>
<td>5,0%</td>
<td>-1,8%</td>
</tr>
<tr>
<td>RENAULT</td>
<td>3,1%</td>
<td>1,2%</td>
<td>-1,9%</td>
</tr>
<tr>
<td>NISSAN</td>
<td>7,2%</td>
<td>5,2%</td>
<td>-2,0%</td>
</tr>
<tr>
<td>TOYOTA</td>
<td>7,6%</td>
<td>5,3%</td>
<td>-2,2%</td>
</tr>
<tr>
<td>PSA</td>
<td>2,1%</td>
<td>-1,5%</td>
<td>-3,5%</td>
</tr>
<tr>
<td>GWM</td>
<td>17,6%</td>
<td>13,6%</td>
<td>-4,0%</td>
</tr>
</tbody>
</table>
6. Benchmark

All five indicators have now been analyzed and through this analysis the necessary information is provided for interpreting the benchmark results. In this chapter the Lean value creation Benchmark is constructed and the results are presented. The calculation method used to produce the benchmark was described in chapter 3.4 and provides a mechanism with which the indicators can be combined into a single score. The highest attained value in the dataset of an indicator is awarded a score of 10 points, the lowest attained value 1 point and all other values get a linearly interpolated score between 10 and 1. All indicators are in this manner translated to the same playing field while conserving the data spread characteristics of each indicator.

6.1. Results

In Figure 21 and Figure 20 the benchmark scores are shown for the years 2003 and 2014, sorted from highest to lowest total score and Figure 24 and Figure 23 show the average benchmark scores for the pre- and post-crisis periods. The individual scores for the indicators are highlighted by color to show the built up of the total scores for every company. These two snapshots of the start and end year of the measured time period show the progression of the companies over the whole period. For example GWM had the highest relative score in 2003 but dropped down to a below average score in 2014. It absolute score also decreased from 30,0 points in 2003 to 20,9 points in 2014. It’s very high total score in 2003 was primarily caused by a exceptionally high T/R&D and T/PPE score compared to the other companies. These indicators decreased in absolute values to more average values resulting in GWM showing a more typical score built up. GWM exhibited tremendous growth over the measured time period. These results can thus be interpreted as GWM struggling with keeping its processes in balance and ultimately achieving a relatively typical and more stable company. The large negative change in score is more clearly shown in Figure 22 and Figure 23. This growth was for the most part only achieved since 2011 which is the reason FHI’s high score is not reflected in its post-crisis average score in . Mitsubishi, Daihatsu and Skoda also achieve high increases in scores from 2003 to 2014 but these are not reflected in the averages in Figure 23 and Figure 24. This again is the result from achieving these growth figures only the last few years of the post-crisis period. These companies form a group which were medium performers before the crisis and received some kind of shock therapy from the crisis, resulting in them actively pursuing greater Lean performance.

The pre- and post-crisis diagrams highlight the more consistent performance trends of the companies. The erratic behavior of GWM for example is tempered by these averages and results in it ranking in the lower parts of both periods. On the other hand, the steady high performance of BMW is clearly visible in these figures; ranking first place in both pre- and post-crisis periods. Ford shows the greatest increase in average score(Figure 25) and joins BMW in a distinct high performance group in the post-crisis period. Ford was financially struggling before the crisis but managed to almost instantly increase its performance after the crisis started. It showed consistent high performance scores in the post crisis period in contrast to the other high growing companies mentioned earlier (FHI, Daihatsu, Skoda, Mitsubishi). This probably explained by the fact Ford was already in a stressed financial condition and was more prepared to instantly react to the crisis. Toyota, the company which introduced Lean Manufacturing to the industry, performs in every statistic shown here negatively. This is partly the result of the whole industry slowly increasing its Lean value creation performance. But the negative change values in Figure 22 and Figure 25 clearly show that Toyota’s performance is decreasing in absolute values also.

(All values associated with the mentioned graphs are listed in Appendix G – Automotive Benchmark Tables, Table 31.)
Figure 20 Value creation performance score for the year 2003. Sorted from left to right on total score.

Figure 21 Value creation performance score for the year 2014. Sorted from left to right on total score.

Figure 22 Change in value creation performance score from 2003 to 2014.
Figure 24 Average performance scores in the pre-crisis period (2003 - 2008). Companies are sorted from highest to lowest total score value.

Figure 23 Average performance scores in the post-crisis period (2009 - 2014). Companies are sorted from highest to lowest total score value.

Figure 25 Change in average performance score between pre-crisis (2003-2008) and post-crisis (2009-2014) periods.
6.2. Research and Development

It was earlier noticed in the indicator analysis section (chapter 5.4) that the T/R&D indicator shows behavior different from the rest of the indicators. The inverse of the indicator, the R&D/T or the R&D expenditure ratio, shows a upper limit cutoff at around 5.5% which was interpreted as being caused by the active management policies of companies. This shows the willingness and actual occurrence of R&D budget management in other ways than initially was reasoned from theory. The initial assumption was that the R&D expenses were more stable like the other aspect Inventory, PPE and number of Employees. The active adjustment of the R&D expenses will impact the meaning of the T/R&D differently. In times of economic hardship, for example, the R&D expenses could be cut significantly to reduce costs while the turnover diminishes less so. The indicator T/R&D would contrarily increase and result in a score increase for the company in the benchmark. This short term crisis management behavior of companies is different from the behavior initially envisioned for the T/R&D indicator. It means that when the T/R&D achieves a high score it could not always be a sign of improved Lean value creation or value flow. Subsequently, the indicator can’t be as straightforwardly be interpreted as the other indicators. For this reason it is interesting to investigate the Lean Value Flow Benchmark without the T/R&D indicator. Figure 29 and Figure 28 show the Lean Value Flow performance scores for the years 2003 and 2014 respectively per company without the T/R&D indicator. Compared to the score results in the previous paragraph, GWM is the most impacted by this change. With T/R&D it ranked the highest in 2003 of all companies but it now resides in the mid segment. BMW and Ford now rank first and second in both years, showing a more consistent picture. On the lower end PSA, Renault and Volkswagen also show consistent behavior because they don’t change their ranking. On the other hand, FHI, Skoda, Daihatsu and Mitsubishi still show the same great increase in score value as in the previous benchmark. This shows they achieved their growth on most or all indicators and are not dependent on the R&D indicator as is the case with GWM. Figure 27 and Figure 26 show the average scores per company for the pre- and post-crisis periods. In these graphs GWM scores consistently low in both periods, which results from dampening its erratic behavior. Honda scores high in the pre-crisis period but drops down to a low rank in the post-crisis period with even an absolute decrease in score. With the T/R&D this effect was much less pronounced. (All values associated with the mentioned graphs are listed in Appendix G – Automotive Benchmark Tables, Table 32.)
Figure 28 Value creation performance score in 2014 omitting the T/R&D indicator. Sorted from left to right on total score value.

Figure 27 Average Lean Value Flow scores in the post-crisis period 2009 – 2014, omitting the T/R&D indicator. Sorted from left to right on total score value.

Figure 26 Average Lean Value Flow scores in the pre-crisis period 2003 – 2008, omitting the T/R&D indicator. Sorted from left to right on total score value.

Figure 29 Value creation performance score in 2003 omitting the T/R&D indicator. Sorted from left to right on total score value.

Performance Score AVG - No T/R&D [2003-2008]

Performance Score AVG - No T/R&D [2009-2014]
6.3. Conclusion

The benchmarks with and without T/R&D show that the overall trends are not severely impacted by omitting the indicator. Only in specific cases can it have major implications in the total score values, as was exemplified by GWM and Honda. Though these specific cases, especially GWM, show that T/R&D can show unsuspected behavior which distorts the measured performance score of a company. The indicator thus can show behavior which does not comply with the expected behavior reasoned from theory. In other words, T/R&D can reward companies significantly in circumstances which are not viewed as improved Lean value creation performance. Investing in R&D is important according to Lean theory because it supports the continuous improvement aspect. But abruptly cutting the R&D budget also results in an increase of the T/R&D indicator and thus can’t be used in this straightforward fashion. More research is needed on how to rightly incorporate the R&D expenses of a company. Because the overall trends in the Lean Value Flow benchmark are not majorly effected, the T/R&D indicator can be excluded in the following case studies. This will prevent complicating the results introduced by the new insights into the T/R&D indicator.
7. Case Studies

7.1. Introduction
In the previous chapters, the Lean Value Flow benchmark was constructed and analyzed. In this chapter, the benchmark will be tested for its applicability by means of six case studies. Two automotive companies, three manufacturing companies and one supplier of industrial MRO\(^2\) products are selected as case studies (see Table 19). These companies provide a set of case studies with varying core businesses and backgrounds though all are associated with the manufacturing industry. In this manner, the benchmark can be tested on companies with different characteristics but still are relatively comparable to the automotive industry.

It turns out that Research and Development expenses aren’t generally listed in annual reports by the manufacturing companies used as case studies in this research. The use of this indicator can thus not be tested using this industry. Van Stuyvesant in his research (van Stuyvesant Meyen, 2015) already points out that different industries have different focuses on indicators and this now becomes apparent on the aspect of R&D. Some companies do not list the R&D expenses and others, like SEW, don’t have a recognizable R&D department. Often the engineering department functions as the R&D department in these type of companies. Together with the concerns put forth in the previous chapter, it is decided to omit the T/R&D indicator concerning the case studies.

Table 19 List of the case study companies with average values for the turnover, profit, number of employees, inventory value and PPE value in millions of euro’s. \(\Delta T\) is the percentage of change in turnover between the year 2003 and 2014.

<table>
<thead>
<tr>
<th>Company</th>
<th>Turnover [MIO €]</th>
<th>(\Delta T) [%]</th>
<th>Profit [MIO €]</th>
<th>Employees [#]</th>
<th>Inventories [MIO €]</th>
<th>Plant, Property and Equipment [MIO €]</th>
<th>Core business</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEW Eurodrive The Netherlands</td>
<td>€ 61,33</td>
<td>46%</td>
<td>€ 5,13</td>
<td>178</td>
<td>€ 2,96</td>
<td>€ 5,69</td>
<td>Manufacturer of drive products</td>
</tr>
<tr>
<td>Intergas Verwarming</td>
<td>€ 63,03</td>
<td>141%</td>
<td>€ 15,21</td>
<td>155</td>
<td>€ 4,07</td>
<td>€ 2,69</td>
<td>Manufacturer of Central Heating products</td>
</tr>
<tr>
<td>LELY Industries</td>
<td>€ 189,22</td>
<td>364%</td>
<td>€ 8,37</td>
<td>369</td>
<td>€ 29,80</td>
<td>€ 2,00</td>
<td>Manufacturer of agricultural machines</td>
</tr>
<tr>
<td>Brammer Group</td>
<td>€ 593,14</td>
<td>143%</td>
<td>-€ 0,72</td>
<td>2,557</td>
<td>€ 99,91</td>
<td>€ 17,57</td>
<td>Supplier of industrial MRO products</td>
</tr>
<tr>
<td>Daimler (Mercedes-Benz)</td>
<td>€ 118,592</td>
<td>-5%</td>
<td>€ 6,540</td>
<td>304,206</td>
<td>€ 16,660</td>
<td>€ 23,893</td>
<td>Automotive manufacturer</td>
</tr>
<tr>
<td>Porsche</td>
<td>€ 9.378</td>
<td>208%</td>
<td>€ 2,241</td>
<td>14.147</td>
<td>€ 925</td>
<td>€ 2.288</td>
<td>Automotive manufacturer</td>
</tr>
</tbody>
</table>

Automotive Manufacturers: Porsche and Daimler

The two automotive companies selected are Porsche and Daimler. Porsche is a manufacturer of sports cars in a higher price class than the standard automobile but below the high end sports cars segment like Ferrari and Maserati. It was not initially included in the automotive benchmark because it has a complicated history with Volkswagen. Porsche and Volkswagen were from the beginning separate companies with significant stakes in each other's companies. This changed with the onset of the financial crisis, when the Porsche holding became the owner of Volkswagen and subsequently Volkswagen became the owner of the Porsche AG (manufacturing department) (PorscheSE, 2009). This process was reflected in major swings of the annual report figures, especially the profit, which made Porsche unsuitable for inclusion in the benchmark. Daimler had a similar experience with the demerger with Chrysler in 2007. This resulted in a discontinuity

\(^2\) MRO: Maintenance, Repair and Overhaul. This involves products like electric power drives and bearings for example.
in the annual report figures which made it unable to justly compare Daimler’s performance over the years for purposes of this research. It thus could not be included in the benchmark dataset. A proxy to investigating Daimler can be found in its major car brand Mercedes-Benz. All necessary figures are issued for this brand over the whole analyzed time period and thus Mercedes-Benz as a Daimler substitute will be used as a case study.

Miscellaneous Manufacturers: SEW, Intergas and Lely
SEW, Intergas and Lely are Dutch manufacturers selected as case studies for this research. The represent the manufacturing industry in a different size category than the automotive from the benchmark. This provides the opportunity to potentially identify any characteristics associated with company size. The three companies together range in size (turnover) from €35 million (Intergas, 2003) to €325 million (Lely, 2012).

SEW Eurodrive The Netherlands is a subsidiary of the German based SEW Eurodrive concern. SEW The Netherlands is run in practice as an independent company with basically one supplier (the SEW Eurodrive concern). Their core business is assembling drive products and delivering engineering solutions associated with their products. All components and designs that are used for their products are delivered by the other SEW-Eurodrive companies which explains the lack of R&D expenses. The Lean Philosophy has been implemented at their plant since 2002 and the company has subsequently experienced great performance improvement.

Intergas Verwarming is a manufacturer of central heating systems and products (boilers etc.) and claim to have a leading position in developing highly efficient boilers (Intergas_Verwarming_B.V., 2016). Intergas experienced a steady growth in turnover from 2003 to 2014 with a total increase of 143%.

Lely Industries is a manufacturer and developer of agricultural machines and is an important player on the international market. Since 2005 it has seen remarkably turnover growth, going from €62 million to €239 million in 2008. The crisis stagnated the growth at first but eventually it picked up again and peaked in 2012 with €326 million. 2013 and 2014 saw an episode corporate restructuring. This resulted in administratively transferring the PPE assets to Lely Industries in 2013 and then transferring these assets away again from Lely Industries to other subsidiaries.

Industrial MRO products Supplier: Brammer
Brammer Group is a supplier of industrial MRO² products and engineering services based in the UK but with a large presence in the Netherlands. In contrast to other case studies, they do not manufacture their products themselves but are merely a logistical channel for selling MRO products and provide engineering consultancy associated with these products. The logistical side of the company still needs a significant amount of investment in PPE for the sorting machines, warehouses etc. They are tightly associated with many manufacturers which makes them an essential part in the supply chain of this industry. This provides an interesting case for this benchmark to explore the applicability outside the strict manufacturing business. Unfortunately, figures for the year 2003 were not available but this will be not be too much of a hindrance for the analysis when taken into account.

In the next paragraphs, the results from the case studies will be presented. First the total (without T/R&D) Lean Value Flow performance scores will be discussed, followed by an in depth look at the specific indicators. In this manner the benchmark and the individual indicators can be analyzed for their applicability.
7.2. The Lean Value Flow Performance Score

Figure 30 shows the historic progression of the calculated score values for every case study company and the automotive benchmark average. The exceptionally high total score achieved by Lely is immediately visible and dominates the graph, making the results from the other case studies unintelligible. In Figure 31 the same graph is presented but capped at 60 points on the y-axis. Lely now falls for the most part outside the graph but the behavior of the other companies is now visible.

