THE ROLE OF LEAN AND AGILE LOGISTICS DURING PRODUCTION RAMP-UP

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This dissertation is dedicated to

my mother Najah Rida;
my father Fathi Alsoussi;
the memory of my father-in-law Ziyad Abdelrazeq;
my wife Fatima Abdelrazeq;
my daughter Leen;
my son Hamzah;
and
my brothers Issam, Amjad, Ahmad, and Abdelhadi

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ABSTRACT

In addition to the rareness of theoretical and empirical research, which extends to every aspect of the production ramp-up literature, the increasing importance of the ramp-up phase – due to the continuously decreasing product lifecycle in almost all industrial sectors –magnifies the need for more research efforts in this field. Based on a comprehensive literature review, no attempts to investigate the role of lean and/or agile logistics during the ramp-up stage were found. Utilizing the survey method, this research empirically explores the effects of lean and agile logistics on production performance during the ramp-up phase in terms of quantity, quality, and cost.

A special purpose questionnaire was developed to collect primary data based on a literature review in the fields of production ramp-up, lean logistics, lean production, agile logistics, agile production, performance measurement, and product success. The measurement model was evaluated for validity and reliability and tested for temporal consistency and the existence of common method variance; the collected data were tested for measurement and non-response biases; and the results were evaluated for their statistical power and statistical conclusion error. Out of 63 questionnaires collected from industrial organizations operating in 7 countries and in different sectors, 56 responses were used in the statistical analyses.

A two-step methodological approach was utilized in the data analysis. In the first step, the data collected on the research variables were analysed following a theory confirmation procedure to examine the validity of a hypothesized positive effect of lean and agile logistics on ramp-up performance. In addition, the effect of ramp-up performance on new products' success, the moderating effect of some respondent, organizational, and product-related variables, and the mediating effect of outbound logistics were investigated. The partial least squares method of structural equation modelling (PLS-SEM) was employed during the confirmatory analysis.

Different scenarios were evaluated to test the main and subsidiary hypotheses proposed, based on the use of formative and reflective measures and first- or higher-order variable formats. The results of the confirmatory data analysis supported the hypothesized positive effect of lean and agile logistics on production performance during the ramp-up phase.

In the second methodological step, exploratory analyses were conducted to explore further patterns in the data collected. Correlation matrices indicated a greater effect of agility

on quantity performance and a greater effect of leanness on cost performance. Such trends are generally accepted and supported by the theoretical literature and by practitioners.

However, the agreed-upon priorities of time reduction during the ramp-up phase and cost reduction during the steady-state and ramp-down phases motivated the proposition of a mixed model that uses higher levels of agility throughout the ramp-up phase and higher leanness levels thereafter. The proposed mixed system was supposed to outperform the pure lean, pure agile, and leagile strategies.

Among the methods proposed to apply such a mixed production system, the development of a specialized agile ramp-up facility was introduced. It was suggested that all products undergoing a ramp-up phase should be produced with an agile system, in a specialized ramp-up facility, and then moved to a lean facility during the steady-state and ramp-down production phases. To examine the feasibility of the proposed system and the magnitude of investment that might be accepted to gain the expected enhancement, the total lifecycle profitability of each system – lean, agile, leagile, and mixed – was calculated and compared to provide insights into the advantages of the mixed system and the conditions that increase or decrease the appeal of investing in such a strategy.

It was concluded that the adoption of the proposed system and the asset investment magnitude should be evaluated considering different possible combinations of the product’s type, price, cost, contribution, and lifecycle length, among other variables. The proposed system has been proven to be more attractive to adopt as the proportion of the ramp-up time to the total lifecycle increases, as the product’s price drops faster, as the peak sales are reached earlier, or as the number of ramp-ups increases.

Zusammenfassung

Trotz der steigenden Bedeutung des Produktionsanlaufs in der Produktion existieren nur relativ wenige theoretische und empirische Studien zu diesem Thema in der Literatur. Die sich stetig verkürzenden Produktlebenszyklen in praktisch allen industriellen Bereichen erzeugen einen wachsenden Forschungsbedarf in diesem Bereich. Da der Bereich der „Lean/Agile Logistics“-Methoden während des Produktionsanlaufs in der Forschungsliteratur kaum eine Rolle spielt, werden im Rahmen dieser Arbeit die Auswirkungen dieser Methoden auf die Produktionsgüte untersucht, wobei insbesondere die Aspekte der Quantität, Qualität und Kosten betrachtet werden.

In diesem Zusammenhang wurde ein Fragebogen zur Gewinnung von Informationen aus den Bereichen Produktionsanlauf, lean logistics, lean production, agile logistics, agile production, Performance-Messsung und Produkterfolg entwickelt. Das zugrundeliegende Messmodell wurde unter Validität- und Zuverlässigkeitsaspekten sowie zeitlicher Konsistenz und allgemeiner Methodenvarianz geprüft. Darüber hinaus wurden die extrahierten Daten bezüglich ihrer Verwendbarkeit als Messgröße sowie zur Vermeidung von Abweichungen aufgrund nicht gegebener Antworten geprüft. Die entsprechenden Ergebnisse wurden anschließend hinsichtlich ihrer statistischen Aussagekraft sowie unter Berücksichtigung möglicher Schlussfolgerungsfehler ausgewertet. Hierdurch konnten 56 der 63 Fragebögen von Industrieanlagen aus 7 Ländern in die statistische Analyse eingebunden werden.

Für die Datenanalyse wurde ein zweistufiger methodischer Ansatz gewählt, bei dem im ersten Schritt der Einfluss einzelner Variablen auf einen hypothetischen positiven Effekt der lean- und agile logistics auf die Performance des Anlaufverhaltens analysiert wurde und im Anschluss daran der Einfluss des Produktionsanlaufs auf den Produkterfolg. In diesem Zusammenhang wurde auch der moderierende Einfluss einiger Variablen bezüglich Personen, Organisation und Produkten sowie der Einfluss auslaufender logistischer Prozesse berücksichtigt. Für die entsprechende Analyse wurde die „Partial Least Square method of Structural Equation Modeling (PLS-SEM)“-Methode verwendet.

Zur Überprüfung von Haupt- und Nebenhypothesen wurden verschiedene Szenarien eingebunden, wobei formative und reflexive Prozessgrößen sowie Variablen erster und höherer Ordnung eingebunden wurden. Die Ergebnisse bestätigten die Hypothese eines positiven Effekts der lean and agile logistics auf die Produktionsgüte während der Produktionsanlaufphase.

Im zweiten methodischen Schritt wurden weitere Analysen durchgeführt, um weitere Muster zu identifizieren. Mit Hilfe von Korrelationsmatrizen konnte ein starker Zusammenhang zwischen Agilität und Quantität und zwischen Leanness und Kosten gefunden werden, was tendentiell auch den Beschreibungen aus der Literatur und den Erfahrungen der Produktion entspricht.

Für die beabsichtigte Zeitreduktion während des Anlaufs sowie eine Kostensenkung während des stationären Betriebs wurde ein kombiniertes Modell mit einer höheren Agilität während der Anlaufphase sowie einer höheren Leanness im stationären Betrieb verwendet. Für dieses System wurde eine klare Verbesserung im Verglich zu den reinen lean, agile und leagile Strategien erwartet.

Für die Anwendung eines derartigen kombinierten Produktionssystems wurde ein spezielles agiles Produktionsanlaufsystem entwickelt, wobei für alle Produkte ein Produktionsanlauf mit einem agilen System sowie einem spezialisierten System, empfohlen wurde, um anschließend im stationären Betrieb zum Lean-Betrieb überzugehen und anschließend die Produktion herunterzufahren. Um die Eignung des Systems und der damit verbundenen Investitionen zu beurteilen, wurde die Profitabilität des Lebenszyklus bei jedem Teilsystem (lean, agile, leagile, kombiniertes System) berechnet und die Vor- und Nachteile des kombinierten Systems bewertet.

Es konnte gezeigt werden, dass für die Verwendung des vorgeschlagenen Systems und die zugehörigen Güterinvestitionen verschiedene Kombinationen von Variablen zu Produkten, Preisen, Kosten, Beiträge und Lebenszykluslängen sowie weitere Variablen berücksichtigt werden müssen. Mit dem vorgeschlagenen System konnte der Anteil des Produktanlaufs am kompletten Produktzyklus erhöht, eine schnellere Preissenkung sowie ein früheres Erreichen der maximalen Verkaufszahlen erreicht werden und die Gesamtzahl an Produktionsabläufen erhöht werden, was in vielen Fällen einen Einsatz definitiv sinnvoll macht.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
5 S	Systematic arrangement, sort, shine, standardize, and sustain
Acc.	The null hypothesis is accepted
AccumProfitAgile	Accumulated profit using the agile strategy
AccumProfitLeagile	Accumulated profit using the leagile strategy
AccumProfitLean	Accumulated profit using the lean strategy
AccumProfitMixed	Accumulated profit using the mixed-strategy
AIBL	Agility of inbound logistics
AIBL1	The suppliers’ cooperation measure
AIBL2	The measure of using IT to link the company with it’s suppliers
AIBL3	The suppliers’ flexibility measure
AIBL4	The measure of using vendor managed inventory technique
AIIL	Agility of inbound and intra logistics
AITL	Agility of intra logistics
AITL1	The production’s flexibility measure
AITL2	The adaptability to change measure
AITL3	The measure of using modular product design technique
AITL4	The measure of using reconfigurable manufacturing technique
AOE	Agility overall evaluation
AOL	Agility of outbound logistics
AOL1	The adaptability to order’s change measure
AOL2	The ability to predict market changes measure
AOL3	The measure of using third-party logistics technique
AVE	Average variance extracted
CB	Covariance based
CP	Cost performance
CP1	The variable cost measure
CP2	The production system preparation measure
CP3	The repair, rework, and scrap costs measure
CPOE	Cost performance overall evaluation
CSCMP	Council of supply chain management professionals
D: P ratio	Delivery lead time to production lead time ratio
F. goods	Finished goods
HRM	Human resource management
HTMT	Heterotrait-monotrait
IT	Information technology
JIT	Just in time
LIBL	Leanness of inbound logistics
LIBL1	The material inventory level measure
LIBL2	The match between material supply and the actual requirements measure
LIBL3	The material transportation cost measure
LIBL4	The measure of using material requirement planning technique
LIBL5	The measure of using supplier milk run technique
LIIL	Leanness of inbound and intra logistics
LITL	Leanness of intra logistics
LITL1	The work-in-process inventory level measure
LITL2	The standardization level measure
LITL3	The measure of using just-in-time technique

LITL4	The measure of using Kanban technique
LITL5	The measure of using cross-docking technique
LOE	Leanness overall evaluation
LOL	Leanness of outbound logistics
LOL1	The finished goods inventory level measure
LOL2	The finished goods transportation cost measure
LOL3	The customer involvement level measure
M. handling	Materials handling
MPD	Modular product design
MRP	Material requirement planning
NPS	New product success
NPS1	The sales return measure
NPS2	The net profit measure
NPS3	The market share measure
NPS4	The customer satisfaction measure
OEM	Original equipment manufacturer
OPM	Operations and production management
P. Correlation	Pearson correlation
PCIs	Process capability indices
PDMA	Product development and management association
PLS	Partial least square
Prob.1	Problems related to the supply of material
Prob.2	Problems related to the production machines
Prob.3	Problems related to the equipment and tooling
Prob.4	Problems related to the production employees
Prob.5	Problems related to the mismatch between the design and the process
Prob.6	Problems related to wrong product design
Prob.7	Problems related to the use of inappropriate technology
Prob.8	Problems related to the poor cooperation among departments
Prob.9	Problems related to the information flow
QlP	Quality performance
QlP1	The defective products rate measure
QlP2	The returned products rate measure
QlP3	The quality level deviation measure
QlPOE	Quality performance overall evaluation
QnP	Quantity performance
QnP1	The productivity measure
QnP2	The cycle time reduction measure
QnP3	The learning rate measure
QnP4	The unplanned production stops measure
Rej.	The null hypothesis is rejected
RM	Raw material
RMS	Reconfigurable manufacturing system
RUP	Ramp-up performance
RUPOE	Ramp-up performance overall evaluation
Sce.	Scenario
SD	Standard deviation
SEM	Structural equation modeling
Sig.	Significance level
SMED	Single minute exchange of die
SMEs	Small and medium-sized enterprises

SPSS	Statistical package for the social sciences
SRMS	Standardized root mean square
St. error	Standard error
TPL (3PL)	Third-party logistics
TPOE	Time performance overall evaluation
TPS	Toyota production system
TQM	Total quality management
VIF	Variance inflation factor
VMI	Vendor managed inventory
VPOE	Volume performance overall evaluation
WIP	Work in process

LIST OF NOTATIONS

Notation	Name
F^2	Effect size
R^2	Coefficient of determination (multiple regression coefficient)
T_f	Time to functionality
T_o	Time to optimization
T_q	Time to quality
T_r	Time to ramp-up
a_i	Initial demand = $d_{(0)}$
$b_{(x)}$	Demand growth factor
c_{ir}	Increase rate for the effective capacity
d_d	Demand during the decline phase
d_g	Demand during the growth phase
d_i	Demand during the introduction phase
d_m	Demand during the maturity phase
e_i	Measurement error
l_i	Standardized outer loading
p_i	Initial price
$\bar{x}$	Arithmetic mean or average of x scores
ρ_c	Composite reliability
C	Cost per unit
D	Total lifecycle demand
Ha	Alternative hypothesis
Ho	Null hypothesis
N	Sample Size
R	Sample correlation coefficient
T	Lifecycle length
TP	Total lifecycle profit
UP	Profit per unit
ec	Effective capacity
i	Indicator variable
$p\ value$	The attained level of significance
r	Pearson correlation coefficient
sc	Starting capacity
t	Time
$t\ value$	Ratio of departure from notional value
tc	Targeted capacity
$var\ (e_i)$	Variance of the measurement error
α	Parameter to determine the slope of the production curve
β	Parameter to determine the slope of the production curve
δ	Capacity increase rate

CHAPTER 1

GENERAL FRAMEWORK

1.1. Introduction

Among the important characteristics of current marketplaces, increasing levels of competition – particularly in the manufacturing sector (Chenhall, 1997) – and rapidly changing customer needs and requirements are agreed-upon predominant characteristics (Pufall et al., 2007; Winkler et al., 2007; Cedergren et al., 2010; Schmitt and Schmitt, 2013; Roh et al., 2014). These two characteristics, in addition to the huge technological advances (Da Silveira et al., 2001; Kontio and Haapasalo, 2005) and the accompanying increased variety of products (Fleischer et al., 2003), are the main causes of the continuously diminishing product lifecycle (Terwiesch and Bohn, 2001). Iwaarden and Wiele (2012) indicated that increasing product variety and shortening product lifecycles are important trends in the current business climate. Sturm et al. (2003) indicated that the product lifecycle is decreasing in almost every industrial sector. For automotive original equipment manufacturers (OEM), as an example, Schuh et al. (2005a) argued that products' lifecycles have decreased by 60% during a time period of 4 decades.

The shorter product lifecycle has increased the importance of continually developing new products (Winkler et al., 2007; Surbier et al., 2010; Surbier et al., 2014), which has been considered, for most modern companies, as the only way to survive (Mallick and Schroeder, 2005). Audretsch (1991) mentioned the importance of innovation to the survival of new entrants to the market. Furthermore, Olson et al. (1997) indicated that 49% of sales in the best-performing firms are from new products, while in less successful firms, this percentage drop to only 22%.

In response, the frequency of new product introductions in manufacturing firms has increased (Eisenhardt and Brown, 1998; Wan et al., 2005) and is expected to grow even more in the future (Schuh et al., 2005b). A continuously increasing rate of innovation can be captured in almost all industrial sectors. In addition, shrinking lifecycles force organizations to pay the same amount of attention to cutting the time-to-volume as to cutting the time-to-market of new products (Terwiesch and Bohn, 2001).

The shorter product lifecycles, more frequent new product development, and increasing importance of reducing time-to-volume shed more light on the phase of production ramp-up (Berg and Säfesten, 2006; Winkler et al., 2007; Du et al., 2008; Simon et al., 2008; Fjällström et al., 2009; Schmitt and Schmitt, 2013).

As shown in figure 1.1, production ramp-up takes place after completing the development process of a certain product and continues until the product is being produced in a steady-state manner (Abernathy and Baloff, 1973), with which the targeted levels of quantity, cost, and quality are reached (Wheelwright and Clark, 1992). In addition to each new product, ramp-up is experienced with new production processes (Terwiesch and Xu, 2004), new factories (Willmann et al., 2014), or even new technology introduction (Gross and Renner, 2010). However, some authors have referred to cases of new lines or factories as production start-up (Terwiesch et al., 2001).

Reducing the ramp-up duration can be as beneficial as reducing the development time, since the ultimate goal is to make the product available on the market within the smallest possible time period. In addition, Terwiesch et al. (2001) argued that the timing of revenue depends more on time-to-volume than on time-to-market. Furthermore, House and Price (1991) reported striking figures showing that companies might lose 3.5% of the after-tax profit when they overspend by 50% during product development, but they might lose as much as 33% when their shipments are 6 months late.

Ramp-up greatly influences cost structures (Terwiesch and Bohn, 2001). Concerning the automotive industry as an example, Schuh et al. (2005a) showed that production ramp-up is one of the major cost drivers. Consequently, more control over the production ramp-up phase will greatly affect profitability in terms of both revenues and costs.

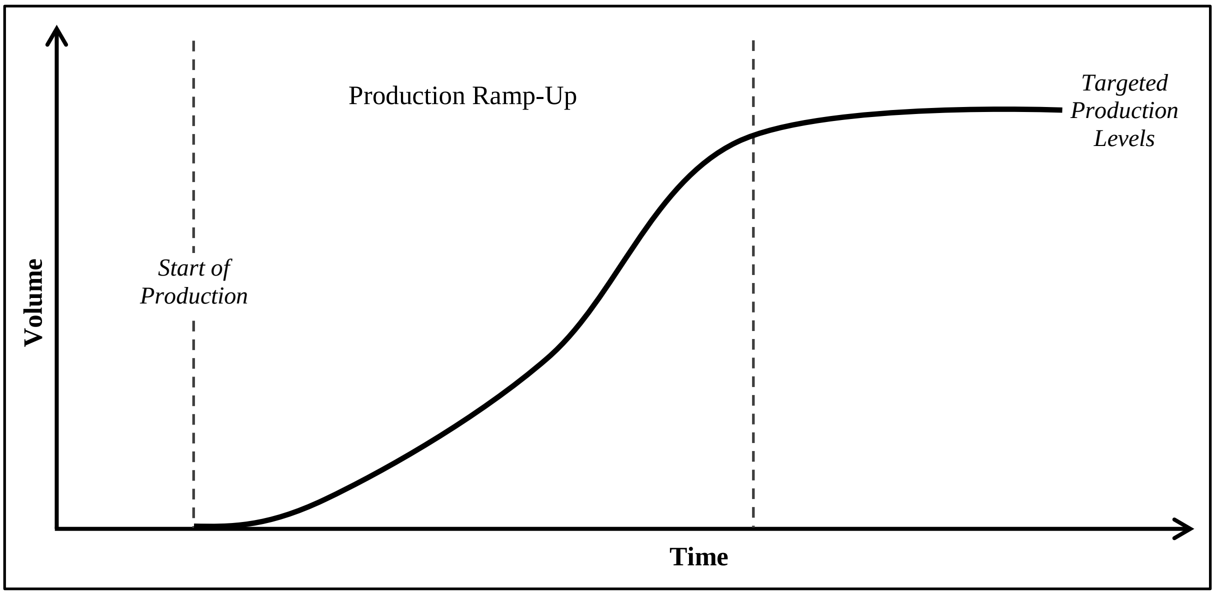


Figure 1.1: Production ramp-up phase

Despite the great importance of production ramp-up, as well as the magnificent benefits that might be gained from better performance during this period, little or – at the very least – insufficient research efforts have been directed toward this area. Terwiesch et al. (2001) indicated that less attention has been paid in the literature to time-to-volume reduction than to time-to-market reduction. In addition, Schuh et al. (2005a) declared that 'no or only less meaningful' information for the ramp-up phase exists in the scientific literature. Many other authors have indicated the lack of sufficient literature and research attempts concerning production ramp-up (e.g. Almgren, 2000; Terwiesch et al., 2001; Berg and Säfesten, 2006; Juerging and Milling, 2006; Ball et al., 2011; Doltsinis et al., 2013).

Some researchers have attributed the scarcity of research in this area to the complexity of the ramp-up phase. Kuhn et al. (2002), van der Merwe (2004), Schuh et al. (2005a), Doltsinis et al. (2013), Schmitt and Schmitt (2013), and others mentioned the complexity of this production phase. Reuter et al. (2014) also stressed this fact and referred to ramp-up as a non-linear socio-technical system.

Among the research efforts exploring the factors that affect ramp-up performance (e.g. Terwiesch and Bohn, 2001; Kuhn et al., 2002; Fjällström et al., 2009; Glock et al., 2012; Niroomand et al., 2014), few researchers have highlighted the role of logistics during this phase (e.g. Bowersox et al., 1999; Pfohl and Gareis, 2000; Risse, 2003; Filla and Klingebiel, 2014); despite the appreciation of the role of logistics during production ramp-up in some research, these studies targeted limited logistical dimensions and lacked a detailed analysis of a wide range of logistics activities. Studying limited logistics activities and generalizing the results to include the entire logistics system represent oversimplification of the complex role that logistics might play during this phase.

Logistics thinking and practice have developed rapidly (Gundlach et al., 2006). Two currently popular paradigms in logistics are lean and agile logistics. With lean logistics, waste should be minimized, but this strategy might not be able to respond quickly to high volatility in the marketplace. On the other hand, an agile strategy improves the responsiveness but may ultimately increase the total cost (Naylor et al., 1999). Researchers have explored the contributions and potentials of lean and agile logistics to improve firms' performance and competitiveness (e.g. Damen, 2001; Wu, 2002; Jirsák and Holman, 2012). However, the efforts to compare the two doctrines and evaluate how performance differs when utilizing either of them seem to be very limited. Christopher and Towill (2001) argued that lean and agile are not mutually exclusive paradigms and that they might be combined to advantage in a number of different ways.

This research aims to explore empirically the roles of lean and agile logistics in enhancing production ramp-up performance. Exploring the role of logistics system leanness and agility during the ramp-up phase could be of great importance for reducing the cost and time needed to reach full capacity utilization. Unlike research that attempted to use general concepts, this research aims to study the effect of certain logistics trends and practices on certain ramp-up performance measurement criteria. In addition, it intends to explore how ramp-up performance affects different indicators of new product success. To achieve the main objective of this research, the theory confirmation methodology was basically utilized, since research hypotheses that propose the existence of significant relationships between ramp-up performance's constructs and lean/agile logistics were formulated based on the theoretical literature trends and practitioners' opinions. However, the magnitude of the effect and the correlations between sub-variables are more exploratory in nature.

While companies typically aim to minimize their production cost to be price competitive (Heizer and Render, 2008), this focus might change significantly during the production ramp-up phase. The main focus during the ramp-up phase is on reducing the time period needed to reach full-scale production with the aim of making the highest possible profits from early introduction to the market (Almgren, 1999a; Terwiesch and Bohn, 2001; Niroomand et al., 2014). Shortly after introducing a new product to the market, similar products will be made available and the competition will be more on the base of price than on the base of novelty (Terwiesch et al., 2001). Consistent with these facts, and building on the investigated relationships between lean/agile logistics and production ramp-up, this research introduces a model proposing that companies require different levels of leanness or agility according to the specific phase of the lifecycle and that phase's goals. Hence, different combinations of lean and/or agile logistics might be employed in different lifecycle phases. The most suitable levels of leanness and agility for the ramp-up phase will be tested and compared with the steady-state and ramp-down production phases.

Some researchers (e.g. Naylor et al., 1999; Mason-Jones et al., 2000a; Mason-Jones et al., 2000b) have traded off and combined the lean and agile paradigms to achieve a balanced level of flexibility and cost control. However, due to the different goals involved in different production stages, companies might require a switch or a move between the lean and the agile paradigm rather than a combination of the two. Production ramp-up could serve as a typical example of such a situation, since its goals might differ significantly from those of the steady-state or ramp-down production stages. Due to the increasing importance of the lean and agile paradigms, linking these concepts to the ramp-up phase, and building a model of relationships between lean and agile logistics on the one hand and production ramp-up performance parameters on the other, might be of great importance as a decision-making support tool.

1.2. Problem Statement

Possessing more control over the outcomes of the production ramp-up phase largely contributes to the profitability and the success of a newly developed product. In their attempts to achieve such a purpose, researchers have examined the prospective effect of many variables on ramp-up performance. Among these research efforts, a limited number of researchers have emphasized the role of logistics, in most cases using a naive and simplified view of logistics activities. Detailed classifications of logistics activities and special logistics behaviours have largely been ignored in the context of the ramp-up phase. In addition, despite their unquestionable importance, lean and agile logistics have never been linked to the ramp-up phase.

This research aims to explore the effect of lean and agile logistics on production ramp-up performance with the aim of evaluating how each sub-variable under the constructs of lean and agile logistics affects the performance of production ramp-up in terms of quantity, quality, and cost. In addition to the type of the effect – specifically positive or negative – of each sub-variable under the lean and agile logistics constructs, the magnitude of these effects are considered; thus, the relative importance of each dimension of lean and agile logistics to the ramp-up phase can be evaluated. With limited abilities and resources available to enhance the logistics system, the results of this research can guide the decision maker regarding the aspects that are most worthy of consideration. In addition, the moderating role of some respondent-, organization-, and product-related variables are analysed. Therefore, variation according to these variables should be taken into consideration while using the research results.

Ultimately, the results of the analysis enhance our understanding of the relationship between the research variables in terms of the most influential dimensions of lean and agile logistics on certain performance parameters during the ramp-up phase and the moderating variables that might significantly affect this relationship.

1.3. Research Significance

This section sheds light on two types of significance related to the current research: (1) the importance of the topic and the variables investigated and (2) the significance of the current research for the already-existing literature. The importance of the topic under study is supported and clarified using research addressing the issues of production ramp-up, lean logistics, and agile logistics from different organizational perspectives.

On the other hand, the current research’s significance is demonstrated by the unique contributions and addition of this research to the available knowledge and the main research gaps that it helps to fill.

1.3.1. Significance of the Fields Investigated

Production ramp-up, lean logistics, and agile logistics are worthy of consideration in their own right. Almgren (1999a) pointed to a case of consensus among industrial managers regarding the importance of the ramp-up phase. The literature has elucidated the importance of the ramp-up phase for organizational performance (Ball et al., 2011), revenues and profits (Ulrich et al., 1993), the timing of returns (Terwiesch et al., 2001), product quality (Almgren, 2000), and many other pivotal aspects. Moreover, Schmitt and Schmitt (2013) deemed the ramp-up phase to be a central point of a product’s entire lifecycle. Due to high demand and premium product selling prices during the initial introductory phase, reducing the ramp-up time can produce extraordinarily higher financial compensation. However, Du et al. (2008) pointed out that the current industrial practice in reducing the ramp-up phase’s duration is ‘far less than satisfactory’.

The importance of production ramp-up varies from one industry to another based on many factors, including the level of competition, technological content, lifecycle length, customer preferences, and so on. Section 2.2.1 discusses the importance of the production ramp-up phase in more detail. In addition, section 2.2.2 highlights the importance of lean and agile logistics activities.

1.3.2. Research Contributions

According to Doltsinis et al. (2013), significant potential for improvement is possible in the production ramp-up phase. Zeugträger (1998) argued that the fundamental chances to reduce the efforts exerted during the ramp-up phase are unemployed. Bischoff (2007) showed that – unlike serial production – enormous potential to enhance goal achievement during ramp-up still exists. Although – and in comparison with steady-state production – Ball et al. (2011) indicated less availability of literature on non-steady-state production, such as production ramp-up, the authors also indicated the absence of ‘a commonly accepted body of knowledge’ regarding production ramp-up. Since most researchers have concentrated on product development (for a review see Krishnan and Ulrich, 2001; Ernst, 2002; Kuwashima, 2012; Kuwashima, 2013; Majava et al., 2013) and steady-state production (Neely et al., 1995; Neely, 2005; Taticchi et al., 2010 provided comprehensive reviews of research on performance measurement issues in steady-state production), a focus on the gap between these two bodies of literature is necessary (Terwiesch et al., 2001; Juerging and Milling, 2005; Juerging and Milling, 2006).

This research contributes to a more comprehensive view of production ramp-up through the exploration of previously unresearched possible driving factors and unrevealed potential contributions of lean and agile logistics practices during this important production stage. A thorough review of the production ramp-up literature was conducted to provide a comprehensive reference for future research efforts in this critical field.

While the lack of research on production ramp-up is largely agreed upon, the other variables in this research are – to different extents – characterized by a similar status. Narasimhan et al. (2006) and Hallgren and Olhager (2009) noted a lack of clarity in the extant literature regarding what constitutes leanness and agility, how they differ, and when to employ each one. Shah and Ward (2003) mentioned relatively little published empirical evidence about the implementation of lean practices and the factors that can influence their implementation.

As regards logistics in general, while many studies have acknowledged the role of logistics and supply chain management in improving production (see Cooper, 1993a; Gustin et al., 1994; Stank et al., 2001; Gimenez and Ventura, 2003), very few studies have analysed this role empirically (Gimenez and Ventura, 2005; Christopher, 2011). This research empirically links the three important – but sketchily researched and formerly unlinked – concepts of lean logistics, agile logistics, and production ramp-up, therefore providing a wider and more integrated view of these constructs with, however, a greater focus on production ramp-up.

In addition, Terwiesch et al. (2001) stated that more research is needed to overcome the problem of the single-company research approach that hinders the ability of other companies with different operational environments to benefit from it. While very limited research has been conducted in multi-company settings (e.g. Langowitz, 1988; Clark and Fujimoto, 1991; Di Benedetto, 1999; Li et al., 2014), the single-company approach has been followed by the vast majority of researchers in this field (e.g. Adler and Clark, 1991; Merwe and Frizelle, 2003; Scholz-Reiter et al., 2007; Du et al., 2008; Fjällström et al., 2009). The current research collected and analysed data from different companies operating in different industrial sectors and investigated possible variations according to the differences in sector, product type, country, and other variables.

Furthermore, this research contributes to the efforts devoted to developing a measurement tool for ramp-up performance. Per se, developing and employing measurement methods of logistical leanness/agility levels and ramp-up performance are helpful in providing appropriate feedback for employees in the corresponding areas, which should be positively reflected in their performance. In an empirical study, Stansfield and Longenecker (2006) recorded an approximate 10% productivity improvement as a result of providing feedback on performance. Doltsinis et al. (2013) mentioned the role of feedback and goal-setting clarity in supporting decision making during ramp-up and, consequently, in reducing the time required.

However, instead of the traditional generic view of logistics, this research considers two streams of logistics activities linked to the significant objectives of waste elimination and flexibility, namely lean logistics and agile logistics. A logistics system with unknown or undetermined levels of flexibility and cost control is less relevant to the current business environment. Any logistics activity should be judged according to its ability to achieve certain levels of leanness and/or agility. In addition, logistics activities are classified into three categories: inbound, intra, and outbound logistics.

Furthermore, this research takes a further step forward by analysing the effect of ramp-up performance on the overall success of the product being ramped up. Such an analysis provides an additional insight regarding which ramp-up performance criterion leads to more desirable outcomes in terms of the product’s performance after introduction.

Beside the theoretical and practical contributions of this research, a methodological contribution is also made through the use of two methodological approaches, confirmatory and exploratory, in addition to the complexity of the model used, which includes mediating and moderating variables as well as the dependent and independent variables. Furthermore, the data analysis utilizes a wide variety of statistical tools to test the measurement model, the structural model, and the proposed hypotheses.

1.4. Objectives

In addition to enhancing our theoretical understanding of the production ramp-up phase, this research aims to enhance practically the phase control and outcomes by evaluating the relationship between the production performance during this phase and the key activities of lean and agile logistics, which are increasingly considered as the most influential paradigms in the logistics literature. Exploring and analysing the effect of lean and/or agile logistics on production ramp-up performance parameters could substantially affect ramp-up phase performance. This major objective and the other objectives of the current research are detailed in the following goals:

- Providing a comprehensive review of the production ramp-up literature, which is becoming increasingly necessary.
- Contributing to the available research efforts with the aim of constructing a measurement tool for ramp-up performance.
- Exploring the effect of lean logistics and its sub-variables on production ramp-up performance in terms of quantity, quality, and cost.
- Exploring the effect of agile logistics and its sub-variables on ramp-up's quantity, quality, and cost performance.
- Exploring the direct effect of the variation in ramp-up performance on new product success in terms of sales return, net profit, market share, and customer satisfaction.
- Clarifying the moderating effect of selected respondent-, organization-, and product-related variables on the strength of the relationship between lean and agile logistics on the one hand and production ramp-up performance on the other.
- Investigating the mediating role of outbound lean and agile logistics activities on the relationship between production ramp-up and new product success (since outbound logistics take place after the end of production and studying their effect on ramp-up is irrelevant).
- Proposing a model that employs lean and agile logistics during the ramp-up phase and afterwards during the steady-state production phase in a way that supports the different goals of these different phases.

- Validating the proposed model using lifecycle profitability analysis.

Forza (2002) indicated the importance of identifying the unit of analysis while forming the research questions and objectives. Flynn et al. (1990) indicated that the unit of analysis in OPM research could be individuals, groups, plants, divisions, companies, projects, systems, and so on. In the current research, the unit of analysis is the ramp-up process for a single product; this might include different divisions, time periods, and systems. Some researchers (e.g. Gross and Renner, 2010) have considered the ramp-up process as a distinctive time-limited project; therefore, the unit of analysis could be considered as the ramp-up project for a specific product. The data collection process and concluding results and findings should consider the same reference level. However, since the use of the ramp-up process as a unit of analysis comprises different divisions, activities, organizational levels, and even supply chains together, cross-level inference becomes more relevant, as explained by Babbie (1990).

Figure 1.2 provides a simplified research model that illustrates the proposed relationships between the research variables, including the direct relationships between dependent and independent variables and the moderating effect of the respondent-, organization-, and product-related variables. The research's sub-variables and the detailed research model were identified and formed based on a comprehensive literature review and are presented in figure 4.3 on page 101. The research's main and sub-hypotheses were formulated according to the proposed model of relationships (see section 5.3.1).

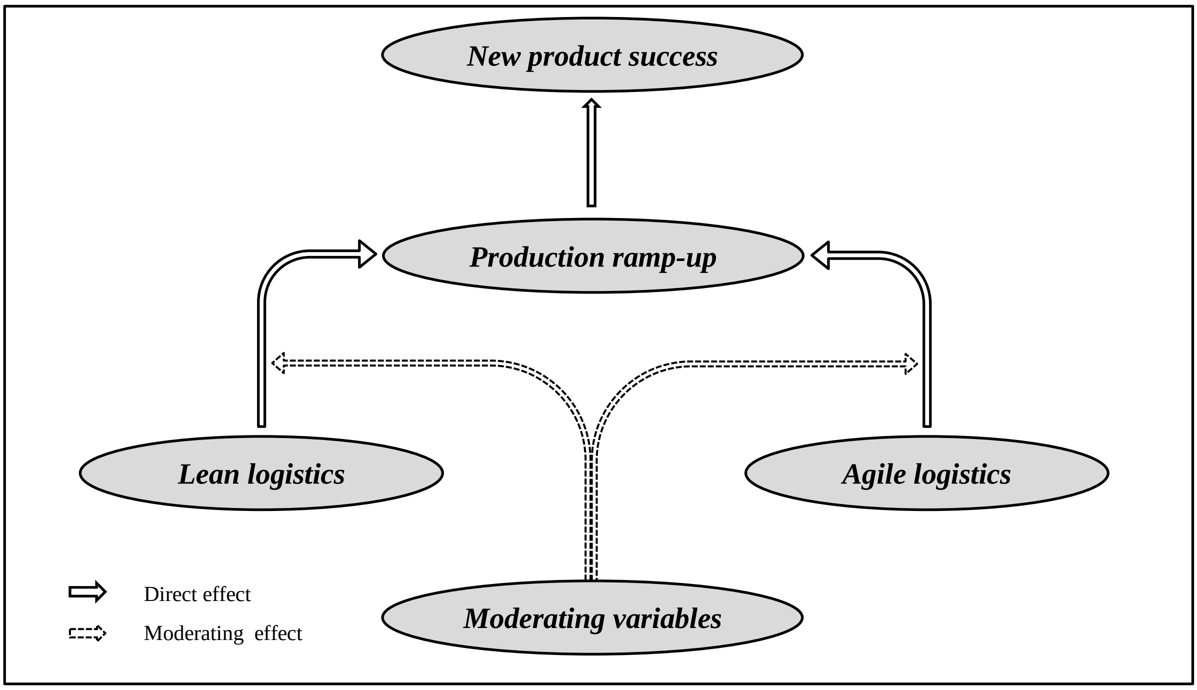


Figure 1.2: Basic structural model

Building on the results obtained from testing the hypotheses and on the examination of the strength of the relationships between variables, constructs, and single measures, a mixed production model was introduced (see chapter 6) to support higher levels of flexibility during the ramp-up phase and higher levels of cost control during the steady-state and ramp-down phases. These are achieved through the employment of different lean and/or agile logistics activities during the different production stages. The proposed preliminary model was further validated using lifecycle profitability analysis. The cumulative lifecycle profitability for the mixed production system will be compared with those of the lean system, agile system, and leagile system.

Consequently, the results of this research help to create an elementary model for a logistics system that switches between lean and agile logistics according to the requirements of the production phase, rather than combining lean and agile logistics in one system, which might produce a level of flexibility lower than that required by the ramp-up phase and a level of waste reduction lower than that required by the steady-state and ramp-down production phases. Such a strategy might maximize the overall product lifecycle profitability and success.

1.5. Positioning

To position the current research in the related body of literature, a review of the literature in the fields of production ramp-up, lean logistics, and agile logistics was carried out and a graphical illustration of the researched variables is introduced to simplify the detection of this research position within the existing literature and to explore more points of research and gaps.

Enhanced performance during production ramp-up might be accomplished through enhancing the production ramp-up activities themselves or, alternatively, through enhancing other activities that can directly affect ramp-up performance. In accordance with these two ways, two main streams of research have arisen in the literature. The first stream, which aims to enhance ramp-up performance internally, has focused on such variables as ramp-up patterns and strategies (Terwiesch and Bohn, 2001; Schuh et al., 2005a), ramp-up management and control (Nyhuis and Winkler, 2004; Lee and Matsuo, 2012), and key ramp-up success factor identification (Di Benedetto, 1999). On the other hand, the research stream that has focused rather on the variables affecting ramp-up performance has included many aspects, such as the type and source of information (Fjällström et al., 2009); product complexity, newness, and novelty (Frizelle and Gregory, 2000; Pufall et al., 2007; and Merwe and Frizelle, 2003, respectively); product change (Scholz-Reiter et al., 2007); tooling and equipment (Almgren, 2000; Haller et al., 2003); lot size (Sturm et al., 2003); work organization (Almgren, 1999b); space requirements (Ball et al., 2011); and many other factors. Section 2.3.1 provides a more detailed review of the wide range of factors affecting ramp-up performance.

Among the factors affecting ramp-up performance, logistics has frequently been mentioned; however, only a limited set of logistics variables or activities have actually been researched. Such variables include logistics facilities and the design of logistics (Pufall et al., 2007), material flow (Almgren, 2000), parts supply (Almgren, 1999a), material quality (Fjällström et al., 2009), and supplier network collaboration (Li et al., 2014).

This research investigated a wider range of logistics activities that are related to the specific practices of lean and agile logistics and divided the underlying logistics activities into inbound, intra, and outbound logistics, as shown in the detailed research model (figure 4.3, page 101). The direct effect of inbound and intra logistics activities on ramp-up performance and the mediating role of outbound logistics in the relationship between ramp-up performance and new product success were considered.

In addition to the two previously mentioned streams of research, many researchers have indicated the effect of ramp-up on other variables or outcomes, such as the learning rate (Haller et al., 2003; Ball et al., 2011), reconfiguration time (Matta et al., 2007; Niroomand et al., 2012), yields (Schuh et al., 2005a), timing of revenue (Terwiesch et al., 2001), profitability (Carrillo and Franza, 2006), cost of lost sales (Cantamessa and Valentini, 2000), and total costs (Glock et al., 2012). The current research empirically investigates the effect of production ramp-up performance on new product success in terms of sales return, net profit, market share, and customer satisfaction.

The inclusion of moderating variables in the analysis of the relationships between ramp-up and other variables is greatly lacking in the literature. Moderating variables affect the strength of the relationships between dependent and independent variables (Baron and Kenny, 1986; Krishnaswamy et al., 2009). Including respondent-, organization-, and product-related variables as moderating variables can be helpful for understanding the variation in the results from one situation to another and identifying organizations that can benefit more from the research results.

Figure 1.3 identifies the current research’s position in and contributions to the related literature. Beside those mentioned in figure 1.3, other streams of research within the ramp-up literature include conceptual frameworks aiming to enhance the understanding of this phase (e.g. Lenfle and Midler, 2009; Schmitt and Schmitt, 2013) and literature reviews (Elstner and Krause, 2013; Surbier et al., 2014).

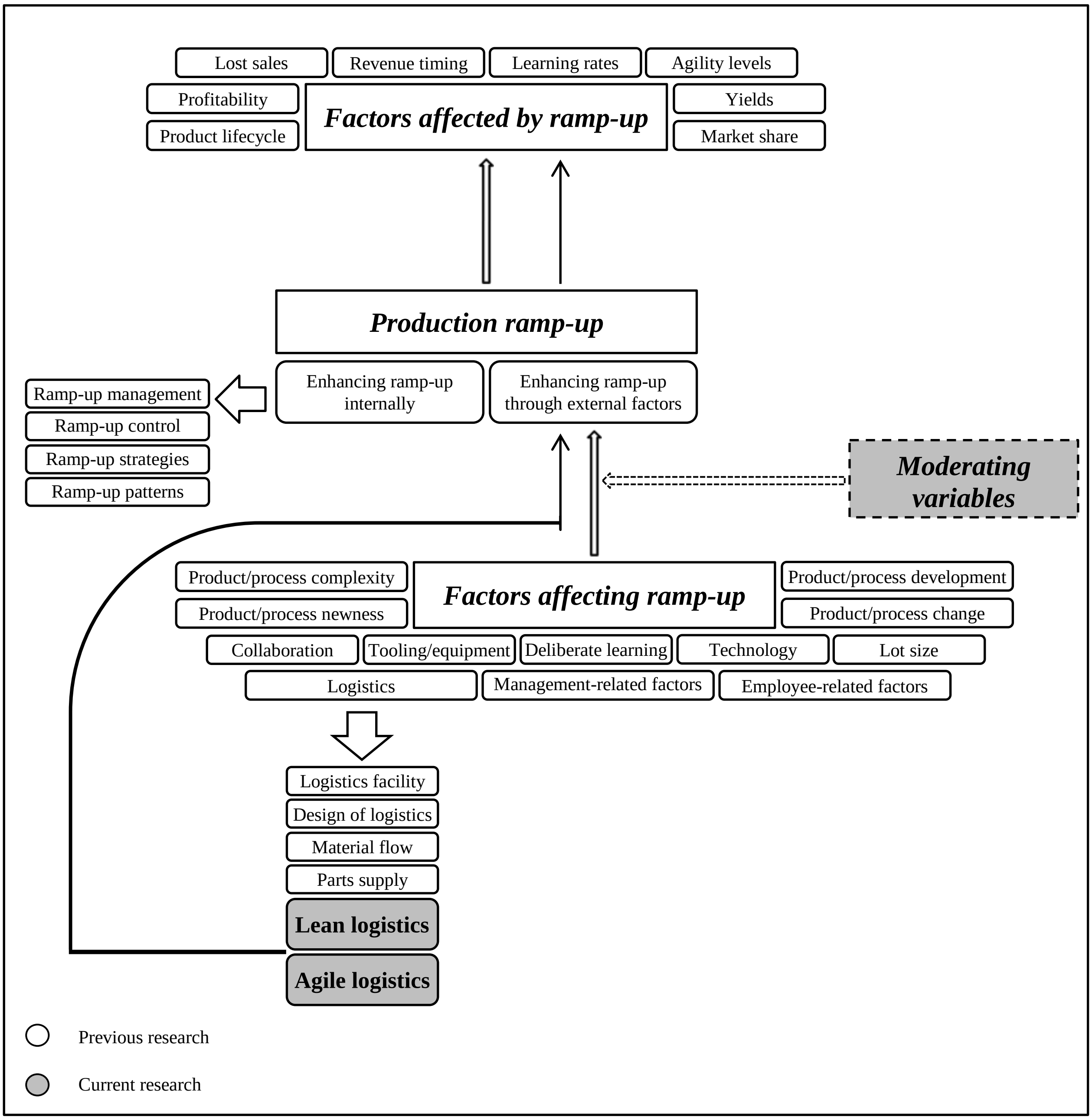


Figure 1.3: Research positioning

1.6. Methodological Approach

This empirical research followed the survey research methodology (Malhotra and Grover, 1998; Forza, 2002; Groves et al., 2009; Fowler, 2014). The importance of conducting empirical research to bridge the gap between theory and practice in the operations and production management (OPM) field was highlighted by Flynn et al. (1990), and the significance of survey research in OPM was indicated by Flynn et al. (1990) and Malhotra and Grover (1998). The starting point was to identify gaps and research points in the literature; prolonged reading in the fields of production ramp-up and logistics revealed an important gap representing the absence of any attempt in the literature to link production ramp-up to lean and/or agile logistics. Beside this gap, additional gaps could be identified as follows:

- The lack of sufficient understanding of the production ramp-up phase.
- The lack of comprehensive reviews of the ramp-up literature.
- The lack of sufficient attempts to compare and combine the lean and agile logistics paradigms.
- The absence of a model that encompasses leanness and agility in analysing the total product lifecycle performance and considers the three phases of ramp-up, steady-state, and ramp-down.
- Relatively little empirical research is available in the fields of production ramp-up, lean logistics, and agile logistics.
- The employment of both mediating and moderating variables in the ramp-up research is limited.
- Researches targeting multiple companies and considered different environments are very rare.