Figure 30 Historic progression of the Lean Value Flow performance score. The score value combines the values for the indicators T/E, T/I, T/PPE and P/T. Automotive AVG is the average score value of the automotive benchmark.
What is most noticeable are the much larger scores attained by the non-automotive companies than the automotive companies from the benchmark. To put it in perspective, the highest score achieved by the benchmark in any year never rises above 32.5 points. Intergas, Lely and Brammer always score higher than the highest scoring benchmark company. SEW, on the other hand, start off with an average score in 2003 and then steadily rises to 38.9 points in 2014. It is the only one of the non-automotive companies to show a relatively modest turnover growth of 46% compared to 141%, 143% and 364% growth figures of Intergas, Brammer and Lely respectively. The size of these companies is also a couple of orders of magnitude smaller than the automotive companies (average turnover of the benchmark is €57.709 million). High growth figures combined with smaller averages company sized could signal different mechanics at work which produce these very high score values. Though Great Wall Motors started off with similar turnover figures (€354 million in 2003) as the non-automotive companies and increased it with over 2200%, it didn’t show the same high scores. Porsche shows a great swing in its total performance score in the years 2008 and 2009. This is probably caused by the great corporate restructuring project with Volkswagen though it also coincides with the onset of financial crisis which most likely also had some effect on the performance of the company. Daimler forms a typical automotive case as exemplified by it scoring around the automotive average. Expected shocks by the demerger with Chrysler in 2007 are not clearly visible but this can be explained by the fact we are only looking at the Mercedes-Benz figures. The slight negative bump visible with Daimler also coincides with the crisis thus these results can’t be simply attributed to the demerger.

The high scores attained by the non-automotive companies would imply that they are high Lean value creating performers. To see if this true we need to investigate the individual indicator of the total performance score for their impact on the total score. It could be possible that a specific indicator shows atypical behavior and subsequently dominates the total score. Figure 32 and Figure 33 show the constituent parts of the total performance score for pre and post-crisis periods and indeed suggest that one indicator,
T/PPE, dominates the scores. In the next paragraphs, the specific indicators from which the total performance score is built up will be investigated to gain a better understanding of the high score causes.

Figure 32 Average Lean Value Flow scores in the pre-crisis period 2003 – 2008. Sorted from top to bottom on total score value.

Figure 33 Average Lean Value Flow scores in the post-crisis period 2009 – 2014. Sorted from top to bottom on total score value.
7.3. T/E

In this paragraph, the turnover per employee (T/E) indicator is examined to see how the case studies perform on this aspect. Figure 34 shows the historic progression of the T/E scores.

![T/E SCORE Historic progression](image)

*Figure 34 Historic progression of performance score for the T/E indicator. The highest score attainable by an automotive company from the benchmark is by definition 10 points. The automotive avg represents the benchmark average.*

In contrast to the total scores, all case studies score much more moderately compared to the benchmark average. Lely starts beneath the automotive benchmark average, increases to 9.5 points in 2008 and then descends to around average values. By definition, 10 points is the maximum value achieved by the automotive benchmark dataset and 1 point the lowest value. Lely, and all the other companies except Porsche stay within these boundaries for T/E and thus perform in the same value range. Porsche achieves just over 10 points in 2012 and 2014 and thus performs higher on this indicator than any other automotive company or case study has done. Its T/E scores are on the other not disproportionally higher than the rest, as was the case with Lely for the total score, and thus can be interpreted as a real high performer on T/E. SEW shows a large increase in performance score, increasing from a very low score of 2.92 to above an average score of 7.19 in 2014. In fact, Table 20 shows that all case studies except Porsche score rather low or average compared to the automotive benchmark companies in the years 2003 and 2014.
Table 20 List of performance scores for the T/E indicator in 2003 and 2014 per company. Companies are sorted from highest to lowest score per year. Case studies are printed in bold. *For Brammer no figures were available in 2003 and is substituted with its 2004 value in this table.

<table>
<thead>
<tr>
<th>Company</th>
<th>2003</th>
<th>Company</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAZDA</td>
<td>8,62</td>
<td>PORSCHE</td>
<td>10,26</td>
</tr>
<tr>
<td>HYUNDAI</td>
<td>7,25</td>
<td>FHI (SUBARU)</td>
<td>10,00</td>
</tr>
<tr>
<td>PORSCHE</td>
<td>7,13</td>
<td>AUDI</td>
<td>9,35</td>
</tr>
<tr>
<td>TOYOTA</td>
<td>6,84</td>
<td>BMW</td>
<td>9,28</td>
</tr>
<tr>
<td>HONDA</td>
<td>6,65</td>
<td>FORD</td>
<td>8,56</td>
</tr>
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<td>HYUNDAI</td>
<td>8,30</td>
</tr>
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<td>MITSUBISHI</td>
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<td>GM</td>
<td>8,05</td>
</tr>
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<td>6,20</td>
<td>NISSAN</td>
<td>7,98</td>
</tr>
<tr>
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<td>6,14</td>
<td>LELY</td>
<td>7,84</td>
</tr>
<tr>
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<td>TOYOTA</td>
<td>7,81</td>
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<td>5,72</td>
<td>MITSUBISHI</td>
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<td>5,55</td>
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</tr>
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<td>SEW</td>
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<td><strong>Brammer</strong></td>
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<td><strong>Brammer</strong></td>
<td><strong>3,75</strong></td>
</tr>
<tr>
<td>GWM</td>
<td>1,24</td>
<td>GWM</td>
<td>1,97</td>
</tr>
</tbody>
</table>
7.4. T/I
Figure 35 shows the historic progression of the performance scores for the inventory turnover indicator (T/I) for all case studies and the automotive benchmark average. In Table 21 are the score listed per company for the years 2003 and 2014 with the case study companies highlighted in bold.

The graph and the table show no disproportionally high or low scores, as was also the case with the T/E indicator. SEW again shows a large increase in score value but this time starts at an average value of 3.95 and rises to the highest absolute score value achieved by any company of 12.35. Intergas follows the same growth trend as SEW until 2009 (value of 6.92) but then steadily declines again. Lely, as the high scorer in of the combined performance scores, surprisingly scores very poorly here. It starts off with a score of 0.88 and decreases to 0.53 before cautiously increasing more average values. These first low scores of Lely are even lower than the lowest achieved score by the benchmark dataset. Though, as could be seen in the analysis of the T/I indicator (Chapter 5.2), the data distribution is quite skewed to the lower end of the spectrum. This shows that many companies are struggling with their performance on this indicator compared to the few high performers and consequently the low scores of the case study companies fit within this trend. Porsche performs on average for most of the measured period but decreases in the last two years to a fourth lowest place. Daimler performs medium at first but then starts to decline in 2006 and subsequently performs poorly the rest of the period together with Brammer, ranking second last and last in 2014 respectively.
Table 21 List of performance scores for the T/I indicator in 2003 and 2014 per company. Companies are sorted from highest to lowest score per year. Case studies are printed in bold. *For Brammer no figures were available in 2003 and is subsequently substituted with its 2004 value.

<table>
<thead>
<tr>
<th>Company</th>
<th>2003</th>
<th>Company</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKODA</td>
<td>7,00</td>
<td>SEW</td>
<td>12,35</td>
</tr>
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<td>PSA</td>
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<td>3,80</td>
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<td>FHI (SUBARU)</td>
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<td>VOLKSWAGEN</td>
<td>2,00</td>
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<tr>
<td>GWM</td>
<td>1,96</td>
<td>VOLKSWAGEN</td>
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</tr>
<tr>
<td><strong>BRAMMER</strong></td>
<td>1,49</td>
<td>DAIMLER (MB)</td>
<td>1,61</td>
</tr>
<tr>
<td>LELY</td>
<td>0,88</td>
<td>BRAMMER</td>
<td>1,30</td>
</tr>
</tbody>
</table>

The inventory turnover indicator shows besides the value created per inventory also the inventory overturn in year. From the actual ratio values of the T/I indicator, it can be calculated how long a product (or more correctly, the value) resides in the inventory. The turnover is the amount of value created in a year and the inventory is the amount of value (in euros) that resides at the end of the year (the moment of measurement) in the inventory. For example, the best automotive performer in 2014, Daihatsu, had an T/I value of 26,9. In other words, it had its inventory overturned 26,9 times that year and thus the value stored in inventory resided on average 365 days/26,9 cycles = 13,6 days. In comparison, the automotive benchmark average in that year was 13,6 cycles or 26,8 days and the lowest performer of that year, Brammer, attained only 5,4 cycles or 67,6 days. The highest performer of 2014, SEW, reached 34,7 cycles which translates to an average residence of value in inventory of 10,5 days. Because inventory is one of the main wastes (muda) according to Lean theory it is a prime indicator of high Lean performance. Having a short overturn of inventory or many cycles a year shows the degree of Flow attained in the process of a company. SEW and Daihatsu have a much better Flow in their processes, flowing roughly twice as fast as the benchmark average and about 5 to 6 times as fast as the worst performer. SEW performs better than the best automotive company because it has barely any finished goods inventory. They ship all products the same day they are finished and thus effectively eliminated this kind of inventory.
7.5 T/PPE
In Figure 36 are the historic progressions plotted for the Turnover per PPE indicator. The graph is dominated by the extremely high scores from Lely as was also seen with the combined performance scores in paragraph 7.2. Figure 37 is subsequently presented to bring out the results from the other companies by means of constraining the y-axis to a value of 45 points.

**Figure 36** Historic progression of performance score for the T/PPE indicator. The highest score attainable by an automotive company from the benchmark is by definition 10 points. The automotive avg represents the benchmark average.

**Figure 37** Historic progression of the performance score of the T/PPE indicator. The y-axis is capped at 45 points to make the other companies besides Lely better visible.
It is visible in Figure 36 that Lely achieved its largest scores after the year 2010, with a large drop in 2013. Lely performed a corporate restructuring in those years and this resulted in the administrative transfer of the Property, Plant and Equipment assets. Lely Industries, the specific part of the Lely concern under consideration showed a large growth of its turnover from €216 million in 2010 to €326 million in 2012 and then a lesser decrease to €279 million in 2014. At the same time, due to the restructuring program, the PPE assets first declined and then suddenly increased tremendously in 2013. The next year the PPE assets were again the pre 2013 level. This sudden increase explains the large drop seen in the T/PPE indicator and could attributed to an administrative decision to put all PPE assets in the books of Lely Industries for that year and then transfer them back to another part of the company. The multi-year trend of increasing T/PPE values can be attributed to the steady growth of the turnover and the decrease in PPE assets. This trend is can more probably be attributed to a real performance increase though the accounting practices also are suspected to play a large part. The other non-automotive case study companies, SEW, Intergas and Brammer, also have exceptionally large scores for the T/PPE indicator compared to the benchmark with SEW showing values which still fall within the range of the benchmark. The suspicion is now raised that the T/PPE indicator behaves considerably different in the non-automotive companies compared to the automotive companies. One difference between the automotive companies and the other case studies is the size of the companies. In Figure 38 the size, in turnover, is plotted against the absolute value of the T/PPE indicator (here the actual values of the T/PPE indicator are plotted and not the converted score values). The shows the entire dataset of benchmark(in blue) and the case studies(in red) with axes in logarithmic scale. The automotive companies from the benchmark form a clear cluster with Porsche and Daimler falling right within it. The blue “tail” to the lower turnover values consists of GWM’s datapoints. Intergas, Lely and Brammer are clearly outside the range of the benchmark with SEW covering part of the upper range.

**Figure 38 Company size, measured in turnover, plotted against the absolute T/PPE values. The datapoints from the automotive benchmark are colored blue and the case studies are colored red. The labels indicate the presence of the specific case study companies. Both axes have a logarithmic scale and the scatter plot shows the entire dataset.**
The blue tail comprising Great Wall Motors overlaps in size with Lely and Brammer but does not show the same high indicator values. SEW is even smaller but shows more comparable indicator values. A size effect on the characteristic of T/PPE thus seems unlikely. A characteristics which is shared between GWM and Lely, Intergas and Brammer is their large growth figures but GWM does not show the same high T/PPE figures as the other do. It thus seems that the T/PPE shows different characteristics for different industries though this is based on a very restricted set of case studies and thus needs more research. In the case of Lely Industries, it also seems like the T/PPE indicator is artificially high because a large part of the PPE assets are not administrated in the annual reports of Lely Industries but with other companies in the Lely concern.
7.6. P/T

The profit margin, P/T, is the last indicator of the Lean Value Flow performance score. It represents in one way the ratio between costs and created value and is also an important measure of the financial health of a company. Figure 39 shows the historically achieved score values by the case study companies and the automotive benchmark average.

![P/T SCORE Historic progression](image)

*Figure 39 Historic progression of performance score for the P/T indicator. The highest score attainable by an automotive company from the benchmark is by definition 10 points. The automotive avg represents the benchmark average.*

Porsche shows a large positive and negative swing in its indicator score which is mostly caused by the acquisitions and restructuring with Volkswagen. The transactions coupled with these efforts resulted in abnormally high and low profits which probably do not reflect the real performance of the company. Instead it is an result of the financial procedures. Daimler, SEW and Lely lie very close the benchmark average through the measured time period. Table 22 shows that SEW made a large improvement between 2003 and 2014, increasing from a very low rank to third highest in 2014. Intergas performs very well with the profit margin and continuously scores very high, with its highest score in 2009 (10.69). Brammer exhibits a large depression in its profits in 2008 and 2009, showing that the financial crisis had a great impact on it. Overall, the P/T scores show a steady and relatively flat trend over time with only short bursts of high or low scores. These flat trends are partly the result of the high and low scores attained by the benchmark companies GM and Great Wall Motors, which push the 10 and 1 points boundaries up and down. Which also shows that the behavior of this indicator is mostly governed by a relatively constrained distribution with occasional outbursts.
Table 22 List of performance scores for the T/I indicator in 2003 and 2014 per company. Companies are sorted from highest to lowest score per year. Case studies are printed in bold. *For Brammer no figures were available in 2003 and is subsequently substituted with its 2004 value.

<table>
<thead>
<tr>
<th>Company</th>
<th>2003</th>
<th>Company</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWM</td>
<td>9.55</td>
<td>INTERGAS</td>
<td>8.74</td>
</tr>
<tr>
<td>INTERGAS</td>
<td>9.40</td>
<td>PORSCHE</td>
<td>8.12</td>
</tr>
<tr>
<td>PORSCHE</td>
<td>8.29</td>
<td>SEW</td>
<td>7.95</td>
</tr>
<tr>
<td>NISSAN</td>
<td>7.28</td>
<td>GWM</td>
<td>7.94</td>
</tr>
<tr>
<td>TOYOTA</td>
<td>7.09</td>
<td>FHI (SUBARU)</td>
<td>7.93</td>
</tr>
<tr>
<td>BMW</td>
<td>6.67</td>
<td>AUDI</td>
<td>7.29</td>
</tr>
<tr>
<td>HONDA</td>
<td>6.61</td>
<td>BMW</td>
<td>7.23</td>
</tr>
<tr>
<td>HYUNDAI</td>
<td>6.33</td>
<td>TOYOTA</td>
<td>7.21</td>
</tr>
<tr>
<td>AUDI</td>
<td>6.13</td>
<td>HYUNDAI</td>
<td>6.81</td>
</tr>
<tr>
<td>DAIMLER (MB)</td>
<td>6.04</td>
<td>DAIMLER (MB)</td>
<td>6.77</td>
</tr>
<tr>
<td>RENAULT</td>
<td>5.96</td>
<td>SKODA</td>
<td>6.58</td>
</tr>
<tr>
<td>SKODA</td>
<td>5.93</td>
<td>MAZDA</td>
<td>6.49</td>
</tr>
<tr>
<td>FHI (SUBARU)</td>
<td>5.92</td>
<td>VOLKSWAGEN</td>
<td>6.41</td>
</tr>
<tr>
<td>PSA</td>
<td>5.89</td>
<td>MITSUBISHI</td>
<td>6.41</td>
</tr>
<tr>
<td><strong>Brammer</strong></td>
<td>5.88</td>
<td>LELY</td>
<td>6.39</td>
</tr>
<tr>
<td>DAIHATSU</td>
<td>5.80</td>
<td>DAIHATSU</td>
<td>6.38</td>
</tr>
<tr>
<td>MAZDA</td>
<td>5.72</td>
<td>NISSAN</td>
<td>6.22</td>
</tr>
<tr>
<td>VOLKSWAGEN</td>
<td>5.63</td>
<td>HONDA</td>
<td>6.15</td>
</tr>
<tr>
<td>GM</td>
<td>5.53</td>
<td><strong>Brammer</strong></td>
<td>5.88</td>
</tr>
<tr>
<td>LELY</td>
<td>5.33</td>
<td>RENAULT</td>
<td>5.77</td>
</tr>
<tr>
<td>SEW</td>
<td>5.26</td>
<td>GM</td>
<td>5.75</td>
</tr>
<tr>
<td>FORD</td>
<td>5.12</td>
<td>FORD</td>
<td>5.61</td>
</tr>
<tr>
<td>MITSUBISHI</td>
<td>4.60</td>
<td>PSA</td>
<td>5.36</td>
</tr>
</tbody>
</table>
7.7. Conclusions

The Lean Value Flow performance scores turn out to be dominated by the effects of the T/PPE indicator and for a lesser extent by the P/T indicator. When we look at the individual indicators it becomes apparent that the T/PPE indicator shows very different behavior in the non-automotive case studies. The effect of size or the turnover growth of the individual companies are probably not the cause of the apparent difference and the cause must be sought in the specific characteristics of the non-automotive industries and partly be accountancy effects in the case of Lely Industries. The difference in industry characteristics was already proposed by Van Stuyvesant (van Stuyvesant Meyen, 2015) and more research is needed to identify these industry characteristics. The T/PPE indicator does perform well in comparing automotive companies to each other and thus can be used for intra-industry comparisons, at least in the automotive industry.

The P/T indicator also has a dominating effect on the total performance score, albeit much less so than the T/PPE indicator. Thus is caused by the fact that indicator is prone to sudden large swings when companies undergo unusual events like the bankruptcy of GM, the tremendous growth of Great Wall Motors or the acquisition of Volkswagen by Porsche. These large swings have the effect of pushing the maximum and minimum boundaries of the benchmark ranking to extreme values. Thus has the result of flattening all the other smaller trends and subsequently reducing their impact on a company’s score. The calculation method used in this research for the performance scores could thus be improved to dampen the large swings. The T/E and T/I on the other perform as expected and provide a good means of comparing company performances across industries, at least concerning the very restricted case study analysis of this research.

Looking at the individual case study companies shows some interesting results. SEW shows steady performance increase on every indicator and compared to the automotive benchmark increases from an average performer to above maximum performer. It outperforms the automotive industry in 2014. They started implemented the Lean Philosophy in their processes at the start of measured time period and this analysis thus shows a correlation between Lean and performance increase. According to these indicators at least. Intergas exhibits a large performance increase in the first part of the time period but then slightly decreases over the last part of the time period. Their turnover keeps growing over the whole period but significantly flattens in the last couple of years, signaling potential stagnation or deterioration of company’s processes. Brammer scores quite low on the T/E and T/I indicators which can be characteristic of the company’s business: supplier logistics. Its P/T indicator is on average with a large slump around the financial crisis and its T/PPE indicator quite erratic behavior. The company acquired a couple of smaller companies over the course of the measured time period and this could explain the erratic behavior. Lely experienced a large growth of the T/E indicator, peaking in 2008, but decreased significantly after that to average values. It performs poorly on the inventory turnover indicator over much of the period, only pull up to average values in the last couple of years. This could show a performance increase in the inventory management. The slight decrease in turnover in these last years strengthens this idea because an unexpected decrease in turnover could results in an oversized inventory. The profit margin is on average and the T/PPE indicator is extremely high compared to the rest. In 2013 a large dip occurred which can be attributed to accountancy practices in which the PPE is shifted around within the larger concern.

Porsche and Daimler perform overall within the boundaries of the automotive industry. Daimler, represented here by the Mercedes-Benz figures performs on the lower mid-range of the benchmark but performs outright poorly on its inventory turnover. The expected shock effect of the demerger with Chrysler isn’t readily visible in the results probably because of the constrained view on the Mercedec-Benz figures. Porsche is a rather high performer in the total performance score though this partly obscured by the large P/T swing. Besides P/T, it performs well on the created value per employee (T/E) but shows medium results on the T/I indicator with a negative trend in the end years.
Overall it can be concluded that the Lean Value Flow performance benchmark is useful in comparing performance results between automotive companies but more research is needed on the indicators T/PPE and P/T to extend it to other industries. Besides this, the innovation capability indicator T/R&D was not tested because of a lack of data with the case studies and perceived fundamentally different behavior within the automotive dataset. More research is needed on this indicator to be able to incorporate the innovation and continuous improvement aspects of a company.
8. Conclusion and Recommendations

8.1. Conclusions

Nine indicators were selected for further analysis following a literature review. These are T/E, T/I, T/PPE, T/R&D and P/T, P/E, P/I, P/PPE, P/R&D. The indicators were subsequently analyzed for their usefulness with a data set consisting of the automotive industry. From a bivariate correlation and statistical analysis it was concluded that the profit variable showed too much spread for it to be useful. It deluded the trends in the other variables to such an extend as to effectively reduce them to constants. The profit indicators thus effectively measure only the profit and are dropped for use in the Lean Value Flow benchmark. The profit margin indicator (P/T) was kept in order to incorporate the aspect of profit in the performance measurement. Because it relates to the turnover instead of other company characteristics it was deemed useful in measuring the profitability aspect of a company. The remaining indicators (T/E, T/I, T/PPE, T/R&D and P/T) were then analyzed in depth using the automotive dataset. The T/R&D indicator showed divergent behavior from the other indicators and seemed to defy the prerequisite assumption of showing improved performance with higher values. The results were interpreted as showing active regulation of the R&D expenditure ratio by companies and abnormally high values most probably signaled not an improved performance but some other processes at work. This suspicion was further corroborated with the analysis of the benchmark scores. The fact that most case study companies did not provide R&D figures provided the final decision to exclude the T/R&D indicator from the benchmark because its behavior could not be further investigated.

In the last chapter the final set of indicators (T/E, T/I, T/PPE and P/T) were combined into a Lean Value Flow benchmark performance score and tested using six case studies. The final analysis showed that the non-automotive companies had very different characteristic values for the indicator T/PPE which dominated in the total score. An in depth investigation of the T/PPE indicator did not conclusively show the cause of this behavior. Company size or turnover growth did not seem to produce an explanation of the high values and it is thus suspected to be an intrinsic characteristic of these companies’ industries. More research is needed to explain the difference. It was also shown that the profit margin showed sudden swings in value for some companies which distorted the benchmark score calculation method. Though the indicator was deemed useful in measuring the performance of a company, more research is needed to developed a scoring method which dampens these large swings.

It is concluded that the T/E and T/I indicators are potentially useful value creation indicators in combination with the used ranking system and that the T/PPE and P/T indicators need more research for full inclusion. The T/R&D indicator turned out to show very different behavior to other indicators and to the initial expectations and could not be used in its current form. Because it represents the innovation capability of a company, which is an important Lean aspect, it is important to develop in future research an improved or alternative indicator.

Through the research and analysis presented in this thesis report, the main research question can now be answered. The main research question:

How can a Lean value creation benchmark be developed to provide a means of comparing company performances to each other?

From an initial nine indicators selected from literature and theory, five (T/E, T/I, T/PPE, T/R&D and P/T) showed potential for use in the benchmark. Using a score calculation method, these indicators were combined into one performance score. T/R&D was eventually dropped because of divergent behavior and T/PPE and P/T need more research for a fully functioning benchmark. Two indicators, T/E and T/I, showed consistent behavior and can be readily used for benchmarking purposes. This research showed that different
industries can show different characteristics, especially in the case of T/PPE, and provides ample opportunity for follow up research.
8.2. Recommendations

It is recommended to further test the proposed Lean Value Flow performance benchmark on other industries to validate its use and explore characteristics of other industries. The explorative nature of the use of case studies in this research precludes it from drawing definitive conclusions on the characteristics of other industries. Constructing statistically solid datasets covering other industries will provide more insight in the mechanics of the indicator in those industries. This will greatly increase the value of the benchmark in the use of Lean performance measurement.

It is further recommended to investigate the use of other indicators to measure more aspects of a company. It is highly recommended to redesign or replace the T/R&D indicator to measure the innovation capability of a company.

It is recommended to re-evaluate the calculation method used to assign scores to indicators. The P/T indicator showed that this scoring method is sensitive to outliers in the data set. Other scoring methods could mediate these outliers better and should be investigated.

Value Added, consisting of all costs and activities the company does itself, was a third way mentioned for measuring Lean value creation. It is a good Lean value creation indicator because it measures only that part of the total value the company contributes itself, whereas the Turnover measures the value created by the whole supply chain. This variable could not be used however in this research because conventional accountancy practices don’t discriminate between bought-in costs (materials, products and services) and the own costs. They rather group all costs associated with the production process into the term Costs of Goods Sold. Some (automotive) companies do present their value adding costs in their annual reports, signifying a high degree of Lean awareness throughout these companies. Companies listing value adding costs are for example Audi, BMW and Skoda. It is recommended in further Lean value creation research to investigate this variable.
References


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Appendix A – Lean Performance Models

Descriptions of several Lean performance models from literature. The original list of indicators was acquired from these papers. The timeline below (Figure 40) shows the development of Lean over time.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1927 and before</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Henry Ford outlines his production philosophy and the basic principles underlying the revolutionary Ford Production System (FPS) in &quot;Today and tomorrow&quot; in 1927.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1937—78 Toyota in Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>1937 - Toyota (later Toyota Motor Company) is established in Koromo, Japan.</td>
</tr>
<tr>
<td>1938 - Toyota establishes the Toyota Production System (TPS).</td>
</tr>
<tr>
<td>1939 - Toyota introduces the just-in-time (JIT) production method as a key component of TPS.</td>
</tr>
<tr>
<td>1978 - According to Ohno, the primary goal of TPS is cost reduction (waste elimination); it can be achieved through quantity control, quality assurance, and respect for humanity. He recommends producing only the kind of units needed, at the time needed and in the quantities needed.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1973-88 TPS arrives in North America</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973 - Oil crisis hits North America and generates immense interest in the (new) Japanese manufacturing and management practices followed by publication of numerous academic and practitioner books and articles.</td>
</tr>
<tr>
<td>1977 - First academic article is published by Sagimori et al.; Narrowly focused articles on topics such as Kanban and just-in-time production (Monden, 1981b), production smoothing and level loading (Monden, 1981c) appear.</td>
</tr>
<tr>
<td>1984 - NUMMI, a joint venture between Toyota Motor Company and General Motors opens in California.</td>
</tr>
<tr>
<td>1984 - Noteworthy books including Monden's Toyota Production System (1983); Ohno's Toyota Production System: Beyond large-scale production (1985) are published in English.</td>
</tr>
<tr>
<td>Mid 1980s - There is only a piecemeal understanding of TPS and its constituent elements; equivalence between JIT production, kanban and TPS is suggested (see Table 2).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1988-2000 Academic progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988 - Krafcik coins the term “lean” to describe the manufacturing system used by Toyota.</td>
</tr>
<tr>
<td>1990 - The machine that changed the world by Womack, Jones and Roos is published.</td>
</tr>
<tr>
<td>1990 - The machine establishes &quot;lean production&quot; to characterize Toyota’s production system including its underlying components in the popular lexicon.</td>
</tr>
<tr>
<td>1990 - The book describes a lean system in detail, but does not offer a specific definition.</td>
</tr>
<tr>
<td>Mid 1990s - Articles related to measuring just-in-time (Sakakibara et al., 1993; Flynn et al., 1995; McLaughlin, 1997), total quality management (Ross, 1993; Dean and Bowen, 1994; Sittkin et al., 1994; Flynn et al., 1995), their interrelationships (Flynn et al., 1995; Sakakibara et al., 1997) and the impact of other organizational variables on their implementation are published in the academic journals.</td>
</tr>
<tr>
<td>1994 - Lean Thinking by Womack and Jones is published. The book extends the philosophy and guiding principles underlying lean to an enterprise level.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2000-present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numerous books and articles by practitioners and consultants, and a few academic conceptual (Hopp and Spearman, 2004; de Treville and Antonakas, 2006) and empirical articles (Shah and Ward, 2003) highlighting the overarching nature of lean production are published; yet no clear and specific definition is available.</td>
</tr>
<tr>
<td>2006 - Toyota Motor Company is projected to become #1 automobile manufacturer in North America.</td>
</tr>
</tbody>
</table>

Figure 40 Development of Lean in practice and academics through time. Adapted from (Shah and Ward, 2007).
The 3C model

The value chain of Porter (shown in Figure 41) was first defined in 1985 to describe the value chain of companies. Since then, the nature of the business processes had changed and new insights have been acquired about the functioning of the value chain under the influence of Lean thinking (Beelaerts van Blokland et al., 2007). This resulted in the canting of Porter’s value chain, redefining primary and supportive activities. Three drivers (Conception, Continuation and configuration) were formulated (Beelaerts van Blokland and Santema, 2006), which drive the value chain innovation processes. Together they form the 3C model and were subsequently applied on the value chain of Porter to develop the updated Lean Value Chain (Figure 42). The 3C model was originally used to form a framework for measuring the degree of value leverage of company on its value chain. Later it became apparent that the specific indicators used for measuring the value leverage also measured the leanness of a company. Figure 43 shows the 3C model with the indicators which measure leanness on company level.

Why is the 3C model important for this research? The model constitutes an attempt at modelling and measuring the performance of companies in respect to their value leverage capabilities. Value leverage is
the concept of focusing on the core activities and leveraging other value adding activities on the suppliers
(value chain). Two important Lean concepts are captured in this model: value chain integration and core
activity focus. In previous research the 3C model was validated on company level through statistical analysis
on the automotive industry (Beelaerts van Blokland et al., 2009, Beelaerts van Blokland et al., 2010), and
the aerospace industry (Beelaerts van Blokland et al., 2009, Beelaerts van Blokland et al., 2012, Kinik et
al.). The company level indicators are, as shown in Figure 43, T/E, P/E and R&D/C. The PMP indicator,
originally designed on product level, has shown to have potential too on company level as a ratio of turnover
per profit (Beelaerts van Blokland et al., 2010). The indicator for PMP, T/P, was eventually discarded in the
paper for showing negative correlations to the other variables. It was pointed out that it is essentially the
inverse of the profit margin, which can be very well of interest for this performance model when using the
right profit metric.