To investigate the role of lean and agile logistics empirically during ramp-up, a survey questionnaire was formed, based on the literature, to measure each of the research variables. Each item used in the questionnaire was supported by the literature and the entire questionnaire was tested for its validity and reliability. The next step was to use the survey questionnaire in primary data collection, then the collected data were analysed using many qualitative and quantitative statistical techniques. Both confirmative and explorative methodologies were utilized. The confirmative methodology was used to test the proposed hypotheses, based on the relational model suggested, and further explorative analyses were conducted to examine the additional potentials of the data collected.

The results of the explorative data analysis were used to develop a preliminary model to employ lean and agile logistics during and after the ramp-up phase to enhance the total product lifecycle performance. This model was tested and verified using lifecycle profitability analysis. Finally, the conclusions and recommendations were developed and the limitations mentioned. Figure 1.4 illustrates the steps followed in the research’s construction. These steps were close to the process proposed by Forza (2002). Chapter 3 elucidates the details of each step in the research methodology.

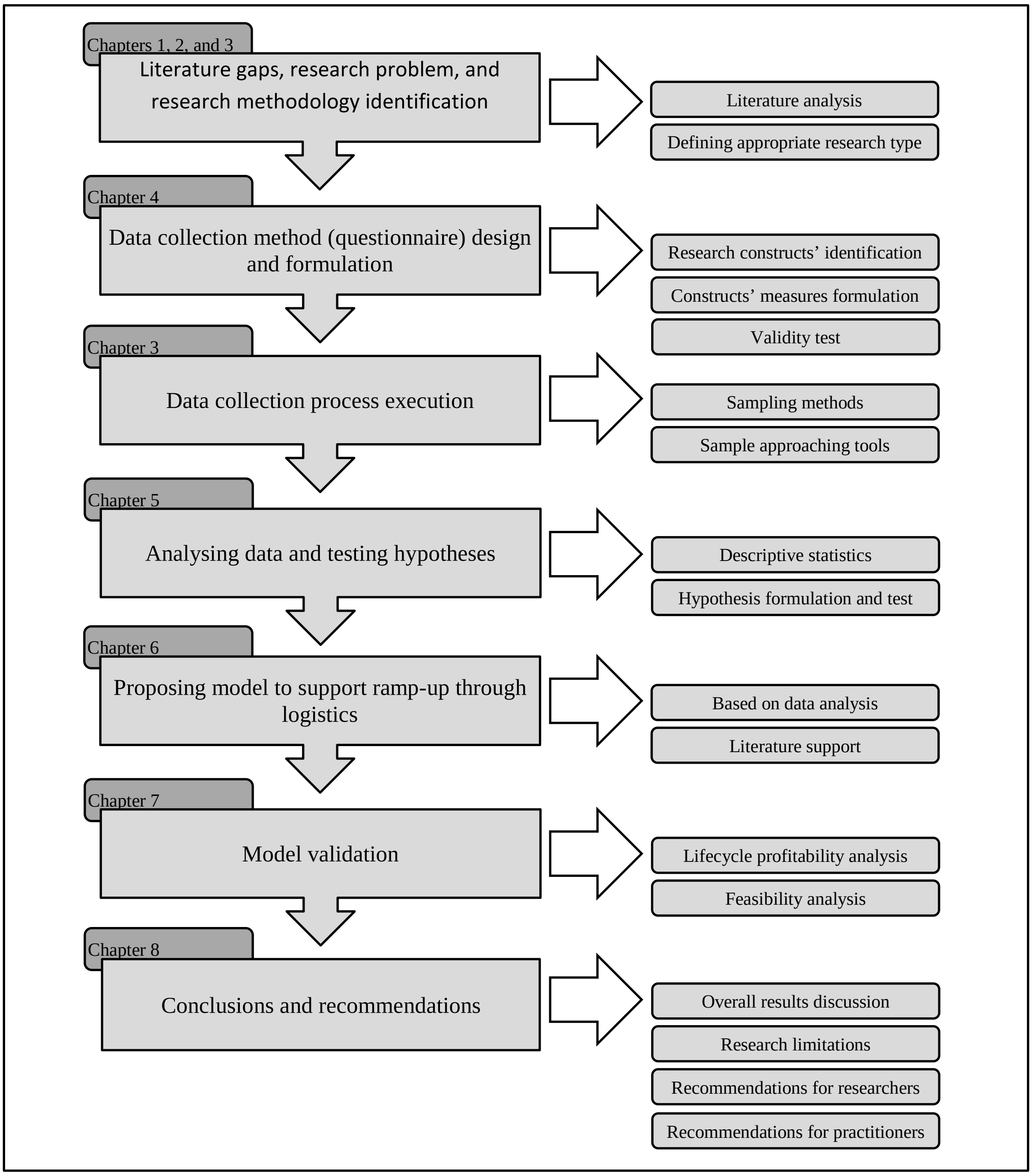


Figure 1.4: Research steps

1.7. Layout

This thesis is organized in eight chapters. After the introductory chapter, which introduces the main framework of the research, chapter 2 starts with the theoretical background, which introduces and explains the research concepts, followed by a comprehensive literature review of the field of production ramp-up – as the main research variable – and a limited review of the fields of lean logistics, agile logistics, and product success. Research investigating the interaction between different research variables is also considered. In chapter 3, the methodology of research is completely clarified, including the steps followed and the rationale behind each step. More focus was directed to the data collection tool, the data collection process, and the statistical analyses conducted. The statistical tests used to examine the quality of the measurement model, the collected data, and the data analysis are presented in this chapter.

The development of the data collection tool and the dimensions used to measure each research variable are the focus of chapter 4, which aims to show how the literature supports the use of the selected measurement tools. The results of the statistical analysis are presented in chapter 5, including descriptive statistics, correlations between research variables, and testing of the main and subsidiary hypotheses. Different scenarios are used and compared according to certain statistical parameters.

Chapter 6 provides a model based on the results of the hypothesis testing and further statistical analysis, aiming to utilize different lean and agile logistics tools considering the ramp-up phase's special environment. A mixed production model with greater agility during ramp-up and greater leanness thereafter is introduced, and the tools required to apply such a model are discussed, with a special focus on the idea of investing in a specialized agile ramp-up facility.

This model is further tested and validated using profitability analysis over the entire product lifecycle in chapter 7. Additionally, different strategies are compared according to their overall lifecycle profitability. In chapter 8, the research results are discussed and compared with the existing literature; in addition, the concluding limitations and recommendations for researchers and practitioners are presented.

CHAPTER 2

BACKGROUND AND LITERATURE

2.1. Introduction

This chapter is divided into two main sections. The first section introduces the main research variables, namely production ramp-up, lean logistics, and agile logistics. The second section provides a review of the related literature that considers the ramp-up process, lean logistics, and agile logistics and the attempts to link the research variables together. In both sections, more attention is devoted to production ramp-up as the main research variable due to the lack of sufficient understanding and research efforts in this field, as noted by most researchers in the field.

2.2. Theoretical Background

This section aims to help readers from different backgrounds to become more familiar with the terms and concepts used throughout this research. This, in turn, helps to reduce the misunderstandings, misconceptions, and probable confusion caused by the multifaceted nature of the fields researched. In addition, a concrete theoretical background helps to make the research – to some extent – more self-contained. This research draws on three strands of research, as it considers the role of *lean logistics* and *agile logistics* during *production ramp-*

up. Ramp-up is primarily the dependent variable. However, the effect of ramp-up performance (here as an independent variable) on product success is also considered. While the effect of ramp-up performance on new product success is measured, developing a theoretical background or a literature review for the dimensions of product success is beyond the scope of this research.

2.2.1. Production Ramp-Up

In any factory, every new product introduced must undergo a ramp-up process (Terwiesch and Bohn, 2001). However, production ramp-up is not restricted to new products. Modified products (Gross and Renner, 2010; Doltsinis et al., 2014), new production processes (Terwiesch and Xu, 2004), new manufacturing facilities (Terwiesch and Bohn, 2001; Simon et al., 2008; Willmann et al., 2014), new production lines (Terwiesch et al., 2001), new production technology (Salomon and Martin, 2008; Gross and Renner, 2010), the reintroduction of old products (Chatzimichali and Tourassis, 2008), or even a sudden increase in the demand for an existing product require a ramp-up process. In general, the concept of production ramp-up implies a steep increase in the production curve followed by a relatively stable production phase called the stead-state production phase (see figure 2.1).

Wheelwright and Clark (1992) elucidated the start of commercial production at relatively low levels of volume and the increase in these levels as the manufacturer develops confidence in its manufacturing (as well as its suppliers') abilities. During the ramp-up phase, production builds up its output levels to the targeted quantities (Woodcock et al., 2000) and reaches a steady-state or serial production (Abernathy and Baloff, 1973).

Terminology and Chronology

The literature has provided several definitions of production ramp-up. In general, authors have agreed on the inclusion of the sharp increase in production rates in the ramp-up phase. However, they have disagreed about its chronological limits (Ball et al., 2011). The definition of the ramp-up phase is frequently linked to its temporal boundaries, the phase into which it should be categorized, and the outcomes that should be achieved by its end. Researchers have presented different arguments regarding all the variables related to the definition of the ramp-up phase, including the starting point, the ending point, the categorization, and the outcomes.

The current research considers a similar approach by adopting the definition of ramp-up as the production phase starting with the preparations to produce the first lot intended for sale and ending with the attainment of the targeted stable production level. This definition excludes pilot production and steady-state production from being part of the ramp-up phase.

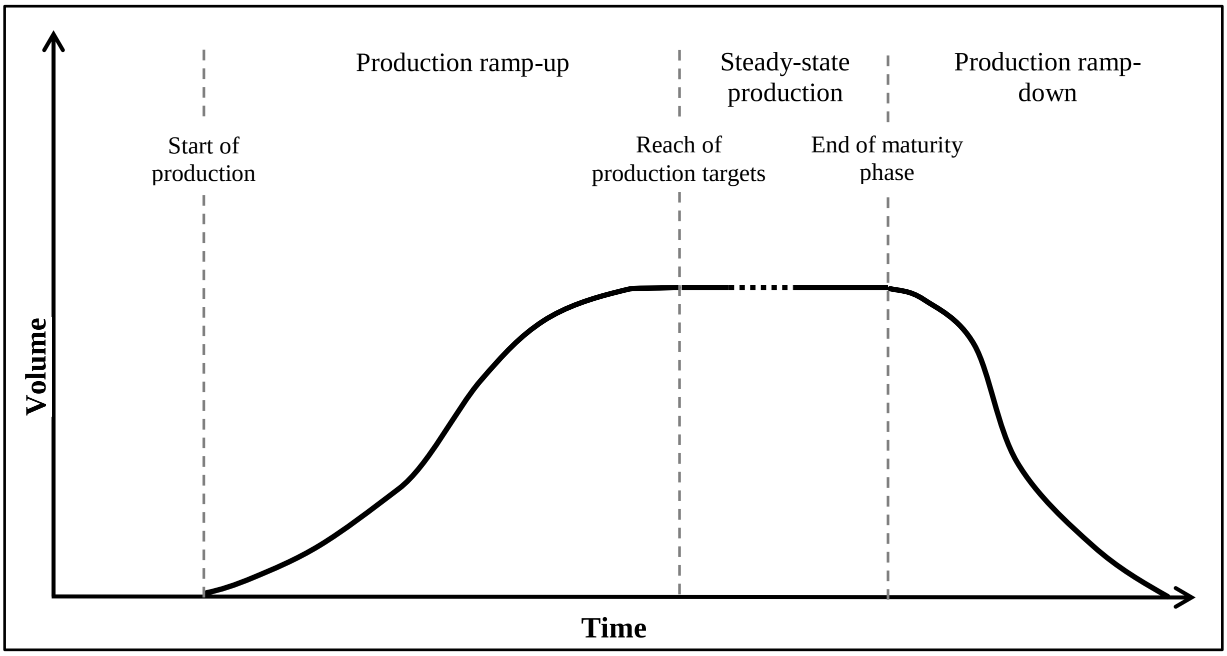


Figure 2.1: Simplified illustration of the ramp-up phase

Some researchers have followed different alternatives to define production ramp-up. Doltsinis et al. (2013) defined ramp-up in terms of a sequence of adaptations and adjustments applied to a production system in which: (1) each adjustment changes the system's condition; (2) the system remains stable between adjustments; and (3) a short time period elapses between one adjustment and another. Gustmann et al. (1989) referred to ramp-up as the process of integrating innovation and industrial production. Concentrating on the auto industry, Gross and Renner (2010) stated that the ramp-up phase includes all the developing and improving activities taking place after product development or product modification. Different arguments on the ramp-up phase's start, end, expected outcomes, time (time-to-volume) consideration, categorization, and alternative concepts are explained in the following sections.

Ramp-Up Phase's Start, End, and Outcomes

Many different points have been mentioned by different researchers as the start of the ramp-up phase, including the completion of the new product development process (Bohn and Terwiesch, 1999); the end of the designing and building of the production system (Doltsinis et al., 2013); the end of the prototyping phase (Sturm et al., 2003); the release of pilot production (Buescher et al., 2012); the zero production point (Terwiesch et al., 2001); low-level production (Ball et al., 2011); the start of production, the first item produced, or the first lot produced (Fjällström et al., 2009; Simon et al., 2008; Haller et al., 2003, respectively); small laboratory-like production (Terwiesch and Xu, 2004); the reconfiguration of the manufacturing system (Koren et al., 1999; Matta et al., 2008); and the start of commercial production (Surbier et al., 2014). In addition to the actual execution of ramp-up activities, Romberg and Haas (2005) considered the ramp-up planning process and stated that it might start as early as the beginning of a new product development process, since the ramp-up planning needs to take place long before the actual production starts.

Similarly, the ending point of the ramp-up phase has been reported differently as reaching full capacity utilization (Terwiesch and Bohn, 2001), full operation (Doltsinis et al., 2013), peak production (Schmitt and Schmitt, 2013), high-volume production (Terwiesch and Xu, 2004), full-volume production (Sturm et al., 2003), production maturity (Surbier et al., 2014), a steady-state output rate (Simon et al., 2008), the initial production targets (Fjällström et al., 2009), or the required production rate (Ball et al., 2011).

By the end of the ramp-up phase and the reaching of the targeted volume, the production system should be at or near the targeted levels of cost and quality (Terwiesch et al., 2001; Säfsten et al., 2006), meet the predetermined production lead time (Juerging and Milling, 2006), achieve the targeted operational characteristics (Doltsinis et al., 2013), and reach the targeted levels of yields (Säfsten et al., 2006). Additionally, Almgren (1999a) elucidated that by reaching the steady-state production phase: (1) the output rate is uniform, (2) the workforce is stabilized, (3) knowledge and skills are developed, (4) machines and equipment are debugged, and (5) support systems are fine-tuned. However, the end of the ramp-up process does not necessarily imply the achievement of all these targets. Clark and Fujimoto (1991) showed, with a practical example from the auto industry, that achieving the targeted quality might take more or less time than needed to achieve the targeted volume of production. In addition, Salomon and Martin (2008) mentioned the dynamic nature of yields and indicated that yields may take a long time, after achieving the targeted capacity, to improve.

Time-to-Volume

While the duration of the development time is labelled as time-to-market (Terwiesch et al., 2001), the duration of the ramp-up phase is frequently labelled as time-to-volume (Sturm et al., 2003). However, some researchers (e.g. Juerging and Milling, 2005) have indicated that the ramp-up time equals the difference between time-to-market and time-to-volume. Figure 2.2 illustrates the ranges of time-to-market, time-to-volume, and ramp-up time. However, Matta et al. (2007, 2008) considered time-to-volume as encompassing both time-to-market and ramp-up; hence, the ramp-up duration is only part of time-to-volume. Salomon and Martin (2008) used the term time-to-build to describe the time required to build and ramp up production at a new facility and, hence, considered ramp-up time (or time-to-volume) as part of the time-to-build in new facilities.

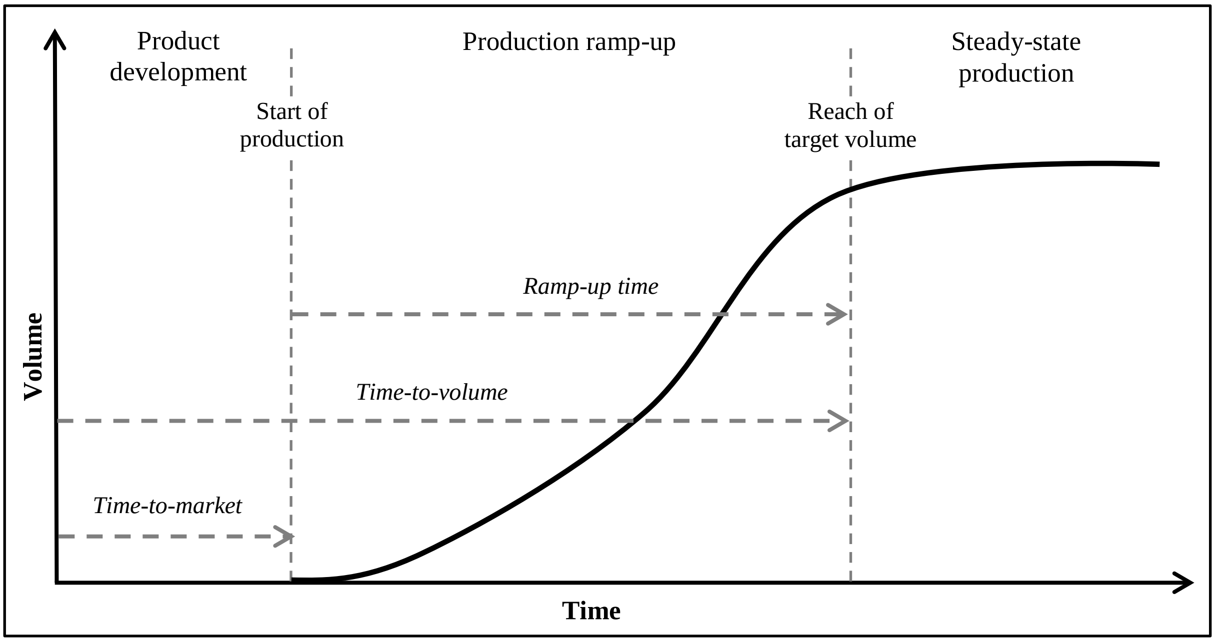


Figure 2.2: Time-to-market and time-to-volume

Ramp-Up Phase Categorization

The ramp-up literature includes three main directions in which to categorize production ramp-up: the first direction is to consider ramp-up as a separate stage that takes place between product development and steady-state production (e.g. Bohn and Terwiesch, 1999; Terwiesch and Bohn, 2001; Du et al., 2008; Lenfle and Midler, 2009), the second direction is to consider ramp-up as part of the new product development process (e.g. Woodcock et al., 2000; Surbier et al., 2010), and the third direction followed in the literature is to consider ramp-up as part of the commercial production stage (e.g. Juerging and Millin, 2006; Fjällström et al., 2009).

Alternatively, in some articles, the ramp-up phase has rather been considered as the interface between the development and the commercial production phase (e.g. Riedel, 2000; Scholz-Reiter et al., 2007). Scholz-Reiter et al. (2007) indicated that the ramp-up phase is not an accepted part of either the development process or the production process; rather, it is a transition phase that takes place at the beginning of the product lifecycle, and ramp-up process activities are included in the development and manufacturing processes (see figure 2.3).

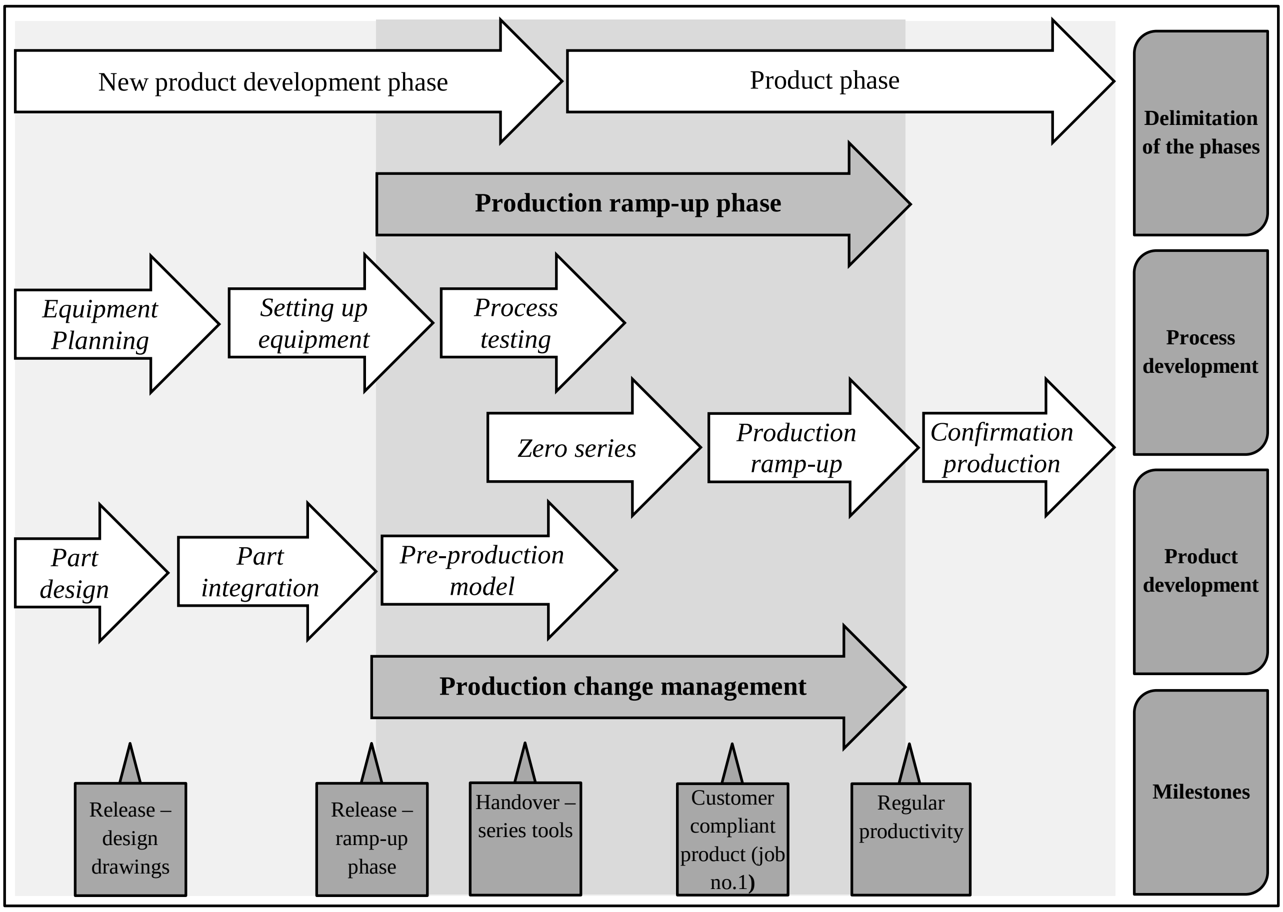


Figure 2.3: Ramp-up phase as illustrated by Scholz-Reiter et al. (2007)

Concerning research that has considered ramp-up as a separate phase, instead of referring to the entire time period between the end of development and the achievement of full capacity utilization as the production ramp-up phase, Almgren (2000) considered ramp-up as one of the different components of this phase, which was referred to as the ‘final verification phase’. According to Almgren (1999c) and Almgren (2000), the final verification phase includes pilot production and production starts-up. The latter is further divided into low-volume and high-volume or ramp-up phases. In this classification, the concept of ramp-up refers to the sharp rise in the production volume during the unit of time in relation to a target. Alternatively, Lenfle and Midler (2009) considered ramp-up and the commercial launch of a new product as two different processes, together composing the product launch phase. Winkler et al. (2007) stated that the development phase ends with the approval for production ramp-up and proposed an initial classification of the development, production ramp-up, and production phases.

Considering the second direction, in which many researchers have attempted to mention production ramp-up as part of the development phase (e.g. Fujimoto, 1989; Clark and Fujimoto, 1991; Cooper, 1993b; Krishnan and Ulrich, 2001), Fujimoto (1989) inserted pilot production and manufacturing start-up into the rubric of manufacturing engineering. Clark and Fujimoto (1991) attempted to consider pilot production and production start-up as the final steps in the new product development process. Cooper (1993b) indicated that new product development consists of four stages: (1) concept and development, (2) product planning, (3) product and process engineering, and (4) pilot production and ramp-up. Krishnan and Ulrich (2001) included production ramp-up and product launch within the same phase when they divided the product development project decisions into four categories: concept development, supply chain design, product design, and production ramp-up and launch. Furthermore, Surbier et al. (2014) indicated that the ramp-up issue stems from the new product development literature and defined the ramp-up phase as the last step of the new product development process.

On the other hand, regarding the third direction, which refers to ramp-up as an inseparable part of the commercial production phase, Juerging and Milling (2006) considered production ramp-up as part of series production and including only the stage of a steep increase in the production curve. The authors referred to the starting process with a flatter shape of the production curve as production start-up. Furthermore, Fjällström et al. (2009) considered production ramp-up as the initial period of commercial production that takes place after finishing the product development phase.

Regardless of the categorization approach, Doltsinis et al. (2013) mentioned the dearth of such a clear separation between the phases in the real world. Figure 2.4 illustrates the product lifecycle stages and shows the different spans of ramp-up activities according to the different studies in the literature.

The division of the production lifecycle into different stages should be based on the characteristics of each stage. Therefore, the classification of production ramp-up within a certain stage should be consistent with the agreed-upon characteristics of the ramp-up process (see page 26). The existence of many specific characteristics of production ramp-up supports the attempt to classify ramp-up as a separate stage. In addition, while the units produced during ramp-up are intended for sale, the units produced during pilot production are not. Furthermore, while considering ramp-up as part of the development process, the sketchy analysis of ramp-up in Wheelwright and Clark (1992) and Ulrich and Eppinger (2008) compared with other product development stages (this was mentioned by Surbier, 2010 and

Surbier et al., 2014) supports the argument to consider ramp-up as a separate stage rather than as part of the development process.

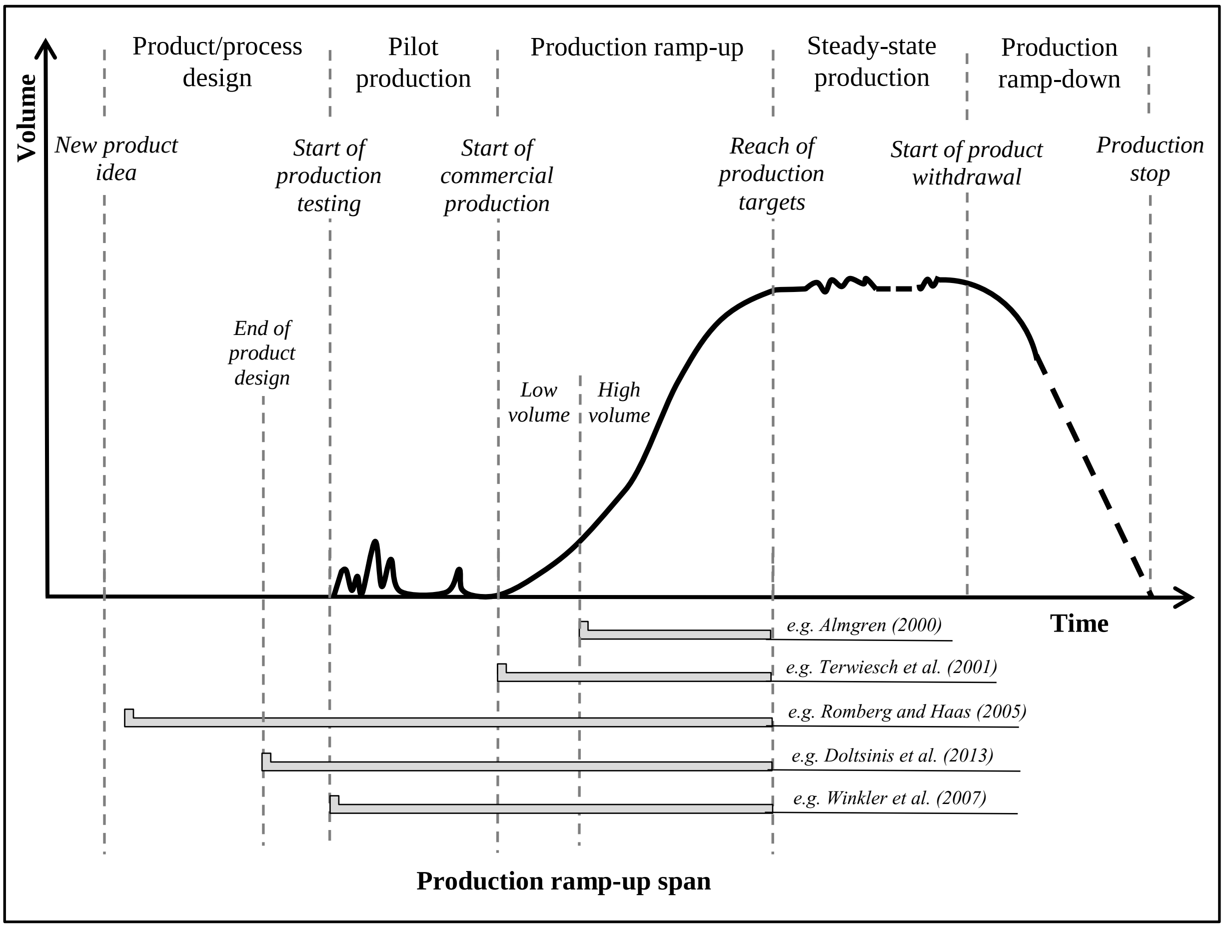


Figure 2.4: Stages of development and production and ramp-up span

Ramp-Up Phase Classification

Winkler et al. (2007) indicated that a generally accepted classification of the ramp-up phase does not exist. Similarly, Schmitt and Schmitt (2013) stated that the stages of the production ramp-up are not described consistently in the literature. However, few attempts to classify production ramp-up can be found in the literature. Winkler et al. (2007) proposed a division of the ramp-up phase into the two stages of preparation and run-up. The preparation phase is further divided into the phases of start-up and pilot production. Lee and Matsuo (2012) mentioned that the ramp-up process usually consists of two phases; while in the first phase frequent experimental batches are interspersed with regular production batches, few such experimental batches are run in the second phase. Basse et al. (2014b) stated that ramp-up encompasses three different phases: pre try-out serial, try-out serial, and serial production start-up.

Doltsinis et al. (2013) proposed a three-stage division of the ramp-up phase. The focus of the first ramp-up stage is on the functionality of the process, the focus of the second stage is on the output quality, and the focus of the third stage is on performance optimization. Scholz-Reiter et al. (2007) described the components or processes involved during the ramp-up period of the manufacturing process. The authors stated that three chronological processes encompass the ramp-up process: testing, pre- and zero-series production (producing the product for the first time), and production ramp-up. Further details of the testing process were mentioned by the authors, indicating the sub-processes of development, production facility planning and construction, and production planning.

Alternative Concepts

In addition to different definitions of ramp-up, different labels have been used in the literature to study this production phase. Beside production ramp-up (e.g. Schuh et al., 2005b; Surbier et al., 2009; Stauder et al., 2014) and product ramp-up (e.g. Pufall et al., 2007; Willmann et al., 2013; Willmann et al., 2014), the following labels can be found in the literature: initial commercial manufacturing (e.g. Langowitz, 1988), manufacturing start-up (e.g. Baloff, 1966; Abernathy and Baloff, 1973; Clawson, 1985; Almgren, 2000), manufacturing scale-up (Meyer, 2007), product launch (e.g. Di Benedetto, 1999; Cantamessa and Valentini, 2000), product transfer (Terwiesch et al., 2001), and industrialization (Bassetto et al., 2011). Slamanig and Winkler (2012) used the term ‘product change’ and stated that product change combines the phasing out and ramping up of two consecutive product generations. Nevertheless, studies using the rubric of production ramp-up are more numerous, more detailed, and more popular.

Terwiesch et al. (2001) distinguished between ramp-up and start-up by connecting ramp-up to the production of new products and start-up to the production process in new production lines and new factories. Terwiesch and Bohn (2001) indicated the case of ramping up production using a new process or a new plant. The authors clarified the additional difficulties and challenges in such a situation, due to the need to learn about many traditional variables, which might be much more obvious in an already-existing process or facility. Ball et al. (2011) stated that in spite of using the terms ramp-up and start-up interchangeably in some cases, start-up should be used to represent the whole phase of output rate increase, while ramp-up represents the phase of a steep rise in the output rate. Ball et al. (2011) further detailed that sometimes the earlier part of start-up is very short so that the two terms coincide.

Some researchers, however, have considered ramp-up and start-up as the same concept. For example, Juerging and Milling referred to the time span that represents the difference between time-to-market and time-to-volume as production ramp-up in Juerging and Milling (2005) and as production start-up in Juerging and Milling (2006). Haller et al. (2003) differentiated between ramp-up and the ‘initial ramp-up’ and stated that, while ramp-up reoccurs with each new product and product generation during the lifecycle of a factory, the initial ramp-up – which takes place at the start of the factory lifecycle – remains the most difficult and challenging. Witt (2006) considered ramp-up as a phase (the production phase) among the four phases composing the product launch process.

Characteristics of the Ramp-Up Phase

Many features that characterize the ramp-up period can be directly connected to performance indicators, such as production volume, product quality, yields, time, and costs. The production volume and total production time are functions of the cycle time, which is typically reduced in a constant manner over time during the ramping up of the production (Abernathy and Baloff, 1973; Sturm et al., 2003). However, this contributes to the difficulty of output rate prediction (Sturm et al., 2003). Constant cycle time reduction, along with other factors, leads to increased production rates. In a study conducted in the steel industry, Baloff (1966) indicated that the steady-state production rate was around ten times more than the first month’s average production rate.

In addition to the production volume, Matta et al. (2007) indicated an increased rate of product quality. While the existence of low but continuously increasing yields was mentioned by Salomon and Martin (2008) and Hatch and Mowery (1998), respectively, other features related to the manufacturing performance include sensitivity to time and cost (Bischoff, 2007), cost intensity (Winkler et al., 2007), a reduction in the unit production cost (Glock et al., 2012), instable production processes (Fleischer et al., 2003), and constrained capacity (Bohn and Terwiesch, 1999).

Other characteristics of the ramp-up phase are related to the nature of the phase. This nature is frequently characterized by the originality of the product, the uninhabited production process, and the limited employee experience. The ramp-up characteristics resulting from this nature include: complexity (Schuh et al., 2005a; Doltsinis et al., 2013); dynamics (Juerging and Milling, 2006); variability (Haller et al., 2003; Sturm et al., 2003; Pufall et al., 2007); instability (Basse et al., 2014a); uncertainty (Haller et al., 2003; Sturm et al., 2003); being non-recurring, non-repetitive, and unique (Gross and Renner, 2010; Doltsinis et al., 2013);

fuzzy states of information (Scholz-Reiter et al., 2007); interdependencies of processes executed in parallel (Juerging and Milling, 2006); and interdisciplinarity (von Cube and Schmitt, 2014). Almgren (1999a) indicated that the complexity during ramp-up increases even more when new technology is introduced into the production process. Winkler and Slamanig (2011) mentioned greater complexity and more ramp-up challenges when multi-variant serial production exists. Pufall et al. (2007) stated that greater complexity is experienced when more facilities, and more supply chains, are engaged. Furthermore, Leitão et al. (2013) indicated higher levels of uncertainty and instability in ramping up complicated and highly customized products.

In general, production ramp-up is a phase of continuous change and high process variability. Equipment capacity, yields, rework, work-in-process, dispatch policies, and other production parameters are subject to considerable change during ramp-up (Sturm et al., 2003). On the technical side, Haller et al. (2003) stated that, during ramp-up, the production line is characterized by being highly unbalanced, and variation in the utilization rate among different steps usually appears. Furthermore, Doltsinis et al. (2013) stated that production ramp-up is characterized by trial and error decision making, which, in turn, results in frequent reiterations and unnecessary repetition.

Initiatives to improve the production process and the installation of new tools, equipment, and technology in addition to extensive engineering experiments, more measurement, more analysis, and even more production stops are all sources of variation during ramp-up (Haller et al., 2003). Such variation in production makes the ramp-up process more difficult to plan and structure in advance (Doltsinis et al., 2013).

While some of the features characterizing the ramp-up phase are considered to be – to some extent – controllable, such as those related to cost, quality level, and yields, many other features are not – or are less – controllable, such as time pressure (Gross and Renner, 2010), which is produced mainly by the customer demand levels.

Problems and Challenges during Ramp-Up

Unlike the steady-state production phase, during which the production lines are balanced, the flows of hardware and paperwork are smooth, and no major changes in product design are assumed (Clawson, 1985), the ramp-up phase is complicated by many factors that cause more frequent production problems and a more complicated managerial decision-making process. The production challenges combined with the previously mentioned characteristics of the ramp-up phase might produce production problems, such as machine breakdowns (Terwiesch and Bohn, 2001; Haller et al., 2003), process stops (Haller et al., 2003), a long setup time (Terwiesch and Bohn, 2001), mismatch between the new product characteristics and the production process (Langowitz, 1988), and more frequent production disturbances (Almgren, 1999b).

In addition, engineering changes are critical issue that interrupt ramp-up and hinder efforts to reduce the time that it takes (Ball et al., 2011). These changes aim to align the product design with the production process to guarantee the manufacturability of new products (Chatzimichali and Tourassis, 2008). Ball et al. (2011) indicated that the majority of engineering changes are made during production ramp-up. More engineering changes lead to a lower production yield, more scrap, and more delays (Li et al., 2014). In general, production problems during ramping up processes include more and greater delays (Winkler et al., 2007; Doltsinis et al., 2013), higher requirements and special operations to correct wrong processes or output products (Terwiesch and Bohn, 2001), and the generation of more quality issues (Winkler et al., 2007).

Other problems mentioned in the literature include less accurate capacity forecasting (Haller et al., 2003), less than optimal decisions (Doltsinis et al., 2013), poor cooperation and information exchange (Surbier et al., 2009), miscommunication between employees from different disciplines (Scholz-Reiter et al., 2007), and supply delay and material quality problems (Langowitz, 1988; Terwiesch et al., 2001).

Schmitt and Schmitt (2013) indicated that most ramp-up problems are not solved. Pufall et al. (2007) also mentioned that the planned targets for production volume, cost, and quality are frequently not achieved. The research conducted by Schuh et al. (2005c) in the auto industry showed that around 47% of ramp-ups were neither technically nor economically successful. Also concerning the auto industry, Straube and Fitzek (2004) stated that 60% of all ramp-ups conducted by European manufacturers missed their technological and/or economic goals. Furthermore, in the study conducted by Kuhn et al. (2002), the authors mentioned that not even a single company claimed that the ramp-up process was under control.

The sources of ramp-up problems have frequently been discussed in the literature; such problems include a poor understanding of the production process during ramp-up (Terwiesch and Bohn, 2001; Doltsinis et al., 2013), many of the produced items or designed systems not working properly the first time (Terwiesch and Bohn, 2001), the process frequently being driven by trial and error rather than an overall systematic strategy (Doltsinis et al., 2013), fast transfer from research to commercial production (Zangwill and Kantor, 1998), immaturity of production lines (Nyhuis and Winkler, 2004), and time pressure (Gross and Renner, 2010). Both Terwiesch and Bohn (2001) and Haller et al. (2003) agreed that ramping up production in a new facility is more difficult, more complicated, and more challenging.

Additional sources of ramp-up problems include the two conflicting factors that usually appear during production ramp-up: the high customer demand caused by the newness of the product and the low production levels (Terwiesch and Bohn, 2001; Terwiesch et al., 2001). The conflict between high demand and low production causes well-known two-sided pressure called the nutcracker effect (Mclvor et al., 1997).

Importance of Enhancing Ramp-Up Performance

Most often, the importance of enhancing ramp-up performance is linked in the literature to the reduction of ramp-up time. An agreement on the importance of reducing ramp-up time and increasing yields and production rates as rapidly as possible exists among researchers (e.g. Almgren, 1999b; Terwiesch and Bohn, 2001; Doltsinis et al., 2013; Li et al., 2014) and industrial managers (Almgren, 1999a). Quick volume ramp-up is important for many reasons (Pisano and Wheelwright, 1995). Quick ramp-up enhances the financial indicators and affects the financial success of a product (Haller et al., 2003). For instance, quicker ramp-up leads to higher returns (Terwiesch et al., 2001; Haller et al., 2003), higher net present value (Ball et al., 2011), maximized profits (Doltsinis et al., 2013), shorter time-to-revenue (Li et al., 2014), less investment payback time (Ball et al., 2011), lower lost sales costs (Schuh et al., 2005a), and lower opportunity costs (Ball et al., 2011). Additionally, the timing of the sales return depends highly on the length of the ramp-up period (Terwiesch et al., 2001). Furthermore, a delay in ramp-up might lead to substantial damage claims by customers (Elstner and Krause, 2014).

Beside the financial aspects, Pisano and Wheelwright (1995) illustrated that rapid ramp-up leads to faster market penetration, broader market acceptance, an earlier start in accumulating experience with high-volume production, and quicker freeing up of resources to support other development projects. Furthermore, rapid ramp-up is a source of competitive advantage (Almgren, 2000; Glock et al., 2012) and maintaining a leading market position (Li et al., 2014). In addition, the market value of the firm will be significantly affected if the announced launch dates are not met (Hendricks and Singhal, 1997), exerting additional pressure on production to cut the ramp-up time.

The importance of ramp-up time reduction might also be promoted by certain cases, such as when the season is approaching in the case of seasonal products (Li et al., 2014), when the differentiation level of a product is low (Hatch and Mowery, 1998), when the competition is strong (Ball et al., 2011), when the demand is high (Adler and Clark, 1991), when the product price falls quickly (Terwiesch et al., 2001; Haller et al., 2003), and when the lifecycle becomes shorter (Winkler et al., 2007).

In many sectors, such as electronics, the ramp-up phase itself might account for a considerable proportion of the rapidly decreasing product lifecycle (Sturm et al., 2003). In some cases, the entire product lifecycle might come to end before the full ramp-up has been achieved. Haller et al. (2003) stated that in the wafer fabrication industry the full ramp-up of a new product requires up to two years. However, Sturm et al. (2003) stated that the lifecycle for such a product lasts for less than two years. According to Terwiesch and Bohn (2001), the ramp-up phase might last for a quarter of the product lifecycle in the case of a hard disk drive. Many other authors (e.g., House and Price, 1991; Matta et al., 2007; Gross and Renner, 2010) have mentioned that the ramp-up phase constitutes a significant fraction of the total lifecycle of a product, which renders it an essential component of the sales period.

Effective production ramp-up is vital for the success of new product introduction. Frequently developing new products is considered as a key factor of leading companies' success (Clark and Fujimoto, 1991; Carrillo and Franza, 2006). Many authors have demonstrated the importance of introducing new products for any manufacturer. Ball et al. (2011) stated that the quick introduction of new products is positively reflected in the performance of a company. Terwiesch and Bohn (2001) showed that high-tech products' launches are often either delayed or scaled back because of ramp-up problems. In addition, the late introduction of new products affects a company's ability to maintain its market share (Niroomand et al., 2014). Furthermore, Scholz-Reiter et al. (2007) claimed that the ramp-up phase plays an important role in the overall business success.

The overlap between time-to-market and time-to-volume represents another point of significance for the ramp-up phase. Since the products produced during the pilot production phase are not intended for sale, the initial lots produced during production ramp-up are the first ones introduced to the market; hence, it is not only time-to-volume that depends on the pace of the ramping up of the new product but also time-to-market. Strubelt and Zadek (2010) indicated that ramp-up management aims to reduce both time-to-market and time-to-volume. Scholz-Reiter et al. (2007) indicated that the management of technical product changes taking place during ramp-up ultimately affects time-to-market.

Ramp-Up and Learning

Learning is one of the highly relevant fields that has frequently been mentioned in the ramp-up literature (Almgren, 2000; Terwiesch and Bohn, 2001; Haller et al., 2003; Ball et al., 2011). Terwiesch and Xu (2004) referred to learning during the ramp-up phase as the process of reducing the discrepancies between the way in which the process is specified in the process recipe and the way in which it is actually performed. Zangwill and Kantor (1998) referred to this learning process as waste reduction. Ball et al. (2011) conveyed an agreement through the literature on the existence of a strong correlation between ramp-up and learning curves. The strength of the relationship between ramp-up and learning led Pegels (1976) to deal with the start-up curve and the learning curve as the same thing. Almgren (1999a) stated that the increase in manufacturing performance during start-up is frequently represented in terms of learning curves. Abernathy and Baloff (1973) stated that, in producing a new product, productivity increases significantly as employees gain familiarity with the new product and process. Similarly, Glock et al. (2012) considered the ramp-up phase as a result of learning.

Researchers have continued to explain the learning effect during ramp-up. Terwiesch et al. (2001) mentioned that with the learning process that takes place over time, the yields and capacity utilization increase. Lenfle and Midler (2009) emphasized the effect of worker learning on enhancing the ramp-up efficiency, and Juerging and Milling (2006) added that efficiency enhancement during start-up is mostly based on learning effects that take place on the individual, group, and organizational levels. Other learning effects include better equipment utilization, more quality improvement, and fewer labour requirements (Glock et al., 2012).

The effect of learning, however, might have another side. Terwiesch and Bohn (2001) mentioned some drawbacks to learning (represented in experiments) during ramp-up, including the consumption of capacity that should be used for regular production and increased deviation from the optimal process control, which, in turn, reduces yields. This effect necessitates a kind of balance or trade-off between experiments and production.

Beside the effect of learning on ramp-up performance, researchers have indicated the opposite-direction effect of ramp-up on the learning process. While Carrillo and Gaimon (2000) mentioned that change in the production process will reduce the production capacity in the short term, Terwiesch and Xu (2004) claimed that change affects the learning process itself and therefore should be delayed until an acceptable level of knowledge has been accumulated. Terwiesch and Bohn (2001) indicated that learning might be driven by volume or even by time, and they indicated the role of management in the learning process during ramp-up. Similarly, Almgren (1999a) stated that the output rate is used to measure the experience levels. Considering the effect of the output rate on learning, Ball et al. (2011) concluded that low-volume products involve slower learning than high-volume products.

While Haller et al. (2003) indicated that a shorter cycle time leads to a shorter learning cycle, which ultimately affects the learning process positively, Ball et al. (2011) stated that learning increases as the ramp-up time duration increases. A shorter cycle time duration will definitely reduce the total ramp-up time; hence, a trade-off between the promising benefits of the duration of the learning cycle and the frequency of these cycles might be helpful, taking into account the opportunity cost of learning as a whole. This opportunity cost was mentioned by Terwiesch and Bohn (2001).

Lenfle and Midler (2009) stressed the importance of the ramp-up phase for learning and referred to it as a ‘key learning opportunity’. However, Chatzimichali and Tourassis (2008) stated that in the case of new products, learning becomes more complex, unlike mature products that have been reintroduced into the production line several times and for which the difficulties of the ramp-up phase have already been overcome and the forecasting of future quality using the learning curve is easier.

The consideration of different types of learning has been another point of interest in the ramp-up literature. Pisano (1997) differentiated between learning by doing and learning before doing in field research in the pharmaceutical industry; Terwiesch and Xu (2004) illustrated that learning before doing takes place prior to the commercial production phase. Alternatively, Terwiesch and Bohn (2001) differentiated between induced learning (such as experimentation) and autonomous learning – that is, production experience. Alongside this, Almgren (1999a) distinguished the learning curve from the function and experience curve, and stated that the latter includes factors other than direct labour learning. Other researchers have investigated the role of learning in production ramp-up, including Hatch and Mowery (1998), Cantamessa and Valentini (2000), Säfsten et al. (2008a, 2008b), Scrimieri et al. (2013), Doltsinis et al. (2014), and Hansen and Grunow (2015).

2.2.2. Lean and Agile Logistics

Logistics means different things for different researchers with different backgrounds and perspectives. Russell (2000) highlighted some of these perspectives, including the military, engineering, business, events, and process perspectives. Many accepted definitions of logistics exist (Rutner and Langley, 2000). Considering business logistics, the Council of Supply Chain Management Professionals (CSCMP) defined logistics as ‘that part of the supply chain process that plans, implements, and controls the efficient and effective, forward and reverse, flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements' (CSCMP, 2014). This definition has been utilized by many authors (e.g. Cooper et al., 1997; Bowersox et al., 1999; Bardi et al., 2006; Langley et al., 2008; Sutherland, 2009; Simchi-Levi et al., 2014).

Baudin (2004) indicated some issues that restrict the use of the previous definition, including ignorance of monetary flows, negligence of inefficient and ineffective logistics, and a focus on customers' requirements, which can prevent enhancements to the logistics system that might not be directly related to meeting these requirements. In addition to the points mentioned by Baudin (2004), it is not worthwhile mentioning the points of origin and destination since logistics includes any movement and storage activity regardless of the origin and destination. Furthermore, using the word 'inventory' instead of 'good' might be more obvious in considering the three types of inventory – namely raw materials, work in process, and finished goods.

Taking all of these points into account and considering only the manufacturing environment, logistics in this research will be defined as follows: *the process of managing the two directional movement and storage activities of inventory, related information, and funds*. More attention, however, will be dedicated to the inventory and information flows, since the financial flow is frequently handled by the finance department rather than the logistics or production department. Simply the movement and storage activities of physical inventory and related information will be considered throughout this research. A similar, but abbreviated, definition was provided by Delaney (1996), who stated that logistics refers to the management of inventory in motion and at rest.

Figure 2.5 provides an overview of logistics flows, including inventory, information, and money, and divisions, including inbound, intra, and outbound logistics. Only the first tier of suppliers and distributers or customers is shown, since this research does not address the supply chain management perspective (Houlihan, 1985; Stevens, 1989; Cooper and Ellram, 1993; Cooper et al., 1997). Alternative definitions of logistics have been provided by Shapiro and Heskett (1984), Frazelle (2001), Baudin (2004), Gundlach et al. (2006), Heizer and Render (2008), Christopher (2011), and others. A wide range of activities can be listed under the logistics function; classifying a certain activity under logistics or other organizational functions is considered to be problematic. The interfaces between logistics and each of operation and marketing have been discussed by Baudin (2004), Gimenez and Ventura (2005), Langley et al. (2008), Christopher (2011), and many other researchers.

As for lean and agile logistics, the origins of the two disciplines can be tracked to their manufacturing counterparts, namely lean and agile manufacturing (Jones et al., 1997; Damen, 2001). Consequently, the researching and analysing of lean and agile logistics cannot be accomplished in isolation from lean and agile manufacturing systems. In the next sections, the theoretical basis for leanness and agility is introduced.

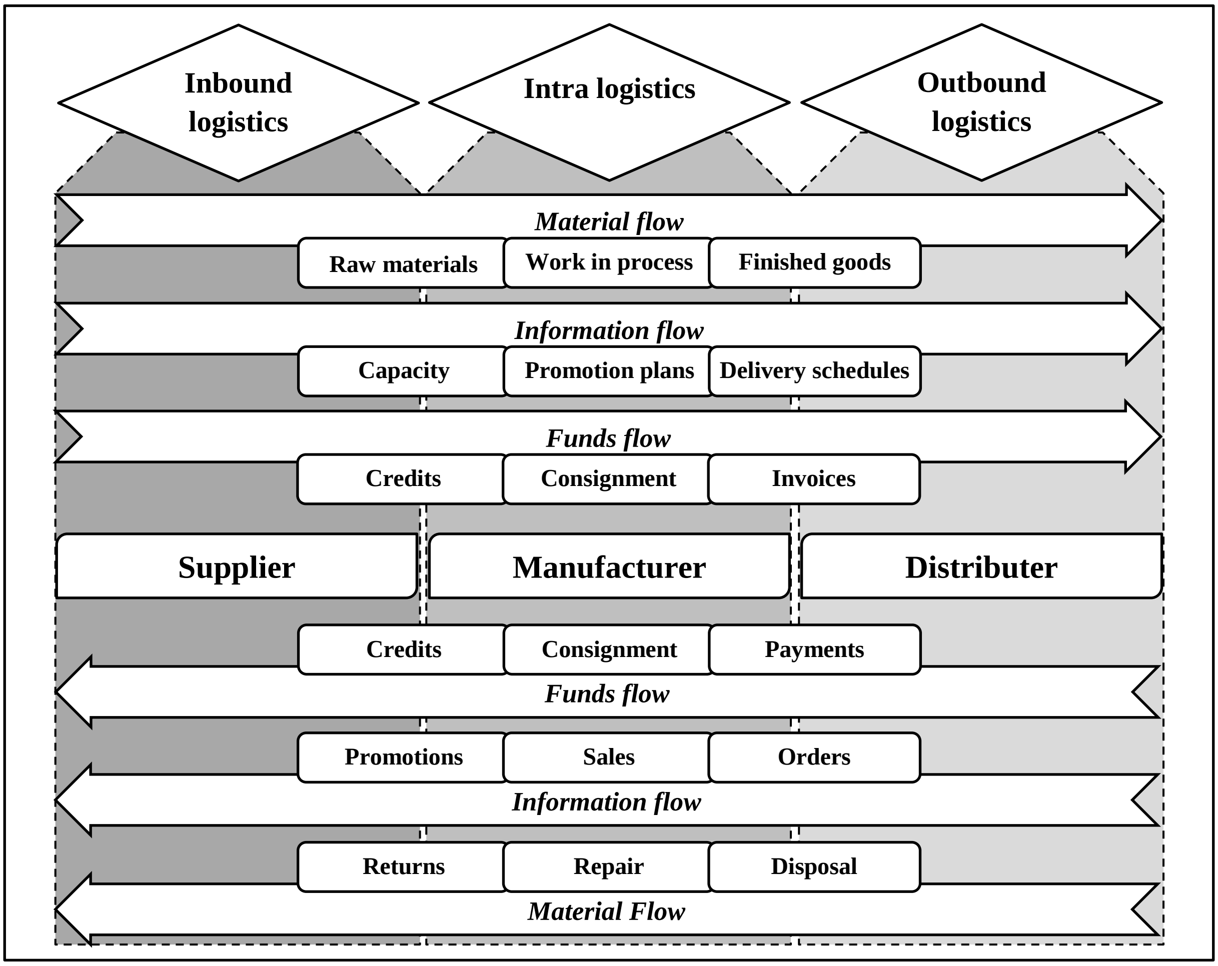


Figure 2.5: Logistics flows and divisions, adapted from Langley et al. (2008)

Lean Logistics

Jones et al. (1997) argued that many of the steps required in a factory to create a product physically add little or no value for the customer. Furthermore, Womack and Jones (1994, 1996) stated that it is not uncommon to find that as few as 5% of all the activities actually add value, 35% of the activities are necessary but also non-value-adding activities, and around 60% add no value at all. Therefore, eliminating these non-value-adding activities and the costs related to them offers the biggest opportunity for performance improvement (Jones et al., 1997). Such facts form a concrete base for adopting lean strategies.

Lean manufacturing, which was previously known as the Toyota Production System (TPS) or the just-in-time (JIT) system, has attracted a great deal of attention (Wu, 2002), and major manufacturers around the world have adopted this approach to enhance their competitiveness (Zarei et al., 2011). Naylor et al. (1999) defined lean manufacturing as developing a value stream to eliminate all waste, including time, and to ensure a level schedule. Seven common forms of waste were defined by Taiichi Ohno: excess production, excess processing, excess movement, excess transport, excess stock, waiting, and rectification of mistakes (Japan Management Association, 1985; Monden, 1994).

Since many of the non-value-adding activities and waste are related to inventory movement and storage, lean logistics contributes significantly to this process. Wu (2002) demonstrated that the elimination of any waste in a firm’s logistics system will result in substantial savings. Similarly, Alderton (1999) argued that between 55% and 60% of all transport costs refer to unproductive transportation. In addition, lean manufacturing cannot be enabled without a lean logistics system, because lean manufacturing is related to every aspect of the logistics process (Wu, 2002).

Donald et al. (2002) defined lean logistics as the superior ability to design and administer systems to control the movement and geographical positioning of raw materials, work-in-process, and finished inventories at the lowest cost. Baudin (2004) stated that lean logistics could be viewed as the logistics dimension of a lean manufacturing system (see figure 2.6: A); this might be right but on different levels. For example, it might be more acceptable for intra logistics activities than for external logistics activities, as the manufacturing process takes place within the facility, and it is also more acceptable for inbound logistics than for outbound logistics, since outbound logistics deals with finished products. Therefore, it might be more precise to indicate that part of lean logistics is not simply a dimension of lean manufacturing (see figure 2.6: B).

Figure 2.6: A proposes the containment of lean manufacturing to lean logistics. The breadth of the interior shape is controversial and dependent on the boundaries between what is considered as logistics activity and what is not. In the majority, the classification of activities into logistics and operations categories is a theoretical matter, but practically it could rather be a managerial decision (Baudin, 2004).

The lean concept can be extended from a single company to the entire supply chain. Ilyas et al. (2008) argued that the lean supply chain process is a process in which the system is streamlined to reduce or eliminate waste or non-value-added activities. However, eliminating waste as measured in time, inventory, and cost across the complete supply chain requires continuous effort and improvement (Ilyas et al., 2007).

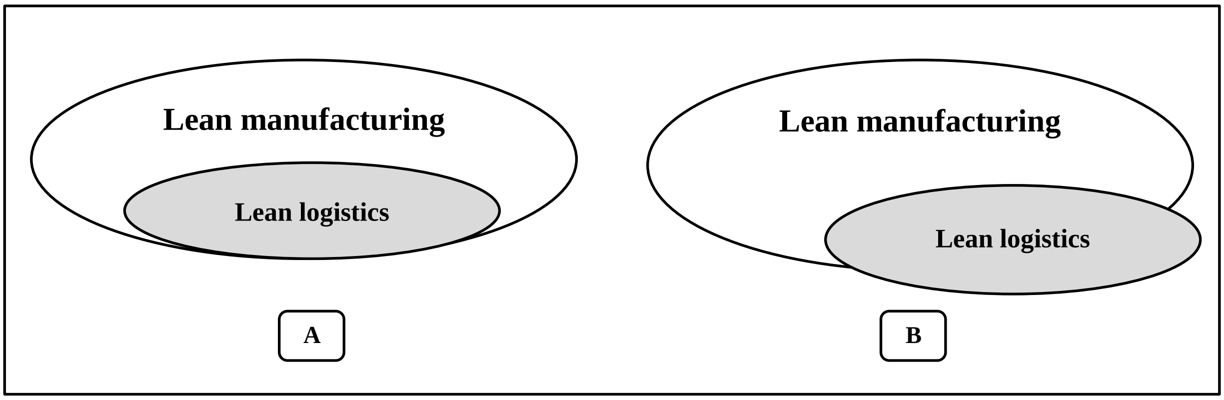


Figure 2.6: Lean logistics and lean manufacturing

Agile Logistics

In the production and operation research literature, most of the attempts to consider agility have highlighted the issues of linking together internal and external business environments, knowledge-based strategies, and moving quickly in the continuously changing economy (Katayama and Bennett, 1999; Sharifi and Zhang, 1999; Yusuf et al., 1999). Agility is a business-wide capability that embraces organizational structures, information systems, logistics processes, and – in particular – mindsets (Christopher and Towill, 2001). Naylor et al. (1999) defined agility as ‘using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile marketplace’. Gunasekaran (1998) defined an agile manufacturing enterprise in terms of four dimensions, among which cooperation and adapting to change and uncertainty play a critical role.

Because of the volatile markets and the increasingly dynamic performance requirements, agility is increasingly mentioned as one of the important challenges to the international business world (van Hoek et al., 2001). Goldsby et al. (2006) found that agile systems are often deployed in companies with short product lifecycles or very erratic demand. Xu et al. (2003) stated that the elements behind the need for agility include complexity, uncertainty, and heterogeneity. Agile systems rely more on actual demand than on forecasting. Hallgren and Olhager (2009) indicated that agility is recommended for make-to-order operations.

Damen (1994) indicated that conventional logistics systems lack the ability to react quickly to the continuously changing environment. More intensified use of e-commerce, global sourcing and distribution, and many other factors (see Zhang and Sharifi, 2000) necessitate the development of an agile logistics system. Harrison et al. (1999) introduced the concept of agile supply chains. The idea of agility in the context of supply chain management focuses on responsiveness (Lee and Lau, 1999; Christopher and Towill, 2000). An agile supply chain is able to sense and respond quickly, predictably, and with high quality and easily adapt to changes in demand.

Flexibility is a key characteristic of an agile system (Christopher and Towill, 2001). In addition to an agile production system (Zhang, 2011) and agile logistics (Damen, 2001), production and logistics system flexibility has been researched under a wide variety of titles, including flexible manufacturing system (Elmaraghy, 2005), reconfigurable manufacturing system (Niroomand et al., 2012), rapid/quick response manufacturing (Chen, 2001; Liang and Guo, 2010; Luan et al., 2013), logistics flexibility (Zhang et al., 2005), supply chain flexibility (Chuu, 2011; Merschmann and Thonemann, 2011; Thomé et al., 2014), transport flexibility (Naim et al., 2006, 2010), manufacturing resilience (Ismail et al., 2011), supply chain resilience (Christopher and Peck, 2004; Pettit et al., 2010), responsive supply chain (Gunasekaran et al., 2008), and factory/production fitness (Ferdows and Thurnheer, 2011).

Niroomand et al. (2012) explained the features of flexible manufacturing systems, including their ability to address changes in work orders, schedules, and tooling and their ability to produce a variety of products within the one manufacturing system. In addition, the authors indicated the drawbacks of such systems, including the high initial cost and the investments required. Lee (2004) differentiated between agility, adaptability, and alignment in the context of supply chain performance. Neely et al. (1995) stated that different authors use the term ‘flexibility’ to represent different things, such as varying production volumes (Wheelwright, 1984) or the ability to introduce new products rapidly (Tunälv, 1992). Niroomand et al. (2012) affirmed that a reconfigurable manufacturing system has better scalability than a flexible manufacturing system. In addition, a reconfigurable manufacturing system combines the advantages of both dedicated and flexible manufacturing systems and occupies the middle ground between their levels of quantity and variety.

More details about the concepts of lean and agile logistics can be viewed in section 4.4, page 90, which considers the development of measurement tools for lean and agile logistics, including the inbound, intra, and outbound logistical activities.

2.3. Literature Review

Since production ramp-up is the main variable in this research, and due to the pressing need for a comprehensive literature review in this field, greater emphasis is placed on reviewing its related literature. A classification of ramp-up research was made according to the main streams appearing in the literature. On the other hand, less attention was paid to lean and agile logistics. However, more attention was dedicated to the attempts made in the literature to link different research variables together, such as ramp-up and logistics, ramp-up and leanness, ramp-up and agility, and leanness and agility. Due to the nature of this research, more attention is paid to exploratory and empirical research.

2.3.1. Production Ramp-Up Literature

In this section, the literature related to production ramp-up is reviewed to set a thorough description of the current research situation, to establish a concrete foundation for the concepts used as starting points for the current research, and to explore gaps that might be bridged by the current research efforts. Although substantial research efforts have been directed to production ramp-up, this phase has in general received less attention than its preceding and following phases. Terwiesch et al. (2001) and Pufall et al. (2007) stressed this fact and stated that the lack of understanding of this stage resulted from concentrating on the product development and mass production stages and ignoring the link between them. In addition, Doltsinis et al. (2013) mentioned that ramp-up is a stage with large potential for further improvements, which in turn highlight the insufficient research efforts conducted in this area; these improvement potentials were also mentioned by Pufall et al. (2007). Similarly, Ball et al. (2011) indicated that, in comparison with the importance of ramp-up, the literature provides insufficient information about this phase.

The lack of consensus on ramp-up’s definition and temporal ambit (as shown in section 2.2.1) indicates the immaturity of the ramp-up literature. Schuh et al. (2005a) stated that a complete overview of this complex phase does not exist. Furthermore, Doltsinis et al. (2013) indicated that a systematic approach to ramp-up time reduction has yet not been defined. In reviewing the ramp-up literature, Surbier et al. (2014) devoted more attention to the most recent work, due to its greater impact on the domain and relevance to current issues. However, older research should be considered since no previous reviews have been presented.

A great deal of overlapping exists between the production ramp-up literature and the new product development literature. To a lesser extent, the ramp-up literature is related to other fields of research, including new product commercialization (Ginn and Rubenstein, 1986; Mu and Di Benedetto, 2011; Aarikka-Stenroos and Sandberg, 2012), product rollovers (Lim and Tang, 2006; Koca et al., 2010; Billington et al., 2012), and product replacement (Saunders and Jobber, 1994).

Ramp-Up Research Directions

Research efforts in the field of production ramp-up have taken different directions and aimed at different goals. Most research has aimed to enhance ramp-up performance by making changes either to the ramp-up process itself or to other factors that directly affect the ramp-up process. In this sense, the ramp-up literature can be classified into two main categories: ramp-up management and ramp-up predictors. In addition to these two main categories, other research directions can be identified, such as exploring the effect of ramp-up variation on other organizational variables.

Ramp-Up Management

Like other production phases, the management of ramp-up includes planning, organizing, and controlling activities (Gross and Renner, 2010). Managing the ramp-up phase properly is an important element to decrease the lead time and accelerate the target volume achievement (Ball et al., 2011). Researchers have investigated the potential for enhancing ramp-up performance through modelling the ramp-up process (Terwiesch and Bohn, 2001; Ball et al., 2011), exploring ramp-up strategies (Clark and Fujimoto, 1991; Schuh et al., 2005a; Winkler and Slamanig, 2011), ramp-up planning (Hüntelmann et al., 2007), enhancing the control of the process (Winkler et al., 2007; Lee and Matsuo, 2012), or measuring the ramp-up performance (Pufall et al., 2012b; Doltsinis et al., 2013) to enable more reliable evaluation.

However, Gross and Renner (2010) stated that ramp-up management has not been investigated empirically in the literature and that only conceptual frameworks exist. Berg and Säfesten (2006) noted a lack of sufficient knowledge and skills in the field of managing new products' ramp-up. Lee and Matsuo (2012) indicated that only a few researchers have discussed the managerial issues related to production ramp-up. Schuh et al. (2005a) showed that, in spite of the existence of some research efforts concerning ramp-up management in the auto industry that utilized methods such as simultaneous engineering, project management, and total quality management (TQM), each method provides only a limited view of ramp-up management without actually addressing present or future problems. Basse et al. (2014a) stressed the difficulties involved in managing the ramp-up process due to the high degree of instability inherent in this phase.

As a starting point, modelling the ramp-up process and describing its components are a valuable tool to enhance the realization of this important phase. Ball et al. (2011) mentioned that only a few examples of ramp-up modelling can be found in the literature and stated that a better understanding of the ramp-up process requires the consideration of the equipment requirement, space requirement, recurring and non-recurring costs, production plan, and learning curve. Van der Merwe and Frizelle (2003) presented a framework based on the three dimensions of novelty, learning, and performance. Terwiesch and Bohn (2001) highlighted the importance of yields, production speed, and output quality in evaluating the progress of the ramp-up process.

Concerning ramp-up strategies and planning, Clark and Fujimoto (1991) mentioned three different ramp-up strategies that link the ramp-up process to the production of the previous products. As shown in figure 2.7, these strategies are complete shutdown, block introduction, or a step-by-step change.

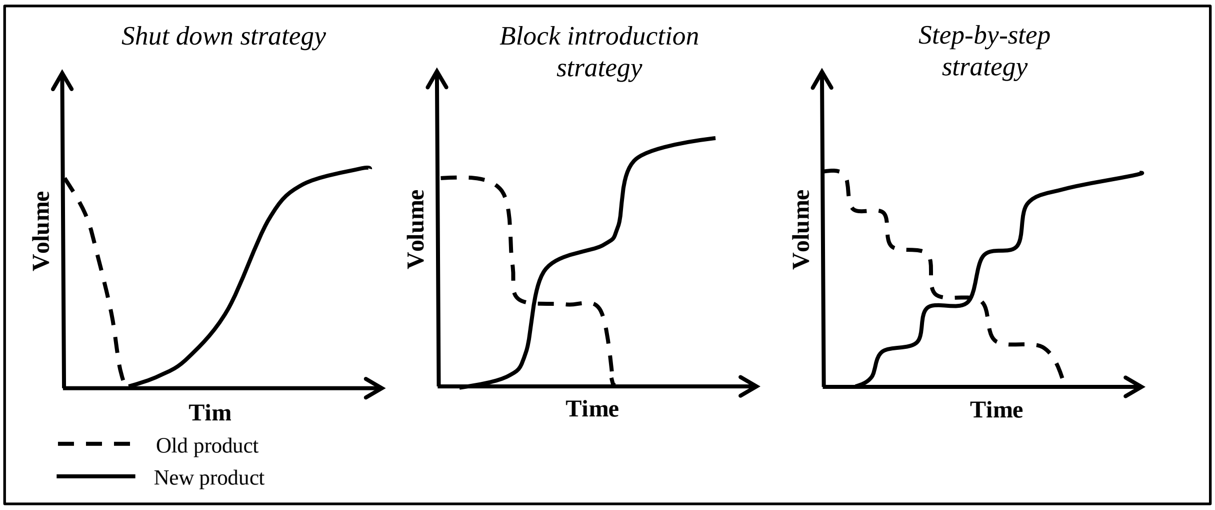


Figure 2.7: Ramp-up strategies according to Clark and Fujimoto (1991)

Schuh et al. (2005a) introduced a holistic approach to production ramp-up that includes the three stages of ramp-up strategy, ramp-up planning, and finally ramp-up evaluation and benchmarking. The authors used the parameters of variety, decoupling level, time, and utilization to express four different ramp-up strategies, namely dedication, step-by-step, volume first, and slow motion (see figure 2.8). Slamanig and Winkler (2011) proposed two ramp-up strategies (high-volume-low mix and low-volume-high mix) for manufacturers with mass customization operations.

Researchers have investigated the development of decision models that enhance the control of the ramp-up process (Glock et al., 2012). Among those, Winkler et al. (2007)

proposed a prognosis system based on cause-and-effect relationships aiming to exercise more control over the ramp-up phase and reduce the potential disturbances in the process. Haller et al. (2003) presented a methodology to enhance ramp-up performance through managing the cycle time by monitoring work in process. Lee and Matsuo (2012) proposed a non-stationary statistical process control that combine the learning model and statistical process control for the ramp-up process in the semiconductor industry.

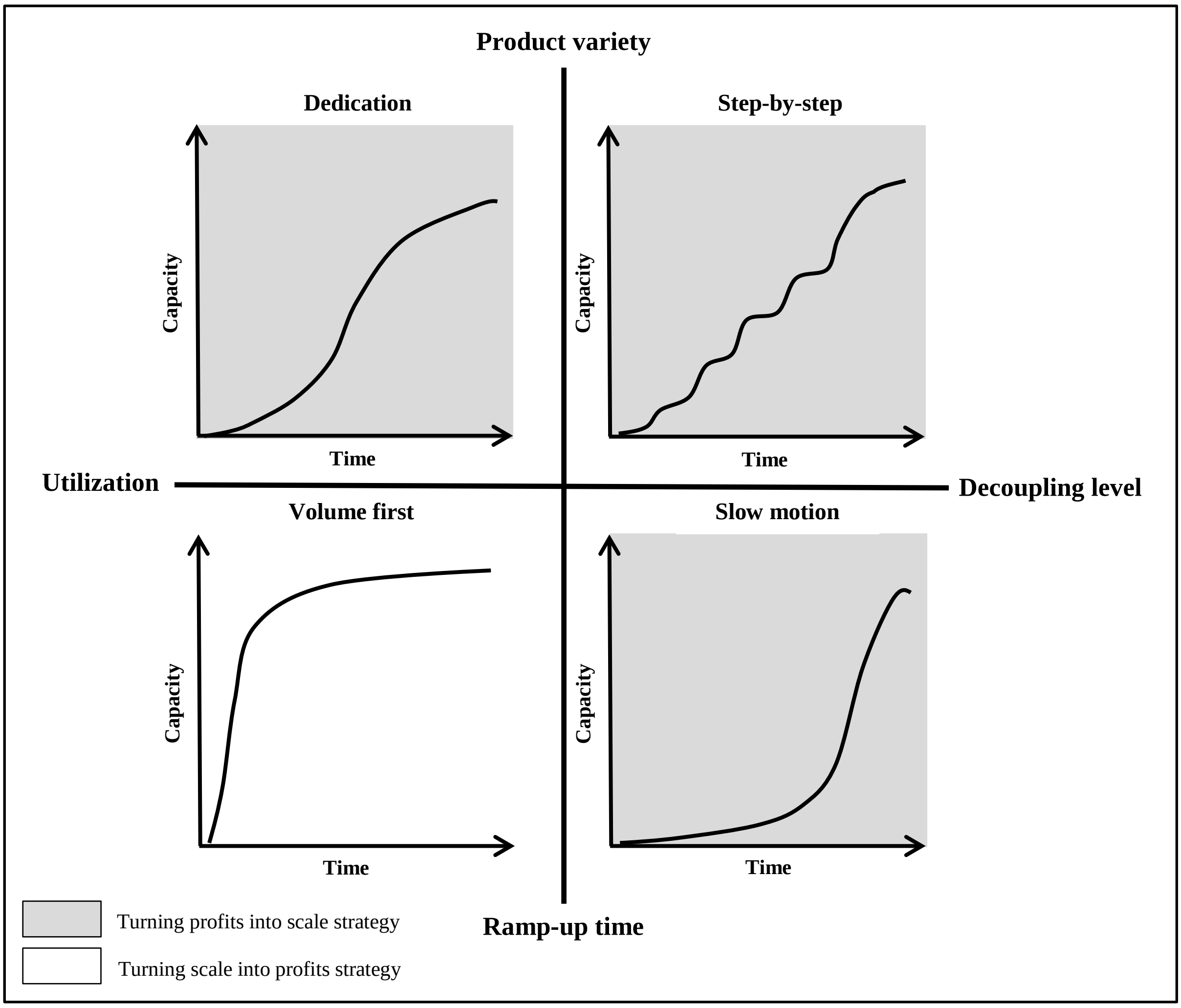


Figure 2.8: Ramp-up strategies according to Schuh et al. (2005a)

Rapid identification of the root causes of manufacturing errors is required to enhance quality, increase productivity, and reduce the time consumed during ramp-up (Du et al., 2008). Accordingly, Du et al. (2008) evaluated the potential role of the stream of variation methodology (a mathematical analysis tool used in complex manufacturing systems) in this field. Similarly, Ceglarek et al. (2004) and Barhak et al. (2005) shed light on the utilization of the stream of variation methodology in the context of production ramp-up. Willmann et al. (2014) proposed a knowledge-based system that examines the available parts and current production steps to recommend reusable parts and steps that fit the requirements of the new ramp-up process. Other researchers interested in controlling the ramp-up period include Nyhuis and Winkler (2004), Schuh et al. (2005b), and Du et al. (2015).

Due to its importance in evaluating the ramp-up phase’s outcomes, considerable work has been dedicated to measuring ramp-up performance. Doltsinis et al. (2013) developed a framework for measuring performance during production ramp-up. In this framework, the authors tried to formalize a ramp-up index that includes functionality-, quality-, and performance-based metrics. This ramp-up index aims to guide and support human decision making. Two ramp-up processes were emulated and the comparison used to evaluate the resulting measurement framework. Wheelwright and Clark (1992) mentioned the important measures of development projects’ performance. Of these, many can be linked directly to the ramp-up of new products, such as the time from concept to introduction (which includes both development and ramp-up), production rate, and frequency of new product introductions. Section 4.3 provides more details on ramp-up performance measurements.

In addition to the previously mentioned managerial aspects, many management approaches have been utilized to enhance ramp-up management, including project management (Gross and Renner, 2010), knowledge management (Slamanig and Winkler, 2010), lean management (Dombrowski and Hanke, 2009; Scholz-Reiter and König, 2010; Dombrowski and Hanke, 2011), change management (Adler and Clark, 1991; Scholz-Reiter et al., 2007), and risk management (Filla and Klingebiel, 2014; von Cube and Schmitt, 2014). Other researchers who have considered ramp-up management include Szulanski (1996), Basse et al. (2014a), and Steiner (2014).

Ramp-Up Predictors

Salomon and Martin (2008) mentioned the limited knowledge available about the factors that determine the performance of the ramp-up process. Similarly, Juerging and Milling (2006) pointed out the scarcity of research exploring the factors affecting efficiency during ramp-up. However, Fjällström et al. (2009) indicated that many factors affecting production ramp-up in different ways have been studied in the literature.

Categorization of the factors affecting ramp-up is common in the literature. The aim is to facilitate firms’ ability to deal with these factors (Fjällström et al., 2009). For example, Clark and Fujimoto (1991) revealed four essential categories affecting the ramp-up phase: strategy choice, manufacturing capabilities, production pattern, and workforce policy. In addition, Pufall et al. (2007) presented a conceptual framework supported by a case study in a cell phone manufacturing company, showing that the factors that determine production ramp-up performance can be categorized according to one of the following characteristics: the product architecture, the product development process, the logistics system, the manufacturing capability, and the external environment. Furthermore, Kuhn et al. (2002) mentioned that the factors that affect ramp-up can be tracked to one of the following main categories: the development process, the production process, the organizational characteristics, the employees, the logistics system, the information flow, the cooperation level, and the managerial methods used. Similar categorization attempts have also been made by Almgren (1999a, 1999b, 2000), van der Merwe (2004), Fjällström et al. (2009), and others.

Due to the multitude of unanticipated problems that can occur during production ramp-up, scarcity of a stable ramp-up phase is experienced in the real world (Winkler et al., 2007). Thus, researchers have focused on identifying and analysing failure, disturbances, and problems during this phase (Simola et al., 1998; Burmer and Görlisch, 2006; Surbier et al., 2009). Almgren (2000) indicated the role of early identification of the sources of disturbances in the success of the start-up process. In addition, Glock et al. (2012) proposed that costs can be minimized through the elimination of interruptions during the ramp-up period.

Almgren (1999a) investigated the start-up phase in an advanced manufacturing system and diagnosed three internal (workforce policy, organization design, and information) and one external (material supply) sources of disturbances. These sources cause three types of disturbances (breakdown, idling, and minor stoppage), which in turn produce down time and speed losses that ultimately affect the overall effectiveness of the equipment. However, Almgren (2000) studied different types of disturbances in the auto industry and concluded that performance during the final verification process in terms of time and efficiency was affected by four types of disturbances, specifically materials supply, machinery and equipment, personnel, and the product concept. Kuhn et al. (2002) identified different sources of ramp-up problems, including a lack of sufficient inter-functional knowledge, late recognition of disturbances, and depending solely on employees’ experience – which is in many cases insufficient – in solving ramp-up problems. Stauder et al. (2014) mentioned the insufficient process capabilities as one of the main sources of disturbances during ramp-up, and Schmitt and Schmitt (2013) indicated that quality-related issues are one of the important causes of delay during production ramp-up and hence introduced a quality-oriented approach to handle the ramp-up phase.

Many factors affecting production ramp-up performance belong to the product development process. The relationship between the development process and the ramp-up performance is unquestionable in the literature (Clark and Fujimoto, 1991; Apilo, 2003; Juerging and Milling, 2006). The development’s phase-related dimensions that affect ramp-up include incomplete development (Almgren, 2000), the levels of investment in development (Pisano and Wheelwright, 1995), the development lead time (Pufall et al., 2012b), the development team’s experience level (Pufall et al., 2007), and concurrent execution of the development tasks (Juerging and Milling, 2005). Other development-related factors that affect ramp-up significantly are the complexity of product design (Frizelle and Gregory, 2000; Pufall et al., 2012a), the process design (Schuh et al., 2005a), and the technology used (Langowitz, 1988; Schuh et al., 2005a). Additionally, the developed product’s newness (Juerging and Milling, 2005), novelty (Merwe and Frizelle, 2003), and maturity (Pufall et al., 2007) all affect the ramp-up process.

Incomplete or incorrect product or process design during the development phase is reflected in the form of subsequent product or process change (Almgren, 2000; Terwiesch and Xu, 2004; Scholz-Reiter et al., 2007). Such change causes higher costs (Matta et al., 2008), excessive downtime (Carrillo and Franza, 2006), reduced yields (Almgren, 2000), and short-term disruptions and reduced capacity (Carrillo and Gaimon, 2000). Fewer engineering changes and less debugging lower the uncertainty during ramp-up (Pufall et al., 2007). Additionally, Langowitz (1988) attributed most problems that appear during the initial production of the product, such as production process and work schedule deviations, to mismatching the new product characteristics to the manufacturing process. Furthermore, Terwiesch and Xu (2004) examined Intel’s ‘copy exactly’ ramp-up strategy, which recommends a delay in process change that hinders the learning process until a sufficient level of knowledge is developed in the process. This was imperially proved by McDonald (1998). Based on mathematical modelling, the authors proved that such a strategy is considered beneficial with a low initial level of knowledge, short lifecycle, steep demand growth, and difficult learning process.

The major consequences of change for ramp-up have motivated researchers to present tools to facilitate coping with these changes. In this context, and considering its importance for accelerating the ramp-up process, process reconfiguration has been investigated in many ramp-up-focused studies (e.g. Koren et al., 1999; Matta et al., 2008). Similarly, Xu and Albin (2002) considered process adjustment during ramp-up. Niroomand et al. (2014) stressed the effect of manufacturing process configuration characteristics on ramp-up duration, and Scholz-Reiter et al. (2007) showed the significance of fast product change implementation for the pace of the ramp-up process.

Another aspect of investigating the relationship between product development and production ramp-up is to explore the interaction between time-to-market and time-to-volume. In their two papers in 2005 and 2006, Juerging and Milling highlighted the relationships between time-to-market and time-to-volume and showed that shorter time-to-market might negatively affect time-to-volume and, hence, the financial performance of the new product. The authors concluded that minimum time-to-volume should be the goal. With some similarities, the mathematical model proposed by Carrillo and Franza (2006) linked time-to-market and ramp-up time together and concluded that the optimal ramp-up time is the minimum time required to reach the production volume that matches the peak demand. They also proposed that a company should invest to the maximum in production capacity until this intended production level is reached. The model proposed by Carrillo and Franza (2006) could be more relevant since the capacity utilization should be linked to the actual demand rather than to the system's capabilities.

Beside the development-relevant variables, the effect of many process-related variables and technical issues regarding ramp-up have been investigated in the literature, including process capability (Ball et al., 2011), process development (Pisano and Wheelwright, 1995), process standardization (Juerging and Milling, 2005), system robustness (Schuh et al., 2005a), work organization (Almgren, 1999b), system capacity (Carrillo and Franza, 2006), tooling, equipment, and equipment qualification time (Haller et al., 2003; Pufall et al., 2007; Fjällström et al., 2009), dispatch rank policy and lot size (Sturm et al., 2003), materials flow (Almgren, 2000), and space requirements (Ball et al., 2011).

The information availability and flow during ramp-up have captured considerable research efforts. The research conducted by Säfsten et al. (2008a) on the critical events emerging during production ramp-up showed the need to develop an information strategy to support decision making and proactive behaviour. In this context, Surbier et al. (2010) developed diagnosis tools aimed at a better understanding, identification, and analysis of the information exchange among different stakeholders in the ramp-up process, which proposed to be helpful in problem solving and process enhancement. Fjällström et al. (2009) explored how different types of information from different sources affect 30 different critical events during production ramp-up. The authors studied the effect of information on the factors that affect ramp-up performance, while the direct effect of information on ramp-up performance parameters was beyond the research's scope. However, some of the quality-related critical events investigated by Fjällström et al. (2009) have widely been considered in the literature as a performance parameter or output of the ramp-up process rather than a mediating factor affecting the process. Willmann et al. (2013) introduced an information exchange and knowledge management approach aiming to shorten the product ramp-up time.

Due to the interdependency and interdisciplinary nature of the ramp-up phase, the roles of collaboration between different organizational departments, suppliers' involvement, and the use of cross-functional teams have also been investigated. Woodcock et al. (2000) indicated the importance of involving the production department personnel in the design process for enhancing ramp-up quality and time performance. Cantamessa and Valentini (2000) highlighted the importance of considering the interface between production and marketing by explaining the relationship between the new product launch and the product diffusion effect. Apilo (2003) showed the importance of suppliers' collaboration for ensuring the new product's manufacturability and the speed of the ramp-up. Similarly, Li et al. (2014) proved that – in the case of their specific research sample – the ramp-up time can be reduced through more collaborative relationships with the inter-company manufacturing supply network. In addition to the collaboration with suppliers and distributers, Gross and Renner (2010) indicated the importance of interaction with the customers for a successful ramp-up process. Schuh et al. (2005a) mentioned that constructing a ramp-up team with members from different departments enhances communication and coordination during the ramp-up phase. The importance of developing a cross-functional ramp-up team was also mentioned by Di Benedetto (1999) and Pufall et al. (2007). While most researchers have considered collaboration in the context of in-house production ramp-up, Witt (2006) investigated the collaboration issues in the context of outsourcing the production activities of auto manufacturing parts.

Some researchers have paid more attention to factors related to human resources during production ramp-up, such as employee development (Goerke and Gehrmann, 2014), employee training (Kampker et al., 2014), personnel planning (Lanza and Sauer, 2012), and workforce policy (Almgren, 1999a). The employee-related factors affecting ramp-up include education (Fjällström et al., 2009), knowledge (Terwiesch and Xu, 2004), skills (Ball et al., 2011), worker requirements (Winter et al., 2014), recurring costs (Ball et al., 2011), the number of employees (Glock et al., 2012), and the attendance and work rotation levels (Almgren, 2000). Bassetto et al. (2011) focused on the issue of teaching ramp-up for engineers and proposed a game-based tool that combines lessons and exercises to allow participants to experience the production ramp-up phase in a controlled environment.