The 3C model was combined with new indicators based on asset specificity and tested with a case study on
aerospace maintenance companies (Beelaerts van Blokland and De Jong, 2016). The new indicators are
Gross Margin, Inventory and Turnover per Fixed Asset (shown in Table 23). It was found through linear
regression analysis that they form a model which was subsequently named the Lean Transaction Cost
Efficiency Model. They are an addition to the 3C model by adding the asset specificity perspective in
performance measurement. Lean implementation was measured using Turnaround Time (TAT) and On
Time Performance (OTP) and the 3C indicators (T/E, P/E and R&D/E) were used to compare the new
indicators to.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAT</td>
<td>Turnaround Time</td>
</tr>
<tr>
<td>OTP</td>
<td>On Time Performance</td>
</tr>
<tr>
<td>GM/FA</td>
<td>Gross Margin versus Fixed Assets</td>
</tr>
<tr>
<td>I/FA</td>
<td>Inventory versus Fixed Assets</td>
</tr>
<tr>
<td>T/FA</td>
<td>Turnover versus Fixed Assets</td>
</tr>
<tr>
<td>T/E</td>
<td>Turnover per Employee</td>
</tr>
<tr>
<td>P/E</td>
<td>Profit per Employee</td>
</tr>
<tr>
<td>R&amp;D/E</td>
<td>Research &amp; Development per Employee</td>
</tr>
</tbody>
</table>

The 3C model forms a good model for measuring Lean performance on company level, especially with
respect to value leverage. Operational performance of a company is on the other hand less well represented
in the model. This research continues in the same school of thought but tries to widen the scope of the model
to encompass operational performance as well as general performance. In the next paragraph other models
are explored which will form a source of inspiration for this research.
Bayou and De Korvin (2008) proposed a lean measuring method in order to compare the performance of two automotive companies (Ford and GM). The performance of these companies are benchmarked to Honda which is deemed a Lean industry standard. Leanness, in this research, is defined as a combination of efficiency and effectiveness (see Figure 44). This basic definition is subsequently used to construct a measurement model which measures three aspects of Lean (JIT, Kaizen and quality management). Each aspect is operationalized through a couple of indicators (Table 24) and with the use of fuzzy logic, the automotive companies are then rated on their Leanness compared to Honda.

Though they start their reasoning here, they continue defining their measurement method using indicators which measure specific techniques. A set of eight indicators is subsequently presented which measure the techniques JIT, Kaizen and quality management. The three techniques are chosen from a more extensive list (constructed by (Shah and Ward, 2003)) because, they “received substantial attention” and are considered as “more philosophical concepts than concrete instruments”. This is contrasted by the original use by Shah and Ward (2003) who grouped all listed techniques into four Lean bundles (JIT, TPM, TQM and HRM) based on statistical relationships.

The techniques, from Bayou and De Korvin, thus seem to be chosen fairly arbitrarily which makes their model less useful in this research. The indicators, subsequently developed to measure these techniques, could be useful but the focus on only these three techniques gives a limited scope on Lean practices without a justifiable reasoning. On a more fundamental scale, measuring lean techniques implicitly assumes that these techniques are absolutely beneficial. But the techniques are only a means of achieving a Lean company thus measuring techniques is not an absolute measure of leanness. On the other hand, the lean definition of efficiency and effectiveness, presented by Bayou and De Korvin(2008) earlier in their paper, provides a more unbiased starting point for measuring performance. The combination as while as the separate use of efficiency and effectiveness provides for a balanced view on performance. As the authors pointed out, cutting costs to increase efficiency while at the same decreasing effectiveness, results in a shortsighted shrinkage and not in performance growth, exemplifying the need of both measures.
Table 24 Indicators used for measuring the Leanness of Ford and General Motors. Adapted from Bayou and De Korvin (2008).

<table>
<thead>
<tr>
<th>Technique</th>
<th>Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Just-In-Time</td>
<td>RM&amp;WIP/EA</td>
<td>Ending raw-materials (RM) and work-in-progress (WIP) inventory as a ratio of current assets (CA)</td>
</tr>
<tr>
<td></td>
<td>FG/CA</td>
<td>Ending finished goods (FG) inventory as a ratio of current assets (CA)</td>
</tr>
<tr>
<td>Kaizen</td>
<td>Combined Inventory/CA</td>
<td>Combined inventory as a ratio of current assets (CA)</td>
</tr>
<tr>
<td></td>
<td>$\frac{EI_t - EI_{t-1}}{\frac{1}{2}(CA_t + CA_{t-1})}$</td>
<td>Combined ending inventory(EI) balances of current year (t) and previous year (t-1)</td>
</tr>
<tr>
<td>Quality</td>
<td>CGS/Sales</td>
<td>Cost of Goods Sold (CGS) as a ratio of Sales</td>
</tr>
<tr>
<td>Management</td>
<td>$\frac{MS_{Ford}}{(MS_{Ford} + MS_{GM} + MS_{Honda})}$</td>
<td>Relative Market Share (MS) of company for cars</td>
</tr>
<tr>
<td></td>
<td>$\frac{MS_{Ford}}{(MS_{Ford} + MS_{GM} + MS_{Honda})}$</td>
<td>Relative Market Share (MS) of company for trucks</td>
</tr>
<tr>
<td></td>
<td>$\frac{MS_{Ford}}{(MS_{Ford} + MS_{GM} + MS_{Honda})}$</td>
<td>Relative Market Share (MS) of company for both products combined</td>
</tr>
</tbody>
</table>

In Table 24 are the indicators listed according to their associated technique used by Bayou and De Korvin (2008). Interesting is the use of different sorts of inventory as a ratio to current assets. The ratio is used to measure the relative decrease or increase of the inventory as a result of implementing JIT and Kaizen. The current assets are composed of all assets which can be liquefied within a year and includes inventory (van Beek, 2009). Current assets without inventory are called quick assets which is also commonly used in accounting. Inventory is often not that easily converted into cash thus quick assets are used as a more realistic measure of the ability to quickly free up cash (van Beek, 2009). The ratio inventory/current assets as basically measures the percentage inventory contributes to the current assets. If inventory decreases relatively to the size of the company’s business, then this ratio should decrease also. The quick assets show the amount of cash the company has or can quickly free up. This is used in this ratio to represent the size of the company but this a very derived measure. Having more or less quick assets depends on other things besides the size of the business and thus this ratio is assessed to be too unreliable for measuring the behavior of inventory. CGS/Sales is presented as a measure of long-term kaizen in this study. Kaizen is a process of improving the (production) process with the aim of reducing waste and thus costs. Cost of goods sold are the costs of raw materials, products and services bought by the company plus the costs directly attributable to the main (manufacturing) process (Investopedia, 2015). In other words, cost of goods sold are the difference between the revenues and the gross profit. This measure aims at relating the product costs to the total sales revenue and when the indicator decreases this is interpreted as the successful implementation of Kaizen and thus Lean Manufacturing by the authors.
The “Lean Assessment Tool”

Pakdil and Leonard (2014) developed a “Lean Assessment Tool” which combines quantitative and qualitative measures in an effort to provide a broad view of Lean implementation in companies. They define eight quantitative dimensions and five qualitative dimensions shown in Table 25. All dimensions are subdivided into several variables which were found through a literature study. Their goal was to construct an inclusive model which would cover all facets of Lean. In their quest of this model, they compiled a very extensive list of indicators. The extensiveness of the list and the fact that many variables aren’t readily available resulted in not being able to test the model in practice. This makes their specific model of less use for this research but their extensive coverage of Lean indicators will provide valuable information. The ratio’s sales per employee, stock turnover rate and total inventory to total sales are some examples of potentially useful indicators. The measured indicators in the LAT are analyzed through the fuzzy logic methodology and the results, combined in the LAT dimensions, is presented in a radar chart. This provides an easy way, according to the authors, for reading the results and making decisions by management.

**Table 25 The dimensions of the LAT model and the associated seven Lean wastes. Adapted from (Pakdil and Leonard, 2014).**

<table>
<thead>
<tr>
<th>LAT Dimension</th>
<th>Seven wastes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quantitative</strong></td>
<td></td>
</tr>
<tr>
<td>Time effectiveness</td>
<td>Waiting time</td>
</tr>
<tr>
<td>Quality</td>
<td>Correction of defects</td>
</tr>
<tr>
<td>Process</td>
<td>Over processing</td>
</tr>
<tr>
<td>Cost</td>
<td></td>
</tr>
<tr>
<td>Human resources</td>
<td>Over motion</td>
</tr>
<tr>
<td>Delivery</td>
<td>Over handling</td>
</tr>
<tr>
<td>Customer inventories</td>
<td>Excess inventory and over production</td>
</tr>
<tr>
<td><strong>Qualitative</strong></td>
<td></td>
</tr>
<tr>
<td>Quality</td>
<td>Correction of defects</td>
</tr>
<tr>
<td>Customer inventories</td>
<td>Over processing</td>
</tr>
<tr>
<td>Process</td>
<td>Over motion</td>
</tr>
<tr>
<td>Human resources</td>
<td>Over motion</td>
</tr>
<tr>
<td>Delivery inventories</td>
<td>Over handling</td>
</tr>
</tbody>
</table>

Benchmarking the performance of the high-tech manufacturing industry

Tseng, et al. (Tseng et al., 2009) performed a leanness benchmarking assessment of five Taiwanese TFT-LCD panel companies using quantitative as well as qualitative indicators. The Indicators are shown in Figure 45. They developed an intricate performance evaluation model which uses three different data analysis methods (DEA, AHP and Fuzzy multi-criteria approach) and identified five performance dimensions. After analyzing the five companies, the final ranking turned out to be identical with the ranking of companies ranking on their market share. It is, then, proposed that market share is one of the most important indicators of business performance.
Constructing a model through multiple variable correlation analysis

Beelaerts, Elfrink and Van der Zwan (2010) developed a performance measurement method based on the five performance “pillars” (or performance indicators) from Tseng, et al (2009). Several potential variables were selected for the performance indicators and, through a bivariate correlation analysis, these variables were reviewed on their applicability. For each pillar one variable was ultimately selected. Table 26 shows the pillars with the associated variables. The variables in bold are the ones ultimately chosen for their performance measurement method.

Using weighing factors, a performance index, IP, could be constructed which combines the 5 indicators into one equation. The model was tested successfully using figures from the annual reports of 33 automotive companies. A subsequent test on the aerospace industry proved to be less successful because there was insufficient data to reliably construct the aerospace weighing factors.
Table 26 Performance indicators and variables analyzed for measuring the performance of automotive companies. Adapted from (Beelaerts van Blokland et al., 2010). Bold variables were ultimately used in the performance model.

<table>
<thead>
<tr>
<th>Performance Indicator</th>
<th>Variables</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competition Performance</td>
<td>Sales growth rate (ΔT)</td>
<td>(Tseng et al., 2009)</td>
</tr>
<tr>
<td>Turnover (T)</td>
<td>Market Share (MS)</td>
<td>(Tseng et al., 2009)</td>
</tr>
<tr>
<td>Financial Performance</td>
<td>Share Price (ΔSP)</td>
<td>(Tseng et al., 2009)</td>
</tr>
<tr>
<td>Manufacturing Performance</td>
<td>In final form as SP</td>
<td></td>
</tr>
<tr>
<td>Innovation capability</td>
<td>Profit per Employee (P/E)</td>
<td>(Tseng et al., 2009)</td>
</tr>
<tr>
<td>Manufacturing Performance</td>
<td>Inventory Turnover (T/I)</td>
<td>(Murman et al., 2002)</td>
</tr>
<tr>
<td>Innovation capability</td>
<td>Vehicles per employee (V/C)</td>
<td>(Tseng et al., 2009)</td>
</tr>
<tr>
<td>Innovation capability</td>
<td>R&amp;D efficiency (P/R&amp;D)</td>
<td>(Tseng et al., 2009)</td>
</tr>
<tr>
<td>Innovation capability</td>
<td>Own R&amp;D efforts (R&amp;D/C)</td>
<td>(Beelaerts van Blokland, 2010)</td>
</tr>
<tr>
<td>Supply Chain Relationships</td>
<td>Turnover per employee(T/E)</td>
<td>(Beelaerts van Blokland, 2010)</td>
</tr>
<tr>
<td>Supply Chain Relationships</td>
<td>Profit leverage (T/P)</td>
<td></td>
</tr>
</tbody>
</table>

**KPI concept for measuring Lean implementation methodologies**

Stamm and Neitzert (Stamm and Neitzert, 2008) introduce a performance measuring model which measures the implementation of Lean methodologies in Make-To-Order Small-and-Medium-sized-Enterprises. In the paper a Key Performance Indicator concept is presented which constitutes five dimensions: Leadership, Costs, Quality, Time and People/Organization. These five dimensions all have a number of measurement parameters associated with them of which two of them specifically measure Lean implementation: Relative Value Velocity and Process Velocity over Time. The Relative Value Velocity was originally defined by (Botha, 2004) as the rate at which value is added by a company. This was subsequently measured through the ratio of profit(EBIT) over the amount of inventory days (equation shown in Figure 46). Stamm and Neitzert adapted this to fit the Make-To-Order business as shown in Figure 47 on the right.

![Figure 46 Value Velocity equation (Botha, 2004)](image)

* Figure 46 Value Velocity equation (Botha, 2004)

![Figure 47 Relative Value Velocity (Stamm and Neitzert, 2008)](image)

* Figure 47 Relative Value Velocity (Stamm and Neitzert, 2008)

The Process Velocity measures the ratio between total process time and value added process time and is intended to either measure the flow of products through the value stream or the value adding efficiency of one process. The original concept was taken from (Davis and Heineke, 2005) and subsequently adapted to use in a Make-To-Order environment (equation shown in Figure 48).