Other factors investigated in the literature in relation to their potential effects on production ramp-up include accurate forecasting (Pufall et al., 2007), organizational design

(Almgren, 1999a), logistics (Pfohl and Gareis, 2000; Filla and Klingebiel, 2014), customer requirements (Bischoff, 2007), and industry experience (Salomon and Martin, 2008). Hatch and Mowery (1998) stated that even the geographical proximity between development and production facilities affects the ramp-up process. However, Terwiesch et al. (2001) reported an example that questions such a relationship; the different sectors researched by the two studies might partially explain the contrary results and observations. Carrillo and Franza (2006) mentioned some factors that further motivate the reduction of ramp-up time, such as the decrease in demand and revenue from older products and the increase in revenue associated with the new product’s sales. Blum et al. (2014) considered different quality and demand policies during ramp-up. Additionally, Glock et al. (2012) noted the importance of synchronizing the levels of production and demand for cost minimization during production ramp-up; to achieve synchronization, the authors proposed that the learning rate or alternatively the number of employees should be adjusted. Furthermore, Apilo (2003) considered the use of contract manufacturers to shorten the ramp-up period.

Variables Affected by Ramp-Up

Production ramp-up has also been researched in relation to its effect on other organizational variables. Almgren (2000), Winkler and Slamanig (2011), Elstner and Krause (2014), and others confirmed the effect of ramp-up on the success of new products. Niroomand et al. (2012) stated that the ramp-up duration affects the agility level promised by a reconfigurable manufacturing system through its impact on the reconfiguration time. Steiner (2014) investigated the role of ramp-up management in mitigating the negative effects of instabilities arising in the high-variant business environment.

Strubelt and Zadek (2010) empirically proved that ramp-up management affects the controllability of customer order processing. Terwiesch et al. (2001) indicated that suppliers’ ramp-up duration affects not only a single company but the entire supply chain. In addition, the authors mentioned the role of fast ramp-up in enhancing the lifetime sales of the new product. More details about the effect of ramp-up on the company’s financial indicators were mentioned in section 2.2.1 on page 18.

Researched Sectors and Industries

The vast majority of ramp-up research has focused on manufacturing operations. The industrial sectors that have received more attention are auto manufacturers and electronics producers; this is due to many reasons, including the special characteristics of these industries that make production ramp-up a remarkably critical phase. Both industries depend heavily on new technologies and are described as complex multistage manufacturing systems (Du et al., 2008). The auto industry is also characterized by increasing competition and market fluctuation (Niroomand et al., 2014) along with the increasing speed of innovations and product differentiation efforts (Schuh et al., 2005a). In addition, auto producers have been reported in the literature to be more open to the research community, which provides a better chance of a higher response rate and collaboration. The short and continuously declining product lifecycle in the electronics industries sector has motivated greater emphasis from researchers. Terwiesch and Bohn (2001) mentioned that the lifecycle for products such as disk drives and telecommunications has shrunk to less than a year. In addition, Li et al. (2014) stated that the short lifecycle – less than nine months – in the optical storage industry enabled the observation of the ramp-up process for many new models or generations of products within the research time span. Furthermore, the prices of electronic products generally fall very rapidly (Matta et al., 2007); therefore, in the electronics industry, obtaining the highest financial payoffs during the early phases of the product lifecycle acquires great importance (Hatch and Macher, 2004).

Regarding electronics and high-tech products, researchers have investigated manufacturers of semiconductors and wafer fabrication (Hatch and Mowery, 1998; Sturm et al., 2003; Lee and Matsuo, 2012; Chang and Chen, 2014), cell phones (Pufall et al., 2007; Pufall et al., 2012a), hard disk drives (Bohn and Terwiesch, 1999; Terwiesch et al., 2001), optical storage devices (Li et al., 2014), wire harnesses (Kontio and Haapasalo, 2005), and other undefined electronics (Adler and Clark, 1991; Apilo, 2003; Surbier et al., 2010). On the other hand, a significant number of researchers have investigated the auto manufacturing sector, including auto manufacturers (e.g. Fujimoto, 1989; Clark and Fujimoto, 1991; Almgren, 2000), OEM (e.g. Schuh et al., 2005a), and automotive suppliers (e.g. Held, 2010). Additional studies have been conducted in other industrial sectors, such as engineering products (Ball et al., 2011), aerospace and aviation (Clawson, 1985; von Gleich et al., 2012), the steel industry (Baloff, 1966), the pharmaceutical industry (Pisano and Wheelwright, 1995; Pisano, 1997; Hansen, 2013), and medical injection pens (Scrimieri et al., 2013).

Most researchers have considered a single-company case, which has generally been mentioned as a research limitation that impedes the generalization of the findings. Fewer studies have been conducted on a multi-company base (e.g. Di Benedetto, 1999; Salomon and Martin, 2008; Gross and Renner, 2010; Winkler and Slamanig, 2011). Li et al. (2014) tried to overcome the disadvantages of limiting the research scope to the intra-company level and considered the inter-company manufacturing supply network. Since most researchers have adopted a case study methodology focusing on a single company, research conducted in different countries simultaneously has been very limited (e.g. Slamanig and Winkler, 2012; Li et al., 2014).

While most research efforts have targeted large and multinational companies (Ball et al., 2011), usually producing high-volume products, such as auto and electronics manufacturers, Woodcock et al. (2000) and Meier and Homuth (2006) directed their research toward small and medium-size enterprises (SMEs). In addition, Leitão et al. (2013) concentrated on companies that produce small lots. Some researchers have focused on special production systems and production environments. For example, Nau et al. (2011), Klocke et al. (2012), and Basse et al. (2014b) investigated ramp-up with hybrid manufacturing technologies and Nugroho et al. (2011) concentrated on built-to-order supply chains.

Service Ramp-Up

Lenfle and Midler (2009) attempted to use the ramp-up concept in the field of product-related service launch concentrating on the service characteristics, including the simultaneous production and consumption of the service, which drive two types of learning – technical and sales – to occur simultaneously. Due to the impossibility of separating service production and marketing (Grönroos, 1990), the separation between production ramp-up and commercial launch cannot be made in the case of services. Similarly, Winter et al. (2014) investigated ramping up the service provided by contract logistics firms. Enz et al. (2014) considered hotels' performance ramp-up.

2.3.2. Lean and Agile Logistics Literature

In a review of the literature, studies related to lean and agile logistics cannot be separated from the lean and agile manufacturing literature. Conducting a comprehensive review of leanness and agility is beyond the scope of this research. However, Kisperska-Moron and de Haan (2011) indicated that, despite the wide consideration of mass, lean, and agile production systems in the literature, these philosophies still cause confusion for academics and practitioners. While considerable research efforts have been dedicated to the fields of leanness and agility, limited efforts have been directed toward investigating these paradigms empirically. Empirical research focusing on lean or agile logistics is very scarce. In this preliminary literature review, more focus was placed on the factors affecting lean and agile logistics, in addition to the factors affected by the implementation of lean and agile logistics strategies; finally, the supply chain perspective was also considered.

Leanness Literature

Many researchers have investigated how lean strategies and lean logistics affect the production process and the company as a whole. Wu (2002) stated that any reduction of waste in the logistics systems can produce substantial savings. Wincel (2004) showed that lean strategies lead to higher levels of customer satisfaction. The role of lean logistics in improving customer service was also mentioned by Fynes and Ennis (1994). Wu (2002) indicated some tools that support the lean logistics system, including third-party logistics; transportation consolidation; consistent transportation; close carrier relationships; milk runs or compound deliveries; and the use of returnable, reusable, and standardized container sizes. Other factors influenced by leanness include manufacturing performance (Flynn et al., 1995b), inventory turnover (Demeter and Matyusz, 2011), and competitive advantage (Flynn et al., 1995a).

Other research streams have been concerned with the factors that affect the implementation and the results of lean strategies. Definitely the main factor affecting lean logistics is the existence or absence of a lean manufacturing system (Wu, 2002). Fynes and Ennis (1994) discussed the interface between lean manufacturing and lean logistics and considered logistics from a marketing perspective. Lewis (2000) found that the success of the lean system is dependent upon contextual factors, such as the type of market, dominant technology, and supply chain structure. Shah and Ward (2003) argued that several organizational factors may enable or inhibit the implementation of lean practices among manufacturing plants. Sakakibara et al. (1997) showed that JIT practices affect manufacturing performance only when combined with infrastructure practices.

In addition, many researchers have investigated leanness within the context of supply chain management. Rathje et al. (2009) indicated that lean tools and techniques aim to reduce waste not only within the plant but also along the entire supply chain. Jones et al. (1997) argued that the optimization of each piece of the supply chain in isolation does not produce the lowest-cost solution. Consequently, it is necessary to look at the entire sequence of events in the supply chain as a whole. The study conducted by Liker and Wu (2000) showed that buyers’ lean logistics practices can support suppliers’ ability to improve their operations. Kisperska-Moron and de Haan (2011) mentioned the environmental characteristics required for a lean supply chain to operate, including stability, controllability, and predictability. In addition, due to the important role that logistics plays in linking suppliers and customers, lean logistics provide a means to achieve total system improvements (Wu, 2002).

A comprehensive review of the lean literature was conducted by Stone (2012) and Gupta and Jain (2013). Hasle et al. (2012) reviewed the literature on the effect of lean on the employees and on the work environment, and Zhang et al. (2012) reviewed the literature related to lean six sigma practices.

Agility Literature

Naim et al. (2010) indicated that, instead of the well-documented flexible manufacturing in the literature, aspects such as definition, role, and measurement considering the whole supply chain are less understood. Van Hoek et al. (2001) stated that the existing literature mainly presents agility as a general management or a strongly manufacturing-biased concept. Damen (2001) stated that the current logistics systems’ ability to react quickly to changes in the business environment is restricted and mentioned the importance of implementing agile logistics strategies.

Miao and Xi (2008) highlighted the effect of uncertainty and the importance of agile forecasting of demand to enhance logistics performance and customer service levels. In addition, Miao and Xi (2008) indicated that providing agile and quick delivery will force competitors to increase their inventory levels to enhance their ability to reduce their delivery time. This increase is usually reflected in higher costs and, hence, higher prices. Inman et al. (2011) and Merschmann and Thonemann (2011) investigated the effect of agility on firms’ performance. Zhang et al. (2005) proved a significant effect of lean logistics on the customer satisfaction level, and Ismail et al. (2011) investigated the role of agility in achieving resilience.

Yusuf et al. (1999) indicated that change is the major driving force behind agility. Gunasekaran (1998) illustrated the enablers of an agile system, including a virtual enterprise, rapid partnership, concurrent engineering, integrated information systems, rapid prototyping, and electronic commerce. Undoubtedly, the use of information technology to share data between buyers and suppliers is crucial to achieve an agile supply (Harrison et al., 1999).

Evers et al. (2000) and Damen (2001) focused on the service sectors and researched the concepts of service-oriented and service-controlled agile logistics, respectively. Ismail et al. (2011) highlighted the terms of agility and resilience in the context of SMEs. Oloruntoba and Gray (2006) and Scholten et al. (2010) explored the role of agility in humanitarian aid supply chains. Similarly, Barahona (2013) highlighted the role of agility in disaster response and relief supply distributions. Ramesh and Devadasan (2007) and Huang and Li (2009) provided a literature review on agility. Gligor and Holcomb (2012) reviewed the agility literature to investigate the role of logistics capabilities in achieving supply chain agility.

2.3.3. Research Linking Ramp-Up, Leanness, and Agility

In this section, the research that has linked different research variables together is briefly introduced to identify the nature of the interactions between the constructs under consideration. A direct investigation of the role of lean or agile logistics during the ramp-up phase cannot be found in the literature. Instead, the links between ramp-up and logistics, leanness, and agility were reviewed. However, research linking production ramp-up, lean logistics, or agile logistics to new product success was not mentioned.

Ramp-Up and Logistics

Bowersox et al. (1999) mentioned the scarcity of research efforts to investigate the effect of ‘place capabilities’, such as logistics and supply chain relationships, on the launch performance. In addition, Pfohl and Gareis (2000) asserted that logistics has been frequently overlooked in the ramp-up literature and indicated the ignorance regarding the testing of the logistics system best suited to this phase. Moreover, few attempts to investigate the role of logistics during ramp-up empirically can be found.

Based on survey research, Di Benedetto (1999) indicated that successful new product launches attempt to involve logistics early in the planning phase. Di Benedetto asserted the important role of logistics in developing a successful strategy and mentioned the importance of involving logistics personnel in strategy development. Similarly, Pfohl and Gareis (2000) conducted survey research that revealed an important role for operational and administrative logistics activities for the ramp-up process. Due to logistics’ interfaces with other functions and supply chains’ and the ramp-up process’s interfaces with other activities, the results highlighted the importance of integration and coordination. Interfaces are represented in the interaction, communication, and collaboration between different functions (Koike et al., 2005). Scholz-Reiter et al. (2007) mentioned the role of logistics in influencing production ramp-up among other factors, such as production and assembly processes, instruments and tolls, product development, and networking and cooperation. In addition, Filla and Klingebiel (2014) considered the pre-series logistics activities in analysing the risk involved in the ramp-up process. While Risse (2003) introduced a logistics-oriented approach to ramp-up management, Hüntelmann et al. (2007) proposed a logistics- and cost-oriented cross-company ramp-up planning model. Pufall et al. (2007) considered the issues of logistics facilities and the design of logistics, and Almgren (2000) elucidated how disturbances in the material supply, such as a lack of materials or materials of a quality lower than required, affect ramp-up in terms of both quantity and quality performance.

Surbier et al. (2014) highlighted the importance of considering the supply chain perspective in treating the ramp-up process and mentioned a gap in the literature in this regard; they stated that many problems might occur due to internal and external logistics in addition to the lack of cooperation with suppliers. Ragatz et al. (2002) indicated the importance of having suppliers within the ramp-up team. In addition, the importance of parts supply, material quality, and supplier collaboration were discussed by Almgren (1999a), Fjällström et al. (2009), and Li et al. (2014), respectively.

With a different research direction, Winkler and Slamanig (2008) indicated that the ramping up of new products leads to changes and adjustments within the production and logistics systems of the firm. Reuter et al. (2014) also discussed the challenges produced by the complexity of the ramp-up process for logistics.

Ramp-Up and Leanness

Limited attempts to explore the role of agility during the ramp-up phase can be traced in the literature. Bowersox et al. (1999) proposed a ‘lean launch’ approach based on the principles of response-based logistics. While traditional logistics’ support for the product launch process is based on the demand forecast, the lean launch approach is based on the pull strategy and the postponement principle. Dombrowski and Hanke (2009) and Dombrowski and Hanke (2011) tried to apply the lean principles to enhancing the ramp-up phase’s performance. Similarly, Scholz-Reiter and König (2010) used lean principles to achieve a faster ramp-up process, von Cube and Schmitt (2014) commented that the work by Scholz-Reiter and König (2010) is better regarding usability and focused strongly on reducing delays, while the work of Dombrowski and Hanke pursued the advantages of the first mover and neglected quality issues.

Regarding the material flow, Haller et al. (2003) indicated that the pull rather than the push principle is more suitable for the uncertain nature of the ramp-up process. The authors indicated that the material flow during ramp-up is not homogeneous and that the early processes in the production line have higher throughput than the later processes. In addition, during ramp-up and due to the constantly increasing production rates for normal and for bottleneck operations, the WIP caps (see Liberopoulos and Dallery, 2002) have to be adjusted through time. According to Haller et al. (2003), these caps should by updated weekly.

Ramp-Up and Agility

Ball et al. (2011) stated that the criticality of the ramp-up phase is mostly related to the flexibility required. Lee (2004) argued that the concept of agility is of particular importance during changing market conditions (e.g. during ramp-ups). Niroomand et al. (2014) pointed out the importance of ramp-up time reduction to enhancing the responsiveness of reconfigurable manufacturing systems by affecting the reconfiguration time. More details about research linking agility to production ramp-up are available in section 6.4 on page 144.

Leanness and Agility

As mentioned before, there is a lack of clarity in the literature concerning what constitutes leanness and agility, how leanness and agility differ, and when to employ each concept (Narasimhan et al., 2006). However, some researchers have compared and/or combined the two paradigms (Naylor et al., 1999; Christopher and Towill, 2000; Bruce et al., 2004; Ilyas et al., 2008; Hallgren and Olhager, 2009; Huang and Li, 2010; Naim and Gosling, 2011). Kisperska-Moron and de Haan (2011) claimed that both leanness and agility aim to achieve flexibility and competitiveness but in different ways.

Naylor et al. (1999) showed that agility is best suited to satisfying a fluctuating demand (in terms of volume and variety) and lean manufacturing requires, and promotes, a level schedule. Similarly, Christopher (2000) argued that lean concepts work well when the demand is stable and predictable and when the variety is low, while agility is required when the demand is volatile and when the variety in customer requirement is high. Van Hoek et al. (2001) argued that agility requires specific capabilities, in addition to those capabilities that can be achieved using lean thinking. Christopher and Towill (2001) connected the ideas of order qualifiers and order winners to the concepts of leanness and agility. They mentioned that the lean paradigm is most powerful when the winning criterion is cost, while agility is required more when service and customer value enhancement are prime requirements for market winning.

Within the context of supply chains, some researchers (e.g. Mason-Jones and Towill, 1999; Mason-Jones et al., 2000a; Agarwal et al., 2006) have found that lean and agile paradigms can be and have been combined within successfully designed and operated total supply chains. Pfohl and Buse (2000), Elkins et al. (2004), and Lee (2004) explained that to cope with the escalating fluctuation in both supply and demand, most supply chains trade off the speed of response with the accompanying costs. However, agile supply chains can respond quickly and – at the same time – in a cost-efficient manner. Beside the supply chain view, this ability to combine speed and efficiency was also argued by Zhang et al. (2005) considering the flexibility of a single company's logistical system.

Some authors have used the concept 'leagile' to combine the lean and agile paradigms (Naylor et al., 1999; Mason-Jones et al., 2000a, 2000b; van Hoek, 2000; Aitken et al., 2002; Bruce et al., 2004; Krishnamurthy and Yauch, 2007). Naylor et al. (1999) stated that the required levels of agility and leanness are determined according to the total supply chain strategy. The authors stressed the importance of combining lean and agile strategies by placing a 'decoupling point' appropriately in the supply chain.

CHAPTER 3

METHODOLOGY

3.1. Introduction

This research empirically investigates the role of lean and agile logistics during production ramp-up based on survey methods (Groves et al., 2009; Fowler, 2014) and utilizes a two-step methodology consisting of the use of a deductive-based approach (Swamidass, 1991) to examine the hypothesized relationships model followed by an exploratory analysis aiming to explore further trends in the survey data.

Flynn et al. (1990) indicated that surveys are a commonly used research method in empirical OPM research. In addition, field-based empirical research in OPM is gaining increasing recognition, as it provides an important alternative to other traditional methodologies, such as simulation and modelling (Malhotra and Grover, 1998). More recently, in an analysis of operations and supply chain management research, with a focus on the health care sector, Dobrzykowski et al. (2014) showed that the empirical research methodology encompasses around 27% of all research attempts. Furthermore, a review undertaken by Craighead et al. (2011) revealed that around 28% of the articles published in the journals reviewed were based on the survey methodology. However, the frequent calls for more relevance and rigour in conducting survey research and the researchers' response by conducting more deductive-based research were mentioned by Barratt et al. (2011).

Compared with the case study methodology, surveys have the advantages of greater controllability, repeatability, and generalizability (Gable et al., 1994). A review of the empirical research in OPM, conducted by Scudder and Hill (1998), reported the existence of more survey research than case studies. A similar figure showing more use of the survey methodology than the case methodology in OPM research was reported by Pannirselvam et al. (1999). However, the production ramp-up literature includes many more case studies than surveys.

The use of the deductive approach to theory testing in OPM fields has been discussed thoroughly in the literature (see Flynn et al., 1990; Meredith, 1998; Wacker, 1998). The procedures followed in this research were close to those described by Forza (2002), starting with choosing research constructs and formulating hypotheses, passing through data collection and analysis, and ending with model rejection or confirmation.

In addition, mediation has become significantly popular among OPM researchers (Malhotra et al., 2014). Mediation refers to the existence of a significant intervening effect of an antecedent variable on a consequent variable (Venkatraman, 1989) or, as stated by Baron and Kenny (1986), it is the ability of an exogenous independent variable to affect its dependent consequence. In the current research, the outbound logistics activities were considered as a mediating variable between production ramp-up (as an independent variable) and new product success (as a dependent variable).

Since the production ramp-up field is still new (Surbier et al., 2014), immature (Schuh et al., 2005a), and insufficiently explored (Berg and Säfesten, 2006), most research in this field is exploratory in nature (e.g. Salomon and Martin, 2008; Pufall et al., 2012a, 2012b; Li et al., 2014). Ball et al. (2011) stated that the disparate nature of the ramp-up literature necessitates more exploratory research. In addition, Sturm et al. (2003) indicated that, due to the change in almost every production parameter during production ramp-up, predicting the production process's operational behaviour during this period through conventional static planning models is not sufficient. Furthermore, Li et al. (2014) mentioned the importance of the qualitative data obtained from empirical research for building the ramp-up literature. Koufteros (1999) stated that exploratory techniques are essential when strong theory may not be available. Such a nature characterizing the ramp-up phase – combined with the absence of any attempts in the literature to investigate the role of logistics' leanness or agility during this phase – motivated the use of the empirical research approach.

3.2. Research Structure

The urgent need for research on production ramp-up can be easily identified through a quick review of the latest work in this field. Sections 1.2, 1.3, and 1.4 explain the rationale behind carrying out the current research and highlight its contributions to the available knowledge. The main research variables are proposed as shown in figure 1.2 (page 10). Thereafter, and based on a literature review in the fields of production ramp-up, lean logistics, agile logistics, and new product success, the research sub-variables and the relationships' directions are identified, as shown in figure 4.3 (page 101). To operationalize the specified sub-variables, the 59 questionnaire items (see appendix 1) were formulated to compose a special-purpose data collection tool, to be used for primary data gathering.

After collecting the data using different tools, including interviews, personal contacts, and mailing, many qualitative and quantitative analyses were conducted to describe the data and to examine the proposed relationships. The data analysis mainly utilized the SmartPLS software (Hair et al., 2014; Lowry and Gaskin, 2014) and the IBM Statistical Package for the Social Sciences (SPSS) program (Bryman and Cramer, 1997; Field, 2013; Pallant, 2013). In addition, and based on the proposed research model, research hypotheses were formulated and tested. The results of the exploratory data analysis and the hypothesis testing were used to propose a model to employ lean and agile logistics practices during the ramping up of a new product and thereafter during the following steady-state and ramp-down production phases. Basically, the model suggests more enabling for agile logistics activities during the ramp-up phase and a greater focus on lean logistics activities during steady-state production.

The proposed model was is then validated and tested through lifecycle profitability analysis. The results of the profitability analyses for different scenarios were compared to evaluate the possible gains of the proposed system. Such analyses enhance the ability to evaluate the feasibility of investing resources in a new mixed system that switches between leanness and agility during different lifecycle stages. Finally, the research results were summarized, discussed, and compared with the results of the closely related research, the research limitations mentioned, and recommendations for researchers and practitioners introduced. Figure 1.4 (page 15) illustrates the steps followed in the research. The following sections in this chapter provide details of the data collection tool, data collection process, statistical analyses, and validation methods. Figure 3.1 illustrates the procedures followed to examine statistically the quality of the data collection and processing methods, focusing on (1) the measurement tool used, (1) the sample targeted, (3) the data collected, and (4) the statistical analysis conducted.

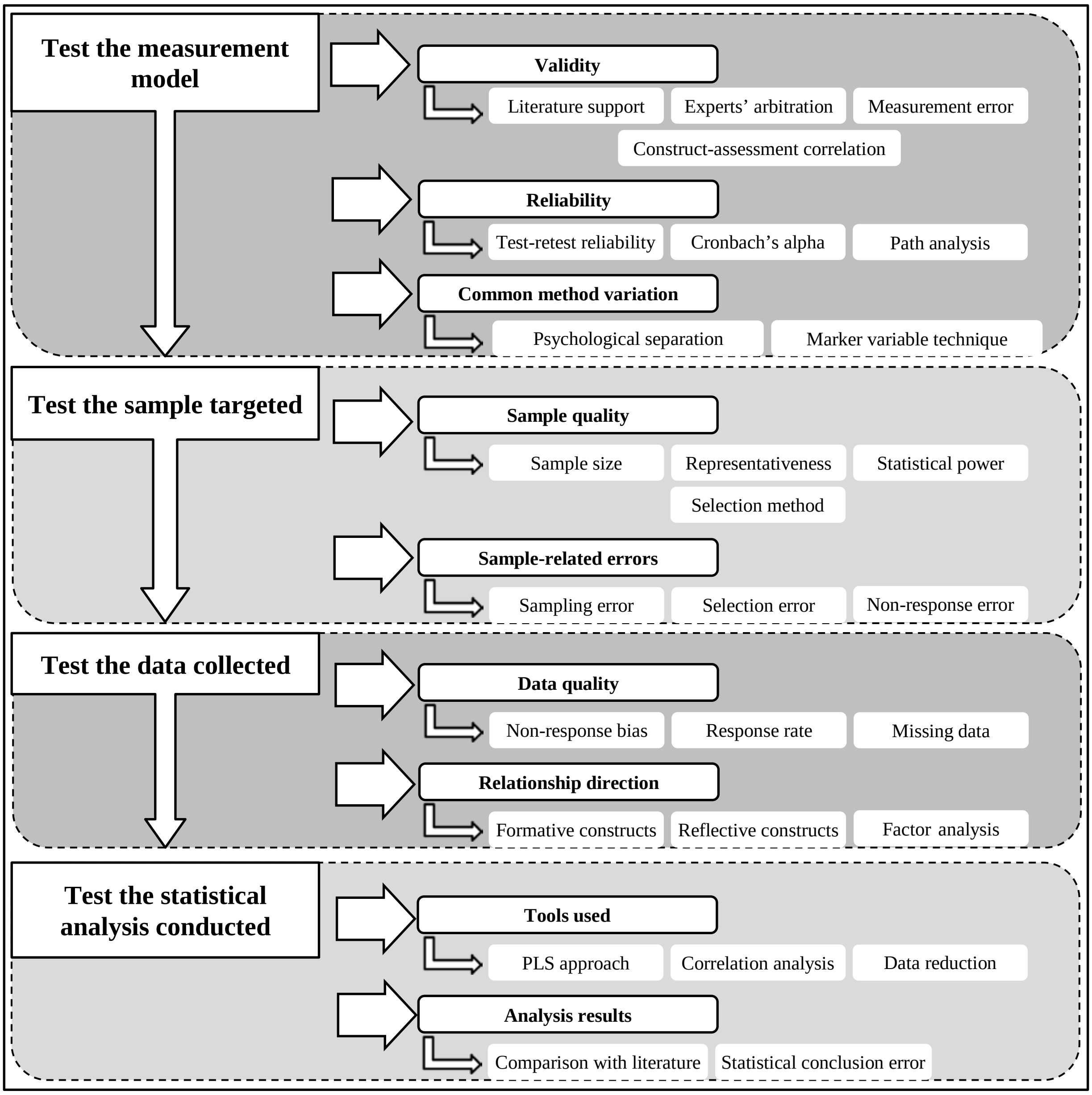


Figure 3.1: Measures, sample, data, and analysis quality

3.3. Data Collection Tool

A questionnaire was the main tool used to capture the data from the targeted industrial companies. A total of 59 questions were developed to measure the research variables, as shown in table 3.1. The production ramp-up questions measured the three performance dimensions of quantity, quality, and cost; the main problems occurring during this phase; and the overall assessment of ramp-up performance. On the other hand, inbound, intra, and outbound logistics activities were measured as the sub-variables for lean and agile logistics. The existence of a degree of overlapping between some lean and agile logistics dimensions (Hallgren and Olhager, 2009) motivated more concentration on the characteristics that can be associated with one paradigm but not the other. An overall assessment of lean and agile logistics was also undertaken. Finally, the questionnaire measured new products' success evaluation to be linked to the ramp-up performance and selected respondent-, organization-, and product-related characteristics to be examined for a potential moderating role.

Table 3.1: Questionnaire items

Variables	Sub-variables	Questionnaire items
Production ramp-up performance	Quantity performance	9, 10, 11, 41
	Quality performance	29, 30, 31
	Cost performance	32, 33, 34
	Ramp-up problems	42, 43, 44, 45, 46, 47, 48, 49, 50
Ramp-up overall assessment	Volume	19
	Time	20
	Quality	21
	Cost	22
Lean logistics	Inbound logistics	12, 35a, 36, 54, 55
	Intra logistics	35b, 38, 51, 52, 53
Lean logistics overall assessment		23
Agile logistics	Inbound logistics	13, 14, 15, 58
	Intra logistics	16, 40, 56, 57
Agile logistics overall assessment		24
New product success	Sales return	25
	Net profit	26
	Market share	27
	Customer satisfaction	28
Mediating variables	Lean outbound logistics	35c, 37, 39
	Agile outbound logistics	17, 18, 59
Moderating variables	Respondent	1, 2
	Organization	3, 4, 5
	Product	6, 7, 8

By asking the respondents to provide an overall evaluation of ramp-up performance as well as the logistics system's leanness and agility, the questionnaire aims to compare sub-dimensions' evaluation with the overall evaluation. A high level of variation between the two might imply biased responses and a higher measurement error may occur when the respondents are unable or unwilling to provide accurate answers (Dillman et al., 2014). Alternatively, the variation can be explained in terms of the differences between the operational definitions provided for ramp-up, lean logistics, and agile logistics and the respondents' actual understanding of these variables.

While the survey questions measured the variables of ramp-up, lean logistics, agile logistics, and new product success, in addition to the moderating variables, the questions were organized according to the evaluation scale rather than the variable measured to reduce the time required to respond. This organization method did not affect the logical sequence of the questions, since the research variables appeared in a common context. In addition, organizing the questions around the research variables sometimes drives respondents to answer according to a certain pattern, which in turn might produce an unreal strong correlation between the research variables and consequently a higher probability of type I error occurrence. Attention was paid to the sequence and organization of the questionnaire due to their significance for attaining reliable, unbiased responses (Rea and Parker, 2014).

3.3.1. Questionnaire Design Characteristics

Survey characteristics such as the formulation, length, scaling, respondent identification, and number of responses can all affect the data collection, the data quality, and even the results of the data analysis (Forza, 2002; Apilo, 2003; Lozano et al., 2008; Peng and Lai, 2012). Apilo (2003) indicated the importance of keeping the questionnaire as simple as possible. Forza (2002) mentioned that the wording of the questions should be consistent with the respondents' levels of understanding. Furthermore, Stern et al. (2014) presented evidence to prove the significant effect of the questionnaire's visual layout on the responses. In the current research, limited interviews were conducted prior to finalizing the questionnaire development. One of the aims of these interviews was to ensure the highest level of simplicity to enhance respondents' understanding of each item.

Another important survey characteristic is the number of questions. Peng and Lai (2012) noted that researchers face a trade-off between questionnaire length and response rate and that more items per study variable will affect the response rate adversely. The relatively large number of questions in the current research was one of the factors that negatively affected the response rate. Of course, the multifaceted nature of the research variables enforced the use of many sub-variables to cover as many dimensions as possible.

While different sectors and industries have different measurement tools for performance, the current questionnaire items were formed to be more general, to suit different industrial environments, and to concentrate on common measurements with which most manufacturers are familiar. The use of common variables aimed to enhance the generalizability of the research results and to overcome the disadvantage of limiting ramp-up research to a single manufacturer or one sector, as recommended by Terwiesch and Xu (2004); this might also be more useful for general theory building and theory testing attempts. However, such an approach comprises the disadvantages of less precise results and a higher probability of application failure in special industrial environments. A pilot or preliminary survey to identify variables that are relevant to a certain industry is commonly undertaken in the operations management literature (Flynn et al., 1990) and in ramp-up research as well (e.g. Fjällström et al., 2009). However, conducting a pilot study is more suitable for research that targets a specified industry or a particular environment.

The questionnaire was also directed to personnel with sufficient engagement with the ramp-up process, such as production or project managers. However, more precise responses might require participation from other personnel on the supervisory level or the non-managerial level. In quite similar research, Fjällström et al. (2009) collected data from managers responsible for planning and realization, engineers executing preparatory work and supervising the process, and employees directly executing the ramp-up. Since collecting data from multiple resources might complicate the data collection process extremely and place further restrictions on the achievement of an acceptable response rate, the general evaluation required in the questionnaire collects the data from a single, well-acquainted person, who is close enough to the real situation of the process investigated.

Some items in the questionnaire were measured in comparison with competitors or with the firm’s steady-state production phase to solve the conflict between different rating systems and to avoid the questionnaire touching on confidential data and using numbers or pure values for performance evaluation. In general, the questions’ formulation focused greatly on confidentiality issues and asked for general evaluation and judgemental-based situation assessment; this was believed to contribute positively to a higher response rate.

The scaling technique has received considerable interest from researchers due to its importance and effect on responses (Flynn et al., 1990; Lozano et al., 2008). Except for the first part of the questionnaire, an 11-point Likert-type scale was used. Flynn et al. (1990) mentioned the advantages of using a Likert-type scale, including more flexibility, a greater ability to measure general constructs, and ease of analysis and interpretation. In addition to the increased levels of sensitivity, Lozano et al. (2008) showed that the reliability of the Likert-type scale increases as the number of response options increases. Leung (2011) investigated the normality and psychometric properties of 4-, 5-, 6-, and 11-point Likert scales and concluded the following: (1) reduced skewness results from using more scale points; (2) an 11-point scale ranging from 0 to 10 comes with the smallest amount of kurtosis and is closest to normal; and (3) using the Kolmogorov–Smirnov and Shapiro–Wilk statistics, only the 6- and 11-point scales follow normal distributions. However, research conducted by Jacoby and Matell (1971) showed that 11-point Likert scales achieve lower values of the test-retest reliability coefficient. Nevertheless, the test-retest reliability coefficient values were satisfactory in this research, as shown in table 3.3.

3.3.2. Measures’ Quality

For an operationally defined concept, the measurement tool should be both valid and reliable (Bryman and Cramer, 1997). Validity means measuring what intended to be measured, whereas reliability is about consistency (Myrtveit and Stensrud, 2012). In addition to validity and reliability, other statistical tools can be used to evaluate the quality of the data collection tool, such as common method variance (Craighead et al., 2011), measurement error evaluation (Forza, 2002), and correlation statistics.

Crawford and Di Benedetto (2011) indicated that the data collected typically become more valid and reliable as the new product development project moves through the process toward commercialization. The current research investigated products that had already been ramped up; thus, more valid and reliable actual data were expected.

Validity

Content validity should be assessed to prove that the constructs used actually measure the variables that they were originally designed to measure (Field, 2013). The questionnaire items were tested for content validity through a jury of arbitrators. The items used in the questionnaire have been assessed by specialized researchers and expert practitioners, whose knowledge and experiences in the fields of production ramp-up and logistics were sufficient to ensure the validity of the measures used. In addition, the construction of the research questionnaire was originally based on a comprehensive literature review, and the rationale behind each item’s use was mentioned, as shown in chapter 4. This also helps to reduce measurement error, as clarified by Forza (2002).

In addition, to validate the research measures further, the correlation between the ramp-up performance’s constructs and the overall assessment of ramp-up performance was examined to evaluate how accurately the items are measured. The same procedure was followed regarding lean and agile logistics. The correlation values are presented in table 3.2. As shown in the table, high correlation values exist between the respondents’ evaluations of the measures used and their evaluation of the overall variables, revealing a high level of consistency between the items used and the respondents’ understanding of the constructs. While the mean differences between measures and evaluation were small, these differences were higher for the standard deviation values. However, it was noted that the overall evaluation has higher mean values and higher standard deviations as well.

Table 3.2: Comparison between the constructs and their overall assessment

Variables	**Correlation**		**% Mean difference**	**% SD difference**
	Statistic	**Values**		
Ramp-up performance - evaluation	Pearson correlation	0.657**	0.059	0.015
	Sig. (2-tailed)	0.000		
	N	56		
Lean logistics measures - evaluation	Pearson correlation	0.727**	0.060	0.202
	Sig. (2-tailed)	0.000		
	N	54		
Agile logistics measures - evaluation	Pearson correlation	0.812**	0.085	0.189
	Sig. (2-tailed)	0.000		
	N	52		

** Correlation is significant at the 0.01 level (2-tailed)
Exclude missing (pairwise)

Reliability

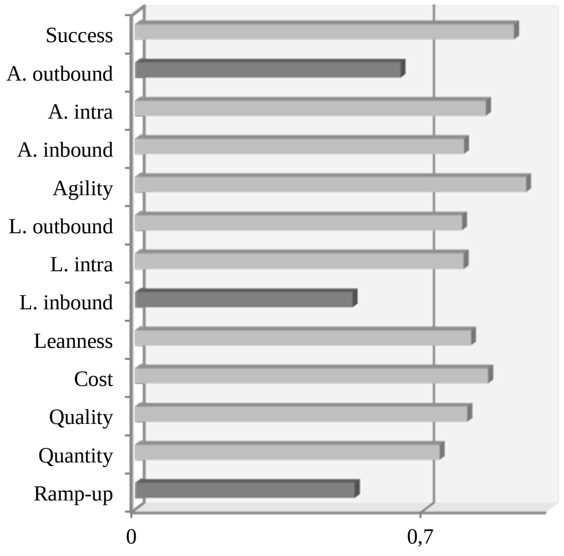
Concerning the tool's reliability, both temporal stability – or external reliability – and internal consistency should be considered (Pallant, 2013). The test-retest procedure (Field, 2013) was followed to examine temporal stability. A small sample of five respondents was targeted by the research survey twice, and the test-retest correlation was calculated for their responses; the results revealed a moderate-to-high test-retest correlation value. Table 3.3 shows the result of this test. The inter-class correlation with two-way random effects and absolute agreement definition was utilized. The average measure of inter-class correlation for respondent 3 is considered to be a problematic value, but for the rest of respondents, highly reliable responses were collected. The time period between the two responses was around one month.

Table 3.3: Test-retest correlation

Responses	**Interclass correlation**		**95% Confidence interval**		**F-test value**
	Single measure	**Average measure**	**Lower bound (single)**	**Upper bound (single)**	
Respondent 1	0.945	0.972	0.909	0.967	35.690
Respondent 2	0.935	0.966	0.892	0.961	29.316
Respondent 3	0.528	0.691	0.317	0.690	3.281
Respondent 4	0.806	.0892	0.693	0.880	9.267
Respondent 5	0.771	0.871	0.642	0.857	7.801

For constructs measured with multiple items, the question of whether each item measures a single idea becomes more important (Bryman and Cramer, 1997). A higher level of internal consistency means that all the sub-variables measure the same underlying construct (Pallant, 2013). The most commonly used tool to measure internal consistency is the Cronbach's alpha, which is based on the average inter-item correlation. The higher is the Cronbach's alpha value, the greater is the internal consistency of the items making up a composite measure (Sekaran and Bougie, 2013). However, Pallant (2013) indicated that Cronbach's alpha values are dependent on the number of items in the scale. Table 3.4 presents the calculated Cronbach's alpha values, which indicate an acceptable level of internal consistency.

Table 3.4: Cronbach's alpha values

Main and sub-variables	Cronbach's alpha	Number of items	Cases	Bar graph
Production ramp-up	0.531	3	56	
Quantity performance	0.736	4	56	
Quality performance	0.803	3	56	
Cost performance	0.853	3	56	
Lean logistics	0.812	3	54	
Inbound	0.526	5	55	
Intra	0.794	5	55	
Outbound	0.790	3	56	
Agile logistics	0.945	3	53	
Inbound	0.795	4	55	
Intra	0.848	4	55	
Outbound	0.642	3	56	
Product success	0.916	4	56	

As shown in the previous table, only three variables have Cronbach's alpha values less than 0.70 (the value proposed by Nunnally and Bernstein, 1994). In the cases of lean inbound logistics and agile outbound logistics, the relatively low Cronbach's alpha values might be due to the inclusion of measures and techniques in the same construct. While the measures are highly agreed upon, some techniques might or might not necessarily be used. The test for these two constructs was repeated but excluding the techniques of MRP, supplier milk run, and 3PL. The new Cronbach's alpha values were 0.711 and 0.740 for lean inbound logistics and agile outbound logistics, respectively.

With regard to production ramp-up performance, to treat the low value of Cronbach's alpha, other measures representing the ramp-up problems were added, and the Cronbach's alpha was recalculated. The new value was 0.717. As illustrated in figure 3.2, all the values represent an acceptable level of reliability after adjusting the measurement model. However, the low Cronbach's alpha value for the ramp-up construct might be due to the formative nature of the construct. Freeze and Raschke (2007) indicated the importance of examining the significance of the path from the indicator to the construct to evaluate the validity of the formative constructs. The PLS path analysis is illustrated in chapter 5.

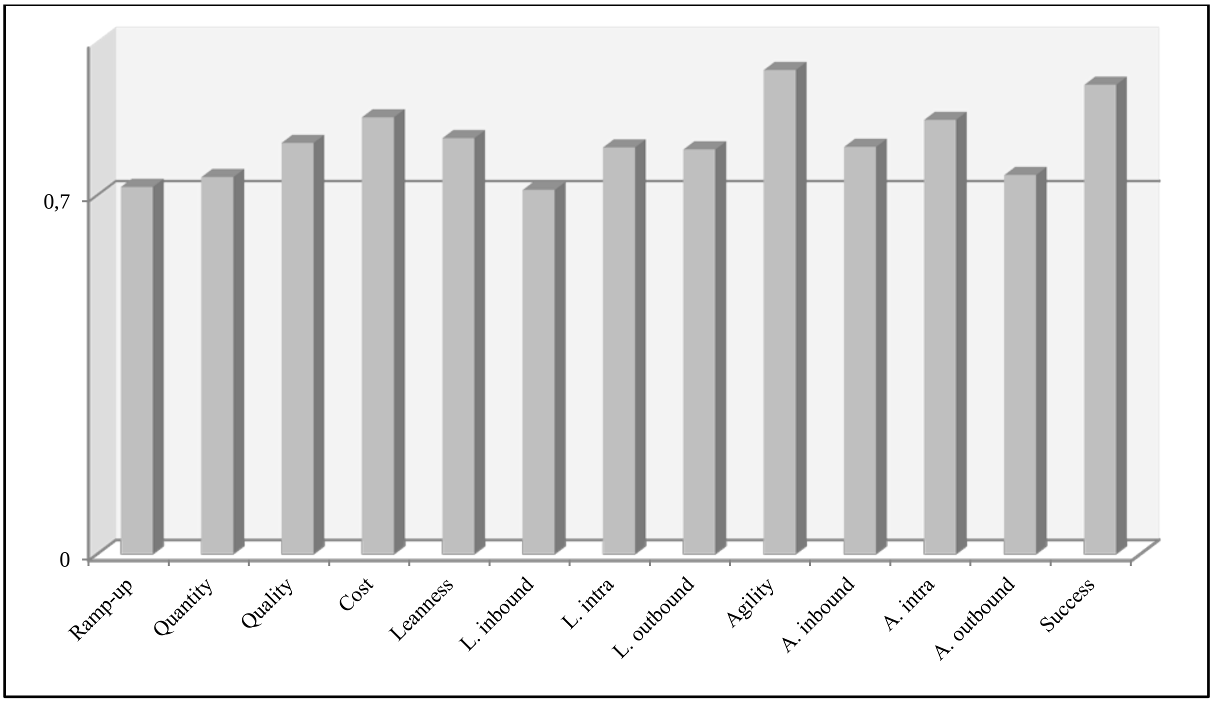


Figure 3.2: Cronbach's alpha values after adjusting the measurement model

Common Method Variation

As stated by Lindell and Whitney (2001), common method variation measures the existence of spurious correlations between research variables arising from the use of the same method to measure both independent and dependent variables in the investigated relationship. Common method variation leads to incorrect conclusions and unreliable research results (Rungtusanatham et al., 2003). A limited review conducted by Craighead et al. (2011) showed that around 87% of OPM research has not addressed the common method variation issue. While some researchers have used methodological, psychological, or temporal separation to reduce or eliminate common method variation, others have used statistical tools. According to the current research's type, and the nature of the data collection tool employed, methodological and temporal separations are not the appropriate tools to utilize. Nevertheless, the questionnaire's item organization according to the measurement scale rather than the variables measured contributed to minimizing the possible effect of common method variation, as a type of psychological separation, as indicated by Ba and Johansson (2008).

In addition, the marker variable technique proposed by Lindell and Whitney (2001) was utilized to identify and treat common method variation statistically. A marker variable construct that theoretically has no relationship with other variables was added to the model, and the correlation between the marker variable and all the other variables was tested. Low and satisfactory correlations values, ranging from 0.006 to 0.163, resulted. However, there are some disadvantages of the marker variable tool, as discussed by Podsakoff et al. (2012).

3.4. Data Collection Process

After formulating the research questionnaire, the following issues should be considered: identifying the targeted population, determining the sample, defining the tools and methods used to reach the respondents, and explaining the response rate and the representativeness of the responses.

3.4.1. Survey Population

Manufacturing firms were targeted in this empirical research due to the increasing importance of ramp-up enhancement in these firms (Almgren, 1999a; Sturm et al., 2003). In addition, the overwhelming majority of ramp-up research has been conducted in manufacturing settings. Limited attempts to consider service ramp-up have been made in the literature (e.g. Lenfle and Midler, 2009; Enz et al., 2014). The literature on lean and agile logistics is also predominantly considered in the context of manufacturing processes.

While many ramp-up-related survey studies have been restricted to a certain industrial sector (e.g. Salomon and Martin, 2008; Gross and Renner, 2010), region (e.g. Winkler and Slamanig, 2011), company size (e.g. Woodcock et al., 2000), or other dimension (e.g. Di Benedetto, 1999), other surveys have targeted less clearly defined populations (e.g. Langowitz, 1988). For research conducted in different industrial sectors, possible differences between the researched sectors have never been investigated. In this research, industrial companies in different sectors, different countries, and with different sizes were targeted to explore the existence of any statistically significant differences in the research results according to these dimensions.

The researched companies were targeted based on the availability of access to these companies to obtain as many responses as possible. While such an approach might imply disadvantages, such as higher sampling and non-observation errors (Scheaffer et al., 2011) and a lower ability to generalize the research results, a similar approach was followed by Langowitz (1988) in investigating production ramp-up problems.

A survey population is a collection of all the elements – people, firms, plants, or things – that the researcher wishes to investigate or to make inferences about (Forza, 2002; Scheaffer et al., 2011). The identification of the survey population aims to determine the elements' parameters and, hence, the measurement specifications (Scheaffer et al., 2011). The results of the survey can then be used by other population elements, due to the similarity of characteristics. The current research variables, and the questionnaire items used to measure these variables, are commonly used and understood by almost all manufacturing companies. Nevertheless, the targeted firms were not contacted randomly. Each contacted firm produces new products continuously and employs some of the lean and/or agile logistics activities.

In the production ramp-up literature, the achievement of the intended goals of identifying the research population is somewhat questionable. For example, Clark and Fujimoto (1991) investigated the auto manufacturers in the US, Europe, and Japan. However, the use of such a population does not mean that auto manufacturers outside these three regions have different characteristics. Moreover, manufacturing companies utilize similar production systems and strategies, but operating in different sectors might represent a more homogeneous population than manufacturing companies that operate within the same sector and employ different production systems or strategies. Di Benedetto (1999) identified his research population as all being practitioner members of the Product Development and Management Association (PDMA). Again, being members of the PDMA does not necessarily reflect common characteristics of the population.

While the current research population was not clearly identified, this was strongly believed to have only a limited effect on the reliability of the research results due to: (1) the nature of the variables used and (2) the similarities in the basic features of the production systems used all around the world because of increased globalization, growing transnational organizations, and the extensive IT revolution worldwide.

3.4.2. Sampling Issues

In addition to the survey population, statisticians have concentrated on identifying the survey sample to determine how representative the sample is for the entire population. Taking into consideration the dependency of the sample size on the population size, and the limited amount of survey research conducted in the production ramp-up field, many researchers have not mentioned their study’s population size (e.g. Langowitz, 1988; Clark and Fujimoto, 1991; Hatch and Mowery, 1998; Winkler and Slamanig, 2011). In a review of survey research in operations management, Rungtusanatham et al. (2003) reported that only 53% of the reviewed articles provided sufficient information about the target population. In addition, many ramp-up survey studies have been based on small sample sizes. For example, Langowitz (1988) analysed a sample of 15 new products produced by 7 facilities in 4 companies; Clark and Fujimoto’s (1991) sample included 22 auto manufacturers in 3 regions; Woodcock et al.

(2000) used a sample of only 6 British SMEs; and the studies by Winkler and Slamanig (2011), Slamanig and Winkler (2011), and Slamanig and Winkler (2012) were based on the same sample of 21 SBUs of manufacturing companies with multi-variant serial production.

De Beuckelaer and Wagner (2012) indicated that a small sample size might lead to lower statistical power, greater representativeness bias, the impossibility of sampling error identification, and a higher probability of unstable results. In the context of production ramp-up, Langowitz (1988) and Li et al. (2014) indicated the limited ability to generalize their research results due to the use of a small sample size (the populations of the research were not mentioned). However, De Beuckelaer and Wagner (2012) indicated that small samples comprise 30 observations or fewer.

The sample size of the current research is considered to be sufficient. Ramp-up research using sizable samples is limited: Salomon and Martin (2008) used a sample size of 265 semiconductor manufacturing plants, Di Benedetto’s (1999) sample included 183 usable responses, and Gross and Renner (2010) analysed responses from 71 manufacturers. While other surveys in the ramp-up literature have used much smaller samples, as previously explained, the majority of empirical research in this field has followed the case study methodology and targeted a single company (e.g. Kontio and Haapasalo, 2005; Miguel, 2008; Lenfle and Midler, 2009; Pufall et al., 2012b; Basse et al., 2014b). In addition, the partial least squares (PLS) approach will be utilized in the structural equation modelling (SEM) tool employed in the statistical analysis of the research model. This method has an advantage over the covariance-based SEM (CB-SEM) method regarding the use of a small sample size. According to the ‘10 times’ rule mentioned frequently in the literature for calculating the appropriate sample size for the PLS method (see Peng and Lai, 2012), a sample size of 40 is sufficient for analysing the current research’s proposed model. Furthermore, Flynn et al. (1990) indicated that, in theory verification, large samples are not necessarily required.

This research used judgement sampling (Forza, 2002), since the information needed can be provided only by experts with sufficient knowledge about the researched variables. Sampling error is related to the representativeness of the sample for the selected population (Malhotra and Grover, 1998). Sampling error’s importance increases when generalization becomes the main focus of the research. In addition, Flynn et al. (1990) connected the importance of using a large sample size to generalization issues. For the current research, generalization to the entire population could not be among the main aims, since this research was the first attempt to investigate the relationships between ramp-up performance and lean and agile logistics. Further research is required to provide verification of the proposed preliminary model.

3.4.3. Survey Methods

Many methods have been used to reach respondents, including personal contacts, telephone calls, mailing, and web-based methods. An evaluation of the different data collection methods used in the field of operations management was provided by Forza (2002), Dillman et al. (2014), and others. In addition to the conventional hard and soft copies, the questionnaire was made available online using Google Forms to facilitate completion, submission, and even data processing activities. Cook et al. (2000) stated that: ‘the potentials of the electronic survey are too great to be ignored’. In most cases, multiple contacts were made with the respondents, who included operations managers, authors in the ramp-up field with a practical background, researchers who had used a similar methodology, colleagues occupying managerial positions in industrial companies, and other persons who had personal contact with targeted practitioners. Dillman et al. (2014) stressed the importance of using a social exchange approach to motivate the respondents. Such an approach was utilized mainly through pre-contacts and other tools.

Since each questionnaire considers the ramp-up process for only a single product, some companies provided more than one response. The questionnaires from the same company were tested for similarities in responses to evaluate the existence of differences between the production systems of different products in addition to differences between the related logistics systems. Companies were asked to fill in only one questionnaire if different products or product types are produced within the same operational and logistical environment. Since contact information was provided by most of the respondents, additional contact was made with the respondent when further information was required, when some missing values existed, or even when an item seemed to have been misunderstood.

3.4.4. Response Rate Issues

The importance of the response rate for survey research success was discussed by Cook et al. (2000) and Frohlich (2002). De Beuckelaer and Wagner (2012) indicated the increased difficulties in attaining a high response rate and a sufficiently large sample. However, Cook et al. (2000) stated that the representativeness of the responses in survey research is more important than the response rate. Furthermore, the authors mentioned that concern about the response rate is important only if the sample’s representativeness is questioned. In addition, little or no relationship between the response rate and non-response bias was expected due to the nature of the research and the lack of exposure to confidential data.

A meta-analysis conducted by Cook et al. (2000) showed that the number of contacts, personalized contacts, and pre-contacts are the most influential factors in enhancing the response rate in survey research. These issues, in addition to other techniques discussed by Frohlich (2002), were used to enhance the response rate. However, the response rate cannot be calculated precisely for this research, since the respondents and colleagues were asked to submit the questionnaire to other potential respondents. Therefore, the total number of contacts made is difficult to specify. Nevertheless, the calculated response rate was around 23.35%, which is generally accepted in the operations management literature (see Malhotra and Grover, 1998). However, the actual rate is expected to be lower.

3.5. Data Evaluation

Finn and Wang (2014) highlighted the importance of distinguishing between formative and reflective measurement for the entire theory testing process. Diamantopoulos et al. (2008) mentioned the negative consequences of incorrectly specifying formative constructs as reflective ones. Freeze and Raschke (2007) explained some differences between formative and reflective variables in terms of identification, validation, and properties. The current research model mainly used reflective constructs, since the direction of the relationships is from the indicators or constructs toward the measures. However, the direction of the relationships with some measures might be more formative in nature. Identifying the nature of the constructs used is particularly important for explaining the results of the statistical analysis employed.

A review of the data used for the statistical analysis revealed that no pattern in responses could be identified and, thus, non-response error was not expected to exist in such a way that affects the results of the analysis. The importance of examining the non-response bias to determine the quality of the survey results was discussed by Clottey and Benton (2013); two questionnaires were eliminated from the statistical analysis due to clearly identifiable biased completion patterns. Some researchers have indicated that a lower response rate might be related to the non-respondent bias (Flynn et al., 1990). However, the response rate was not considered to be problematically low. In addition, the response rate can be explained by the length of the questionnaire, rather than by non-response bias. Furthermore, the importance of response bias minimization is more relevant to the generalization issues, as explained by Forza (2002).

Another aspect of data quality concerns the existence and handling of missing data. Forza (2002) explained the importance of preventing the existence of missing data and discussed some methods to enhance the completeness of the data, including respondent involvement, questionnaire design, and clear instruction availability. The online format of the current questionnaire contributed to minimizing the missing values by providing a progress bar that showed the percentage of questions completed. In addition, some respondents were re-contacted when missing values were identified, especially when these values were related to the main research variables rather than to the moderating variables. While van Buuren (2012) recommended the treatment of missing values with regression methods, this was considered to provide less reliable analysis results. In this research, the cases with missing values were excluded, since fewer than 5% of the values were missing, which was considered to be acceptable and to require no further interference. The results of the pattern analysis in SPSS show that missing values were identified only for 14 variables, 12 cases, and 15 values, as figure 3.3 illustrates.

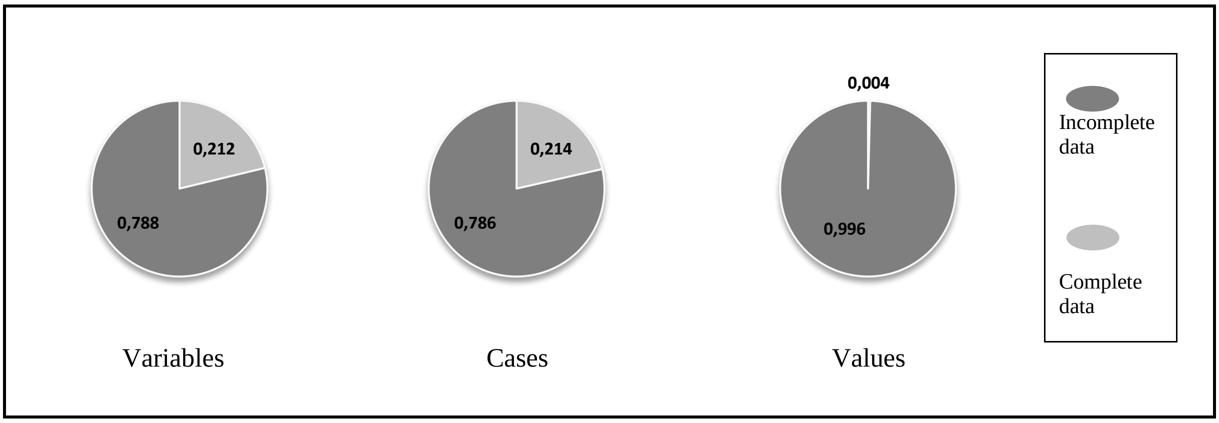


Figure 3.3: Missing values summary of the pattern analysis

3.6. Data Analysis

Preliminary or descriptive methods, including frequencies, percentages, means, and standard deviations, were used to organize, describe, and summarize the data. These provide a general view of the sample characteristics and help to compare these characteristics with those of different industrial environments to evaluate the applicability of the research's findings and recommendations.

Quantitative methods were used to test the proposed model and draw conclusions. Mainly, the PLS methods of SEM were used. Freeze and Raschke (2007) indicated that by using SEM, the researcher can assess the measurement model and the path model simultaneously. While the measurement model refers to the relationship between the constructs and their measures, the path model refers to the relationship between different constructs. Peng and Lai (2012) illustrated the advantages of using the PLS method, including the ability to estimate a model using a small sample without strict distribution assumptions, handle models that include both reflective and formative constructs, and avoid the inadmissible solutions and factor indeterminacy of covariance-based SEM (CB-SEM). Furthermore, Peng and Lai (2012) stated that PLS considers both common and unique variances, while CB-SEM focuses on common factor variances only. The authors also indicated that CB-SEM lacks the ability to estimate models with formative constructs.

Hair et al. (2012) indicated that PLS-SEM requires critical choices that can lead to improper findings, interpretations, and conclusions if not made correctly. Further details about the PLS methods utilized are included in chapter 5. The models' reliability and fitness were evaluated using different statistical indicators including:

- Items' standardized factor loadings, which should have values above 0.5 to indicate sufficient convergent validity (Bagozzi and Yi, 1988).
- Fornell and Larcker's (1981) rule for discriminate validity, whereby the average variance extracted (AVE) for a construct should be higher than its shared variance with any other construct.
- The standardized root mean square (SRMS) should be less than 0.060, as recommended by Hu and Bentler (1999).
- The variance inflation factor (VIF) should be less than 5 (Hair et al., 2011).
- The maximum heterotrait–monotrait (HTMT) ratio should be less than one (Henseler et al., 2011).

CHAPTER 4

MEASUREMENT TOOL DEVELOPMENT

4.1. Introduction

Developing valid measures for the research’s constructs is an important condition for theory building and testing (Finn and Wang, 2014). Empirically investigating the role of lean and agile logistics practices during the production ramp-up phase requires appropriate measures for each of the study variables. This measurement tool was structured as a questionnaire developed specifically for the purpose of the current research as a primary data gathering method. As explained by Flynn et al. (1990), in empirical or field-based research, data are collected from naturally occurring situations, rather than within laboratory or simulation research settings in which the researchers experience more control over the researched events. Special attention was paid to the development of the data collection questionnaire, since its validity, accuracy, and reliability determine the value of the concluding results and recommendations.

While the measures of the dependent variable – production ramp-up – are considered as performance measurement tools that capture the variation in performance during production ramp-up, this is not the case for each measure of the independent variables – lean and agile logistics. Some dimensions used to measure lean and agile logistics could be considered as leanness or agility performance measurement tools, but other items aim only to measure the existence of lean or agile logistics practices and not to measure the variation in their performance levels. However, a general view of the variation in the performance in the three main areas of investigation (ramp-up, lean, and agile logistics), in addition to a general evaluation of new product success, is possible using the data collection method constructed.

The following sections provide a preface for the performance measurement of a manufacturing process and evaluate the measurement tools developed and employed in the related literature to reach acceptable, valid, and comprehensive measures of ramp-up performance and levels of leanness and agility in the logistics system beside the new product's success evaluation and the moderating variables.

4.2. Performance Measurement

The success of any project is judged through the achievement of its predetermined goals (Lim and Mohamed, 1999). Accordingly, organizational performance can be seen as the outputs actually achieved compared with the ones planned (Richard et al., 2009; Yang et al., 2014). The cornerstone in achieving organizational goals lies in the level of efficiency and effectiveness of the actions taken within the organization. Therefore, measuring performance can be defined as the process of quantifying these levels of efficiency and effectiveness of an organizational action (Neely et al., 1995). This process can be used to compare the current system with alternative systems (Beamon, 1999) and to drive improvement programmes (Hon, 2005).

Organizations employ several types of performance measures that deal with different functions and activities. In this research, only measurement criteria related to the manufacturing performance were considered. In addition, the specific settings, requirements, and objectives of the ramp-up process were addressed. However, this phase's specific characteristics were not stressed while measuring the logistics system performance, since the same logistics activities were assumed to take place before and after ramp-up. Performance measurement is considered as an integral part of the management process (Chenhall, 1997). Furthermore, levels of performance cannot be improved without measuring the current performance and comparing it with the planned levels or benchmarks. Dixon et al. (1990) indicated the importance of performance improvement for manufacturing companies' financial well-being.

The literature has shown that considerable efforts have been devoted to clarifying the issues required to develop successful performance measurement systems (Folan and Browne, 2005). More consideration of these issues and characteristics enhances the effectiveness and the validity of the measure. Furthermore, these issues determine the usability, adaptability, and relevance of the measure (Hon, 2005); such characteristics include:

- Simplicity, which concentrates on the ease of data collection (Hon, 2005).
- Inclusiveness, which insists on the consideration of all the related aspects (Beamon, 1999).
- Consistency with the organizational goals (Dixon et al., 1990); this enables the alignment of goals and actions (Hon, 2005). Without such a property, the specific actions proposed by the measurement results cannot affect the overall goal achievement (Fry and Cox, 1989), and, more specifically, Maskell (1991) stressed the importance of being consistent with the manufacturing strategy.
- Pervasiveness (Hon, 2005) or integration (Neely et al., 1995), allowing the use of the measure vertically and horizontally in the organization.
- Adaptability; the measurement framework should be adaptable to the consistently changing external environment (Ghalayini and Noble, 1996) and vary between locations and over time (Maskell, 1991).
- Universality, which enhances consistent comparison abilities with varying conditions (Beamon, 1999).
- Measurability, so unmeasurable items should be ignored (Beamon, 1999).
- Credibility; Kaydos (1991) stated that a creditable measurement is able to explain 80% of the variation in performance.

Some of these characteristics are less related to the context of the current research, since the aim of this research is not to develop a performance measurement system for a certain company; rather, it aims to develop a general system that can be used in a multi-company environment. The consistency with organizational goals, as an example, was considered in a general form since different companies have different goals, but common goals that are usually shared by different organizations, such as profitability and customer satisfaction, were relevant. Similarly, inclusiveness is more related to a single-company performance measurement system, and the achievement of such a property could not be possible using a common system designed for multiple companies. Furthermore, adaptability issues are connected to a continuous measurement process, which is also beyond the scope of the current research and is regarded as a single-time measure. Doltsinis et al. (2013) explained that the measurement tool design and implementation depend on the purpose of measurement.

4.3. Measuring Ramp-Up Performance

The positive contributions of performance measurement to any manufacturing process are indubitable (Hon, 2005). The importance of developing and using accurate performance measurement tools and methods is increasing for both researchers and practitioners (Bourne et al., 2000; Folan and Browne, 2005). Like other manufacturing phases, an appropriate measure of efficiency and effectiveness is required throughout the phase of production ramp-up. In their holistic approach to production ramp-up, Schuh et al. (2005a) stressed the importance of ramp-up evaluation through benchmarking techniques, which include the determination of the relevant qualitative and quantitative performance measurement parameters. Furthermore, Gross and Renner (2010) stated that ramp-up's success should be reinterpreted using performance-related concepts.

Despite the importance of measurement issues and the availability of sufficient research efforts for measuring performance during steady-state production (for a review see Folan and Browne, 2005; Neely, 2005; Nudurupati et al., 2011), a comprehensive measurement of production ramp-up performance is lacking. Doltsinis et al. (2013) confirmed that sufficient research literature on measuring performance in mature manufacturing settings is available. Similarly, Bourne et al. (2000) indicated the existence of multidimensional performance measurement systems for steady-state production. On the other hand, Doltsinis et al. (2013) asserted that the ramp-up literature is lacking sufficient efforts to develop such a measurement system. In addition, a focus on the financial perspective as a predominant single dimension characterized the ramp-up literature (e.g. Bohn and Terwiesch, 1999; Terwiesch and Bohn, 2001; Terwiesch and Xu, 2004; Carrillo and Franza, 2006). Neely (2002) indicated the increasing importance of developing non-financial measures of performance. However, special characteristics of the ramp-up phase limited the prospect of using conventional performance measures for a mature production process.

4.3.1. A Tailored Ramp-Up Performance Measure

The differences between the ramp-up and the steady-state phase take many forms and rage from general goals and objectives to specific technical issues. These differences should be reflected in the measurement of the manufacturing performance during these two phases. For example, in measuring ramp-up performance, more attention should be directed toward the time-based performance, since ramp-up success has always been linked to reducing the time-to-volume duration (Terwiesch and Bohn, 2001; Doltsinis et al., 2013; Schmitt and Schmitt, 2013; Li et al., 2014). In other words, the ramp-up performance measure should concentrate more on effectiveness and time-related goal achievements, while in the steady-state phase following ramp-up, more attention is usually directed toward cost-related aspects and process efficiency, since mature products compete more on the base of price than on the base of differentiated attributes (for more details see chapter 6). This should be linked to the price fall experienced by new products as competitors introduce similar products, turning the new innovative product into a commodity that customers judge through price rather than features. Terwiesch et al. (2001) highlighted this fact with a focus on the hard disk drive industry.

On the technical side, while the cycle time is considered to be stable during the mature production process, it experiences a continuous drop throughout the ramping up of the production process (Baloff, 1966; Terwiesch and Bohn, 2001) due to learning and other factors. Therefore, the rate of the cycle time decrease is critical for evaluating the ramp-up process. However, in addition to the high level of fluctuation, Chen et al. (2009) mentioned some sudden increases in the lot cycle time in the semiconductor industry. Another point made by Chen et al. (2009) regarding the ramp-up process was the rapid increase in the work-in-process and the utilization levels.

Measuring performance during production ramp-up without considering the differences between ramp-up and other production stages might produce misleading results that in turn provide the wrong materials for making managerial decisions during this critical phase.

4.3.2. Categorization of Performance Indicators

Instead of developing narrow and constantly specified measures, authors have frequently tended to group performance measurement indicators into wider and more general categories. This tendency can be noted in the performance measurement literature on both ramp-up and steady-state production. One of the most famous categorization attempts is the balanced scorecard (Kaplan and Norton, 1992; Kaplan and Norton, 1996), whereby performance measures are differentiated into categories with four perspectives: financial, customer, internal business, and innovation and learning. Leong et al. (1990) argued that manufacturing tasks, and consequently the key performance dimensions in a manufacturing process, fall into one of the following categories: quality, delivery speed, delivery reliability, price (cost), and flexibility. In addition, Bourne et al. (2000) distinguished between measures derived from strategy and measures aiming to challenge the strategy. On the other hand, De Toni and Tonchia (2001) differentiated between cost-related measures, such as production cost and productivity, and non-cost measures, such as quality, time, and flexibility. Hon (2005) categorized 442 individual measures collected by Hon and Serna (2005) into the following 5 categories: cost, quality, productivity, time, and flexibility measures. With a service-oriented view, Fitzgerald et al. (1991) considered the dimensions of resource utilization, quality, innovation, and flexibility.

With regard to the production ramp-up literature, most researchers, while developing their measurement tools, have concentrated on performance indicators that fall within one of the following categories: time, quantity, quality, and cost (Surbier et al., 2014). Likewise, Gross and Renner (2010) showed that the dimensions of quality, time, and cost dominate the ramp-up literature (e.g. Urban and Seiter, 2004; Scholz-Reiter et al., 2007; Winkler et al., 2007; Herrmann et al., 2009). In many cases, time and quantity have been considered as one construct, and indicators used to measure time performance have also been used to measure quantity performance. This could be due to the excessive dependence of the ramp-up time on the production rate and cycle time, which are, at the same time, the major indicators of quantity performance. The length of the ramp-up time, however, might depend on factors other than productivity-related factors, such as quality loss, tooling, experimentation rate, and so forth.

In three studies published in 1999 and 2000, Almgren used three different measurement tools for production ramp-up performance (as part of the final verification process). While in Almgren (1999a) the author used the overall equipment effectiveness – which was defined by Nakajima (1989) as the value-added through the use of equipment – and divided the construct into the three variables of availability, operation performance, and quality performance, in Almgren (1999b) he used capacity, quality, and cost to measure ramp-up performance. However, in Almgren (2000) he argued that performance during production ramp-up is subject to two parameters: throughput time and efficiency. Juerging and Milling (2006) used the dimensions of process conformance, product conformance, quantitative ratios, and quality to describe the outcomes of the production ramp-up process. Apilo (2003) measured ramp-up performance through yield, supplier performance (number of missing items), process cycle time, and delivery accuracy. In addition, Scholz-Reiter et al. (2007) and Elstner and Krause (2014) indicated the dimensions of time, cost, and quality in dealing with production ramp-up. Winkler et al. (2007) linked ramp-up performance indicators to the goals pursued during this phase (which was regarded as a time-defined project). The main three goals mentioned by the authors were effectivity, efficiency, and deadline goals. A similar attempt to study ramp-up from the project perspective was undertaken by Kontio and Haapasalo (2005). Alternatively, Ball et al. (2011) considered learning, capacity, and cost to measure ramp-up performance.

Another direction in studying ramp-up variation was taken by Langowitz (1988), who measured 18 ordinal and dummy variables to represent the variation in the performance during initial commercial manufacturing; some of these variables could be linked to the system productivity, such as production process deviation, work schedule deviation, and output and delivery target achievement; others were related to the quality, such as supplier quality mismatch and quality target achievement; and other factors were related to the workers and the equipment used, such as worker errors, poor documentation, and new tooling, material, or software mismatch. All of these might affect cost, quality, or quantity performance. Similarly, Fjällström et al. (2009) categorized 30 empirically deduced critical events during production ramp-up into 6 categories: process, supply, quality, technique, education, and organizational actions.

Doltsinis et al. (2013) argued that the aims of performance measurement should vary according to the specific stage during ramp-up. According to a three-stage classification, Doltsinis et al. (2013) proposed that the focus on the early ramp-up stage should be on the functionality of the process; this focus shifts in the second stage to the output quality, while performance optimization is the focus of the final ramp-up stage (see figure 4.1). The authors referred to the process with all of the cycle time, cycle time phase, and duration within acceptable ranges as an optimized process.

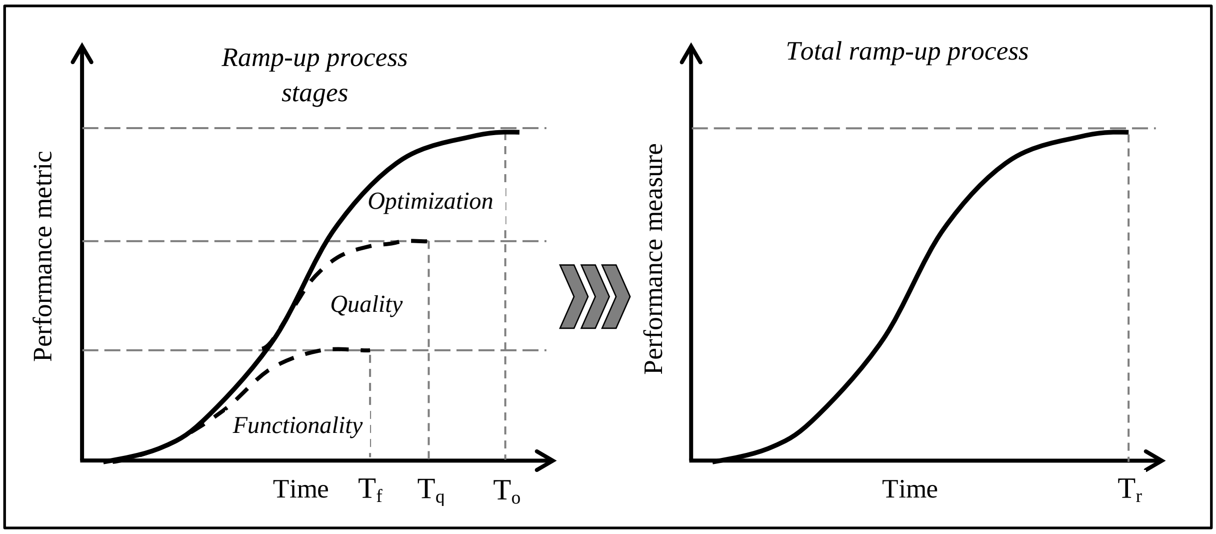


Figure 4.1: Ramp-up temporal classification according to Doltsinis et al. (2013)

Such a temporal classification lacks further support in the literature. In addition, the generalization of this model is greatly restricted due to the nature of the underlying research that considered the environment of an assembly station. Furthermore, the duration of each stage could not be easily defined. For example, while dysfunctional process starts require a prolonged initial stage, a smooth start with minimum functional failures might greatly shorten this stage. However, a similar classification was used in one of the quantity-related measurement items in the current research to examine the validity of such clarification.

4.3.3. The Developed Measure

The current research considered three performance measurement categories, consisting of quantity performance, quality performance, and cost performance. These categories reflect the most important aspects that should be considered in any activity taking place during the production ramp-up phase. Time-related performance was included in the quantity performance, which is composed of a comprehensive measure that includes productivity aspects, in addition to factors that affect the total quantity produced during the ramp-up period (and consequently the total time consumed). Mallick and Schroeder (2005) argued that time could be viewed more as a resource than as an outcome. This was supposed to support the consideration of quantity rather than time for this dimension.

A distinction between economic measures and technical measures that is more relevant to the shop floor and the operating departments was presented by de Ron (1995). Doltsinis et al. (2013) elucidated the two main trends noted in the literature to focus on performance measures that aim either at supporting managerial decisions taken at high organizational levels or at enhancing lower levels’ performance. Di Benedetto (1999) differentiated between strategic and tactical activities in a new product launch. The ramp-up performance indicators used concentrated more on the operational level, which was in line with the explorative nature of the research. Doltsinis et al. (2013) argued that the control loop performance approach, based on the work of Harris (1989), which is used to control the performance variation at the process level, can be linked to production ramp-up through combining process measurements in a higher-level index. This direction is also characterized not only by being company-specific but also by being process-specific; the general measure sought by this research cannot be derived from a specific process control technique. However, since data were also collected on the overall success of the product undergoing the ramp-up process, the results could also support higher levels of the decision-making process.

The details of ramp-up’s performance measurement tool developed according to the three categories of quantity, quality, and cost are the following. In addition to the specific items used to measure each dimension, an overall assessment of the ramp-up goal attainment regarding volume, time, quality, and cost was employed to evaluate the consistency of the responses and to cover other facets of performance that were missed in the current questionnaire or that were specific to the respondents’ company environment. Furthermore, this would help to explore how respondents distinguish – if at all – between quantity-related and time-related performance.

Quantity Performance

As mentioned above, the quantity dimension of the performance measure contains time-related variables in addition to productivity-related variables. The arguments regarding which variable should be mentioned (time or quantity) are less related to the final aim of the measurement tool. Quantity and time dimensions are the most important during production ramp-up, since they are more related to the highly stressed goal of this stage. Scholz-Reiter et al. (2007) affirmed that the primary goal of the ramp-up phase lies in the fast achievement of secure production. Many other authors (e.g. Almgren, 1999a; Terwiesch and Bohn, 2001; Niroomand et al., 2014) have also emphasized this goal.

Many dimensions can be employed to measure this performance dimension, including productivity, capacity utilization, cycle time, D:P ratio – that is, the delivery lead time to production lead time ratio (Maskell, 1991), setup time, and others. Each one of these major categories can be measured using different tools and sub-dimensions. As an example, Hon (2005) indicated some variables used to measure the productivity of a production system, including assembly line effectiveness, machine effectiveness, network effectiveness, equipment effectiveness, direct labour productivity, total productive maintenance, value-added per employee, and so on. Specific measures and dimensions are more related to the cases in which a certain case or system is under consideration. Therefore, more general measures that fit most cases were considered.

Productivity

Regardless of the case or system being investigated, productivity measures are of great importance and should be considered. Researchers in the ramp-up field have used different tools to capture this dimension. Pufall et al. (2007) measured operational performance through the ratio of actual sales to planned sales. Collecting sales data as well as production data requires a comprehensive view that might not be available to all respondents. Furthermore, the ramp-up phase is generally characterized by a high demand rate and a relatively lower production rate (Terwiesch et al., 2001). Consequently, the sales volume and production volume are supposed to be the same during the ramp-up period. Hence, a measure that deals directly with the production rates is more appropriate. Terwiesch and Bohn (2001) concentrated on production starts rather than production time and measured the number of starts per hour, which represents the speed of production. Almgren (2000) measured the rate of actual production to planned production as a representative of quantity performance. Almgren (2000) considered both quantity and quality performance as an operationalization of the throughput time measure, which measures the speed of performing activities required to attain the output targets. Instead of measuring the actual production to planned production ratio, Terwiesch and Bohn (2001) and Terwiesch et al. (2001) measured the actual production to available resources ratio, which is frequently referred to as the utilization rate.

The direct measure of the actual to the planned production rate was employed with an attempt to classify the ramp-up phase into three stages to explore whether significant differences in the rate of production and deviation from targets can be noted among the different stages of ramp-up. Doing so might provide empirical evidence to support or oppose the classification approach developed by Doltsinis et al. (2013).

Cycle Time Reduction

Another quantity-related performance measure is the cycle time (Hon, 2005). Haller et al., (2003) indicated that the cycle time is the main control parameter of the ramp-up process and explained the effect of the cycle time’s length on the learning process, start and output rates, and process yields. The dynamic nature of the ramp-up phase (Chen et al., 2009), side by side with the crucial effect of learning (Terwiesch and Bohn, 2001), contributes to the continuous decrease in the production cycle time throughout the ramp-up process. By the end of the ramp-up phase, the cycle time tends to be more stable and further reductions in the cycle time require significant efforts and changes in the production system. The production rate might be an insufficient measure of the ramp-up process, especially during the early stages of production (Doltsinis et al., 2013); a measure of the change in the production rate over time is more consonant with the characteristics of this phase. Therefore, measuring the rate of reduction in the production cycle time can represent the progress of the process well. A similar attempt to measure the progress of the process considering the dynamic nature of the ramp-up process was made by Flaherty (1992), who focused on the capacity development rate, which represents the ability of the firm to increase the rate of output to the design capacity.

Alternatively, Doltsinis et al. (2013) used the term ‘functionality’ to measure the deviation from the targeted cycle time and linked this term to assembly line operations. No further research has supported the use of this measure within other manufacturing environments. In addition, the forecasting of the cycle time during ramp-up to develop the production plan or to identify the target cycle time is a challenging process (Chen et al., 2009).

Learning Rate

Learning is one of the most influential variables during the ramp-up process. The duration of this period depends heavily on the learning process (Terwiesch and Bohn, 2001; Terwiesch and Xu, 2004). Terwiesch and Bohn (2001) indicated the effect of the experimentation rate aimed to enhance induced learning on production rates during ramp-up. In addition, Haller et al. (2003) explained that the production rate and the experiments designed contribute to enhancing learning. In other words, induced learning affects the production rate, which in turn affects autonomous learning.

A restricted consideration of learning as a separate measure of ramp-up in the literature was attributed to the tendency noted in some research to link learning solely with production volume. On the other hand, some researchers have measured the entire ramp-up performance through learning (e.g. Lee and Matsuo, 2012). However, Juerging and Milling (2006) stated that variation in ramp-up times cannot be based only on the learning curve, especially in auto manufacturing.

Unplanned Production Stops

Layovers in the production process affect the duration of the ramp-up phase and occur for many reasons, such as machine downtime (Hon, 2005), design experiments (Terwiesch and Bohn, 2001; Haller et al., 2003), a lack of materials (Almgren, 2000), and equipment-related problems (Fjällström et al., 2009). In some cases, production stops are planned and aim to enhance the overall performance of the system, such as in the case of designed experiments that contribute to enhanced induced learning levels. Thus, only unplanned stops that increase the deviation from the targeted production and timing goals were considered.

In addition to the main objective of exploring the effects of lean and agile logistics activities on the frequency of production stops, further analysis of the data collected might provide an insight into the co-existence of other problems with unplanned production halts and, hence, reveal other non-logistics reasons for production stops.

Other quantity- and time-related measures were mentioned by Hon (2005), including the average batch processing setup time, takt time, and throughput time. Woodcock et al. (2000) focused on the time needed to reach full productivity. Almgren (1999a) measured the overall equipment effectiveness. Carrillo and Franza (2006) mentioned the importance of design-related knowledge to ramp-up. In addition, famous quantity-related performance measures are the utilization rate (Schuh et al., 2005a) and the effective utilization rate (Terwiesch and Bohn, 2001; Pufall et al., 2007), which are related to capacity and effective capacity, respectively. Terwiesch et al. (2001) listed different components of effective capacity, including takt time, downtime, and yields. To avoid duplication of measurement that might confuse the respondents, no items were dedicated to measuring the utilization; inputs that construct the utilization measure, such as output rate, yields (under different quality-related terms), and cycle time, were considered through other items in the questionnaire.

Quality Performance

Producing quality products has been considered by some authors (e.g. Cooper and Kleinschmidt, 1987; Führer, 2008) as the main objective to be achieved while introducing a new product. Schmitt and Schmitt (2013) stressed the effect of quality requirements' fulfilment on production ramp-up delay. It is worth noting that quality objectives can vary among different products (Doltsinis et al., 2013) and wrongly setting quality standards might produce a high rejection rate and, consequently, more revisions and additional costs (Clawson, 1985). However, Doltsinis et al. (2013) indicated that the low production rate during the early production stages hinders the applicability of quality-related performance parameters, since quality measurement requires relatively large test runs and time. Nevertheless, quality measurements have been used by several researchers. In addition, reaching the required levels of quality is an indicator of the end of the ramp-up phase.

While de Ron (1995) indicated that the types of quality should include the quality of the product and the quality of the process, in the current research, only the product quality was considered. High process quality can be linked to other product-related outcomes, such as cost and quality. In measuring product quality performance, two important perspectives should be considered: the company perspective and the customer perspective. The first one was measured through the rate of defective products to total production, and the latter was measured through the rate of returned products to total sales.

Defective Products Rate

This measure is related to the degree to which the produced unit matches the predetermined specifications and description. Researchers have measured product quality, from an internal perspective, under different rubrics, such as conformance to specifications (Harveya and Green, 1993; Juran and Godfrey, 1999), product quality (Almgren, 2000), and yield (van der Merwe and Frizelle, 2003; Terwiesch and Xu, 2004), and using different tools, including the rework and scrap percentage (Hon, 2005), rate of products without known defects (Almgren, 2000), proportion of output with sufficient quality to sell (Salomon and Martin, 2008), faults per unit (van der Merwe and Frizelle, 2003), rejection rate (Schuh et al., 2005a), and process capability indices (PCIs), which numerically measure whether a manufacturing process meets the quality requirement (Lin and Pearn, 2005). In the current research, an evaluation of the relative number of defective outputs from low to high was used. Since product specifications are usually developed to meet customer requirements, this quality measure can also contribute to the customer perspective of quality. However, when it comes to new products, the actual and the forecasted customer requirements might vary significantly.

Returned Products Rate

Customer-perceived quality is important for reducing lost sales and enhancing customer retention (Pufall et al., 2007). Many tools can be employed to measure this dimension, such as the return rate (Hon, 2005), reliability (Neely et al., 1995), conformance (Neely et al., 1995; Almgren, 2000), and satisfaction with quality (Gross and Renner, 2010). To capture customer-perceived quality without collecting data directly from customers or end-users, the rate of returned products might be an appropriate measure. Defective units are supposed to remain in the company for scrap or rework, not to be sold to the customer. Therefore, the returned products rate is supposed to represent further quality problems that are not discovered within the manufacturing facility.

Quality Level Deviation

Some of the quality troubles may not be related to the nature of the ramp-up process and as such continue after the end of this stage. Therefore, measuring the acceptable deviation in quality level in comparison with steady-state production is helpful in concentrating the investigation on the ramp-up-specific parameters. The measurement of the deviation of quality level from the targeted levels has received a great deal of interest in the process control literature. Deviation of quality from planned targets was mentioned by Winkler et al.

(2007). Another important quality-related measure during production ramp-up is yields (Terwiesch and Xu, 2004; Lee and Matsuo, 2012). Yields significantly affect process economics (Mclvor et al., 1997). Yields have been used as an indicator of product maturity (Haller et al., 2003). Doltsinis et al. (2013) mentioned the importance of the production yield, as it combines both production volume and output. Likewise, Bohn and Terwiesch (1999) showed that a 3% increase in yields can produce about a 6% increase in gross revenue and around a 17% increase in contribution.

Cost Performance

A considerable debate on the use of the cost dimension to measure ramp-up performance has taken place in the literature. Doltsinis et al. (2013) argued that the production cost is already predetermined during the development process and that additional costs might be encountered during ramp-up only if additional resources are used. Doltsinis et al. (2013) also stated that cost metrics are mainly used for managerial decision support rather than for technical decisions, as they are not connected directly to performance. In addition, Möller (2005) indicated that data related to costs are usually available too late. Furthermore, Pufall et al. (2007) clarified that the short-term impact of the cost during production ramp-up is minor compared with the impact of lost sales resulting from delays.

On the opposite side, cost performance has been considered by many researchers (e.g. Terwiesch and Bohn, 2001; van der Merwe and Frizelle, 2003; Hüntelmann et al., 2007; Meyer, 2008; Gross and Renner, 2010; Ball et al., 2011) due to its relevance and importance. Among the frequently mentioned characteristics for the ramp-up phase are fluctuation (Chen et al., 2009) and deviation from plans (Schuh et al., 2005a). Gross and Renner (2010) indicated that cost objectives are less predictable than timing and quality objectives during ramp-up. Even if the ramp-up costs are pre-planned, the deviation from the targeted cost levels should be captured. In addition, while the exact cost figures require a long time to prepare, a general evaluation of these costs is possible even during the ramp-up process. Furthermore, managerial decisions regarding cost should be translated into lower-level technical strategies. Almgren (2000) measured the ratio of standard costs to actual costs. The actual costs include the extra costs incurred during production.

Variable Costs

The per-unit cost represents a wide array of variable manufacturing costs that vary as the quantity produced changes. Hon (2005) and Neely et al. (1995) used the unit manufacturing cost to measure performance. Beside the unit manufacturing cost, Hon (2005) mentioned other variables to be measured, including the overhead cost, setup cost, tooling cost, unit labour cost, and unit material cost. Almgren (2000) used the rate of standard costs to actual costs as a measure of system efficiency during the final verification process, and Terwiesch and Bohn (2001) considered the cost per production start in their mathematical analysis of the ramp-up period.

Other researchers have considered variable costs during production ramp-up, including Ball et al. (2011), who focused on recurring costs that arise with every unit produced, and van der Merwe and Frizelle (2003), who used labour hours. Similarly, Almgren (1999b) employed an engineering cost model based on Kilbridge and Wester (1966) to determine the cost associated with start-up. He operationalized the deviation of output from planned levels as quantity or quality loss. Both quantity and quality loss were considered as sources of additional manufacturing costs; these costs were captured through the additional labour hours (which are a deviation from the planned labour hours) required to achieve the targeted goals. In this case, costs were considered as an indicator of both the output quantity and the output quality. To investigate the trends in the production cost that might be relevant to the ramp-up phase, the unit production costs were compared with the unit production costs during the steady-state production phase.