![Figure 48 Process Velocity over Time (Stamm and Neitzert, 2008)](image)

* Figure 48 Process Velocity over Time (Stamm and Neitzert, 2008)
## Appendix B – List of Lean value creation indicators

The table below features all indicators found in literature which relate turnover or profit to other variables.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Description</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turnover/Capita</td>
<td>Turnover/Revenues/Total Sales per employee. An indicator of configuration in the 3C model. A measure of Human Resources in the LAT.</td>
<td>(Beelaerts van Blokland et al., 2007, Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>Profit/Capita</td>
<td>Profit(EBIT) or operating income per employee. A measure of Continuation in the 3C model and a measure of Manufacturing Capability in the LAT.</td>
<td>(Beelaerts van Blokland et al., 2007, Tseng et al., 2009)</td>
</tr>
<tr>
<td>Inventory/Turnover</td>
<td>Value of the inventories per turnover ratio</td>
<td></td>
</tr>
<tr>
<td>Turnover/Fixed Assets</td>
<td>Turnover versus Fixed Assets ratio</td>
<td>(Beelaerts van Blokland and De Jong, 2016, Maaskant, 2011)</td>
</tr>
<tr>
<td>GM/Fixed Assets</td>
<td>Gross Margin versus Fixed Assets ratio</td>
<td>(Beelaerts van Blokland and De Jong, 2016)</td>
</tr>
<tr>
<td>Turnover/R&amp;D</td>
<td>Turnover versus R&amp;D expenses ratio</td>
<td>(Maaskant, 2011)</td>
</tr>
<tr>
<td>CGS/Sales</td>
<td>Cost of Goods Sold (CGS) as a ratio of Sales. An indicator to measure <em>Kaizen</em> performance in an automotive company.</td>
<td>(Bayou and de Korvin, 2008)</td>
</tr>
<tr>
<td>Total Defectives($) / Total Sales</td>
<td>The ratio of the amount of total defectives (in dollar) to the total sales. One of several measures of Quality in the Lean Assessment Tool (LAT).</td>
<td>(Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>Total Rework($)/Total Sales</td>
<td>Rework to total sales ratio. Also a measure of Quality in the LAT.</td>
<td>(Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>Total Scraps($)/Total Sales</td>
<td>Scraps to total sales ratio. Also a measure of Quality in the LAT.</td>
<td>(Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>Transport Costs/Total Sales</td>
<td>Annual Transportation costs to turnover ratio. A Costs measure in the LAT.</td>
<td>(Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>Inventory Costs/Total Sales</td>
<td>Costs of the inventory to total sales. Also a Costs measure in the LAT.</td>
<td>(Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>Total Warranty Costs/Total Sales</td>
<td>Total Warranty Costs tot total sales ratio. Also a Costs measure in the LAT.</td>
<td>(Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>Total Costs of poor quality/Total Sales</td>
<td>Total Costs of poor quality tot total sales ratio. Also a Costs measure in the LAT.</td>
<td>(Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>Total Prevention Costs/Total Sales</td>
<td>Also a Costs measure in the LAT.</td>
<td>(Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>Net Profit/Total Sales</td>
<td>The profit <em>after</em> interests and tax per turnover. Deemed as an important financial indicator and also a Costs measure in the LAT.</td>
<td>(Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td># of times that parts are transported/total sales</td>
<td>Part movements per total Sales. Delivery measure of the LAT.</td>
<td>(Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>Total transportation distance of materials/total sales</td>
<td>Transportation distance per total sales. Delivery measure of the LAT.</td>
<td>(Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>Total number of products returned by the customer/total sales</td>
<td>Customer measure of the LAT</td>
<td>(Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>WIP/ Total Sales</td>
<td>Work in Process Inventory per Total Sales. Inventory measure of the LAT</td>
<td>(Pakdil and Leonard, 2014)</td>
</tr>
<tr>
<td>ΔT</td>
<td>Sales growth rate</td>
<td>(Tseng et al., 2009)</td>
</tr>
<tr>
<td>R&amp;D/Profit</td>
<td>R&amp;D expenditure ratio as a measure of innovation capability</td>
<td>(Tseng et al., 2009, Beelaerts van Blokland et al., 2010)</td>
</tr>
<tr>
<td>T/P</td>
<td>Profit margin or leverage</td>
<td>(Beelaerts van Blokland et al., 2010)</td>
</tr>
<tr>
<td>$V_v=\text{EBIT/Inventory Days}$</td>
<td>Value velocity. The rate at which value is added by a company and expressed as Profit over nr of inventory days.</td>
<td>(Botha, 2004, Stamm and Neitzert, 2008)</td>
</tr>
</tbody>
</table>
Appendix C – Historic currency exchange rates

Historic currency exchange rates. All rates are recorded on December 31st except for the Yen/Euro rate which is recorded on March 31st the next year. The Yen/Euro ratio is taken on March 31st the next year because all Japanese companies end their financial year on that date. The ratios are extracted from the OANDA historical currency converter tool (OANDAcorporation, 1996-2016).

<table>
<thead>
<tr>
<th>Year</th>
<th>Dollar/Euro</th>
<th>Yen/Euro</th>
<th>Won/Euro</th>
<th>Renminbi/Euro</th>
<th>Pound/Euro</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>1.25820</td>
<td>128,14</td>
<td>1499,56</td>
<td>10,4263</td>
<td>0.70563</td>
</tr>
<tr>
<td>2004</td>
<td>1.35690</td>
<td>138,95</td>
<td>1359,79</td>
<td>11,2439</td>
<td>0.70640</td>
</tr>
<tr>
<td>2005</td>
<td>1.18416</td>
<td>142,64</td>
<td>1188,00</td>
<td>9,56270</td>
<td>0.68818</td>
</tr>
<tr>
<td>2006</td>
<td>1.32027</td>
<td>157,30</td>
<td>1209,67</td>
<td>10,3212</td>
<td>0.67362</td>
</tr>
<tr>
<td>2007</td>
<td>1.47038</td>
<td>157,28</td>
<td>1362,18</td>
<td>10,7545</td>
<td>0.73531</td>
</tr>
<tr>
<td>2008</td>
<td>1.40428</td>
<td>130,92</td>
<td>1754,06</td>
<td>9,62399</td>
<td>0.95246</td>
</tr>
<tr>
<td>2009</td>
<td>1.43686</td>
<td>125,84</td>
<td>1655,43</td>
<td>9,81248</td>
<td>0.88657</td>
</tr>
<tr>
<td>2010</td>
<td>1.33423</td>
<td>117,44</td>
<td>1479,68</td>
<td>8,79554</td>
<td>0.85859</td>
</tr>
<tr>
<td>2011</td>
<td>1.29668</td>
<td>110,51</td>
<td>1502,24</td>
<td>8,27150</td>
<td>0.83480</td>
</tr>
<tr>
<td>2012</td>
<td>1.32047</td>
<td>120,69</td>
<td>1398,15</td>
<td>8,33451</td>
<td>0.81090</td>
</tr>
<tr>
<td>2013</td>
<td>1.37871</td>
<td>141,84</td>
<td>1453,87</td>
<td>8,42581</td>
<td>0.83118</td>
</tr>
<tr>
<td>2014</td>
<td>1.21432</td>
<td>129,32</td>
<td>1324,63</td>
<td>7,47523</td>
<td>0.77697</td>
</tr>
</tbody>
</table>
### Appendix D – Bivariate Correlations

#### Pre-Crisis period: 2003 - 2008

<table>
<thead>
<tr>
<th></th>
<th>T/E</th>
<th>T/I</th>
<th>T/PPE</th>
<th>T/R&amp;D</th>
<th>P/E</th>
<th>P/I</th>
<th>P/PPE</th>
<th>P/R&amp;D</th>
<th>P/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>T/E</td>
<td></td>
<td>0.106</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T/I</td>
<td>0.106</td>
<td></td>
<td>-0.280</td>
<td>-0.136</td>
<td>0.169</td>
<td>-0.191</td>
<td>-0.276</td>
<td>-0.424</td>
<td>-0.313</td>
</tr>
<tr>
<td>T/PPE</td>
<td>0.088</td>
<td>0.425</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T/R&amp;D</td>
<td>-0.280</td>
<td>-0.136</td>
<td>0.020</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/E</td>
<td>0.169</td>
<td>0.006</td>
<td>0.029</td>
<td>-0.047</td>
<td></td>
<td>0.137</td>
<td>0.348</td>
<td>0.637</td>
<td>0.236</td>
</tr>
<tr>
<td>P/I</td>
<td>-0.191</td>
<td>0.137</td>
<td>0.116</td>
<td>0.147</td>
<td>0.886</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/PPE</td>
<td>-0.276</td>
<td>-0.035</td>
<td>0.348</td>
<td>0.348</td>
<td>0.689</td>
<td>0.858</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/R&amp;D</td>
<td>-0.424</td>
<td>-0.146</td>
<td>0.150</td>
<td>0.637</td>
<td>0.397</td>
<td>0.634</td>
<td>0.855</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/T</td>
<td>-0.313</td>
<td>-0.117</td>
<td>0.043</td>
<td>0.236</td>
<td>0.790</td>
<td>0.922</td>
<td>0.891</td>
<td>0.778</td>
<td></td>
</tr>
</tbody>
</table>

#### Post-Crisis period: 2009 - 2014

<table>
<thead>
<tr>
<th></th>
<th>T/E</th>
<th>T/I</th>
<th>T/PPE</th>
<th>T/R&amp;D</th>
<th>P/E</th>
<th>P/I</th>
<th>P/PPE</th>
<th>P/R&amp;D</th>
<th>P/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>T/E</td>
<td></td>
<td>0.096</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T/I</td>
<td>0.096</td>
<td></td>
<td>-0.154</td>
<td>0.112</td>
<td></td>
<td>0.654</td>
<td>0.080</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T/PPE</td>
<td>0.441</td>
<td>0.482</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T/R&amp;D</td>
<td>-0.154</td>
<td>0.112</td>
<td>-0.197</td>
<td></td>
<td></td>
<td>0.178</td>
<td>0.506</td>
<td>0.220</td>
<td></td>
</tr>
<tr>
<td>P/E</td>
<td>0.654</td>
<td>0.102</td>
<td>0.298</td>
<td>-0.006</td>
<td></td>
<td>0.654</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/I</td>
<td>0.080</td>
<td>0.506</td>
<td>0.220</td>
<td>0.178</td>
<td>0.846</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/PPE</td>
<td>0.338</td>
<td>0.256</td>
<td>0.438</td>
<td>0.016</td>
<td>0.846</td>
<td>0.850</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/R&amp;D</td>
<td>-0.040</td>
<td>0.185</td>
<td>-0.037</td>
<td>0.563</td>
<td>0.548</td>
<td>0.778</td>
<td>0.668</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/T</td>
<td>0.158</td>
<td>0.169</td>
<td>0.109</td>
<td>0.166</td>
<td>0.789</td>
<td>0.887</td>
<td>0.903</td>
<td>0.845</td>
<td></td>
</tr>
</tbody>
</table>

#### Groupings

<table>
<thead>
<tr>
<th>Average R</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.777</td>
</tr>
<tr>
<td>0.218</td>
</tr>
<tr>
<td>0.130</td>
</tr>
</tbody>
</table>

#### Notes

- The size of the dataset for the pre- and post-crisis period
- The total size of the dataset
Appendix E - Histograms and Cumulative Distributions
Appendix F – Indicator Analysis Extended

$T/E$

The relative growth of the indicator over time per company filters out the size effect in the data and shows the performance per company. This is shown in Figure 49, where a line is drawn to represent the points were the growth of the variables results in no growth of the indicator. A company plotted above the line shows positive growth of the indicator and a company positioned beneath the line represents negative growth of the indicator $T/E$. All companies originated at the (100,100) point in 2003 and the plotted points are the values achieved in 2014. Mazda showed a negative growth of $T/E$ over the period and thus is positioned under the line. Its amount of employees increased over the period but its turnover stagnated resulting in an negative growth of $T/E$. Skoda showed the largest growth of all companies over this period. It increased both in turnover and employees with achieving a larger growth in turnover than employees which results in a positive growth in $T/E$. Ford, GM and Mitsubishi are also positioned on the upper side of line, which shows a positive growth of $T/E$, although both their turnover and number of employees decreased. This graph thus shows that these companies increased their performance on this indicator while decreasing in size. Their value creation performance with respect to this indicator increased while their operations shrank. Ford and GM experienced great difficulties up until the financial crisis in 2007 with GM even going bankrupt. But despite these hardships they managed to increase their value creation performance which signals their potential recovery.

Figure 49 Turnover growth ($dT$) versus Employee growth ($dE$) per company. Values show the growth achieved in 2014 compared to 2003. Values are indexed on 2003 (100 point). GWM falls outside the diagram because it has coordinates (1193, 2365).
Figure 50 shows the growth \((dT/dE)\) and the absolute value of the turnover per employee indicator in the year 2014. The diagram shows the indicator performance of each company with the associated values per company listed in Table 27. Skoda shows the largest relative growth since 2003 (107.2 % point) but has still a below average absolute score of 438.960 million euro/employee. GWM has by far the lowest absolute score (166.999 million euro/employee) but shows the second greatest growth score (198 % point). GWM is a company which experienced tremendous growth over the measured time period and this is exemplified by the fact that its off the chart in Figure 49; it has a turnover increase of over 2200 %. This enormous growth of the company probably explains the low indicator score because the company isn’t focused on lean value creation in this period. Another explanation can be found in the environment of the GWM. GWM is a Chinese company and because wages are relatively low in China, it doesn’t have as large an incentive to increase employee productivity as most other companies in this dataset.

FHI has the third highest indicator growth and has a high absolute indicator score of €747.356 million euro per employee. This company shows Lean behavior in its growth value and has high value creation performance and thus has the best performance on this indicator of all companies. Figure 50 intuitively shows this because FHI is in the top right corner. Mazda, the company with the largest negative growth, still has scores average on the total indicator. The negative growth could be an sign of failing Lean value creation performance although its absolute value is still on average.
Table 27 Growth and absolute value of T/E in 2014. Growth (dT/dE) is indexed in 2003 at 100 points and T/E is in millions of euro's per employee. The table is sorted on descending order for the growth indicator dT/dE.

<table>
<thead>
<tr>
<th>Company</th>
<th>dT/dE</th>
<th>T/E</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKODA</td>
<td>207.20</td>
<td>438.960</td>
</tr>
<tr>
<td>GWM</td>
<td>198.26</td>
<td>116.999</td>
</tr>
<tr>
<td>FHI (SUBARU)</td>
<td>181.60</td>
<td>747.356</td>
</tr>
<tr>
<td>BMW</td>
<td>173.68</td>
<td>691.182</td>
</tr>
<tr>
<td>AUDI</td>
<td>156.74</td>
<td>696.299</td>
</tr>
<tr>
<td>FORD</td>
<td>152.13</td>
<td>634.483</td>
</tr>
<tr>
<td>VOLKSWAGEN</td>
<td>134.90</td>
<td>341.652</td>
</tr>
<tr>
<td>GM</td>
<td>132.41</td>
<td>594.484</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>130.56</td>
<td>503.958</td>
</tr>
<tr>
<td>NISSAN</td>
<td>125.68</td>
<td>588.814</td>
</tr>
<tr>
<td>MITSUBISHI</td>
<td>122.68</td>
<td>552.923</td>
</tr>
<tr>
<td>DAIHATSU</td>
<td>117.23</td>
<td>330.034</td>
</tr>
<tr>
<td>RENAULT</td>
<td>116.61</td>
<td>349.717</td>
</tr>
<tr>
<td>HYUNDAI</td>
<td>115.52</td>
<td>613.971</td>
</tr>
<tr>
<td>TOYOTA</td>
<td>115.23</td>
<td>575.567</td>
</tr>
<tr>
<td>PSA</td>
<td>107.18</td>
<td>282.460</td>
</tr>
<tr>
<td>HONDA</td>
<td>99.08</td>
<td>479.614</td>
</tr>
<tr>
<td>MAZDA</td>
<td>83.41</td>
<td>532.767</td>
</tr>
</tbody>
</table>
Figure 51 shows the relative growth of the variables turnover (dT) and inventory (dI) over the period 2003 – 2014 for every company. The diagonal line, again, represents the boundary between positive and negative growth of the indicator T/I, which is constructed from these variables. In contrast to T/E, many more companies (7 in total) are positioned on the lower side of the diagonal, where negative growth is measured. These companies are thus struggling to achieve growth in the T/I indicator. This may indicate the industry is close to some sort of barrier or limit in optimizing inventory turnover. What is apparent is that most companies managed to grow both their turnover and inventory. From the three companies which have a decrease in turnover (Ford, GM and Mitsubishi), both Ford and Mitsubishi managed to decrease their inventory levels enough to keep their turnover inventory ratio on the same level. GM on the other showed an increase in inventory which results in a decrease of its indicator score.

![Figure 51 Growth of inventory (dI) versus growth of turnover (dT) over the period 2003 -2014 per company. The diagonal line represents the boundary between positive and negative indicator growth. GWM falls outside the chart with coordinates (936;2365).](image-url)
In Figure 52 the growth of the indicator (dT/dI) is plotted against the absolute value of the indicator (T/I) with the associated values listed in Table 28. GWM showed by far the largest growth and has an absolute indicator value of 18.04. This score is above average, in contrast to its scores on the T/E indicator which was very low. GWM thus manages to keep its inventory levels low relative to its turnover. The very large growth of the company might prevent building up inventory because of the large demand. PSA and Renault show the second and third largest performance increases although they still have average absolute scores for T/I. They thus have caught up to the automotive average over the years. Daihatsu shows the highest indicator score (26.91) and a decent indicator growth (44 %points). Daihatsu is thus showing the best performance by both having a high score and high growth figures. Skoda also shows a high absolute and growth value. In contrast to their average score on T/E, Skoda now has the second highest score, showing their efforts have already paid off on this indicator. Looking at Figure 52, most companies are roughly around a 10:1 turnover inventory ratio and exhibit both modest increase or decrease of the time period. The playing field thus consolidated over the years around the 10:1 ratio for this group of companies. Ford stayed on its relatively high ratio of 18.32:1. BMW, Skoda, Daihatsu and GWM pulled away from the main group.
### Table 28 Values of the growth ($dT/dI$) and absolute indicator ($T/I$) per company in the year 2014. The companies are sorted for highest to lowest growth score.

<table>
<thead>
<tr>
<th>Company</th>
<th>$dT/dI$</th>
<th>$T/I$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWM</td>
<td>252.69</td>
<td>18.04</td>
</tr>
<tr>
<td>PSA</td>
<td>161.58</td>
<td>12.78</td>
</tr>
<tr>
<td>RENAULT</td>
<td>157.19</td>
<td>12.11</td>
</tr>
<tr>
<td>DAIHATSU</td>
<td>143.97</td>
<td>26.91</td>
</tr>
<tr>
<td>HYUNDAI</td>
<td>142.03</td>
<td>12.03</td>
</tr>
<tr>
<td>BMW</td>
<td>121.82</td>
<td>20.83</td>
</tr>
<tr>
<td>FHI (SUBARU)</td>
<td>121.26</td>
<td>9.73</td>
</tr>
<tr>
<td>SKODA</td>
<td>118.43</td>
<td>24.28</td>
</tr>
<tr>
<td>MITSUBISHI</td>
<td>112.63</td>
<td>10.30</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>110.41</td>
<td>13.58</td>
</tr>
<tr>
<td>FORD</td>
<td>102.42</td>
<td>18.32</td>
</tr>
<tr>
<td>VOLKSWAGEN</td>
<td>88.53</td>
<td>6.43</td>
</tr>
<tr>
<td>AUDI</td>
<td>82.20</td>
<td>10.61</td>
</tr>
<tr>
<td>HONDA</td>
<td>79.15</td>
<td>8.44</td>
</tr>
<tr>
<td>TOYOTA</td>
<td>78.30</td>
<td>11.98</td>
</tr>
<tr>
<td>MAZDA</td>
<td>73.56</td>
<td>7.99</td>
</tr>
<tr>
<td>GM</td>
<td>72.01</td>
<td>11.43</td>
</tr>
<tr>
<td>NISSAN</td>
<td>63.44</td>
<td>8.68</td>
</tr>
</tbody>
</table>
The relative growth per company of the turnover and ppe variables are plotted in Figure 53. The variables are indexed on 100 points in the year 2003 for every company and the resulting growth in 2014 is plotted. The diagonal line represents, as in the earlier version of T/E and T/I, the boundary between negative and positive growth of the indicator T/PPE. A number of companies are below the diagonal but most are above, showing a positive growth of the indicator. Only Honda and GWM show a significant decrease in the ratio turnover to PPE. This could mean they are investing a lot in property, plant and equipment but that it doesn’t yet translate into enough increased turnover to result into positive growth of the indicator. The three companies with decreasing turnover (Ford, GM and Mitsubishi) all stay on the upper side of the diagonal and thus manage to achieve a (small) increase of T/PPE. This could mean they are disposing of excess PPE or they postponed investments in new PPE. The first explanation is the preferred one because forestalling investments might result in high maintenance costs later on.

![Figure 53 Growth of turnover (dT) and PPE (dPPE) per company of the period 2003 - 2014. The diagonal line represents the boundary between positive (above) and negative(below) growth of the associated indicator dT/dPPE. GWM at (5459;2365).](image-url)
In Figure 54, the indicator growth and the absolute value of the indicator in the year 2014 are plotted against each other for every company. The same values are also listed in Table 29. It is now clearly visible that FHI achieved the largest increase in T/PPE (dT/dPPE = 197,99) over the period 2003 – 2014, which was obscured in Figure 53 because of the nature of the graph. Its absolute value of 5,59 for T/PPE ranks it a bit lower, among GM, Audi and Mitsubishi. BMW shows the highest Turnover to PPE ratio (7,80:1) and managed to hold this high ratio over the entire period. As can be seen in Figure 53, BMW did not stagnate during this period but instead doubled its Turnover. Because it also doubled its PPE, the resulting T/PPE indicator value stayed the same, high, value. Ford is approaching the BMW ratio but did this by decreasing in both Turnover and PPE. Nissan is the poorest performing company on this indicator, with a ratio of 2,16:1, followed by Toyota and Mazda. Because these companies also showed negative growth over the years, they are positioned in the lower left, poor performance quadrant which should be avoided. Exemplifying Nissan’s performance, it needs almost four times as much PPE per unit turnover as BMW needs. GWM has the greatest percentile decrease of its performance which is caused by the tremendously large increase in PPE of over 5300%, against a 2200% plus turnover increase. Because GWM is growing very rapidly, it is probably investing great amounts in PPE to further accommodate the future Turnover growth. Thus, although they are positioned on the left side of the graph, it can’t be concluded they are poor performers because they need to invest in advance for the expected Turnover increase.
Table 29 Values of $dT/dPPE$ and $T/PPE$ corresponding to Figure 54. Table is sorted on $dT/dPPE$ in a descending order.

<table>
<thead>
<tr>
<th>Company</th>
<th>$dT/dPPE$</th>
<th>$T/PPE$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FHI (SUBARU)</td>
<td>197,99</td>
<td>5,59</td>
</tr>
<tr>
<td>HYUNDAI</td>
<td>151,65</td>
<td>3,96</td>
</tr>
<tr>
<td>MITSUBISHI</td>
<td>150,76</td>
<td>5,37</td>
</tr>
<tr>
<td>FORD</td>
<td>137,92</td>
<td>7,57</td>
</tr>
<tr>
<td>SKODA</td>
<td>137,84</td>
<td>4,54</td>
</tr>
<tr>
<td>AUDI</td>
<td>130,90</td>
<td>5,56</td>
</tr>
<tr>
<td>VOLKSWAGEN</td>
<td>123,32</td>
<td>4,39</td>
</tr>
<tr>
<td>DAIHATSU</td>
<td>118,78</td>
<td>3,38</td>
</tr>
<tr>
<td>GM</td>
<td>115,89</td>
<td>5,62</td>
</tr>
<tr>
<td>PSA</td>
<td>114,22</td>
<td>4,95</td>
</tr>
<tr>
<td><strong>AVERAGE</strong></td>
<td><strong>107,98</strong></td>
<td><strong>4,59</strong></td>
</tr>
<tr>
<td>RENAULT</td>
<td>105,26</td>
<td>3,80</td>
</tr>
<tr>
<td>BMW</td>
<td>99,55</td>
<td>7,80</td>
</tr>
<tr>
<td>NISSAN</td>
<td>93,13</td>
<td>2,16</td>
</tr>
<tr>
<td>TOYOTA</td>
<td>89,00</td>
<td>2,76</td>
</tr>
<tr>
<td>MAZDA</td>
<td>86,71</td>
<td>3,22</td>
</tr>
<tr>
<td>HONDA</td>
<td>65,89</td>
<td>3,79</td>
</tr>
<tr>
<td>GWM</td>
<td>43,32</td>
<td>3,62</td>
</tr>
</tbody>
</table>
**T/R&D**

In Figure 55 the relative growth per company of the variables from Figure 13 at the end of the period are shown. The field is split in half between companies which increased their indicator score and decreased their score. Companies like Skoda, BMW, Honda, Toyota and Ford more or less kept their performance on the same level, exemplified by them being positioned on the diagonal line. GWM showed exceptional growth of its R&D Expenses (9677%) and subsequently falls outside the scope of the diagram. GWM accompanied this growth with a large growth in turnover of over 2000% but this did not match the R&D growth resulting in its indicator decreasing. GWM is transitioning from a small to large automotive company and increased its R&D spending from 1% of its turnover in 2003 to 4% in 2014.

*Figure 55 Relative growth of Turnover and R&D Expenses over the period 2003 - 2014 per company. Values are indexed on the year 2003. The region above the diagonal represents growth of the indicator T/R&D and the region represents a decrease. GWM at (9577;2365).*
Figure 56 Percentage of turnover spend on R&D in 2014 per company. The growth of the indicator over time (dR&D/dT) is compared to the value in 2014.

Figure 57 The absolute versus the growth value of the indicator T/R&D. Companies scoring lower than 100 points on dT/dR&D showed negative growth of the indicator over the concerned time period: 2003 - 2014.
Figure 57 shows the relationship between the absolute and relative values of the indicator T/R&D, just as was done previously with the other indicators T/E, T/I and T/PPE. The inverse of T/R&D, R&D/T, shows the percentage of Turnover that is spend on R&D by a company and provides a view in which turnover is the independent variable and R&D is the dependent. This indicator is plotted against its increase over the years in Figure 56. In Figure 57 GWM forms an outlier but the rest of the field is rather spread out. If we compare this to Figure 57, it becomes more apparent that most companies are tightly clustered and that GWM is a strong outlier in growth. BMW, on the other hand, shows almost no increase or decrease over the years and stays very near to an average value of 19.17 over the years with a standard deviation of 0.32. A roughly equal split between companies which increased and decreased can be seen in these graphs and the figures in Table 30 confirm this (8 against 9). The suspicion is now raised that most companies strive to some intermediate value of the indicator which would indicate that simply scoring higher on this indicator doesn’t necessary mean a better performance.

Table 30 List of growth (dT/dR&D) and absolute values for T/R&D associated with Figure 57 and the equivalent values for R&D/T from Figure 56. The list is sorted on dT/dR&D in descending order. Absolute values are from the year 2014, growth values cover the time period 2003 – 2014.

<table>
<thead>
<tr>
<th>Company</th>
<th>dT/dR&amp;D</th>
<th>T/R&amp;D</th>
<th>dR&amp;D/dT</th>
<th>R&amp;D/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>HYUNDAI</td>
<td>139.91</td>
<td>41.93</td>
<td>71</td>
<td>2.4%</td>
</tr>
<tr>
<td>FHI (SUBARU)</td>
<td>137.76</td>
<td>34.46</td>
<td>73</td>
<td>2.9%</td>
</tr>
<tr>
<td>DAIHATSU</td>
<td>136.91</td>
<td>40.20</td>
<td>73</td>
<td>2.5%</td>
</tr>
<tr>
<td>MITSUBISHI</td>
<td>132.31</td>
<td>48.40</td>
<td>76</td>
<td>2.1%</td>
</tr>
<tr>
<td>NISSAN</td>
<td>107.10</td>
<td>22.48</td>
<td>93</td>
<td>4.4%</td>
</tr>
<tr>
<td>PSA</td>
<td>105.42</td>
<td>26.47</td>
<td>95</td>
<td>3.8%</td>
</tr>
<tr>
<td>HONDA</td>
<td>104.98</td>
<td>19.09</td>
<td>95</td>
<td>5.2%</td>
</tr>
<tr>
<td>TOYOTA</td>
<td>104.94</td>
<td>25.50</td>
<td>95</td>
<td>3.9%</td>
</tr>
<tr>
<td>BMW</td>
<td>100.49</td>
<td>19.44</td>
<td>100</td>
<td>5.1%</td>
</tr>
<tr>
<td>SKODA</td>
<td>97.91</td>
<td>29.30</td>
<td>102</td>
<td>3.4%</td>
</tr>
<tr>
<td>FORD</td>
<td>92.83</td>
<td>20.88</td>
<td>108</td>
<td>4.8%</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>88.49</td>
<td>26.91</td>
<td>248</td>
<td>3.7%</td>
</tr>
<tr>
<td>MAZDA</td>
<td>84.29</td>
<td>27.99</td>
<td>119</td>
<td>3.6%</td>
</tr>
<tr>
<td>RENAULT</td>
<td>79.02</td>
<td>23.86</td>
<td>127</td>
<td>4.2%</td>
</tr>
<tr>
<td>VOLKSWAGEN</td>
<td>76.52</td>
<td>17.54</td>
<td>131</td>
<td>5.7%</td>
</tr>
<tr>
<td>GM</td>
<td>70.94</td>
<td>21.07</td>
<td>141</td>
<td>4.7%</td>
</tr>
<tr>
<td>AUDI</td>
<td>68.78</td>
<td>14.60</td>
<td>145</td>
<td>6.9%</td>
</tr>
<tr>
<td>GWM</td>
<td>24.69</td>
<td>24.34</td>
<td>405</td>
<td>4.1%</td>
</tr>
</tbody>
</table>
### Appendix G – Automotive Benchmark Tables

#### Table 31 List of the total Lean Value Flow scores for four categories: The year 2003, the year 2014, the pre-crisis (2003-2008) and the post-crisis (2009 – 2014) periods. All categories are sorted from highest to lowest value.

<table>
<thead>
<tr>
<th></th>
<th>2003</th>
<th>2014</th>
<th>Pre-crisis</th>
<th>Post-crisis</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWM</td>
<td>30,04</td>
<td>31,94</td>
<td>BMW</td>
<td>28,21</td>
</tr>
<tr>
<td>BMW</td>
<td>26,27</td>
<td>28,68</td>
<td>AUDI</td>
<td>23,71</td>
</tr>
<tr>
<td>MAZDA</td>
<td>23,61</td>
<td>28,58</td>
<td>FORD</td>
<td>23,34</td>
</tr>
<tr>
<td>GM</td>
<td>23,59</td>
<td>27,36</td>
<td>SKODA</td>
<td>23,27</td>
</tr>
<tr>
<td>FORD</td>
<td>23,37</td>
<td>26,83</td>
<td>MAZDA</td>
<td>22,27</td>
</tr>
<tr>
<td>TOYOTA</td>
<td>23,35</td>
<td>26,18</td>
<td>MITSUBISHI</td>
<td>22,07</td>
</tr>
<tr>
<td>HONDA</td>
<td>22,78</td>
<td>25,99</td>
<td>TOYOTA</td>
<td>21,89</td>
</tr>
<tr>
<td>AUDI</td>
<td>21,54</td>
<td>25,57</td>
<td>DAIHATSU</td>
<td>21,57</td>
</tr>
<tr>
<td>NISSAN</td>
<td>21,45</td>
<td>23,80</td>
<td>HONDA</td>
<td>21,53</td>
</tr>
<tr>
<td>SKODA</td>
<td>21,28</td>
<td>23,00</td>
<td>HYUNDAI</td>
<td>21,38</td>
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#### Table 32 List of the total Lean Value Flow scores, excluding T/R&D, for four categories: The year 2003, the year 2014, the pre-crisis (2003-2008) and the post-crisis (2009 – 2014) periods. All categories are sorted from highest to lowest value.