Costs of Preparing the Production System

The ramping up of new products requires substantial modification to the production system; otherwise, the production process might be inefficient (Matta et al., 2008). Thus, preparing the production system for the ramp-up process requires a high level of investment (Ball et al., 2011). Intensified investment in process modification increases the pressure to ramp up the production successfully to repay the fixed costs quickly.

Considering production ramp-up, Ball et al. (2011) investigated the non-recurring costs that arise at the beginning of the product lifecycle. Preparing the production system for producing a new product might include installing different machines, tools, and technologies, providing training programmes, and investing in testing capabilities.

Repair, Rework, and Scrap Costs

In addition to the fixed costs related to preparing the system for new products and the variable costs related to the volume produced, other costs that might be of significance during the ramp-up process are the costs of repair, rework, and scrap. These costs are more related to failures and deviation in the production process from planned targets. Unlike fixed and variable costs, repair, rework, and scrap costs can be significantly reduced as the production process is enhanced. Hon (2005) used the scrap cost to measure the manufacturing performance. Such a type of cost could be an excellent indicator of the smoothness of the ramp-up process, which is characterized by fluctuation, variation, and high failure rates. However, Gross and Renner (2010) used an overall evaluation of cost performance by measuring satisfaction with costs and the achievement of cost targets.

Problems during the Ramp-Up Phase

In addition to the dimensions of quantity, quality, and cost, ramp-up performance has been measured through the frequency of occurrence of production trouble. Some researchers (e.g. Almgren, 1999b; Terwiesch and Bohn, 2001; van der Merwe, 2004) have indicated that late engineering changes and other difficulties, such as production disturbances, a lack of training, and problems with material supply, seem to be very common during production ramp-up. Each problem occurring during the ramp-up process will affect one or more of the three performance parameters used. For instance, Terwiesch and Bohn (2001) indicated the delay occurring in the launch of technology products due to ramp-up problems. Combining the two measurement tools brings additional insights into the overall process performance. Beside its performance indication, data on ramp-up problems were analysed to explore their effect on the overall success of the process as well as its relations with lean and agile logistics activities. The investigation of ramp-up problems is supported by the literature. Researchers who have focused on this matter include Langowitz (1988), Simola et al. (1998), Almgren (2000), Terwiesch and Bohn (2001), Fjällström et al. (2009), and others.

Problems that appear during the ramp-up phase can be classified according to their sources; problems can be linked, for example, to the material supply quantity, quality, or timing (Almgren, 2000); machines (Fjällström et al., 2009); equipment and tooling (Langowitz, 1988); employees’ attendance, rotation, or skills (Almgren, 2000); or mismatch between the new product and the current production process (Langowitz, 1988).

In this research, common problems with the probability of occurrence within different industries and different environments were measured, including problems related to the material supply, production machines, equipment and tooling, production employees, production process, product design, technology employed, cooperation among departments, and information flow.

4.4. Measuring Logistics Performance

Taking into consideration the great deal of overlapping between logistics and production (also see section 8.5.1), the measurement of logistics should be based on a concrete definition of and theoretical separation between the two constructs. As explained in section 2.2.2, logistics in this research was linked to the movement and storage activities of all inventory types. As proposed by Svensson (2003), Baudin (2004), Bardi et al. (2006), Langley et al. (2008), Sadjady (2011), and others, logistics activities were classified into inbound, intra (also in-plant, internal, or materials management), and outbound logistics. Regarding inbound and outbound logistics, only the first tier of suppliers and customers was considered, since investigating the supply chain integration is beyond the objective of this research.

Due to its multifaceted nature, logistics performance should be measured according to different angles (Wu, 2002). In general, measuring logistics' overall performance involves measuring the performance of the activities executed within each one of the logistics divisions. Logistics activities include a broad spectrum of internal and external activities. Some of these activities might also be classified under different labels and functions, such as production, marketing, finance, and so on. A list of logistics activities mentioned in the literature is provided in table 4.1.

Table 4.1: Logistics activities

Activity	In
Transportation/shipping	Duclos et al. (2003), Bardi et al. (2006), Langley et al. (2008)
Warehousing	Bardi et al. (2006), Sadjady (2011)
Inventory management/control	Duclos et al. (2003), Bardi et al. (2006), Langley et al. (2008)
Material handling	Gundlach et al. (2006), Langley et al. (2008), Sadjady (2011)
Industrial packaging	Duclos et al. (2003), Langley et al. (2008), Sadjady (2011)
Order processing	Bardi et al. (2006), Gundlach et al. (2006)
Documentation	Duclos et al. (2003)
Customer service	Bardi et al. (2006), Gundlach et al. (2006), Langley et al. (2008)
Customs transactions	Duclos et al. (2003)
Order fulfilment	Langley et al. (2008)
Distribution planning/physical distribution	Bardi et al. (2006), Gundlach et al. (2006)
Production planning/scheduling	Bardi et al. (2006), Langley et al. (2008)
Requirement planning	Bardi et al. (2006)
Facility location	Langley et al. (2008)
Purchasing/procurement	Bardi et al. (2006), Langley et al. (2008)
Demand forecasting	Bardi et al. (2006), Langley et al. (2008)
Return good handling	Gundlach et al. (2006), Langley et al. (2008)
Part and service support	Langley et al. (2008)
Reverse logistics	Duclos et al. (2003)
Salvage and scrap disposal	Langley et al. (2008)
Tracking	Duclos et al. (2003)
Pricing	Bardi et al. (2006)

In developing the measurement tool, more attention was paid to transportation and inventory activities than other activities due to their importance. Langley et al. (2008) indicated that transportation is the source of the largest variable logistics cost. Bardi et al. (2006) stressed the importance of transportation–inventory trade-offs for total logistics cost minimization. The importance of transportation and inventory as major cost centres was also shown by Christopher (2011).

The manufacturing process significantly affects the logistics activities (Wu, 2002). Thus, using a certain manufacturing technique, such as lean or agile manufacturing, will influence inbound, intra, and outbound logistics activities. Furthermore, many aspects of lean and agile manufacturing cannot be enabled without logistics support. Baudin (2004), as an example, argued that lean logistics can be considered entirely as part of the lean manufacturing system. Therefore, the measurement of the existence and the performance of lean or agile logistics cannot be detached from the measurement of lean or agile manufacturing. Consequently, many items used in the current measurement tool to evaluate lean and agile logistics might also be used, and in many cases were originally used, to measure lean and agile manufacturing. Similarly, some items used to measure logistics might have originated to measure supply chain performance, since logistics is frequently considered in the context of the supply chain (Bardi et al., 2006; Langley et al., 2008; Christopher, 2011; CSCMP, 2014).

In an attempt to measure logistics performance, Fawcett and Cooper (1998) conducted a longitudinal empirical study in which they highlighted 10 of the most important cost-related measures listed according to their importance score. These measures, along with their relative importance score, are shown in figure 4.2. Other attempts include the four-dimensional measure proposed by Wu (2002) that evaluates performance in three fields, consisting of quality, customer satisfaction, and cost. Stank et al. (2001) measured logistics performance from a customer service point of view using seven questionnaire items focused directly on customer satisfaction with logistics activities. Gimenez and Ventura (2003) and Gimenez and Ventura (2005) used the factors of transport cost, order processing cost, stockout, and lead time, among other items, to measure logistics performance. The Nevem Working Group (1989), Chow et al. (1994), Caplice and Sheffi (1995), and Gunasekaran and Kobu (2007) provided a review of the literature regarding logistics performance measurement. In addition, Akyuz and Erkan (2010) reviewed the literature on supply chain performance measurement. The following are the measures developed to evaluate the leanness and agility of the logistics system.

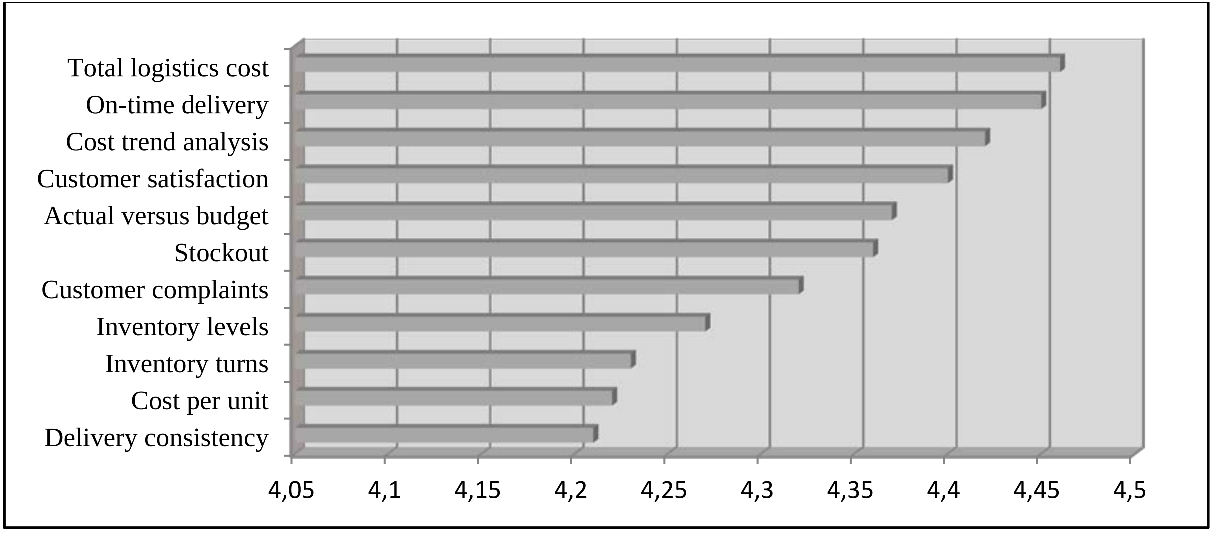


Figure 4.2: Logistics performance measures and their relative importance according to Fawcett and Cooper (1998)

4.4.1. Leanness Measurement

The measurement of logistics system leanness was classified into three dimensions, and the leanness of inbound, intra, and outbound logistics was measured separately to the greatest extent possible. The raw material inventory was linked to inbound logistics, the work-in-process inventory was linked to intra-logistics, and the finished goods inventory was linked to outbound logistics. Other logistics activities related to the three inventory types were linked to the corresponding categories as well.

While many researchers have explored lean production practices (e.g. Shah and Ward, 2003; Li et al., 2005; Mehta and Shah, 2005; Shah and Ward, 2007; Pool et al., 2011), other researchers have investigated similar practices aimed at waste elimination but under different labels, such as JIT practices (e.g. Sakakibara et al., 1997; Koufteros and Vonderembse, 1998; White et al., 1999; Ahmad et al., 2003), TQM practices (e.g. Flynn et al., 1995a, 1995b; Black and Porter, 1996), total productive maintenance (e.g. Mckone and Weiss, 1998; Cua et al., 2001), and time-based manufacturing (e.g. Koufteros et al., 1998). Shah and Ward (2007) proposed a conceptual definition of lean production from which they derived ten measurement items classified into three categories: supplier-related, customer-related, or internal-related. Overboom et al. (2010) adapted the measurement developed by Shah and Ward (2007) to suit the logistics service environment. The classification of lean practices into supplier-, internal-, and customer-related activities is in line with the classification of logistics activities into inbound (supplier-related), intra (internal-related), and outbound (customer-related) activities.

Leanness of Inbound Logistics

Measuring the leanness of inbound logistics activities concentrates on inventory and transportation of materials in addition to the evaluation of supplier relationships. As well as the levels of material inventory, the fitness of the materials delivered by suppliers in terms of quantity, quality, and timing to the real needs of the manufacturing process was also measured. This measure represents the JIT supply of material and was supported by the work of Flynn et al. (1999), Cua et al. (2001), Ahmad et al. (2003), and Shah and Ward (2007).

The materials' transportation costs were considered as another indicator of inbound logistics' leanness level. In addition, the use of material requirement planning (MRP) was measured as an indicator of a push system rather than the pull system provided by JIT (Brar and Saini, 2011). The supplier milk run was considered due to its importance for JIT implementation (Benton and Shin, 1998) and its relatedness to inbound logistics. Other supplier-related lean manufacturing tools are mentioned in table 4.2. All of these tools can be considered as lean logistics tools, since the relationship with suppliers implies the movement and storage of raw material inventory.

Table 4.2: Supplier-related lean manufacturing measures and tools

Measure	In
Supplier relationship	Flynn et al. (1995a), Slack et al. (2013)
Supplier involvement	Ahmad et al. (2003), Olsen (2004)
Supplier partnership	Black and Porter (1996)
Supplier quality management	Sakakibara et al. (1993), Cua et al. (2001)
Supplier development	Shah and Ward (2007)
Supplier feedback	Olsen (2004), Shah and Ward (2007)
Dependable suppliers	Koufteros et al. (1998), Olsen (2004)
JIT supplier relationship	Sakakibara et al. (1997), Flynn et al. (1999), Cua et al. (2001), Ahmad et al. (2003), Shah and Ward (2007)
JIT purchasing	White et al. (1999), Olsen (2004)
Material requirement planning (Negative)	Benton and Shin (1998)
Supplier milk run	Brar and Saini (2011)

Leanness of Intra Logistics

Shah and Ward (2003) categorized lean manufacturing practices into four 'bundles' incorporating inter-related lean practices: JIT, TQM, total preventive maintenance, and human resource management (HRM). Based on a quick review of the literature on 'in-plant' lean manufacturing, some of the most important measures and tools of lean manufacturing with an abbreviated list of authors are mentioned in table 4.3.

Table 4.3: Internal-related lean manufacturing measures and tools

Measure	In
Just-in-time (JIT)	Japan Management Association (1985), Monden (1994), de Haan and Yamamoto (1999), Shah and Ward (2003)
JIT scheduling	Flynn et al. (1995b)
Setup time reduction	Chan et al. (1990), Flynn et al. (1995b), Sakakibara et al. (1997), White et al. (1999), Cua et al. (2001), Ahmad et al. (2003), Li et al. (2005), Shah and Ward (2007)
Lot size reduction	Chan et al. (1990), Flynn et al. (1995b), Li et al. (2005)
Kanban/pull production	Chan et al. (1990), Sakakibara et al. (1993), Flynn et al. (1995b), Sakakibara et al. (1997), Koufteros et al. (1998), Koufteros and Vonderembse (1998), Flynn et al. (1999), Cua et al. (2001), Ahmad et al. (2003), Li et al. (2005), Shah and Ward (2007)
Equipment layout	Sakakibara et al. (1997), Cua et al. (2001), Ahmad et al. (2003)
Continuous flow	Shah and Ward (2007)
Daily schedule adherence	Cua et al. (2001), Ahmad et al. (2003)
Production smoothing	Chan et al. (1990)
Standardization	Chan et al. (1990), Mehta and Shah (2005), Stahl et al. (2015)
Cellular manufacturing	Koufteros et al. (1998), Koufteros and Vonderembse (1998), Rouhollahi (2011), Chiarini (2014)
Cross-functional teams	Chan et al. (1990)
Re-engineering setup	Koufteros et al. (1998), Koufteros and Vonderembse (1998)
Focused factory	White et al. (1999)
Uniform workload	White et al. (1999)
Stock reduction	Pool et al. (2011)
Cross-docking	Rouhollahi (2011)
Resource reduction	Stahl et al. (2015)
Total quality management (TQM)	Shah and Ward (2003)
Statistical process control	Flynn et al. (1995b), Ahmad et al. (2003), Shah and Ward (2007)
Quality improvement	Koufteros et al. (1998)
Quality assurance	Koufteros and Vonderembse (1998)
Product design	Flynn et al. (1995a), Flynn et al. (1995b)
Process management/improvement	Flynn et al. (1995a), Cua et al. (2001), Pool et al. (2011)
Total quality control	White et al. (1999)
Visual control	Stahl et al. (2015)
Cross-functional product design	Cua et al. (2001)
Quality circles	White et al. (1999)
Human resource management	Flynn et al. (1995a), Shah and Ward (2003)
Training	Chan et al. (1990), Mckone and Weiss (1998)
Top management support	Flynn et al. (1995a)
Multifunction workers	White et al. (1999)
Employee involvement	Koufteros et al. (1998), Shah and Ward (2007)
Employee commitment	Dow et al. (1999)
Work attitudes	Flynn et al. (1995a)
Maintenance	Sakakibara et al. (1997)
Total preventive maintenance	Koufteros et al. (1998), Koufteros and Vonderembse (1998), Shah and Ward (2003), Shah and Ward (2007)
Total productive maintenance	Shah and Ward (2007), White et al. (1999), Rouhollahi (2011)
Planned maintenance	Mckone and Weiss (1998), Cua et al. (2001)
Autonomous maintenance	Mckone and Weiss (1998), Cua et al. (2001)
Single Minute Exchange of Die (SMED)	Chiarini (2014)
Value stream mapping	Chiarini (2014), Dal Forno et al. (2014), Stahl et al. (2015)
5 S	Rouhollahi (2011), Chiarini (2014), Stahl et al. (2015)
Six Sigma	Rouhollahi (2011)

As regards inbound logistics, levels of work-in-process inventory were measured, since inventory reduction (or elimination if possible) is one of the main aims of the lean system (de Haan and Yamamoto, 1999). Another dimension was the standardization and smoothing of the materials and parts flow in the manufacturing process, which also represent production levelling; similar constructs were employed by Chan et al. (1990), Mehta and Shah (2005), Shah and Ward (2007), and Stahl et al. (2015). Additionally, lean manufacturing techniques that affect the storage and movement of inventory, such as JIT, Kanban/pull system, and cross-docking, were used to measure the leanness levels of intra logistics.

Leanness of Outbound Logistics

Outbound logistics deals with finished goods and, hence, takes place after the production process has already been completed. Therefore, its effect on the ramp-up process was not analysed. Conversely, the possible effect of ramp-up performance variation on outbound logistics could be investigated. In addition, the effect of outbound logistics on the overall success of the new product can be examined; however, the mediating role of outbound logistics between ramp-up performance as an independent variable and new product success as a dependent variable was included in the research model. For this purpose, the levels of finished goods inventory, the finished goods transportation costs, and the customer involvement level were measured and analysed. Table 4.4 provides some of the customer-related lean practices.

Table 4.4: Customer-related lean manufacturing measures and tools

Measure	In
Customer involvement	Cua et al. (2001), Olsen (2004), Shah and Ward (2007)
Customer focus	Black and Porter (1996), Dow et al. (1999), Flynn et al. (1995b), Ahmad et al. (2003)
JIT links with customers	Ahmad et al. (2003)
Customer feedback	Olsen (2004)

4.4.2. Agility Measurement

Compared with lean measures and practices, much less literature is available regarding agility in production or in logistics. Ilyas et al. (2008) argued that agile systems are built around flexibility. Consequently, measuring logistics system agility levels might utilize measures used in different fields that concentrate on flexibility and adaptability, such as a flexible manufacturing system, reconfigurable manufacturing system, supply chain flexibility, supply chain agility, and so on (see section 2.2.2 for more details).

As for lean logistics, the levels of logistics agility were measured in terms of inbound, intra, and outbound activities. Such a classification was also supported within the agility literature. Naim et al. (2006), for example, distinguished between internal and external flexibility types. Similarly, Barratt (2004) classified vertical collaboration into supplier, internal, and external collaboration. Likewise, Stank et al. (2001) measured internal and external collaborations separately. In addition, Zhang et al. (2005) mentioned physical supply and physical distribution in measuring logistics system flexibility.

Agility of Inbound Logistics

A cornerstone for supporting agility is the shape of suppliers' relationships. Many authors (e.g. Gunasekaran, 1998; Crocitto and Youssef, 2003; Zhang et al., 2005) have stressed the role of suppliers' cooperation in enabling agility, especially in the context of supply chain management (e.g. Lee, 2004; Sharifi et al., 2006; Salvador and Villena, 2013). Hence, measuring the level of collaboration with suppliers was expected to represent an important dimension of agility in the current research. In addition to evaluating the level of supplier collaboration, an evaluation of the information technology that links the firm with suppliers is important to assess the agility level and to investigate the information flow alongside the physical material flow. The IT link and integration with suppliers were also investigated by Swafford et al. (2008).

Furthermore, supplier flexibility was measured because many researchers have appreciated it as a main enabler of agility (e.g. Zhang et al., 2005; Naim et al., 2010; Purvis et al., 2014). Supplier flexibility was measured in terms of the ability to adapt to changes in material requirements' quality, quantity, and timing. Furthermore, the existence and evaluation of the use of the vendor-managed inventory (VMI) technique (see Huang and Li, 2010) were also utilized to measure the agility of inbound logistics activities. A brief list of the measures and tools used to assess agility in the literature is provided in table 4.5.

Table 4.5: Inbound-related agility measures

Measure	In
Suppliers' delivery flexibility	Hon (2005)
Suppliers' transport flexibility	Naim et al. (2006), Naim et al. (2010)
Supplier collaboration	Crocitto and Youssef (2003)
Resource flexibility	Duclos et al. (2003)
Vendor-managed inventory	Huang and Li (2010)
Vendor flexibility	Purvis et al. (2014)
Purchasing flexibility	Zhang et al. (2005)
IT integration	Swafford et al. (2008)
Physical supply flexibility	Zhang et al. (2005)

Agility of Intra Logistics

The intra logistics agility measures were derived from the manufacturing agility and flexibility measures, including the flexibility provided by production machines, the production process, material handling, and the production equipment. Some of these dimensions can be related more to production than to logistics, but the great interaction, overlapping, and interdependencies between the two fields made the use of such measures essential for evaluating logistics agility. These and other similar measures have been used extensively to evaluate the production system, logistics, or supply chain flexibility (e.g. Paixão and Marlow, 2003; Hon, 2005; Naim et al., 2006; Inman et al., 2011).

Many design-related techniques can be used to enable agility, including concurrent engineering, modular design, design for postponement, and rapid prototyping. The use of a modular design was used to measure the agility of the system due to its importance in enhancing the ability to cope with changes in demand (Salvador and Villena, 2013). All design-related activities affect the subsequent production and logistics activities. Additionally, the use of a reconfigurable manufacturing system (see Koren et al., 1999; Matta et al., 2008; Niroomand et al., 2012) and the ability of the internal logistics system to cope with changes in the production mix were considered to measure the internal levels of agility. Table 4.6 illustrates some tools and measures of internal-related activities' levels of agility.

Table 4.6: Internal-related agility measures

Measure	In
Machine flexibility	Hon (2005), Naim et al. (2006)
Process/operation flexibility	Vokurka and Fliedner (1998), Hon (2005), Naim et al. (2006), Inman et al. (2011)
Quick changeovers	Ilyas et al. (2008)
Capacity flexibility	Naim et al. (2006)
Routing flexibility	Paixão and Marlow (2003), Naim et al. (2006)
Manufacturing lead time reduction	Vokurka and Fliedner (1998), Merschmann and Thonemann (2011)
Cross-functional teams	Huang and Li (2010)
Development cycle reduction	Merschmann and Thonemann (2011)
Rapid prototyping	Gunasekaran (1998)
Rapid reconfiguration	Naylor et al. (1999)
Concurrent engineering	Gunasekaran (1998)
Material handling flexibility	Paixão and Marlow (2003)
Virtual enterprise	Gunasekaran (1998)
Multi-product production systems	Carvalho and Azevedo (2014)
Design for postponement	Lee (2004)
Low production cost	Vokurka and Fliedner (1998), Crocitto and Youssef (2003), Ren et al. (2003)
Product quality	Vokurka and Fliedner (1998), Crocitto and Youssef (2003), Ren et al. (2003), Ramesh and Devadasan (2007), Inman et al. (2011)
Contingency planning	Lee (2004)
Volume flexibility	Vokurka and Fliedner (1998), Helo (2004)
Design quality/improvement	Vokurka and Fliedner (1998), Ramesh and Devadasan (2007)

Agility of Outbound Logistics

The agility of the outbound logistics is of great importance, since a focal point of agility is the ability to keep pace with the changing customer requirements (Gunasekaran, 1998; Yusuf et al., 1999; Carlson and Yao, 2008). Therefore, the ability of the logistics system to respond quickly to changes in customers' orders in terms of size, type, or delivery was used to measure the physical distribution system's agility. This was supported by the work of Zhang et al. (2005), who considered the physical distribution and demand management flexibility and focused on the ability to adjust inventory, packaging, warehousing, and transportation in addition to the ability to cope with changes in customer needs for service level, delivery time, or even price. While many firms can enhance their responsiveness but with higher accompanying costs, agile firms respond quickly and efficiently (Pfohl and Buse, 2000; Lee, 2004); this makes it necessary to take into consideration the related cost and efficiency levels when measuring the previously mentioned dimension.

The ability to predict changes in the marketplace is a core competence for agile organizations; some authors, such as Bardi et al. (2006) and Langley et al. (2008), have argued that demand forecasting is also a logistics activity. Similar constructs were used by Ramesh and Devadasan (2007), Scholten et al. (2010), and Inman et al. (2011) to measure agility. The use of outsourcing can bring agility to the system (Christopher and Towill, 2000; Ramesh and Devadasan, 2007), and the use of third-party logistics (3PL) as a popular source of outsourcing can be helpful in measuring the outbound logistics' ability to match changes in demand. For a view of other measures of agility for customer-related activities see table 4.7.

Table 4.7: Outbound-related agility measures

Measure	In
Physical distribution flexibility	Zhang et al. (2005)
Responsiveness to customers' needs	Ilyas et al. (2008), Stank et al. (2001)
Delivery time flexibility/reliability	Vokurka and Fliedner (1998), Hon (2005), Merschmann and Thonemann (2011), Inman et al. (2011)
Transport flexibility	Naim et al. (2006), Naim et al. (2010)
Customer service levels	Vokurka and Fliedner (1998), Mason-Jones et al. (2000a), Merschmann and Thonemann (2011)
Market sensitivity	van Hoek et al. (2001), Scholten et al. (2010), Inman et al. (2011)
Order size flexibility	Stank et al. (2001)
Product mix flexibility	Vokurka and Fliedner (1998), Helo (2004)
Customer response adoption	Ramesh and Devadasan (2007)

Other general measures, tools, and techniques used in the literature to assess or enable agility are listed in table 4.8. Those methods can be used for internal as well as external logistics activities.

4.5. New Product Success

New product success was measured to evaluate how different performance levels during production ramp-up are reflected in the performance of the product in the market in terms of financial and non-financial dimensions. Gross and Renner (2010) indicated the scarcity of ramp-up research investigating the issues of product success and stated that information on most success measures are only available after the completion of the ramp-up phase. However, the ramp-up literature includes some attempts to capture the effect of ramp-up performance on the success of new products launched using different indicators, including sales (Di Benedetto, 1999), profitability (Schuh et al., 2005a; Carrillo and Franza, 2006), timing of revenues (Terwiesch et al., 2001), lost sales (Cantamessa and Valentini, 2000), and market share (Di Benedetto, 1999; Cantamessa and Valentini, 2000). Section 2.1.1 provides more details on how ramp-up performance affects different financial indicators.

Table 4.8: Additional general agility measures

Measure	In
Robustness	Naylor et al. (1999), Ismail et al. (2011)
Coordination flexibility	Duclos et al. (2003)
Integrated information system	Gunasekaran (1998)
Synchronized operations/synchronizing transportation with production	Huang and Li (2010), Carvalho and Azevedo (2014)
Continuous replenishment	Huang and Li (2010)
Speed	Zhang and Sharifi (2000), Ren et al. (2003)
Lifecycle flexibility	Helo (2004)
Innovation	Ren et al. (2003)
Proactivity	Ren et al. (2003)
Outsourcing	Christopher and Towill (2000), Ramesh and Devadasan (2007)

Slamanig and Winkler (2011) considered the relationships between different ramp-up strategies and the product success in the area of mass customization. Ginn and Rubenstein (1986) used technological and commercial success constructs to evaluate the process of transferring technology from development to commercialization.

In the current research, an evaluation of sales return, net profit, market share, and customer satisfaction was used to assess the performance of the new product launched. The relative importance of the success indicator can vary significantly according to the product and industry. However, almost every industrial company pays attention to each one of these measures. Montoya-Weiss and Calantone (1994) conducted a comprehensive review and meta-analysis of the literature on new product performance.

4.6. The Moderating Variables

The first section of the questionnaire requested general information about the respondent, the organization, and the product. The respondent was asked about his/her position and field of experience, work position, and job responsibilities, which revealed the extent to which the respondents are engaged with the ramp-up process and possess information and knowledge about it. Experience affects employees’ sources and types of information; this was also proven by Fjällström et al. (2009), who discussed the role of information in ramp-up performance enhancement.

With regard to organizational characteristics, only size and place of organization were considered. Both size and place affect the organizational structure and work environment and, thus, might have an impact on every aspect of the production or logistical processes. Many comparative studies have shown significant differences between companies operating in different countries in terms of performance, work tools, and other variables. For example, Japanese firms showed an interest in new product manufacturing lead time reduction earlier than US firms (Flaherty, 1992). Furthermore, Bohn and Terwiesch (1999) indicated that differences in the infrastructure among countries might affect the ramp-up process. In addition, organizational size has frequently been configured to be positively related to the levels of innovating new products (Klepper, 1996) and consequently to more ramp-up exposure; Audretsch (1991), however, deduced that technology and knowledge determine small companies’ innovation levels. Company size was measured using the number of employees. This number was represented through ranges rather than a mere figure to keep the respondent comfortable regarding confidentiality issues. In addition, the number of ramp-ups experienced within the last three years was considered. This dimension might reflect the importance of the cumulative experience with the ramp-up process.

In terms of the product itself, the product type and lifecycle length were mentioned due to the very frequent indications in the literature on the relation between these factors and production ramp-up recurrence and, hence, performance. The product type and lifecycle are related to each other, since similar products share an approximate lifecycle length. Nonetheless, the study of these variables as moderating variables is limited in the literature. Different levels of product/process newness were also measured to distinguish between ramp-up processes that involve new products, modified products, new processes, modified processes, or a combination of these options.

Figure 4.3 illustrates the research model, in which production ramp-up performance is the dependent variable for lean and agile logistics and the independent variable for new product success. Outbound lean and agile logistics activities are mediating variables regarding the relationship between ramp-up and product success. Respondent-, organization-, and product-related variables are moderating variables in the relationship between lean and agile logistics and production ramp-up. The latent variables are production ramp-up, lean logistics, agile logistics, and new product success. The research constructs under each latent variable are mentioned, and measures of each construct are listed in the research questionnaire (appendix 1, page 205).

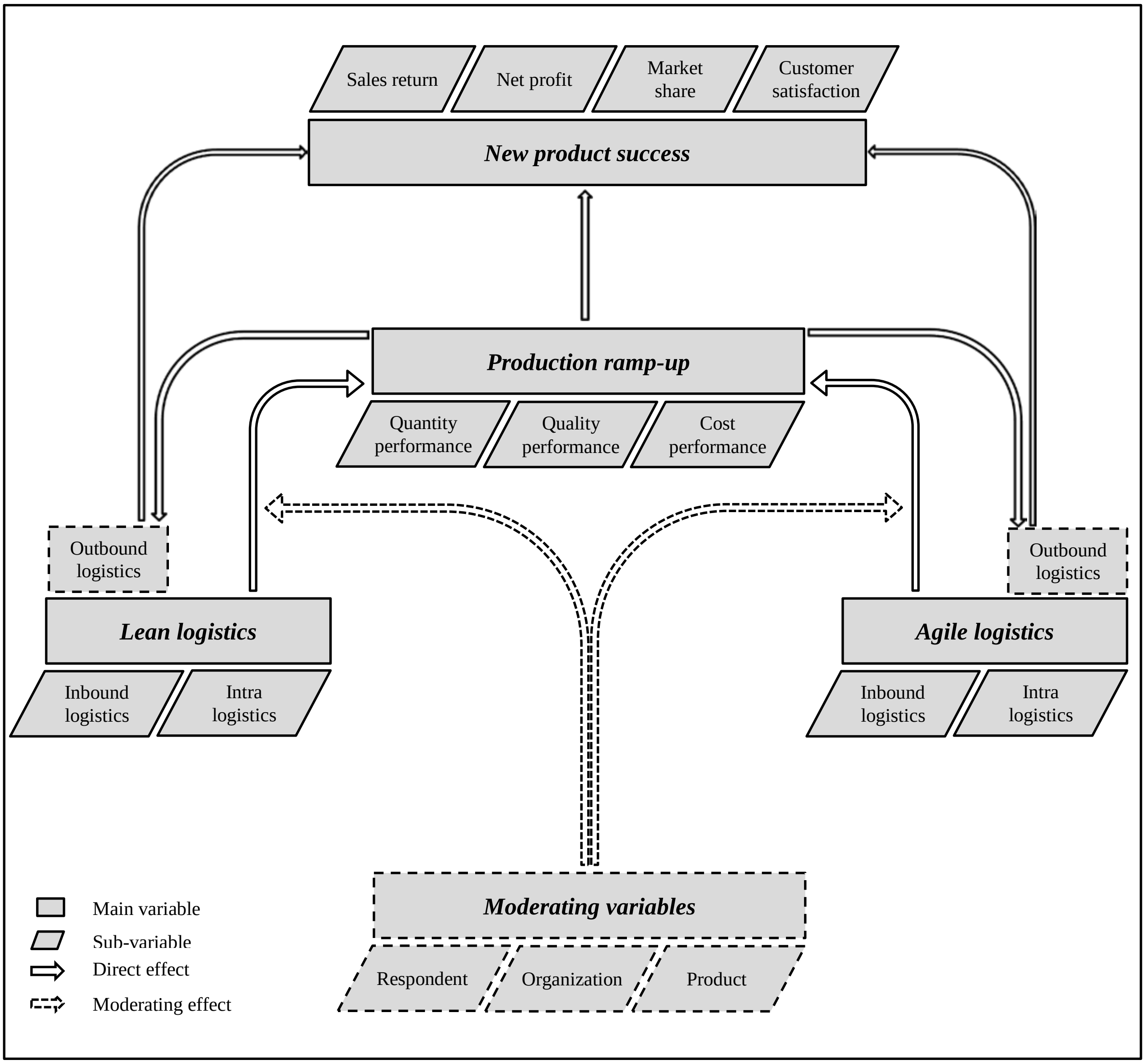


Figure 4.3: Research model

CHAPTER 5

STATISTICAL ANALYSIS

5.1. Introduction

This chapter presents the results of the statistical analysis carried out and includes the following: the distribution of the research sample and a description of the sample characteristics in terms of the respondent-, organization-, and product-related variables; the determination of the statistical relationships between the research variables; the testing of the research hypotheses regarding the direct relationships between the dependent and the independent variables, in addition to the indirect effect of the moderating variables; and finally a graphically summary of the analysis results, as a prelude to presenting a model that employs lean and agile logistics during the production ramp-up phase and afterwards during steady-state and ramp-down production. The rationale behind the statistical methods used in the analysis was detailed in section 3.5. The statistical analyses were conducted mainly using the SmartPLS (V. 3.2.0) and IBM SPSS (V. 21) programs.

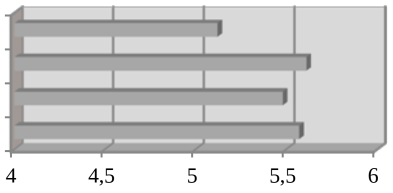
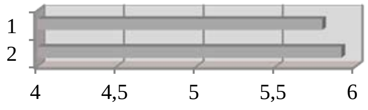
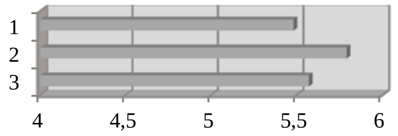
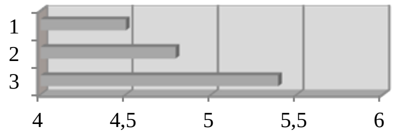
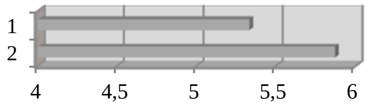
5.2. Descriptive Statistics and Preliminary Analysis

Out of 63 questionnaires collected, 56 questionnaires were used for statistical analysis. Due to missing influential data, clearly biased completing patterns, or irrelevance to the researched population, 7 questionnaires were excluded. Section 3.5 highlighted the status and treatment of the missing values. Compared with the complexity of the research model (see figure 4.3, page 101), the sample size is considered to be small but statistically sufficient to explore the investigated trends, especially utilizing the PLS-SEM tools.

5.2.1. Production Ramp-Up

Table 5.1 describes the respondents' evaluation of production ramp-up performance. The descriptive results show a moderate evaluation for ramp-up performance. Quality performance accounted for the highest performance level, followed by quantity performance, while cost performance during ramp-up showed the worst indicator.

Table 5.1: Production ramp-up performance descriptive statistics

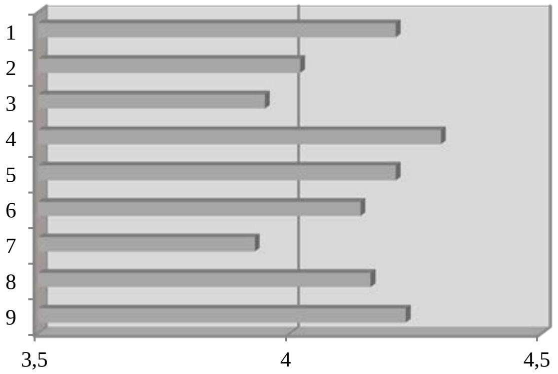
Performance dimension	Measures and constructs	Mean	SD	Diagrams (mean)
Quantity performance	1- Actual to planned	5.12	1.99	
	Initial phase	5.14	2.71	
	Middle phase	4.95	2.13	
	Final phase	5.29	1.95	
	2- Cycle time reduction	5.61	2.229	
	3- Learning	5.48	2.351	
	4- Unplanned stops	5.57	2.743	
	Construct	5.446	1.752	
	1- Volume-related goals	5.79	1.846	
	2- Time-related goals	5.91	1.975	
	Composite evaluation	5.845	1.823	
Quality performance	1- Defective products	5.59	2.255	
	2- Returned products	5.79	2.506	
	3- Quality deviation	5.48	2.320	
	Construct	5.619	2.001	
	Quality-related goals	5.71	1.833	
Cost performance	1- Per unit cost	4.5	2.501	
	2- Preparation costs	4.79	2.627	
	3- Repair costs	5.39	2.349	
	Construct	4.893	2.193	
	Cost-related goals	5.25	1.975	
Production ramp-up performance construct		5.332	1.400	
Overall ramp-up evaluation		5.667	1.377	

No significant differences were found between the initial, the middle, and the final ramp-up phase in terms of matching actual productivity to planned productivity. The inter-class correlations between the three categories proposed by Doltsinis et al. (2013) were 0.642 and 0.843 for the single and average measures, respectively, which reflected a relatively low tendency of the respondents to recognize this temporal classification or, alternatively, close performance among the three sub-phases.

The highest single performance measure was the proportion of products returned by customers, and the lowest was related to the variable cost during ramp-up. In all the cases, the overall evaluation was higher and more optimistic than the single-measure evaluation, which might indicate other dimensions, not included in the questionnaire, that contribute to an enhanced ramp-up performance.

The measurement of ramp-up performance can also performed through the investigation of the frequency of occurrence of the problems or disturbances proved to affect the performance parameters negatively. Table 5.2 shows the results of respondents' evaluation of the frequency of problems experienced during the ramp-up process. This table shows that the least frequent problems come from information flow sources, followed by technology-related problems. As expected, problems from all sources were experienced in the research sample, which is the normal case in all ramp-up processes. Normally, most of the problems are identified after the start of production.

Table 5.2: Production ramp-up problems' descriptive statistics

Ramp-up problem	Mean	SD	Diagrams (means)
1- Material	4.21	2.871	
2- Machine	4.02	2.714	
3- Equipment	3.95	2.568	
4- Employee	4.3	2.427	
5- Design–process mismatch	4.21	2.521	
6- Design mistakes	4.14	2.194	
7- Technology	3.93	2.365	
8- Cooperation	4.16	2.357	
9- Information flow	4.23	2.676	
Composite measure (positive)	4.129	2.074	
Composite measure (negative)	5.871	2.074	

While the Cronbach's alpha for production ramp-up was 0.531, as shown in table 3.4 (page 65), adding the composite measure of ramp-up problems – the inverse or negative one – enhances the reliability significantly with a Cronbach's alpha of 0.717. Additionally, adding the overall evaluation composite measure further enhances the reliability and increases the Cronbach's alpha's value to 0.754, which supports the internal consistency of the ramp-up measures.

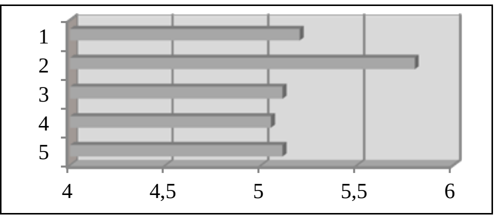
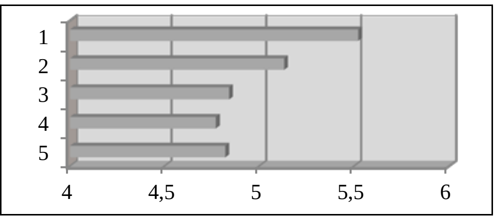
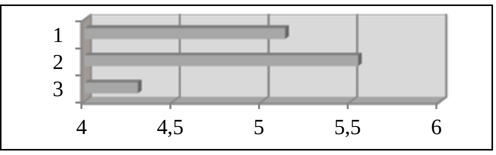
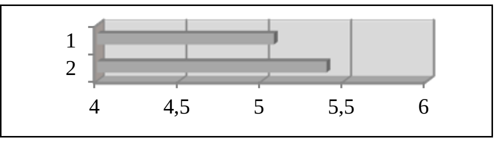
5.2.2. Logistics

The collected data support the division of logistics activities into inbound, intra, and outbound logistics. The outbound logistics seems to be less lean than the inbound logistics. It can be noted that the general leanness and agility measures have higher means than the lean and agile techniques. The fluctuation, reflected in the relatively high SD values, could be due to the use of certain techniques but not others.

Lean Logistics

Table 5.3 illustrates the results of the evaluation of lean logistics practices. Inbound logistics had the highest mean values and the lowest SD at the same time. Intra and outbound logistics were rated a little below the average. The lowest evaluation was for the customer involvement levels. The respondent as the single source of information might have little interaction with the customer, contributing to the lower evaluation of this dimension. On the other hand, the research sample seemed to perform well in aligning the material supply with the actual needs of the production process. Again, the overall evaluation of the logistics' leanness was higher than the evaluation of the measures.

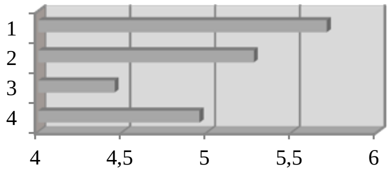
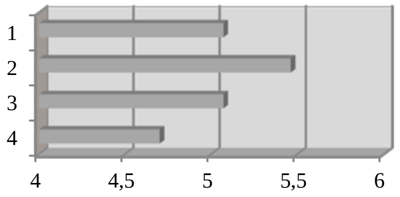
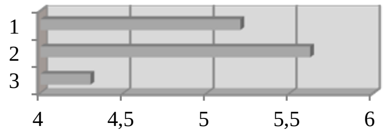
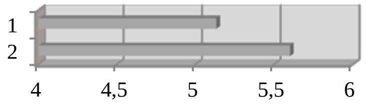
Table 5.3: Lean logistics descriptive statistics

Category	Measures and constructs	Mean	SD	Diagrams (means)
Inbound	1- Material inventory levels	5.20	2.305	
	2- Supply matches process needs	5.80	2.127	
	3- Material transportation cost	5.11	2.349	
	4- MRP (negative)	5.05	2.700	
	5- Supplier milk run	5.11	2.807	
	Construct	5.251	1.448	
Intra	1- WIP inventory levels	5.52	2.224	
	2- Standardization	5.13	2.516	
	3- JIT	4.84	3.014	
	4- Kanban	4.77	2.966	
	5- Cross-docking	4.82	3.001	
	Composite measure	4.964	2.037	
Outbound	1- F. goods inventory levels	5.13	2.313	
	2- F. goods transportation costs	5.54	2.366	
	3- Customer involvement	4.30	2.256	
	Composite measure	4.988	1.940	
Overall leanness measure		5.071	1.556	
Overall leanness evaluation		5.390	1.951	

Agile Logistics

The results for the agile logistics evaluation are reported in table 5.4, which shows relatively lower performance on the inbound side of logistics but higher performance on the intra and outbound sides. While notable problems with suppliers' flexibility were identified, a high level of ability to predict market changes appeared. As for ramp-up performance and lean logistics, a higher overall evaluation was also the case for agile logistics.