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### Appendix H – Indicator Data Tables

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**Note:** The table above represents indicator data tables for various automotive companies from 2003 to 2014.
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Appendix I – Academic Paper
Abstract

Many companies are now in varying stages of Lean implementation and the need arises for a method of comparing their performances. With such a method, companies can monitor their relative Lean Manufacturing performance and steer their actions accordingly. A general method for measuring Lean performance does not exist, although many (partial) attempts have been made in academic literature and practice. This research will focus on the value creation aspect of Lean value creation and develop a Lean Value Flow performance benchmark as a potential method for comparing company performance. Nine indicators were selected from literature for further research. Through an analysis using an automotive industry dataset, four indicators (T/E, T/I, T/PPE and P/T) were deemed useful for incorporation into the Lean Value Flow performance benchmark. The benchmark was subsequently tested using case studies from the automotive and non-automotive manufacturing (related) companies. The T/PPE indicator turned out show substantially different characteristics concerning the non-automotive vs automotive companies. After inspection it was tentatively proposed that this represents an intrinsic difference between these industries. The calculation method used for the benchmark showed to be sensitive to outliers which caused the P/T indicator to be distorted. It is recommended to research the possibilities of mediating these outliers or adjust the calculation method. This research also provides new insights in the characteristic behaviour of Property, Plant and Equipment in varying industries and it is recommended that this should be further investigated.

Keywords: Lean, Value Creation, Automotive Industry

Topics: Benchmarking, Lean Philosophy, Case Study

1. Introduction

This thesis research will investigate the topic of Lean performance measurement with the specific focus on Lean implementation, value creation and the Lean concept of “flow”. Through a rigorous analysis, a performance measurement benchmark model will be presented called the “Lean Value Flow Performance Benchmark”. The benchmark model will be developed from literature and theory and subsequently tested through case studies. The benchmark consists of a representative dataset of automotive companies because this industry is seen as a prime example of Lean Manufacturing. This research will contribute to the field of Lean performance measurement by investigating the potential use of indicators which measure Lean value creation and presents a benchmark model with which companies can compare their performances to each other.

Lean Manufacturing is a widely used business philosophy originating in the automotive industry. After the initial success by Toyota and followed by the rest of the industry, it is now steadily being implemented in a wide field of other industries. Many companies are now in varying stages of Lean implementation and the need arises for a method to compare their performances. With such a method,
companies can monitor their relative Lean Manufacturing performance and steer their actions accordingly. A general method for measuring Lean performance does however not exist, although many (partial) attempts have been made in academic literature and in practice. These attempts often resulted in long lists of indicators which are unwieldy. The large amount of indicators also obscure the deeper trends and mechanisms at play. Also, many studies aim to measure the Lean performance of companies by focusing on measuring the performance and implementation of specific Lean techniques. But implementing a Lean technique in your company doesn’t necessarily mean that your company’s performance will increase. It’s only a means to achieve the goal. To guard for these problems, this research will be focusing on the specific aspect of (Lean) value creation using only quantitative measures. In this manner the Lean performance of a company can be measured more objectively. To make the benchmark model practical in use, it is required that only publicly available measures are used. This overlaps with the requirement to use variables which have a general nature in order to compare companies from varying backgrounds. In short, the subject of this research is measuring Lean value creation using general and publicly available measures.

The goal of this research can be described in the following manner:

Develop a Lean performance benchmark model which measures the Lean performance on company level by using Lean value creation indicators found from literature and theory and is tested using real world data.

The automotive industry, as a long time adopter of Lean Manufacturing, is chosen as the basis for the benchmark to which other companies can be compared to. The benchmark model will subsequently be tested with case studies consisting of two automotive and four non-automotive companies. The four non-automotive companies consist of three manufacturing companies and a supplier of products to the manufacturing industry. These four case studies constitute companies in a general lower size range than the automotive benchmark though some overlap exists. In this way the benchmark model can be tested with case studies which have partly different characteristics and partly the same with the automotive industry. The two automotive cases function as a test to see how it responds to the natural variance within the same industry, in other words if it’s useful to benchmark its own industry.

Taking into account the goal and scope of this research, the following main research question can be formulated:

*How can a Lean value creation benchmark be developed to provide a means of comparing company performances to each other?*

**Lean**

No universally accepted definition of Lean is currently in use (Pettersen, 2009), (Bhamu and Sangwan, 2014) though most practitioners and researchers (in a lesser degree) agree on what constitutes Lean. Bhamu and Sangwan (Bhamu and Sangwan, 2014) performed an extensive literature study on the definition of Lean, analyzing 209 papers for their use of definition, and concluded that this ambiguity exists in part because Lean has evolved over time. In other part it exists because there is also disagreement about what Lean Manufacturing comprises (Shah and Ward, 2007). The definition thus varies between different situations and authors and, according to Pettersen (Pettersen, 2009), should be tailored to the specific situation. Murman, et al (Murman et al., 2002) described Lean as follows: “Becoming lean is a process of eliminating waste with the goal of creating value.” Womack and Jones (2003) define “creating value” more specifically as creating value from the customers perspective, thus ensuring that energy is not wasted in creating unwanted products. In the scope of this research, the following working definition can be formulated:

*Lean is a process of eliminating waste with the goal of creating value for the customer.*

**Value Creation**

Value creation capability is an important aspect of the functioning of a company. It is also an important part of Lean Manufacturing, which states that non-value adding activities must be eliminated (Womack et al., 2007). The definition of Lean says that creating value for the customer while eliminating waste is the basis of a Lean process. Optimizing value creation is thus an inherent focus of any Lean process and is thus for this reason taken as the Lean aspect to be investigated. The value of the product or service is
defined by the customer who is the one who, in the end, pays for the product (Womack and Jones, 2003). According to one definition given by (Parasuraman et al., 1985), customer value is the subjective opinion of the customer as to what extent the provided product and service package meets his/her expectations. The value the customer assigns to the product can be measured, in one way, through the revenues of a company. The assumption is here that the customer is free to choose to buy the product or not which isn’t always truly the case in every branch. Nevertheless, even if the company’s product will have a guaranteed sale, the internal efficiency of the value creation can still be measured using the turnover. In that case, the turnover will function more as a given and the other variables will put it into perspective. From a company’s point of view value is created when profit is made in excess of its cost (Gelei, 2007). In other words, if more value is returned through revenues than is expended in the process. Profit thus forms another way of measuring the value created. Turnover and Profit are thus selected as the value creation variables for this study. Turnover and profit can be considered as the output variables of the system (the company) and other variables which measure aspects of a company can be combined to form basic ratios.

**Indicators**

A set of Lean value creation indicators were selected from the literature through a literature study. Two criteria for selection were set for selection of the indicators: 1. an indicator relates turnover or profit to some other aspect of a company in order to measure value creation. 2. An indicator must comply to the Lean philosophy. The necessary data for the indicators have to be retrievable from publicly available sources (annual reports). Found indicators which fail these criteria will not be selected. The resulting set of indicators is listed in Table 1 with references. Turnover and profit will be considered as the output variables of the system (the company) and thus the indicators are inverted (if necessary) to reflect this. In order to judge if value is created efficiently and effectively, the turnover and profit must be related to important aspects of the value creating system (the company). Through the found indicators, five important aspects were identified in the functioning of the (manufacturing) company: Human Resources (Employees), Process Flow (Inventory), Physical Means (Fixed Assets), Innovation (R&D expenses) and Financial Performance (Profit margin). To measure the value creation performance related to these aspects, the associated variables are combined with the value creation variables to create ratio’s. Only one of the eight resulting ratios was not attested in literature, Profit/Inventory, and is subsequently added by the author of this paper. The aspects are further illustrated in the next section. The combination of these indicators into a benchmarking model will be called the Lean Value Flow Performance Benchmark. This name captures the focus concepts of Lean, Value Creation and the derivative concept of Flow.

**Table 1 List of selected indicators**

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<th>Indicator</th>
<th>Aspect</th>
<th>References</th>
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<td>T/E</td>
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</tr>
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<td>T/FA</td>
<td>Physical Means</td>
<td>(Beelaerts van Blokland and De Jong, 2016, Maaskant, 2011)</td>
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<td>Innovation</td>
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<td>P/E</td>
<td>Human Resources</td>
<td>(Beelaerts van Blokland et al., 2007, Tseng et al., 2009)</td>
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<td>P/R&amp;D</td>
<td>Innovation</td>
<td>(Tseng et al., 2009, Beelaerts van Blokland et al., 2010)</td>
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</table>

**Characterizing a company**

Employees constitute an important aspect of the functioning of a company. They are the ones that ultimately perform and control the processes within the company and effective utilization of the workforce is a prime subject of Lean Manufacturing.
Inventory is the amount of materials and products that are within the system boundaries of the company. The amount of inventory compared to the turnover shows the flow of the process, which is an important part of Lean. Lean emphasizes the constant flow of the products through the process and thus inventory should be minimized to prevent products from not flowing. It is thus in one way a process indicator.

The fixed assets (also called Property, Plant and Equipment) are the means by which the process is performed and constitutes the buildings, equipment etc of a company. According to lean theory, non- or wrongly utilized resources are a source of waste and thus should be eliminated. Thus using too many fixed assets to perform the process is not lean and the ratio turnover to fixed assets should thus be minimized.

R&D expenses are important for the long term survival of the company because it needs to continuously improve its products to fit the needs of the customer. R&D expenses represent the basic innovation capability and is one way of contributing to the continuous improvement aspect of Lean. The financial performance of company is in one way characterized by the steady positive ratio between profit and turnover. Wild swings in the profit margin shows a company which less control over its processes. A steady state ratio between profit and turnover is thus an indicator the right balance between costs and revenues. In other words, it shows the ratio of extra value added by the company(Profit) to the total value created (Turnover).

2. Methodology

Automotive Dataset

The automotive industry will be used as the industry to construct the benchmark from. This industry is chosen because of its long history of Lean implementation and a relative straightforward industry focus: building cars. Other industries could have a more mixed set of focus products which makes comparing the companies to each other more complicated. The chosen time period is from 2003 to 2014 because of practical reasons. The necessary data from before 2003 could not be acquired for every company. The data is extracted from the annual reports and other financial statements of the companies. 17 companies in total were selected and 206 datapoints in total were subsequently gathered.

Case studies

The case studies consisted of two automotive companies (Porsche and Daimler(Mercedes-Benz)), three non-automotive manufacturing companies (SEW Eurodrive, Lely Industries and Intergas Verwarming) and one supplier to manufacturing companies of industrial MRO products(Brammer Group). These case studies were arbitrarily selected from within the manufacturing related industry to test the benchmark.

Linear Regression Analysis

In this research simple linear regression is used to investigate potential correlation relations between different variables and indicators. Pearson’s product-moment correlation coefficient will provide the means of assessing the degree of significance of the analyzed data with Table 2 listing the used critical values associated to the size of the datasets. The critical values are color coded and this color code will be used in subsequent correlation coefficient tables to show the degree of correlation significance. N=12 is used for the amount of years, N=17 for when comparing companies and N=204 for the total data set. Pearson’s correlation is used because it’s a relative straightforward and often used test and it takes into account the absolute distance between data points. This is in contrast to for example Spearman’s Rank Correlation Coefficient (which only takes the relative rank of each data point into consideration) and ensures that only simple linear relations are measured.
Table 2 List of the often used critical values for Pearson’s correlation coefficients.

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<td>0,163</td>
<td>0,180</td>
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**Benchmark Score Calculation**

In this analysis each automotive company is given a benchmarking score relative to each other which is based on the Lean Dynamic Model introduced by Kinik, et al. (Kinik et al.). The basic method was used to rank a set of companies on their performance on the three indicators of the 3C model. This ranking method provides a straightforward way of comparing the performance of different companies and several indicators to each other.

Per parameter the companies receive a score value according to their performance relative to the other companies. The company with the highest parameter value receives 10 points and the lowest receives 1 point and this will set the score range. The scores for every parameter are then summed to give the total score. Equation 1 shows how the grid size of every benchmarking parameter is calculated. The grid size is then used in Equation 2 to calculate the Value Leverage Capability score of the respective parameter per company.

\[ \Delta s = \frac{\text{max}P - \text{min}P}{N} \]  

*Equation 1*

In which:
- \( \text{max}P \) = maximum value of parameter in dataset
- \( \text{min}P \) = minimum value of parameter in dataset
- \( N \) = scale
- \( \Delta s \) = grid size

Every parameter receives a score between 1 and 10 so the scale \( N \) is 9 in this analysis. Equation 2 shows how the total score per company is calculated. Equation 1 and the equation between brackets in Equation 2 are repeated for every parameter and then summarized to obtain the total score. The \( \Sigma \) sign symbolizes the summation of the individual parameter scores.

\[ \text{Total Score} = \sum \left[ \frac{x - \text{min}P}{\Delta s} + 1 \right] \]  

*Equation 2*

In which:
- \( x \) = the parameter
- \( \Delta s \) = grid size
- \( \text{min}P \) = minimum value of parameter in dataset

In the original method (Kinik et al.), the grid size \( \Delta s \) was separately calculated for every year measured and the scores were converted to a ranking. To be able to compare the scores of different years to each other, the grid size in this analysis is calculated using the whole dataset at once. \( \text{max}P \) and \( \text{min}P \) are the maximum and minimum values achieved by any company in any year. In this way the ranking method
provides a way to also compare the relative performance of the companies over the years. With this ranking method a benchmark will be constructed from the automotive data set which was selected earlier. Other companies can then be compared to this benchmark by calculating their ranking scores. Their data will not be included in determining the grid size of the original ranking so that they will be able to score more than points or less than 1 point. This is done in order to not disturb the original benchmark created from the automotive data set and keep ensure that all ranking scores are comparable to each other.

3. Data analysis

Table 3 Bivariate Correlation Analysis with pearson’s r of all variables for all datapoints (204). All variables correlate significantly (99% confidence interval) with each other.