Table 5.4: Agile logistics descriptive statistics

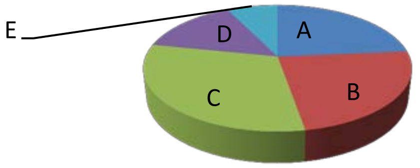
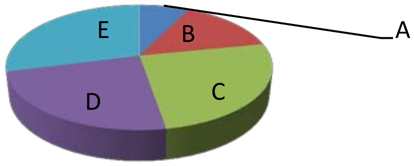
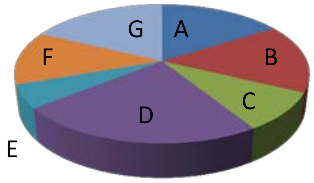
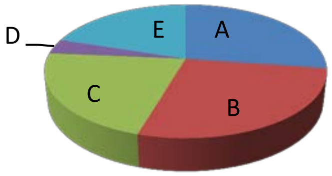
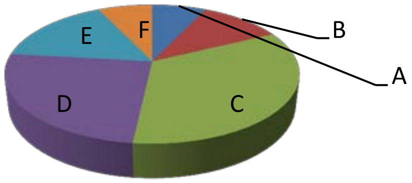
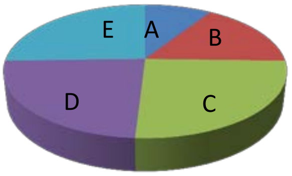
Category	Measures and constructs	Mean	SD	Diagrams (means)
Inbound	1- Supplier cooperation	5.70	2.190	
	2- IT link with supplier	5.27	2.876	
	3- Supplier flexibility	4.45	2.635	
	4- Vendor-managed inventory	4.95	2.921	
	Composite measure	5.064	2.108	
Intra	1- Flexibility of	5.073	2.496	
	Machine	5.0	2.6	
	System	5.2	2.7	
	M. handling	5.3	2.8	
	Equipment	5.0	2.4	
	2- Adaptability to change	5.46	2.397	
	3- Modular product design	5.07	2.922	
	4- Reconfigurable manufacturing	4.70	3.092	
	Composite measure	5.077	2.266	
Outbound	1- Adaptability to orders' change	5.20	2.475	
	2- Predictability of market change	5.62	2.415	
	3- 3PL	4.54	3.051	
	Composite measure	5.142	2.030	
Overall agility measure		5.127	2.052	
Overall agility evaluation		5.600	2.528	

5.2.3. Respondent-, Organization-, and Product-Related Variables

Table 5.5 shows the distribution of the sample's units according to different respondent-, organization-, and product-related characteristics. Two more pieces of information were collected through the research questionnaire about the respondent's job position and the product type. These two dimensions produced a wide variety of responses, making it difficult to contribute significantly to the data analysis process due to the relatively small sample size of the research.

As shown in table 5.5, more responses came from large companies, and the largest experience range was five to eight years. Regarding the newness levels, one point was assigned to a slightly modified product or a slightly modified process, two points to a significantly modified product or process, and three points to a completely new product or production process. The points for product newness and system or process newness were summed to calculate the overall newness level.

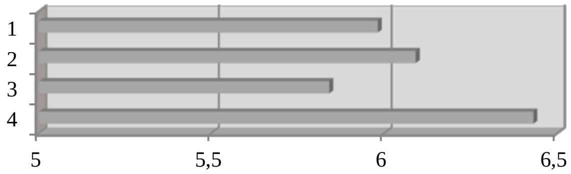
Table 5.5: Respondent-, organization-, and product-related characteristics' descriptive statistics

Category	Measures and constructs		Frequencies	Percentage	Valid percentage	Pie charts (valid percentage)
Respondent	Experience	**A-** Less than 2 years	13	23.2	23.6	
		B- 2 to less than 5 years	13	23.2	23.6	
		C- 5 to less than 8 years	17	30.4	30.9	
		D- 8 to less than 11 years	8	14.3	14.5	
		E- More than 11 years	4	7.1	7.3	
		Missing	1	1.8	0	
		Total	**56**	**100**	**100**	
Firm	Number of workers	**A-** Less than 50	4	7.1	7.3	
		B- 50 to less than 250	8	14.3	14.5	
		C- 250 to less than 500	14	25.0	25.5	
		D- 500 to less than 1000	13	23.2	23.6	
		E- More than 1000	16	28.6	29.1	
		Missing	1	1.8	0	
		Total	**56**	**100**	**100**	
	Country	**A-** China	9	16.1	16.1	
		B- Germany	9	16.1	16.1	
		C- India	5	8.9	8.9	
		D- Jordan	13	23.2	23.2	
		E- Turkey	3	5.4	5.4	
		F- U.A.E	7	12.5	12.5	
		G- U.S.A	10	17.9	17.9	
		Missing	0	0	0	
		Total	**56**	**100**	**100**	
	Number of ramp-ups	**A-** 3 or less	15	26.8	27.3	
		B- 4 to 6	15	26.8	27.3	
		C- 7 to 15	12	21.4	21.8	
		D- 16 to 30	2	3.6	3.6	
		E- More than 30	11	19.6	20.0	
		Missing	1	1.8	0	
		Total	**56**	**100**	**100**	
Product	Newness	**A-** 6 new product + process	4	7.1	7.1	
		B- 5	6	10.7	10.7	
		C- 4	19	33.9	33.9	
		D- 3	14	25.0	25.0	
		E- 2	9	16.1	16.1	
		F- 1 lowest modification	4	7.1	7.1	
		Missing	0	0	0	
		Total	**56**	**100**	**100**	
	Expected lifecycle	**A-** Less than 6 months	5	8.9	9.1	
		B- 6 to less than 12 months	9	16.1	16.4	
		C- 1 to less than 3 years	14	25.0	25.5	
		D- 3 to less than 6 years	13	23.6	23.6	
		E- 6 years or more	14	25.0	25.5	
		Missing	1	1.8	0	
		Total	**56**	**100**	**100**	

New Product Success

An evaluation of new product success is illustrated in table 5.6. The mean for overall success evaluation shows that the targeted sample experienced acceptable levels of product after-launch performance. A very high level of customer satisfaction can be identified. Products that performed highly in one success dimension were most probably high performers in other dimensions. Both sales return and net profit were measured to identify the consistency of the responses, rather than to capture both figures. A normal situation of close performance in the two dimensions appeared.

Table 5.6: New product success descriptive statistics

Dimension	Mean	SD	Diagrams (means)
1- Sales return	5.98	1.931	
2- Net profit	6.09	1.900	
3- Market share	5.84	1.817	
4- Customer satisfaction	6.43	2.223	
Construct	6.085	1.764	

5.3. Variables' Correlations

Analysing the correlations enhances the understanding of the direction and the significance of the relationships between research variables, constructs, and measures. The Pearson correlation coefficient (r, r_{xy}) was used to evaluate these relationships. The r calculation is dependent on the values of the covariance between variable x and variable y and the standard deviation using the following equation:

$$r = r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

The problems occurring during production ramp-up construct an important point of consideration. The concurrence of these problems, their relationships with ramp-up performance, their relationships with logistics activities, and their relationships with product success were investigated. In addition, the correlations between leanness and agility that might represent the use of a combination of lean and agile tools in logistics were analysed. Furthermore, the relationships between respondent-, organization-, and product-related variables on the one hand and selected constructs on the other were illustrated.

5.3.1. Ramp-Up Problems

A very high probability of the occurrence of different ramp-up problems can be derived from table 5.7. In most cases, a high frequency of problems from all sources (or the opposite) was experienced. Only problems related to the mistaken product design were not significantly linked to the material-related problems, which had a relatively small relationship with the occurrence of the problems related to cooperation and coordination between production and other organizational departments. The highest correlation was between machine and equipment sources of problems, followed by employees and the mismatch between the product design and the production process.

Table 5.7: Correlations between different ramp-up problems' sources

		Materials	Machine	Equipment	Employees	Design–process mismatch	Design mistakes	Technology	Cooperation	Information flow
Materials	P. Correlation Sig. (2-tailed) N	1 56								
Machine	P. Correlation Sig. (2-tailed) N	0.674** 0.000 56	1 56							
Equipment	P. Correlation Sig. (2-tailed) N	0.677** 0.000 56	0.916** 0.000 56	1 56						
Employees	P. Correlation Sig. (2-tailed) N	0.614** 0.000 56	0.872** 0.000 56	0.866** 0.000 56	1 56					
Design–process mismatch	P. Correlation Sig. (2-tailed) N	0.637** 0.000 56	0.829** 0.000 56	0.842** 0.000 56	0.911** 0.000 56	1 56				
Design mistakes	P. Correlation Sig. (2-tailed) N	0.249 0.064 56	0.537** 0.000 56	0.511** 0.000 56	0.593** 0.000 56	0.652** 0.000 56	1 56			
Technology	P. Correlation Sig. (2-tailed) N	0.554** 0.000 56	0.742** 0.000 56	0.730** 0.000 56	0.742** 0.000 56	0.850** 0.000 56	0.636** 0.000 56	1 56		
Cooperation	P. Correlation Sig. (2-tailed) N	0.328* 0.014 56	0.483** 0.000 56	0.371** 0.005 56	0.401** 0.002 56	0.490** 0.000 56	0.713** 0.000 56	0.517** 0.000 56	1 56	
Information flow	P. Correlation Sig. (2-tailed) N	0.514** 0.000 56	0.760** 0.000 56	0.700** 0.000 56	0.688** 0.000 56	0.688** 0.000 56	0.384** 0.003 56	0.623** 0.000 56	0.470** 0.000 56	1 56

** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed)
Exclude missing (pairwise)

Another point of interest is the relationships between different ramp-up problems on the one hand and performance indicators and overall performance evaluation on the other. The corresponding correlation values are listed in table 5.8. In general, the performance indicators seemed to have higher correlation values with ramp-up problems than the general evaluation of different ramp-up goal attainment. All the correlations were negative in value, as expected. Quality performance was the most closely related to the ramp-up problems, especially in the cases of employees' mistakes and a poor information flow.

Regarding the performance indicators, only one correlation value was statistically insignificant – between quantity performance and material-related problems. Material-related problems were insignificantly related to the volume and time goal achievement evaluation. Unlike the cost performance indicator, the financial and cost-related goal achievement evaluation was barely significantly related to a few ramp-up problems.

Table 5.8: Correlations between ramp-up problems and ramp-up performance and evaluation

		Performance			Evaluation			
		Quantity	**Quality**	**Cost**	**Quantity**	**Time**	**Quality**	**Cost**
Materials	P. Correlation	- 0.180	- 0.457**	- 0.536**	- 0.149	- 0.074	- 0.368**	- 0.273*
	Sig. (2-tailed)	0.185	0.000	0.000	0.273	0.591	0.006	0.042
	N	56	56	56	56	55	55	56
Machine	P. Correlation	- 0.437**	- 0.530**	- 0.354**	- 0.424**	- 0.377**	- 0.387**	- 0.160
	Sig. (2-tailed)	0.001	0.000	0.007	0.001	0.005	0.003	0.238
	N	56	56	56	56	55	55	56
Equipment	P. Correlation	- 0.352**	- 0.471**	- 0.309*	- 0.317*	- 0.320*	- 0.303*	- 0.047
	Sig. (2-tailed)	0.008	0.000	0.021	0.017	0.017	0.024	0.728
	N	56	56	56	56	55	55	56
Employees	P. Correlation	- 0.350**	- 0.651**	- 0.408**	- 0.318*	- 0.333*	- 0.417**	- 0.194
	Sig. (2-tailed)	0.008	0.000	0.002	0.017	0.013	0.002	0.151
	N	56	56	56	56	55	55	56
Design–process mismatch	P. Correlation	- 0.279*	- 0.612**	- 0.434**	- 0.334*	- 0.343*	- 0.461**	- 0.267*
	Sig. (2-tailed)	0.038	0.000	0.001	0.012	0.010	0.000	0.047
	N	56	56	56	56	55	55	56
Design mistakes	P. Correlation	- 0.418**	- 0.342**	- 0.297	- 0.360**	- 0.307*	- 0.281*	- 0.109
	Sig. (2-tailed)	0.001	0.010	0.026	0.006	0.023	0.037	0.424
	N	56	56	56	56	55	55	56
Technology	P. Correlation	- 0.214	- 0.523**	- 0.381**	- 0.328*	- 0.360**	- 0.451**	- 0.234
	Sig. (2-tailed)	0.112	0.000	0.004	0.013	0.007	0.001	0.083
	N	56	56	56	56	55	55	56
Cooperation	P. Correlation	- 0.367**	- 0.354**	- 0.300*	- 0.493**	- 0.417**	- 0.290*	- 0.267*
	Sig. (2-tailed)	0.005	0.007	0.025	0.000	0.002	0.032	0.047
	N	56	56	56	56	55	55	56
Information flow	P. Correlation	- 0.378**	- 0.643**	- 0.376**	- 0.417**	- 0.394**	- 0.406**	- 0.297*
	Sig. (2-tailed)	0.004	0.000	0.004	0.001	0.003	0.002	0.026
	N	56	56	56	56	55	55	56

** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed)
Exclude missing (pairwise)

The analysis of the correlation between ramp-up problems and lean/agile logistics is related to the core purpose of the current research. Poor lean performance is expected to result in more frequent problems during the ramp-up period (as compared with poor agile logistics), since the overall problems construct had correlation coefficients of 0.521 and 0.455 with lean logistics and agile logistics, respectively. While most values were statistically significant, mistaken product design showed no relationship with leanness or agility levels. Such values were expected, since logistics have nothing to do with the product design.

Surprisingly, an insignificant relationship was configured between agile logistics and material-related problems. Furthermore, the relationships between the problems and the outbound side of both lean and agile logistics require further investigation concerning the direction of the relationships. Since outbound logistics takes place after the end of the production process, the logical relationship direction is from the ramp-up problems to the outbound logistics. Table 5.9 shows these correlation coefficients' values.

Table 5.9: Correlations between ramp-up problems and logistics leanness and agility

		Lean Logistics				Agile Logistics		
		Inbound	Intra	Outbound		Inbound	Intra	Outbound
Materials	P. Correlation	- 0.529**	- 0.451**	- 0.358**		- 0.113	- 0.145	- 0.080
	Sig. (2-tailed)	0.000	0.001	0.007		0.410	0.290	0.563
	N	55	55	56		55	55	54
Machine	P. Correlation	- 0.413**	- 0.412**	- 0.270*		- 0.501**	- 0.481**	- 0.444**
	Sig. (2-tailed)	0.002	0.002	0.044		0.000	0.000	0.001
	N	55	55	56		55	55	54
Equipment	P. Correlation	- 0.346**	- 0.314*	- 0.260		- 0.422**	- 0.379**	- 0.358**
	Sig. (2-tailed)	0.010	0.020	0.053		0.001	0.004	0.008
	N	55	55	56		55	55	54
Employees	P. Correlation	- 0.439**	- 0.385**	- 0.367**		- 0.409**	- 0.373**	- 0.332*
	Sig. (2-tailed)	0.001	0.004	0.005		0.002	0.005	0.014
	N	55	55	56		55	55	54
Design–process mismatch	P. Correlation	- 0.467**	- 0.350**	- 0.390**		- 0.393**	- 0.360**	- 0.319*
	Sig. (2-tailed)	0.000	0.009	0.003		0.003	0.007	0.019
	N	55	55	56		55	55	54
Design mistakes	P. Correlation	- 0.222	- 0.140	- 0.335*		- 0.304*	- 0.265	- 0.264
	Sig. (2-tailed)	0.103	0.309	0.011		0.024	0.051	0.054
	N	55	55	56		55	55	54
Technology	P. Correlation	- 0.367**	- 0.278*	- 0.435**		- 0.367**	- 0.380**	- 0.312*
	Sig. (2-tailed)	0.006	0.040	0.001		0.006	0.004	0.022
	N	55	55	56		55	55	54
Cooperation	P. Correlation	- 0.324**	- 0.442**	- 0.349**		- 0.257	- 0.306*	- 0.280*
	Sig. (2-tailed)	0.016	0.001	0.008		0.058	0.023	0.040
	N	55	55	56		55	55	54
Information flow	P. Correlation	- 0.342*	- 0.460**	- 0.240		- 0.480**	- 0.398**	- 0.448**
	Sig. (2-tailed)	0.011	0.000	0.075		0.000	0.003	0.001
	N	55	55	56		55	55	54

** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed)
Exclude missing (pairwise)

Another worthy step is to consider the effect of different problems occurring during the ramp-up phase on the overall new product success. As shown in table 5.10, all the success indicators are affected by problems occurring during production ramp-up and, hence, by ramp-up performance. No unexpected positive values were detected. According to an analysis conducted between success indicators and a composite measure of ramp-up problems, more frequent ramp-up difficulties lead to a more negative effect on customer satisfaction and market share than on sales and profits.

Problems related to materials' unavailability or inappropriateness had no statistically significant effect on either success indicator. Referring to tables 5-8 and 5-9, the same construct seems to have a special – and inconsequential – trend with outbound logistics' agility and with quantity performance, revealing a sort of measurement problem related to this measure that requires further analysis and statistical treatment.

Table 5.10: Correlations between ramp-up problems and new product success

		Sales return	Net profit	Market share	Customer satisfaction
Materials	P. Correlation	- 0.068	- 0.030	- 0.213	- 0.197
	Sig. (2-tailed)	0.618	0.825	0.115	0.146
	N	56	56	56	56
Machine	P. Correlation	- 0.427**	- 0.371**	- 0.405**	- 0.432**
	Sig. (2-tailed)	0.001	0.005	0.002	0.001
	N	56	56	56	56
Equipment	P. Correlation	- 0.330*	- 0.249	- 0.240	- 0.305*
	Sig. (2-tailed)	0.013	0.065	0.075	0.022
	N	56	56	56	56
Employees	P. Correlation	- 0.418**	- 0.373**	- 0.475**	- 0.419**
	Sig. (2-tailed)	0.001	0.005	0.000	0.001
	N	56	56	56	56
Design–process mismatch	P. Correlation	- 0.433*	- 0.410**	- 0.397	- 0.422**
	Sig. (2-tailed)	0.001	0.002	0.002	0.001
	N	56	56	56	56
Design mistakes	P. Correlation	- 0.304*	- 0.269*	- 0.268*	- 0.236
	Sig. (2-tailed)	0.023	0.045	0.046	0.051
	N	56	56	56	56
Technology	P. Correlation	- 0.363**	- 0.310*	- 0.307*	- 0.319*
	Sig. (2-tailed)	0.006	0.020	0.021	0.017
	N	56	56	56	56
Cooperation	P. Correlation	- 0.331*	- 0.239	- 0.346**	- 0.326*
	Sig. (2-tailed)	0.020	0.076	0.009	0.014
	N	56	56	56	56
Information flow	P. Correlation	- 0.471**	- 0.351**	- 0.486**	- 0.494**
	Sig. (2-tailed)	0.000	0.008	0.000	0.000
	N	56	56	56	56

** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed)
Exclude missing (pairwise)

5.3.2. Leanness and Agility Co-existence

The current research's sample showed no significant negative or positive relationship between lean and agile logistics. Only lean intra logistics and agile intra logistics showed a significant relationship (at the 0.05 significance level). The correlation values are reported in table 5.11.

The correlation values between lean and agile logistics are of great importance as indicators of collinearity and multicollinearity. The existence of multicollinearity might be problematic for the analysis results. The correlation matrix in table 5.11 indicated no severe collinearity and no multicollinearity at all.

As mentioned in section 2.3.3, leanness and agility can co-exist, and concentrating on one paradigm does not mean ignoring the other. Therefore, a negative relationship between lean and agile logistics is not confidently expected. Naylor et al. (1999), van Hoek (2000), Bruce et al. (2004), Krishnamurthy and Yauch (2007), and others considered combining leanness and agility.

In addition, table 5.12 presents the correlation coefficients for the relationships between different techniques measured in the questionnaire to assess the levels of leanness and agility. The tools used to enhance the agility have higher inter-correlations than the leanness enhancement tools.

Table 5.11: Correlations between lean and agile logistics constructs

Agility / Leanness		Inbound	Intra	Outbound	Total	Evaluation (flexibility)
Inbound logistics	P. Correlation Sig. (2-tailed) N	0.022 0.874 55	0.124 0.373 54	- 0.016 0.908 54	0.039 0.783 53	- 0.028 0.839 54
Intra logistics	P. Correlation Sig. (2-tailed) N	0.131 0.344 54	0.285* 0.037 54	0.102 0.468 53	0.189 0.179 52	0.111 0.425 54
Outbound logistics	P. Correlation Sig. (2-tailed) N	- 0.060 0.662 55	0.098 0.477 55	- 0.081 0.562 54	- 0.018 0.900 53	0.006 0.965 55
Total	P. Correlation Sig. (2-tailed) N	0.034 0.805 54	0.196 0.159 53	0.001 0.997 53	0.083 0.560 52	0.043 0.761 53
Evaluation (waste reduction)	P. Correlation Sig. (2-tailed) N	0.057 0.679 55	0.136 0.324 55	- 0.055 0.695 54	0.050 0.721 53	0.143 0.298 55

** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed)
Exclude missing (pairwise)

As shown in table 5.12, a very strong relationship was found between the use of third-party logistics (3PL) in distribution and the use of vendor-managed inventory (VMI) techniques, which means that firms relying on outsourcing of their inbound logistics activities attempt to outsource their outbound logistics as well.

Table 5.12: Correlations between different lean and agile techniques

		MRP (-)	Supplier milk runs	JIT	Kanban	Cross-docking	VMI	Modular design	RMS	3PL
MRP (-)	P. Correlation Sig. (2-tailed) N	1 56								
Supplier milk runs	P. Correlation Sig. (2-tailed) N	0.258 0.055 56	1 56							
JIT	P. Correlation Sig. (2-tailed) N	0.057 0.676 56	0.320* 0.016 56	1 56						
Kanban	P. Correlation Sig. (2-tailed) N	0.112 0.411 56	0.610** 0.000 56	0.632** 0.000 56	1 56					
Cross-docking	P. Correlation Sig. (2-tailed) N	0.153 0.265 55	0.600** 0.000 56	0.668** 0.000 55	0.819** 0.000 55	1 55				
VMI	P. Correlation Sig. (2-tailed) N	0.223 0.101 55	0.170 0.214 55	0.209 0.126 55	0.246 0.070 55	0.104 0.454 54	1 55			
Modular design	P. Correlation Sig. (2-tailed) N	0.178 0.189 56	0.398** 0.002 56	0.204 0.132 56	0.354** 0.007 56	0.200 0.142 55	0.673** 0.000 55	1 56		
RMS	P. Correlation Sig. (2-tailed) N	0.333* 0.012 56	0.442** 0.001 56	0.307* 0.021 56	0.365** 0.006 56	0.335* 0.012 55	0.806** 0.000 55	0.795** 0.000 56	1 56	
3PL	P. Correlation Sig. (2-tailed) N	0.227 0.093 56	0.110 0.420 56	0.116 0.393 56	0.126 0.353 56	0.004 0.980 55	0.923** 0.000 55	0.658** 0.000 56	0.763** 0.000 56	1 56

** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed)
Exclude missing (pairwise)

Another high correlation was detected between the evaluation of the Kanban system and the evaluation of the cross-docking activities. Significant correlations also existed between some lean techniques and agility tools, such as the use of suppliers' milk runs and the use of the Kanban system.

5.3.3. Respondent-, Organization-, and Product-Related Variables

A full correlation matrix between respondent-, organization-, and product-related variables on the one hand and all the constructs used in the research on the other hand was constructed. The results indicated very limited significant values. Table 5.13 shows only the statistically significant correlation values.

Table 5.13: Significant correlations between moderating variables and other main research variables

		Organization-related		Product-related
		Size	Ramp-up frequency	Lifecycle
Organizational size	P. Correlation Sig. (2-tailed) N	1 55	0.578** 0.000 54	
Ramp-up frequency	P. Correlation Sig. (2-tailed) N	0.578** 0.000 54	1 55	
Lean intra logistics	P. Correlation Sig. (2-tailed) N	0.402** 0.003 54	0.420** 0.002 54	
Logistics leanness	P. Correlation Sig. (2-tailed) N	0.322* 0.019 53	0.314* 0.022 53	
Logistical waste reduction evaluation	P. Correlation Sig. (2-tailed) N		0.325* 0.16 55	
Agile intra logistics	P. Correlation Sig. (2-tailed) N	0.464** 0.000 54		
Agile outbound logistics	P. Correlation Sig. (2-tailed) N	0.373** 0.006 53		
Logistics agility	P. Correlation Sig. (2-tailed) N	0.396** 0.004 52		
Flexibility evaluation	P. Correlation Sig. (2-tailed) N	0.275* 0.044 54		
Ramp-up's quality goal achievement	P. Correlation Sig. (2-tailed) N			0.401** 0.003 54
Ramp-up's problems	P. Correlation Sig. (2-tailed) N			0.366** 0.006 55
Overall ramp-up evaluation	P. Correlation Sig. (2-tailed) N			0.339* 0.013 53
Market share	P. Correlation Sig. (2-tailed) N	0.273* 0.044 55		

** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed)
Exclude missing (pairwise)

Job position and product type were measured but led to a very wide range of alternatives that could not produce any meaningful statistical figures due to the small size of the sample. Therefore, these two dimensions were ignored.

As shown in the table, companies with more employees – as a measure of the company size – had a higher innovation rate reflected by the number of new product ramp-ups experienced. Lean intra logistics was significantly correlated with both size and ramp-up frequency. The agility of the intra logistics activities was positively related to the company size. The researched sample also showed that the product lifecycle was significantly related to the overall evaluation of ramp-up quantity goal achievement, ramp-up problems (the inverse scale of problems' frequency), and the overall respondents' evaluation of the ramp-up performance.

5.4. Hypothesis Formulation and Testing

Following the articulation of the constructs and their potential relationships, the propositions describing the relationships between constructs must be translated into hypotheses (Forza, 2002). Based on the research model introduced in figure 4.3 on page 101 and on the literature review presented in section 2.3, the research's main and sub-hypotheses (in their null forms) were formed to illustrate the nature and the direction of the relationships between the research variables.

With regard to the research's main focus concerning the relationship between lean/agile logistics activities and production ramp-up performance, the hypotheses were formed as directional hypotheses that suggest a positive relationship between the levels of leanness/agility and the levels of production performance during the ramp-up phase. Forza (2002) mentioned that non-directional hypotheses might be formed on the relationship between variables that have never been explored previously or when conflicting results exist. While lean and agile logistics have never been investigated during the ramp-up phase, researchers have appreciated the role of logistics in general during this phase. Based on the results of these studies, the direction of the relationship can be confidently proposed. Figure 5.1 and the following null hypotheses illustrate these relationships:

H_0:1 More leanness in the logistics <u>does not</u> lead to better ramp-up performance.

- **H_0:1.1** More leanness in the logistics activities does not enhance ramp-up **quantity** performance.
- **H_0:1.2** More leanness in the logistics activities does not enhance ramp-up **quality** performance.
- **H_0:1.3** More leanness in the logistics activities does not enhance ramp-up **cost** performance.

H_0:2 More agility in the logistics <u>does not</u> lead to better ramp-up performance.

- **H_0:2.1** More agility in the logistics activities does not enhance ramp-up **quantity** performance.
- **H_0:2.2** More agility in the logistics activities does not enhance ramp-up **quality** performance.
- **H_0:2.3** More agility in the logistics activities does not enhance ramp-up **cost** performance.

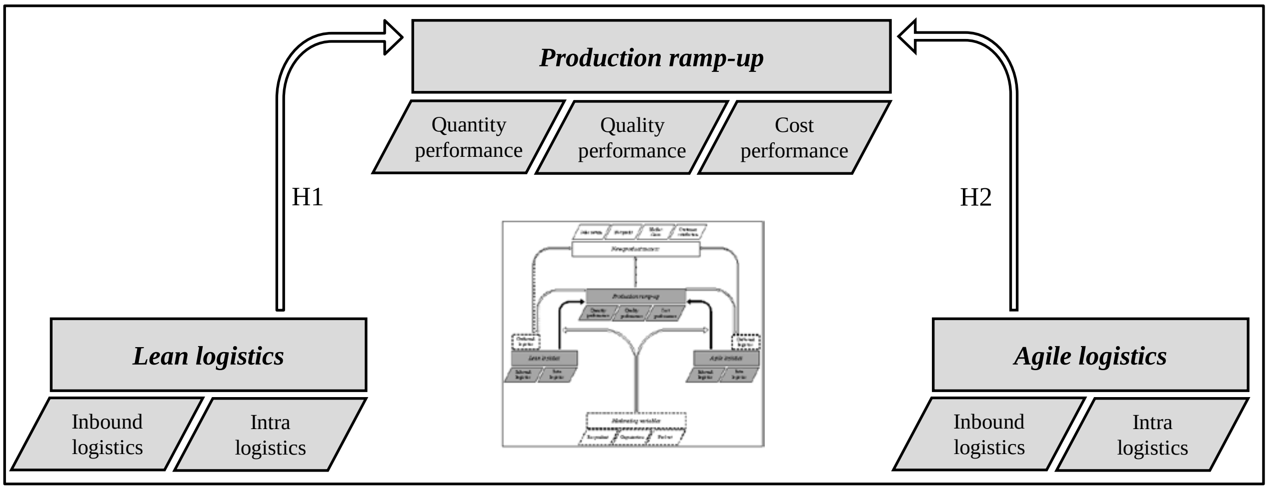


Figure 5.1: Logistics/ramp-up hypothesized relationships

The direct relationship between ramp-up performance and new product success (figure 5.2) was also formulated in terms of directional hypotheses, since the literature supports the hypothesized effect. The null hypotheses concerning this relationship are:

H_0:3 Better ramp-up performance <u>does not</u> enhance new product success.

- **H_0:3.1** Better ramp-up **quantity** performance does not enhance new product success.
- **H_0:3.2** Better ramp-up **quality** performance does not enhance new product success.
- **H_0:3.3** Better ramp-up **cost** performance does not enhance new product success.

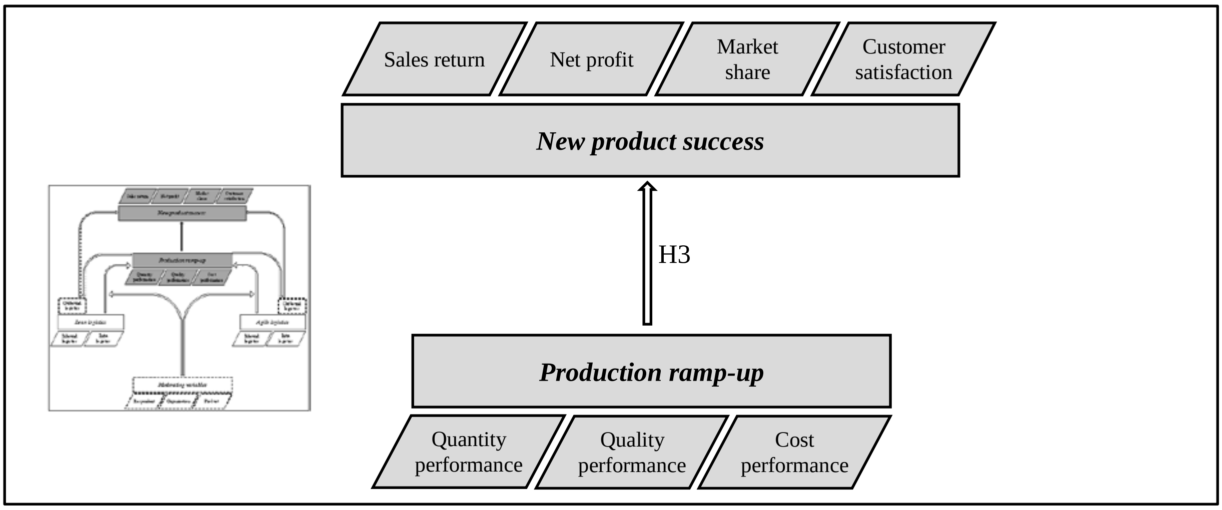


Figure 5.2: Ramp-up/success hypothesized relationships

The hypotheses regarding the mediating role of outbound lean and agile logistics in the relationship between production ramp-up performance and new product success, in addition to the hypotheses proposing a direct effect of ramp-up performance on outbound logistics' leanness and agility and the direct effect of outbound lean and agile logistics on new product success, are illustrated in figure 5.3 and formulated below:

H_0:4 Better ramp-up performance does not enhance the leanness of outbound logistics.

- **H_0:4.1** Better ramp-up **quantity** does not enhance the leanness of outbound logistics.
- **H_0:4.2** Better ramp-up **quality** does not enhance the leanness of outbound logistics.
- **H_0:4.3** Better ramp-up **cost** does not enhance the leanness of outbound logistics.

H_0:5 Better ramp-up performance does not enhance the agility of outbound logistics.

- **H_0:5.1** Better ramp-up **quantity** does not enhance the agility of outbound logistics.
- **H_0:5.2** Better ramp-up **quality** does not enhance the agility of outbound logistics.
- **H_0:5.3** Better ramp-up **cost** does not enhance the agility of outbound logistics.

H_0:6 Lean outbound logistics does not mediate the effect of ramp-up performance on new product success.

- **H_0:6.1** Lean outbound logistics does not mediate the effect of ramp-up **quantity** performance on product success.
- **H_0:6.2** Lean outbound logistics does not mediate the effect of ramp-up **quality** performance on product success.
- **H_0:6.3** Lean outbound logistics does not mediate the effect of ramp-up **cost** performance on product success.

H_0:7 Agile outbound logistics does not mediate the effect of ramp-up performance on new product success.

- **H_0:7.1** Agile outbound logistics does not mediate the effect of ramp-up **quantity** performance on product success.
- **H_0:7.2** Agile outbound logistics does not mediate the effect of ramp-up **quality** performance on product success.
- **H_0:7.3** Agile outbound logistics does not mediate the effect of ramp-up **cost** performance on product success.

H_0:8 More leanness of outbound logistics does not enhance new product success.

H_0:9 More agility of outbound logistics does not enhance new product success.

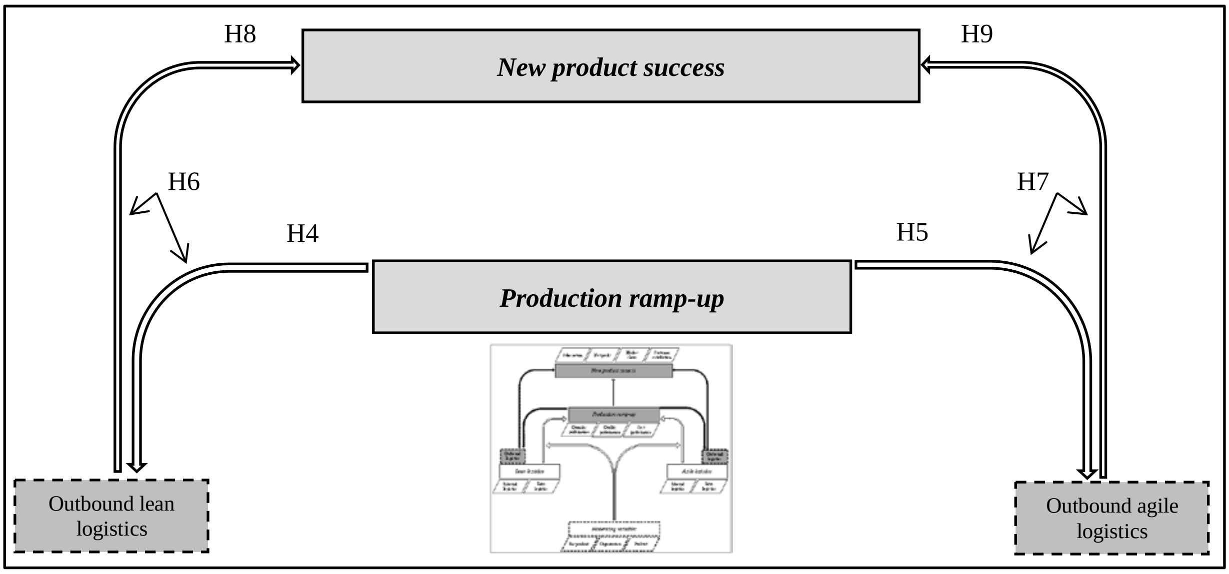


Figure 5.3: Ramp-up, outbound logistics, and success relationships

Figure 5.4 illustrates the hypothesized moderating effect of respondent-, organization-, and product-related characteristics on the relationship between lean logistics and ramp-up performance and between agile logistics and ramp-up performance. The related null hypotheses are H_0:10 and H_0:11.

Job position, country, and product type were removed from the analysis, since these categories have a wide range of respondents' answers and, hence, may not produce any significant indications with such a small sample size. Therefore, the sub-hypothesis related to the respondent-related variable was represented only by the length of working experience. The organization-related variable was represented by the company size and the number of ramp-ups, and the product-related variable was represented by the newness of the product and the expected lifecycle length.

H_0:10 Respondent-, organization-, and product-related characteristics do not moderate the relationship between ramp-up performance and lean logistics.

- **H_0:10.1** **Experience** does not moderate the relationship between ramp-up performance and lean logistics.
- **H_0:10.2** **Organizational size** does not moderate the relationship between ramp-up performance and lean logistics.
- **H_0:10.3** **Ramp-up frequency** does not moderate the relationship between ramp-up performance and lean logistics.
- **H_0:10.4** **Product/process newness** does not moderate the relationship between ramp-up performance and lean logistics.

H_0:10.5 **Product Lifecycle length** does not moderate the relationship between ramp-up performance and lean logistics.

H_0:11 Respondent-, organization-, and product-related characteristics do not moderate the relationship between ramp-up performance and agile logistics.

H_0:11.1 **Experience** does not moderate the relationship between ramp-up performance and agile logistics.

H_0:11.2 **Organizational size** does not moderate the relationship between ramp-up performance and agile logistics.

H_0:11.3 **Ramp-up frequency** does not moderate the relationship between ramp-up performance and agile logistics.

H_0:11.4 **Product/process newness** does not moderate the relationship between ramp-up performance and agile logistics.

H_0:11.5 **Product lifecycle length** does not moderate the relationship between ramp-up performance and agile logistics.

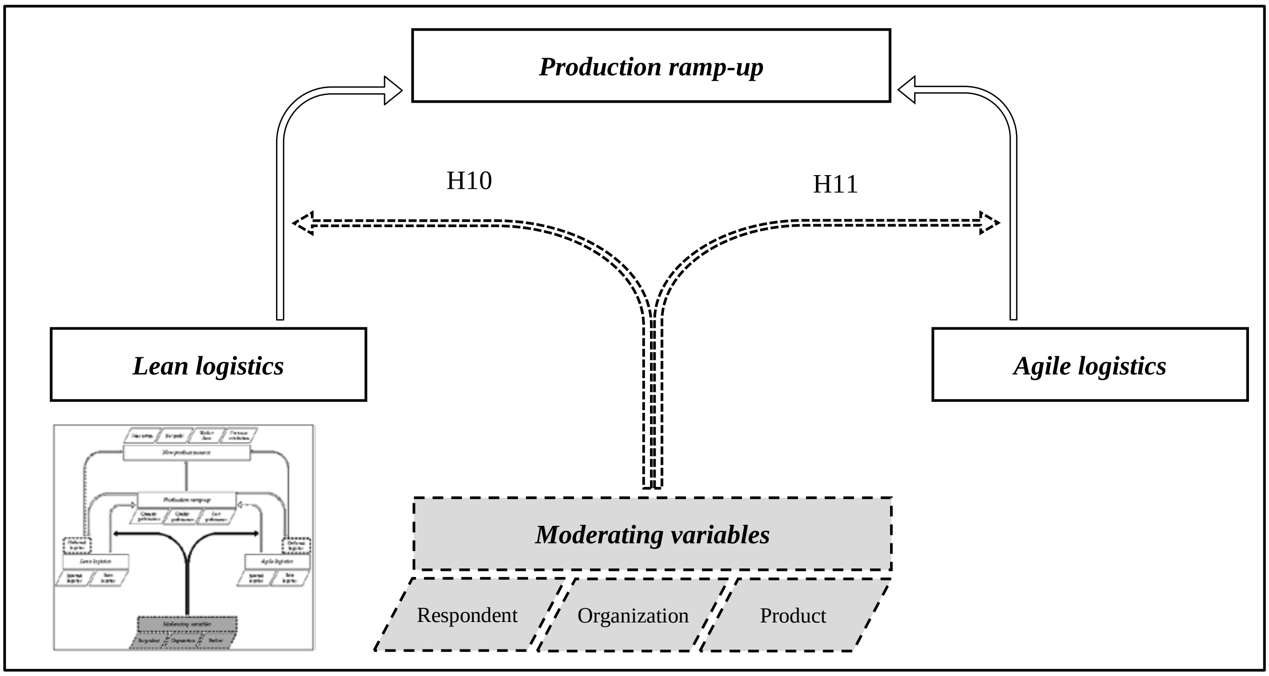


Figure 5.4: Moderating effects of respondent-, organization-, and product-related characteristics

5.4.1. Hypothesis Testing

Similar to the situation illustrated by Calvo-Mora et al. (2013), the attempt to predict dependent variables, the complexity of the research model, and the use of a small sample size motivated the use of the PLS method. In addition, PLS is more appropriate for testing models with formative and reflective constructs (Lowry and Gaskin, 2014). In the following sub-sections, the results of testing the main and sub-hypotheses are presented and discussed.

Main Hypotheses

Different scenarios were used to test the main hypotheses based on whether the variables were considered to be in the first- or second-orders and, hence, to be formative or reflective. These modelling scenarios were then compared and evaluated based on the statistical indicators and the fitness of each model. While the formative and reflective perspectives of the research variables have already been identified, the use of a first- or higher-order model should be deliberated. In addition, the use of different indicators might provide further insights into the research's results.

Scenario 1: First-Order Reflective

All ramp-up performance and problem measures were set as direct reflective measures for the overall ramp-up construct; the same was applied to the inbound and intra logistics measures. Figure 5.5 (A and B) shows the result of the path analysis conducted for this model. Figure 5.5 A illustrates the coefficient of determination (R^2) values for the dependent variables. The values between the constructs and their measures – the outer model – represent the outer loadings, while the values between different dependent and independent variables – the inner model – represent the path coefficients. In figure 5.5 B, all the values in the inner and the outer models represent the t values. The values of the t statistic, composite reliability (ρ_c), and average variance extracted (AVE) indicated some reliability and fitness issues and necessitated further modifications.

While the measures of ramp-up problems were added and the three measures related to 3PL, MRP, and suppliers' milk run were removed, standardization, cycle time reduction, employees' learning levels, and the costs of preparing the system for the ramp-up all had lower loading values than were acceptable according to this model. Therefore, the removed items were reinstalled and then eliminated one by one and the model was retested after each adjustment was made. The following changes were made to the reflective model:

- The measures of cycle time reduction, learning, and MRP were removed due to low t values; as indicated by Hair et al. (2014), t values lower than 1.960 and p values lower than 0.050 are statistically insignificant.
- The measures of system preparation costs and standardization were removed to enhance the AVE values.