<table>
<thead>
<tr>
<th>Bivariate Correlation Analysis with Variables</th>
<th>T</th>
<th>P</th>
<th>E</th>
<th>I</th>
<th>PPE</th>
<th>R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>1.0</td>
<td>0.308</td>
<td>0.924</td>
<td>0.874</td>
<td>0.867</td>
<td>0.964</td>
</tr>
<tr>
<td>P</td>
<td></td>
<td>1.0</td>
<td>0.250</td>
<td>0.346</td>
<td>0.353</td>
<td>0.300</td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td>1.0</td>
<td>0.931</td>
<td>0.799</td>
<td>0.911</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
<td>0.789</td>
<td>0.885</td>
</tr>
<tr>
<td>PPE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
<td>0.810</td>
</tr>
<tr>
<td>R&amp;D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
</tr>
</tbody>
</table>

The correlation coefficients between the absolute values of all the variables are shown in Table 3. All variables correlate significantly within a 99% confidence interval with each other. This probably reflects the size effect of the companies; larger companies have in general more employees, more turnover, more PPE etc. By combining all data points of all companies, the dominating factor for correlation becomes the size of the company. So Table 3 only shows the obvious fact that all variables scale with the size of a company. One exception is the profit variable which does correlate in the 99% interval but has a clearly lower range of correlation coefficients than the other variables: 0.250 – 0.353 range for profit compared to 0.789 – 0.964 range for the other variables. This indicates, as with the other variables, that the profit is highly significant to size but also shows a much higher data spread compared to the other variables. The variance of the variables can be further investigated by using boxplots. The boxplots of the datasets of each variable are shown in Figure 1. The datasets were indexed on the mean value of each dataset in order to better compare the spread of data points. Indexing on the median value (assigning the median a value of 100) results in aligning all the box plots and at the same time retaining the relative positions of data points of each. In this manner all datasets are scaled to the same scale so their spread can be compared easily. The y-axis of the graph is constrained between +1000 and -1000 in order to keep the graph readable. Only some of the outliers of the profit variable are outside the graph in this manner. Table 4 lists the value for the quartiles of the variable its box plots shown in Figure 1. From the graph it can be noted that the spread of the profit variable is much larger than other variables and Table 4 shows that the 75% quartile of the profit variable does indeed significantly exceed the values of the other variables. Boxplots are centered on the median of the dataset and thus the same amount of datapoints are above and below the median (50% quartile) line. Also all datasets of the variables have the same number of datapoints so it can be concluded that the profit variable has a much higher spread than the other variables when we compare the 75% quartile values. The same amount of datapoints (25%) are spread over a larger distance, 350-100=250 points in the case of profit and 87.5 points in the case of employees (C) for example. This larger spread of the profit variable could explain the lower correlation coefficient values in Table 3.
Figure 1 Boxplots of all the data points of each variable. The data is indexed on the mean value of each variables dataset. Y-axis is constrained between +1000 and -1000.

Table 4 Values of the quartiles per variable for the boxplots shown in Figure 1. Figures a normalized on the median value.

<table>
<thead>
<tr>
<th>Quartiles</th>
<th>T</th>
<th>P</th>
<th>E</th>
<th>I</th>
<th>PPE</th>
<th>R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
<td>30.94</td>
<td>24.42</td>
<td>35.60</td>
<td>39.14</td>
<td>33.14</td>
<td>18.70</td>
</tr>
<tr>
<td>50%</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>75%</td>
<td>169.95</td>
<td>349.80</td>
<td>187.50</td>
<td>184.20</td>
<td>171.29</td>
<td>205.37</td>
</tr>
</tbody>
</table>

In Table 6, the bivariate correlation analysis of the value creation indicators is shown. The profit based indicators show strong positive correlations among each other in the 99% confidence interval. P/E, P/I, P/PPE and P/T have correlation coefficients with each other between 0.775 and 0.897. This is suspiciously high for such a large dataset of 204 data points. P/R&D shows some lower correlation coefficients (0.444 - 0.796) but this is still substantially higher than the rest of the correlation matrix. The average correlation coefficient for different selection of indicators is shown in Table 5. This table clearly shows that the profit indicators form a group of very high correlating indicators. The other indicator groupings, Turnover vs profit indicators and turnover versus turnover indicators, do sometimes show significant correlations but on average have a very low correlation coefficient. They thus do not show general trends in contrast to the profit group.

Table 5 Average correlation coefficients for different groupings of indicators.

<table>
<thead>
<tr>
<th>Groupings</th>
<th>Average R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profit vs Profit Indicators</td>
<td>0.765</td>
</tr>
<tr>
<td>Turnover vs Profit Indicators</td>
<td>0.143</td>
</tr>
<tr>
<td>Turnover vs Turnover Indicators</td>
<td>0.096</td>
</tr>
</tbody>
</table>
Table 6 Value creation indicators compared to each other by bivariate correlation analysis.

<table>
<thead>
<tr>
<th></th>
<th>T/E</th>
<th>T/I</th>
<th>T/PPE</th>
<th>T/R&amp;D</th>
<th>P/E</th>
<th>P/I</th>
<th>P/PPE</th>
<th>P/R&amp;D</th>
<th>P/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>T/E</td>
<td>0,117</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T/I</td>
<td>0,293</td>
<td>0,462</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T/PPE</td>
<td>-0,206</td>
<td>0,001</td>
<td>-0,089</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T/R&amp;D</td>
<td>0,455</td>
<td>0,012</td>
<td>0,046</td>
<td>0,001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0,009</td>
<td>0,032</td>
<td>0,164</td>
<td>0,775</td>
<td></td>
</tr>
<tr>
<td>P/I</td>
<td>0,052</td>
<td>0,125</td>
<td>0,399</td>
<td>0,192</td>
<td>0,766</td>
<td>0,854</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/PPE</td>
<td>0,023</td>
<td>0,001</td>
<td>0,081</td>
<td>0,592</td>
<td>0,444</td>
<td>0,668</td>
<td>0,778</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/R&amp;D</td>
<td>-0,068</td>
<td>0,032</td>
<td>0,084</td>
<td>0,204</td>
<td>0,781</td>
<td>0,897</td>
<td>0,896</td>
<td>0,796</td>
<td></td>
</tr>
</tbody>
</table>

Table 7 shows the correlation coefficients between the value creation indicators and the turnover and profit. Again the profit based indicators and profit margin systematically have high correlations with profit. On the other hand, the turnover based indicators have poor correlations with any general performance indicator. Turnover(T) does show some significant correlations with the indicators but these are mostly negative, especially with all profit indicators.

Table 7 Value creation Indicators versus Turnover and Profit.

<table>
<thead>
<tr>
<th></th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>T/E</td>
<td>0,279</td>
<td>0,219</td>
</tr>
<tr>
<td>T/I</td>
<td>-0,004</td>
<td>-0,031</td>
</tr>
<tr>
<td>T/PPE</td>
<td>0,132</td>
<td>0,033</td>
</tr>
<tr>
<td>T/R&amp;D</td>
<td>-0,426</td>
<td>-0,124</td>
</tr>
<tr>
<td>P/E</td>
<td>-0,039</td>
<td>0,774</td>
</tr>
<tr>
<td>P/I</td>
<td>-0,228</td>
<td>0,633</td>
</tr>
<tr>
<td>P/PPE</td>
<td>-0,187</td>
<td>0,575</td>
</tr>
<tr>
<td>P/R&amp;D</td>
<td>-0,288</td>
<td>0,322</td>
</tr>
<tr>
<td>P/T</td>
<td>-0,207</td>
<td>0,667</td>
</tr>
</tbody>
</table>

The profit variable showed a significantly higher spread of data points than the other variables which explains the substantially lower correlation coefficients compared to the other variables in the bivariate analysis. Its associated indicators (P/E, P/I, P/PPE and P/R&D) showed substantially higher correlation coefficients among each other than the other combinations of indicators. This could be taken as a sign that they constitute a natural model. But when the high data spread and relative low correlation coefficients of the profit variable are taken into account, it becomes more likely that the profit variable overwhelms the other variables E, I, PPE and R&D. The high variance of the profit variable obscures the trends in the other variables which reduces them to effectively a constant. Subsequently, when correlating the profit indicators with each other, you are effectively correlating profit to profit. This explains the high correlation coefficients of the indicators and the relatively low correlation coefficients of the profit variable. Table 7 clearly shows this effect were the profit indicators show an exceptional degree of correlation with the plain profit variable. The same effect of the profit variable again becomes apparent in the equally high correlation coefficients with the indicator P/T. This makes the profit indicators unfit for use in the benchmark and thus they are discarded.
In further in depth analyses of the indicators it was noticed that the T/R&D indicator shows behavior different from the rest of the indicators. The inverse of the indicator, the R&D/T or the R&D expenditure ratio (shown in Figure 2), shows a upper limit discontinuity at around 5.5% which was interpreted as being caused by the active management policies of companies. This shows the willingness and actual occurrence of R&D budget management in other ways than initially was reasoned from theory. The initial assumption was that the R&D expenses behaved like the other variables Inventory, PPE and number of Employees, i.e. that an increase of the indicator represents an increase in Lean performance. The active adjustment of the R&D expenses will impact the meaning of the T/R&D differently. In times of economic hardship, for example, the R&D expenses could be cut significantly to reduce costs while the turnover diminishes less so. The indicator T/R&D would contrarily increase and result in a score increase for the company in the benchmark. This short term crisis management behavior of companies is different from the behavior initially envisioned for the T/R&D indicator. It means that when the T/R&D achieves a high score it could not always be a sign of improved Lean value creation or value flow. Subsequently, the indicator can’t be as straightforwardly be interpreted as the other indicators and thus will be dropped from the final benchmark.

![Distribution of the inverse of the T/R&D indicator to reflect the R&D expenditure ratio in companies.](image)

Figure 2: Distribution of the inverse of the T/R&D indicator to reflect the R&D expenditure ratio in companies.
4. Results

Figure 3 shows the historic progression of the calculated score values for every case study company and the automotive benchmark average. The exceptionally high total score achieved by Lely is immediately visible and dominates the graph, making the results from the other case studies unintelligible. In Figure 4 the same graph is presented but capped at 60 points on the y-axis. Lely now falls for the most part outside the graph but the behavior of the other companies is now visible.

Figure 3 Historic progression of the Lean Value Flow performance score. The score value combines the values for the indicators T/E, T/I, T/PPE and P/T. Automotive AVG is the average score value of the automotive benchmark.

Figure 4 The historic progression of the Lean Value Flow performance score capped at 60 points.
What is most noticeable are the much larger scores attained by the non-automotive companies than the automotive companies from the benchmark. To put it in perspective, the highest score achieved by the benchmark in any year never rises above 32.5 points. Intergas, Lely and Brammer always score higher than the highest scoring benchmark company. SEW, on the other hand, start off with an average score in 2003 and then steadily rises to 38.9 points in 2014. It is the only one of the non-automotive companies to show a relatively modest turnover growth of 46% compared to 141%, 143% and 364% growth figures of Intergas, Brammer and Lely respectively. The size of these companies is also a couple of orders of magnitude smaller than the automotive companies (average turnover of the benchmark is €57.709 million). High growth figures combined with smaller averages company sized could signal different mechanics at work which produce these very high score values. Though Great Wall Motors started off with similar turnover figures (€354 million in 2003) as the non-automotive companies and increased it with over 2200%, it didn’t show the same high scores. Porsche shows a great swing in its total performance score in the years 2008 and 2009. This is probably caused by the great corporate restructuring project with Volkswagen though it also coincides with the onset of financial crisis which most likely also had some effect on the performance of the company. Daimler forms a typical automotive case as exemplified by it scoring around the automotive average. Expected shocks by the demerger with Chrysler in 2007 are not clearly visible but this can be explained by the fact we are only looking at the Mercedes-Benz figures. The slight negative bump visible with Daimler also coincides with the crisis thus these results can’t be simply attributed to the demerger.

The high scores attained by the non-automotive companies would imply that they are high Lean value creating performers. Figure 6 and Figure 5 show the constituent parts of the total performance score for pre and post-crisis periods. It can be seen from these graphs that the scores of the non-automotive case studies is dominated by extremely high values of indicator T/PPE.
**T/PPE**

In Figure 7 are the historic progressions plotted for the Turnover per PPE indicator. The graph is dominated by the extremely high scores from Lely and to a lesser extend the other non-automotive case studies. Figure 8 is subsequently presented to bring out the results from the other companies by means of constraining the y-axis to a value of 45 points.

It is visible in Figure 7 that Lely achieved its largest scores after the year 2010, with a large drop in 2013. Lely performed a corporate restructuring in those years and this resulted in the administrative transfer of the Property, Plant and Equipment assets. Lely Industries, the specific part of the Lely concern under consideration showed a large growth of its turnover from €216 million in 2010 to €326
million in 2012 and then a lesser decrease to €279 million in 2014. At the same time, due to the restructuring program, the PPE assets first declined and then suddenly increased tremendously in 2013. The next year the PPE assets were again the pre 2013 level. This sudden increase explains the large drop seen in the T/PPE indicator and could attributed to an administrative decision to put all PPE assets in the books of Lely Industries for that year and then transfer them back to another part of the company. The multi-year trend of increasing T/PPE values can be attributed to the steady growth of the turnover and the decrease in PPE assets. This trend is can more probably be attributed to a real performance increase though the accounting practices also are suspected to play a large part. The other non-automotive case study companies, SEW, Intergas and Brammer, also have exceptionally large scores for the T/PPE indicator compared to the benchmark with SEW showing values which still fall within the range of the benchmark. The suspicion is now raised that the T/PPE indicator behaves considerably different in the non-automotive companies compared to the automotive companies. One difference between the automotive companies and the other case studies is the size of the companies. In Figure 9 the size, in turnover, is plotted against the absolute value of the T/PPE indicator (here the actual values of the T/PPE indicator are plotted and not the converted score values). The shows the entire dataset of benchmark(in blue) and the case studies(in red) with axes in logarithmic scale. The automotive companies from the benchmark form a clear cluster with Porsche and Daimler falling right within it. The blue “tail” to the lower turnover values consists of GWM’s datapoints. Intergas, Lely and Brammer are clearly outside the range of the benchmark with SEW covering part of the upper range.

![Turnover vs T/PPE](image)

*Figure 9 Company size, measured in turnover, plotted against the absolute T/PPE values. The datapoints from the automotive benchmark are colored blue and the case studies are colored red. The labels indicate the presence of the specific case study companies. Both axes have a logarithmic scale and the scatter plot shows the entire dataset.*

The blue tail comprising Great Wall Motors overlaps in size with Lely and Brammer but does not show the same high indicator values. SEW is even smaller but shows more comparable indicator values. A size effect on the characteristic of T/PPE thus seems unlikely. A characteristics which is shared between GWM and Lely, Intergas and Brammer is their large growth figures but GWM does not show the same high T/PPE figures as the other do. It thus seems that the T/PPE shows different characteristics for different industries though this is based on a very restricted set of case studies and thus needs more research. In the case of Lely Industries, it also seems like the T/PPE indicator is artificially high because a large part of the PPE assets are not administrated in the annual reports of Lely Industries but with other companies in the Lely concern.
5. Conclusion

Through the research and analysis presented in this thesis report, the main research question can now be answered. The main research question:

*How can a Lean value creation benchmark be developed to provide a means of comparing company performances to each other?*

From an initial nine indicators selected from literature and theory, five (T/E, T/I, T/PPE, T/R&D and P/T) showed potential for use in the benchmark. Using a score calculation method, these indicators were combined into one performance score. T/R&D was eventually dropped because of divergent behaviour and needs to be re-evaluated to produce an innovation capability indicator useful for benchmarking. In the last chapter the final set of indicators (T/E, T/I, T/PPE and P/T) were combined into a Lean Value Flow benchmark performance score and tested using six case studies. The final analysis showed that the non-automotive companies had very different characteristic values from the automotive companies for the indicator T/PPE which dominated in the total score. An in depth investigation of the T/PPE indicator did not conclusively show the cause of this behavior. Company size or turnover growth did not seem to produce an satisfactory explanation of the high values and it is thus suspected to be an intrinsic characteristic of these companies’ industries. More research is needed to explain the difference. It was also shown that the profit margin (P/T) showed sudden swings in value for some companies which distorted the benchmark score calculation method. Though the indicator was deemed useful in measuring the performance of a company, more research is needed to developed a scoring method which dampens these large swings. Two indicators, T/E and T/I, showed consistent behavior and can be readily used for benchmarking purposes. This research showed that different industries can show different characteristics, especially in the case of T/PPE, and provides ample opportunity for follow up research.

References