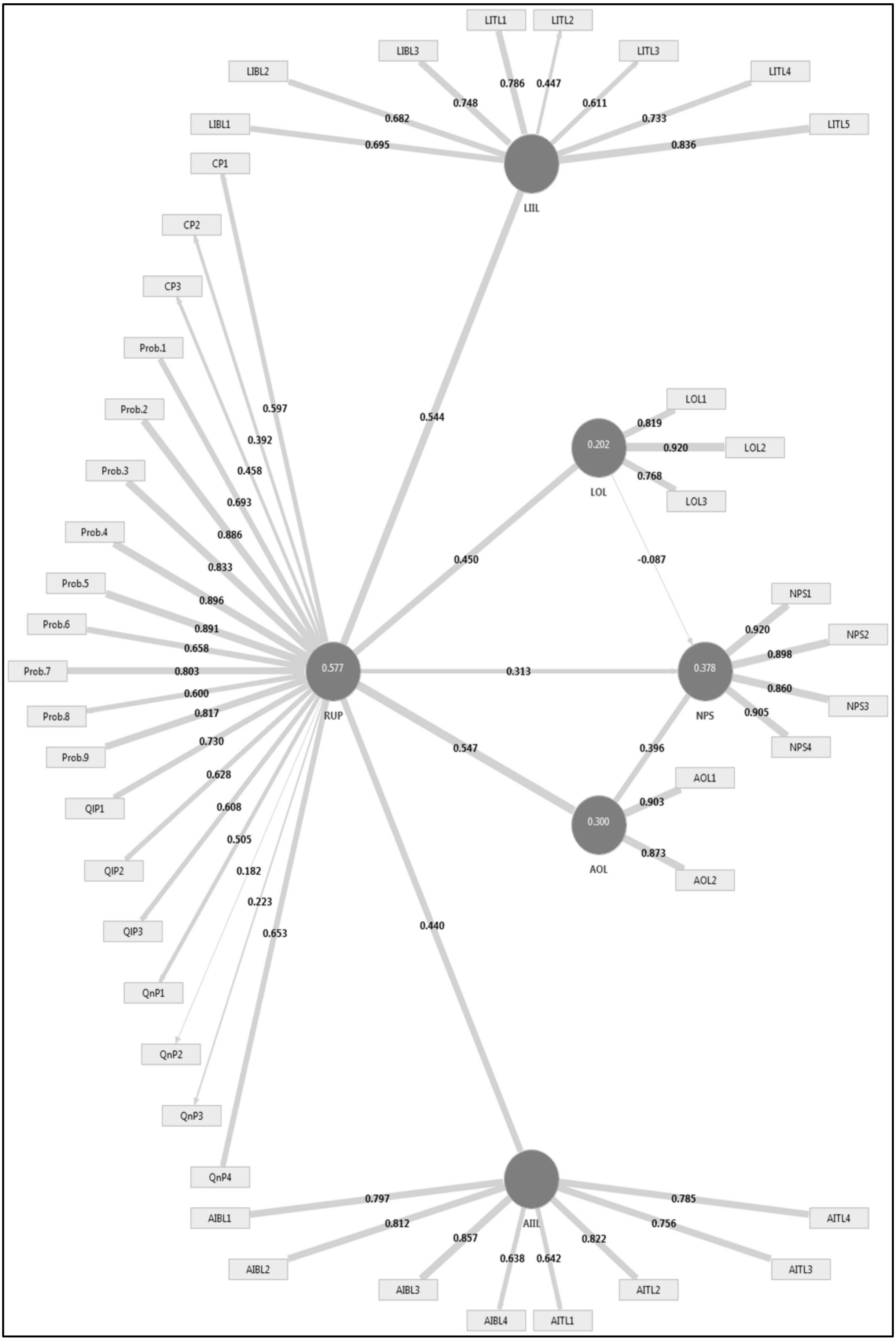


Figure 5.5 A: First-order reflective variables' path analysis results

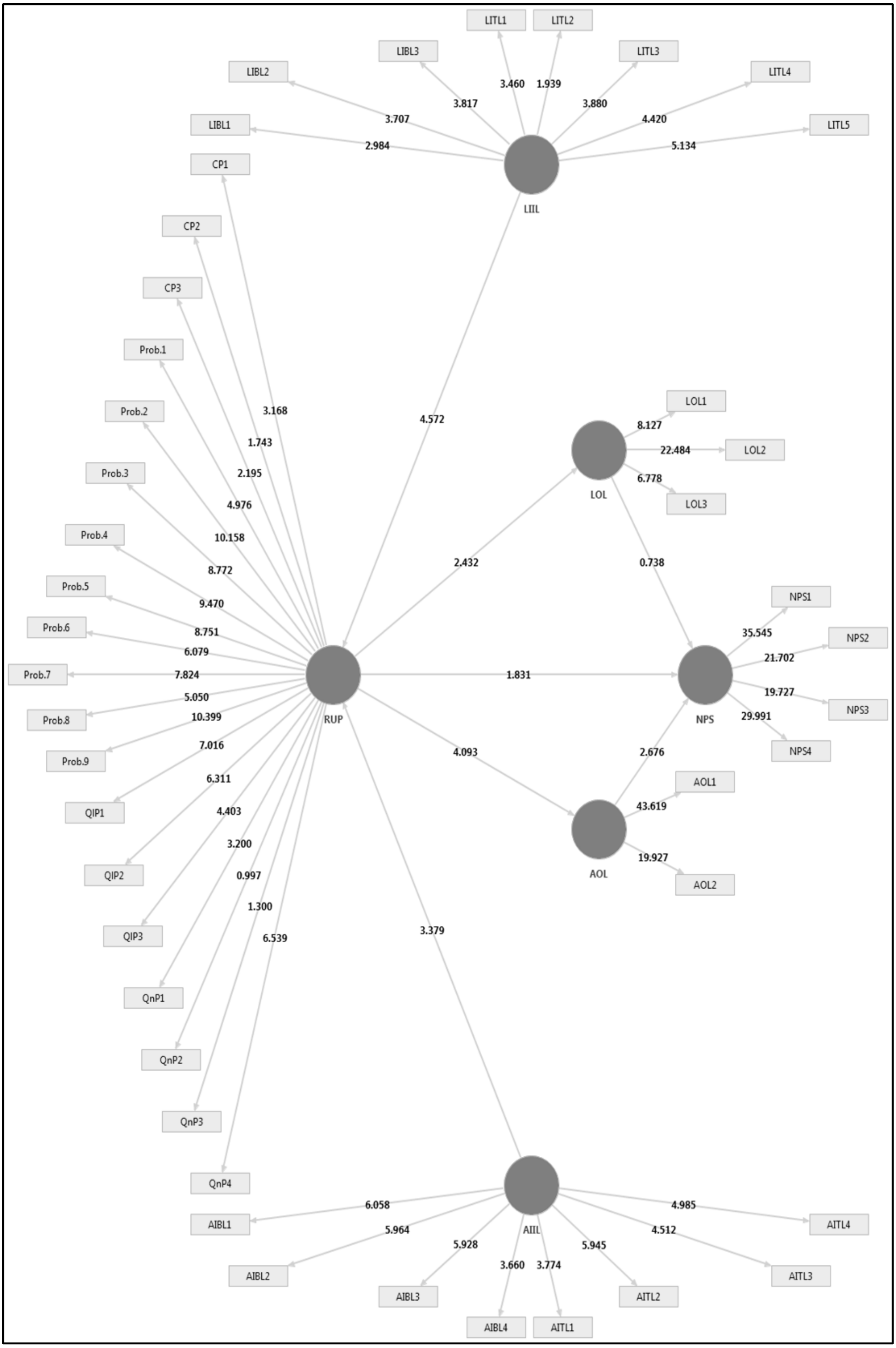


Figure 5.5 B: First-order reflective variables' path analysis significance

- The measure of 3PL activities was removed again to enhance the ρ_c value for the outbound agile logistics construct.

Table 5.14 illustrates the differences between the original model shown in the previous figure and the adjusted model shown in figure 5.6. While no significant change occurred due to this adjustment, the resulting model was considered to be more reliable. The effect of agility on ramp-up was decreased from 0.440 to 0.399, the effect of leanness on ramp-up performance increased slightly, and the effect of ramp-up performance on new product success decreased and remained insignificant.

Table 5.14: The effect of removing measures with insignificant factor loading values

Path	**Path coefficient**		***t* value**		***p* value**		**St. error**	
	Old	**New**	Old	**New**	Old	**New**	Old	**New**
Lean (inbound and intra) >>>> Ramp-up	0.544	**0.550**	4.947	**6.470**	0.000	**0.000**	0.117	**0.085**
Agile (inbound and intra) >>> Ramp-up	0.440	**0.399**	3.465	**3.704**	0.000	**0.000**	0.122	**0.108**
Ramp-up >>>>>>>>>> Product success	0.313	**0.304**	1.845	**1.766**	0.075	**0.078**	0.175	**0.172**
Ramp-up >>>>>>>>>> Lean (outbound)	0.450	**0.462**	2.364	**3.628**	0.016	**0.000**	0.186	**0.127**
Ramp-up >>>>>>>>> Agile (outbound)	0.547	**0.537**	3.912	**4.519**	0.000	**0.000**	0.134	**0.119**
Lean (outbound) >>>>> Product success	- 0.087	**- 0.087**	0.711	**0.693**	0.471	**0.488**	0.121	**0.126**
Agile (outbound) >>>>> Product success	0.396	**0.404**	2.635	**2.799**	0.010	**0.005**	0.153	**0.144**

Lean logistics and agile logistics significantly and positively affect the ramp-up performance levels. According to the model presented in figure 5.6, 55.7% of the variation in ramp-up performance can be explained by the variation in the inbound and intra logistics' levels of leanness and agility.

The direct effect of ramp-up performance on new product success is insignificant. As mentioned by Hair et al. (2014), once the path between the dependent and the independent variables is basically insignificant, further investigation of the mediating effect on this path is not needed, and the mediation effect should also be considered to be insignificant. In addition, the ramp-up was shown to affect the levels of outbound logistics leanness and agility levels significantly.

The moderating role of the respondent-, organization-, and product-related characteristics was evaluated by adding an interactive variable to the path model. The results showed no significant moderating effect for the relationship between leanness and ramp-up performance with a path coefficient equal to -0.092, $t = 1.080$, and $p = 0.280$. Similarly, no significant moderating effect was detected for the relationship between agility and ramp-up performance; the path coefficient equalled -0.002, the t value was 0.021, and the p value was very high (0.983).

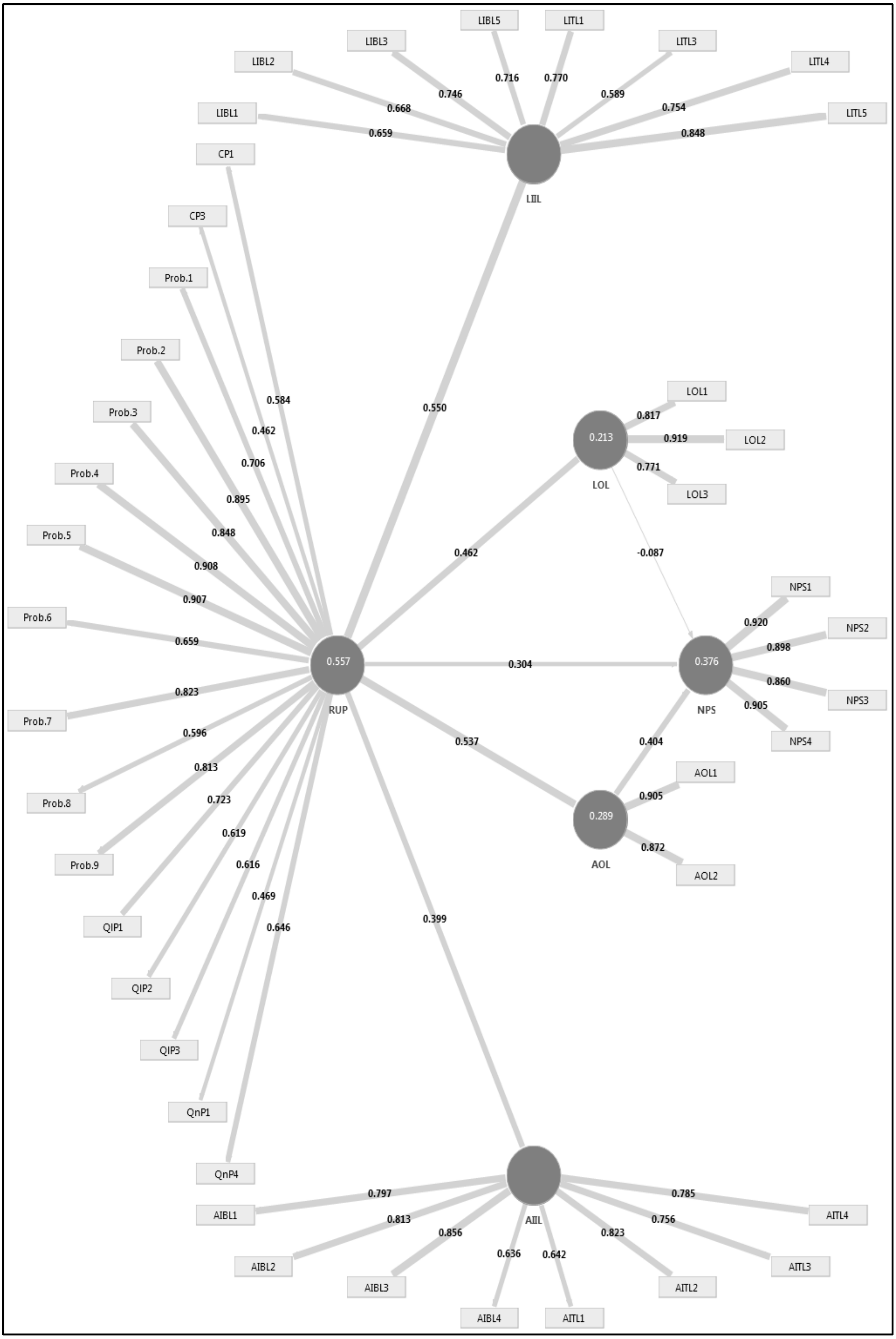


Figure 5.6: Adjusted first-order reflective variables path analysis results

Scenario 2: Second-Order Formative

Lean logistics, agile logistics, and product success were all considered as reflective variables. The results of the constructs' reliability test using Cronbach's alpha supported this argument (see table 3.4, page 65). Using a first-order format for ramp-up performance as a formative variable leads to insignificant outer loadings and weights for most of the model measures, in addition to other reliability and fitness issues (see Appendix 3, figure A.1). The measurement of production problem occurrences during the ramp-up phase was originally added to the structural model to enhance the reliability and to raise the Cronbach's alpha to an acceptable level – all as reflective indicators. Diamantopoulos et al. (2008) mentioned that reliability, in terms of internal consistency, is not meaningful for formative indicators, since the correlation values between different formative indicators could be negative, positive, or zero (Diamantopoulos and Winklhofer, 2001). Consequently, the model was formed with ramp-up performance as a second-order formative variable and the measures of ramp-up problems were eliminated. In addition, the constructs combining inbound and intra logistics for both lean and agile cases should be formed as formative second-order variables.

In this model, the 3PL measure was removed to enhance the ρ_c value, and the MRP measure was eliminated to raise the AVE value of the lean inbound logistics to 0.562. While the construct combining inbound and intra logistics' leanness and the ramp-up performance construct have AVE values less than 0.500, these were ignored since both are formative variables. The final components and the relationship directions for the model are shown in figure 5.7.

To calculate the accurate path coefficients for this model, a two-step procedure was applied. First, the path model coefficients for the model in figure 5.7 were calculated. In this case, the second-order dependent latent variables' variation is completely explained by their corresponding first-order reflective variables and nothing is left for the other independent variables. Therefore, the second step was to use the calculated scores of the latent variables (see table A.1 A, in appendix 4) as individual indicators for the dependent and independent variables included in the main hypotheses. The path coefficients for this model are illustrated in figure 5.8.

According to the analysis results of this model, the p values indicated insignificant relationships between lean outbound logistics and product success ($p = 0.756$) and between ramp-up performance and product success ($p = 0.123$); the coefficient for the indirect effect of ramp-up on success had the value of 0.228 with $p = 0.000$.

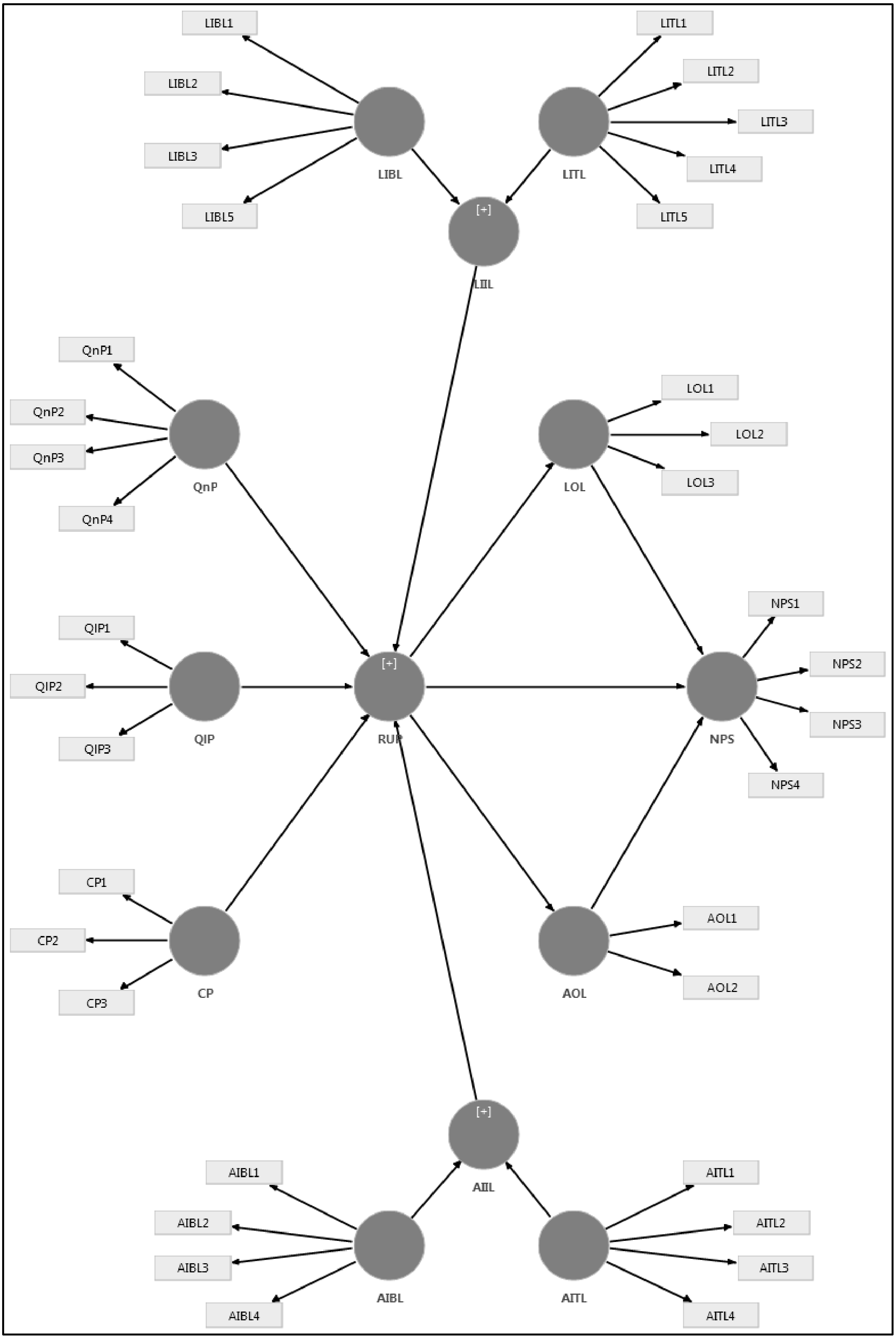


Figure 5.7: Path model with second-order formative variables

In this scenario as well, no significant moderating effects were identified. The statistics for moderating the relationship between leanness and ramp-up were the following: path coefficient = 0.005, $t = 0.041$, and $p = 0.968$. For the relationship between agility and ramp-up, the path coefficient equalled 0.031, $t = 0.268$, and $p = 0.789$.

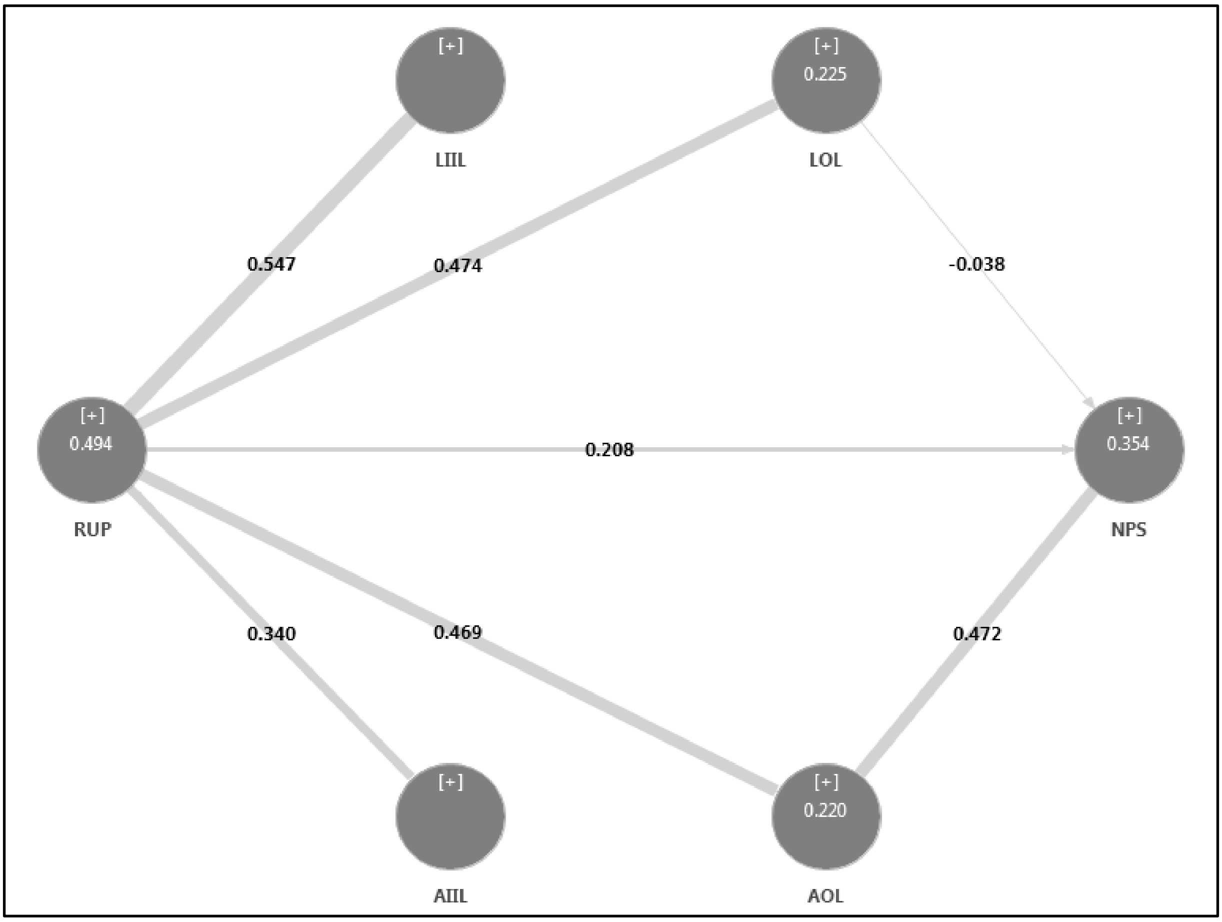


Figure 5.8: Path coefficients for the second-order formative model

Scenario 3: Second-Order Formative Considering the Ramp-Up Problems

In this scenario, the procedure followed in scenario 2 was repeated but with the addition of the dimension of ramp-up problems' performance, as an additional indicator of the overall ramp-up performance, to examine whether any significant enhancement could be achieved. The results obtained from analysing this new model indicated no important enhancements. The differences between scenario 2 and scenario 3 are listed in table 5.15. The calculated values of the latent variables used in the second-step path calculation are illustrated in table A.1 B in Appendix 4.

A greater effect of the logistics system's agility on ramp-up performance was experienced. In addition, the direct effect of ramp-up performance on new product success was closer to being validated with a significantly higher path coefficient, but the significance of this path represented by the *p* value was still lower than needed. The sign of the relationship between lean outbound logistics and new product success changed, but this relationship was statistically insignificant in both cases. The model representing this scenario is presented in appendix 3, figure A.2. In this scenario, the moderating role of respondent-, organization-, and product-related variables was also insignificant, with statistical indicators very close to those of scenario 2.

Table 5.15: The effect of adding the ramp-up problems dimension to scenario 2

Path	**Path coefficient**		***t* value**		***p* value**		**St. error**	
	Sce. 2	**Sce. 3**	Sce. 2	**Sce. 3**	Sce. 2	**Sce. 3**	Sce. 2	**Sce. 3**
Lean (inbound and intra) >>>> Ramp-up	0.547	**0.546**	7.280	**7.347**	0.000	**0.000**	0.075	**0.074**
Agile (inbound and intra) >>> Ramp-up	0.340	**0.402**	3.760	**4.098**	0.000	**0.000**	0.090	**0.098**
Ramp-up >>>>>>>>>> Product success	0.208	**0.511**	1.475	**1.683**	0.141	**0.093**	0.141	**0.163**
Ramp-up >>>>>>>>>> Lean (outbound)	0.474	**0.462**	5.312	**4.920**	0.000	**0.000**	0.089	**0.094**
Ramp-up >>>>>>>>> Agile (outbound)	0.469	**0.530**	5.270	**5.663**	0.000	**0.000**	0.089	**0.094**
Lean (outbound) >>>>> Product success	- 0.038	**0.009**	0.341	**0.085**	0.733	**0.932**	0.113	**0.109**
Agile (outbound) >>>>> Product success	0.472	**0.439**	3.851	**3.185**	0.000	**0.002**	0.123	**0.138**

Scenario 4: First-Order Reflective Based on the General Evaluations

As the respondents were asked to provide their overall evaluation of the main research dimensions, including the ramp-up phase’s volume, time, cost, and quality goal attainment; the overall ability to eliminate waste in the logistics system; and the overall flexibility of the logistics system, these variables can be used as an indicators for ramp-up performance, logistical leanness, and logistical agility. While the measurement process of the research’s variables is complicated and subject to many reliability and validity issues, the use of experts’ general evaluation of constructs might be helpful and provide an accurate judgement that includes all the variables contributing to these constructs.

In this scenario, a simple path model used the dimensions of volume, time, cost, and quality goal attainment evaluation as the indicators of ramp-up performance; the evaluation of logistics’ ability to eliminate waste as a single indicator of logistical leanness; and the logistics system’s overall flexibility as a single indicator of logistical agility. Hair et al. (2014) indicated the advantages of using a single-item measure.

In this model, inbound, intra, and outbound logistics are all included in the leanness and agility constructs. Therefore, the measurement of outbound logistics’ direct and indirect relationships was excluded from this scenario. The analysis of the model revealed a low Cronbach’s alpha value (0.688). However, the ρ_c value indicated a satisfactory level (0.807) and, hence, the model was considered to be sufficiently reliable. In addition, the analysis was conducted twice with and without the cost evaluation indicator, and no significant differences were noted. Figure 5.9 represents the path model of this scenario with the path coefficients and R^2 values.

The model in which the cost evaluation indicator was eliminated is represented in figure A.3 in appendix 3. Higher path coefficients for the relationships between agile logistics and ramp-up and between ramp-up and success were identified, and a lower coefficient for the relationship between lean logistics and ramp-up performance was also noted. In this model, no significant moderating effects were identified for the proposed moderating variables.

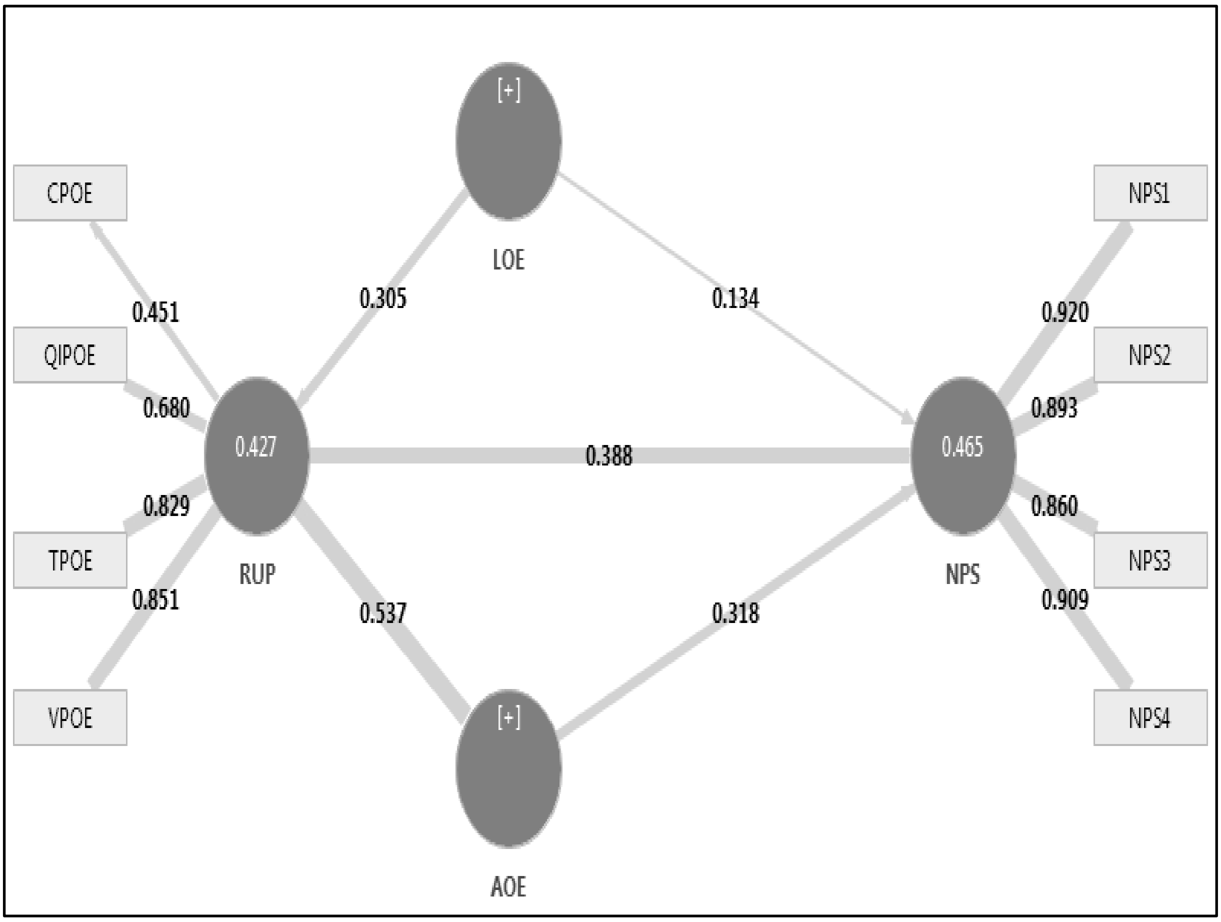


Figure 5.9: Path coefficients for the first-order reflective model using general evaluation dimensions

Scenario 5: Second-Order Formative Based on the General Evaluations

The same model used in scenario 2 was employed again, but instead of using the normal measures as indicators of the second-order formative variables, these measures were replaced by the general evaluation measures used in the previous scenario. The model was also adjusted to enhance the ρ_c, AVE, and heterotrait–monotrait (HTMT) ratio indications. All the coefficients for this scenario are illustrated in figure A.4 in appendix 3. The results showed an insignificant effect of lean logistics on ramp-up performance, of ramp-up on outbound logistical leanness, and of both lean and agile outbound logistics on new product success.

However, the results indicated a significant effect of ramp-up performance on product success, which required further investigation of the possible mediation role of outbound logistics. In the case of lean logistics, while the path between ramp-up and success was significant with $p = 0.014$, the significance of the paths between ramp-up and outbound lean logistics and between outbound lean logistics and success should also be significant (Hair et al., 2014).

This condition was not achieved, since the p values for both were insignificant (the p values were 0.207 and 0.230, respectively). In addition, in the case of agile logistics, the p value for the path coefficient between outbound agile logistics and success was insignificant, with a value of 0.197. Consequently, the moderating effects of both lean and agile logistics were considered to be insignificant. The moderating roles of respondent-, organization-, and product-related variables were insignificant in this scenario as well.

Scenario Summary

The five scenarios explained in the previous sections are summarized in table 5.16. These scenarios were compared according to the different statistical indicators contributing to the model fitness. In addition, the scenarios were judged according to the similarity to the original proposed model.

While the Cronbach's alpha represents the internal consistency of the construct, the use of ρ_c should also be considered. Hair et al. (2014) indicated that ρ_c can be calculated according to the following formula:

$$\rho_c = \frac{(\sum_i l_i)^2}{(\sum_i l_i)^2 + \sum_i var(e_i)}$$

in which, for an indicator variable i of a specific construct:

l_i: is the standardized outer loading
e_i: is the measurement error
$var\ (e_i)$: is the variance of the measurement error

According to table 5.16, and considering the values of AVE, ρ_c, VIF, HTMT, and SRMR, scenarios 2 and 3 were considered to be the most powerful. In addition, scenario 2 was considered to be the closest one to the original model.

Table 5.16: Main hypothesis scenarios' summary

Main hypothesis	**Path**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
H_0:1	Lean (inbound and intra) >>>>>>>>>>> Ramp-up	Rej.	Rej.	Rej.	**Acc.**	**Acc.**
H_0:2	Agile (inbound and intra) >>>>>>>>>>> Ramp-up	Rej.	Rej.	Rej.	Rej.	Rej.
H_0:3	Ramp-up >>>>>>>>>>>>>>>>> Product success	**Acc.**	**Acc.**	**Acc.**	Rej.	Rej.
H_0:4	Ramp-up >>>>>>>>>>>>>>>> Lean (outbound)	Rej.	Rej.	Rej.	-	**Acc.**
H_0:5	Ramp-up >>>>>>>>>>>>>>>> Agile (outbound)	Rej.	Rej.	Rej.	-	Rej.
H_0:6	Ramp-up >>> lean (outbound) >>> Product success	**Acc.**	**Acc.**	**Acc.**	-	**Acc.**
H_0:7	Ramp-up >> agile (outbound) >>> Product success	**Acc.**	**Acc.**	**Acc.**	-	**Acc.**
H_0:8	Lean (outbound) >>>>>>>>>>>>> Product success	**Acc.**	**Acc.**	**Acc.**	**Acc.**	**Acc.**
H_0:9	Agile (outbound) >>>>>>>>>>>> Product success	Rej.	Rej.	Rej.	Rej.	**Acc.**
H_0:10	Moderators >>>>> Leanness /ramp-up relationship	**Acc.**	**Acc.**	**Acc.**	**Acc.**	**Acc.**
H_0:11	Moderators >>>>>>> Agility /ramp-up relationship	**Acc.**	**Acc.**	**Acc.**	**Acc.**	**Acc.**
	Statistics					
	R^2 (ramp-up performance)	**0.557**	**0.494**	**0.542**	**0.433**	**0.608**
	R^2 (product success)	**0.376**	**0.354**	**0.397**	**0.467**	**0.444**
	F^2 (lean >>> ramp-up)	**0.650**	**0.564**	**0.629**	**0.159**	**0.018**
	F^2 (agile >>> ramp-up)	**0.342**	**0.217**	**0.340**	**0.507**	**0.172**
	F^2 (ramp-up >>> success)	**0.068**	**0.035**	**0.058**	**0.156**	**0.216**
	Path coefficient (lean >>> ramp-up)	**0.550**	**0.547**	**0.546**	**0.303**	**0.106**
	Path coefficient (agile >>> ramp-up)	**0.399**	**0.340**	**0.402**	**0.542**	**0.334**
	Path coefficient (ramp-up >>> success)	**0.304**	**0.208**	**0.511**	**0.383**	**0.526**
	Average variance extracted (AVE)	✓	✓	✓	✓	✓
	Composite reliability (ρ_c)	✓	✓	✓	✓	✓
	Highest variance inflation factor (VIF)/inner model	**2.181**	**1.929**	**2.149**	**1.763**	**2.866**
	Maximum heterotrait-monotrait ratio (HTMT)	**0.982**	**0.812**	**0.814**	**0.763**	**1.087**
	Maximum HTMT confidence intervals up	**1.116**	**0.877**	**0.884**	**0.911**	**1.272**
	Standardized root mean square residual (SRMR)	**0.150**	**0.000**	**0.000**	**0.140**	**0.157**

Sub-hypotheses

The research sub-hypotheses were tested according to the model illustrated in figure 5.10. The figure also includes the path coefficients and the R^2 values. Only two constructs were eliminated to enhance the ρ_c value to the acceptable levels in the case of inbound lean logistics and outbound agile logistics. Figure A.5 in appendix 3 shows the model with all the p values to investigate the significance of the relationships.

Table 5.17 illustrates the results of testing the subsidiary hypotheses using the model presented in figure 5.10. However, the sub-hypotheses related to the moderating effect of respondent-, organization-, and product-related variables were tested using the model developed in scenario 2 for the main hypothesis testing (see figure 5.8).

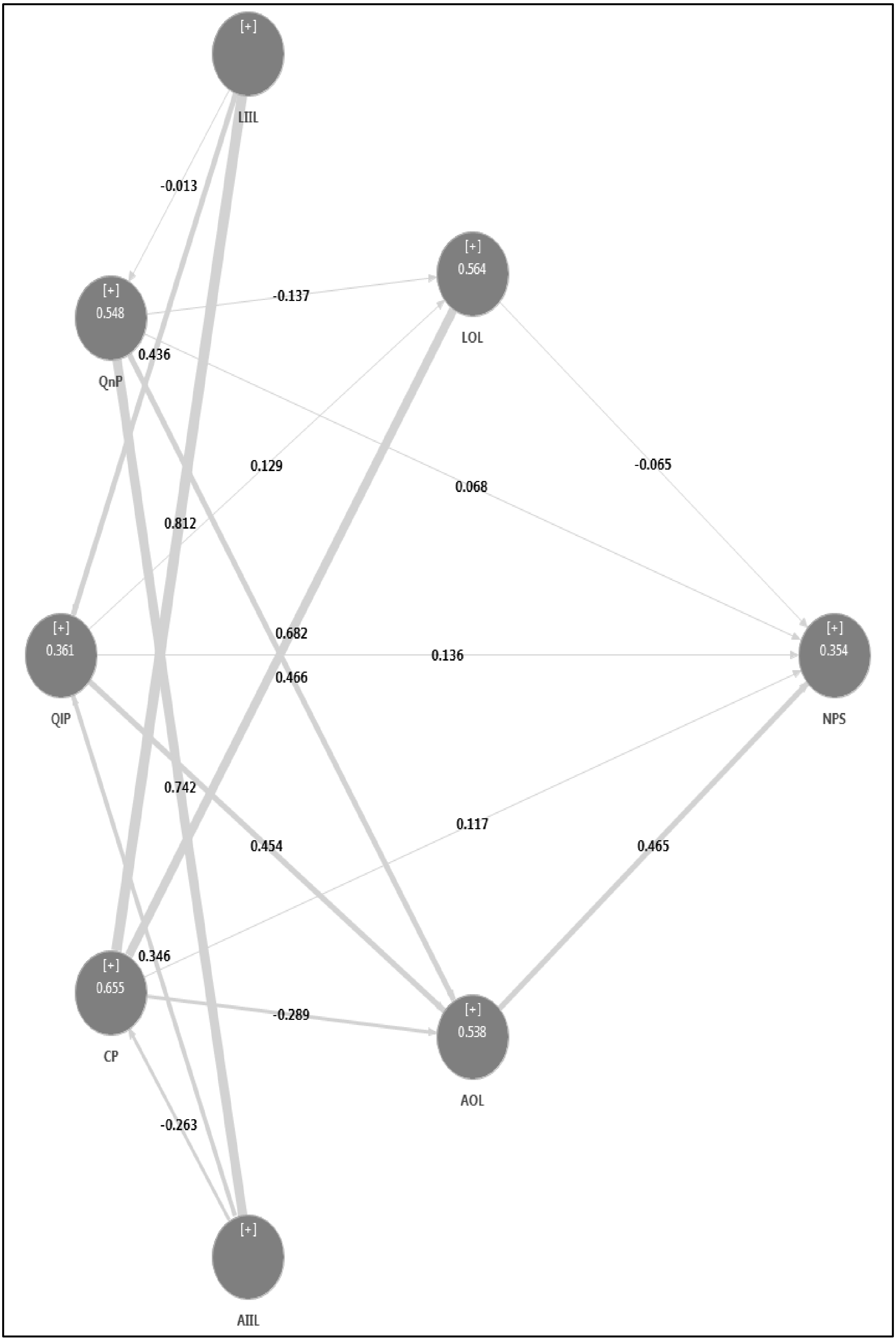


Figure 5.10: Path coefficients for subsidiary hypothesis testing

Table 5.17: Sub-hypothesis testing summary

Sub Hypothesis	**Path**	**Result**	***t* Value**	***p* Value**	**f^2**	**VIF**
H_0:1.1	Lean (inbound and intra) >>>>>>>>>>>> Quantity	Acc.	0.127	0.899	0.000	1.030
H_0:1.2	Lean (inbound and intra) >>>>>>>>>>>>> Quality	**Rej.**	**4.410**	**0.000**	**0.289**	**1.030**
H_0:1.3	Lean (inbound and intra) >>>>>>>>>>>>>>> Cost	**Rej.**	**15.592**	**0.000**	**1.856**	**1.030**
H_0:2.1	Agile (inbound and intra) >>>>>>>>>>> Quantity	**Rej.**	**12.876**	**0.000**	**0.182**	**1.030**
H_0:2.2	Agile (inbound and intra) >>>>>>>>>>>> Quality	**Rej.**	**3.654**	**0.000**	**1.185**	**1.030**
H_0:2.3	Agile (inbound and intra) >>>>>>>>>>>>>> Cost	**Rej.**	**2.780**	**0.006**	**0.195**	**1.030**
H_0:3.1	Quantity >>>>>>>>>>>>>>>>> Product success	Acc.	0.454	0.650	0.004	1.665
H_0:3.2	Quality >>>>>>>>>>>>>>>>>> Product success	Acc.	0.935	0.350	0.015	1.864
H_0:3.3	Cost >>>>>>>>>>>>>>>>>>>> Product success	Acc.	0.641	0.522	0.008	2.494
H_0:4.1	Quantity >>>>>>>>>>>>>>>>>> Lean outbound	Acc.	1.364	0.173	0.037	1.148
H_0:4.2	Quality >>>>>>>>>>>>>>>>>>> Lean outbound	Acc.	1.227	0.220	0.028	1.382
H_0:4.3	Cost >>>>>>>>>>>>>>>>>>>>> Lean outbound	**Rej.**	**10.035**	**0.000**	**0.861**	**1.238**
H_0:5.1	Quantity >>>>>>>>>>>>>>>>> Agile outbound	**Rej.**	**6.228**	**0.000**	**0.410**	**1.148**
H_0:5.2	Quality >>>>>>>>>>>>>>>>>> Agile outbound	**Rej.**	**4.626**	**0.000**	**0.322**	**1.382**
H_0:5.3	Cost >>>>>>>>>>>>>>>>>>>> Agile outbound	**Rej.**	**2.589**	**0.010**	**0.146**	**1.238**
H_0:6.1	Quantity >>> Lean outbound >>>> Product success	Acc.	-	-	-	-
H_0:6.2	Quality >>>> Lean outbound >>> Product success	Acc.	-	-	-	-
H_0:6.3	Cost >>>>>> Lean outbound >>>> Product success	Acc.	-	-	-	-
H_0:7.1	Quantity >>> Agile outbound >>> Product success	Acc.	-	-	-	-
H_0:7.2	Quality >>>> Agile outbound >>> Product success	Acc.	-	-	-	-
H_0:7.3	Cost >>>>> Agile outbound >>>> Product success	Acc.	-	-	-	-
H_0:8.1	Experience >>>>> Leanness /ramp-up relationship	Acc.	0.337	0.736	0.003	1.095
H_0:8.2	Size >>>>>>>>>> Leanness /ramp-up relationship	Acc.	1.592	0.112	0.056	1.051
H_0:8.3	Ramp-ups no. >>> Leanness /ramp-up relationship	Acc.	1.017	0.310	0.018	1.140
H_0:8.4	Newness >>>>>>> Leanness /ramp-up relationship	Acc.	1.319	0.188	0.038	1.011
H_0:8.5	Lifecycle >>>>>>> Leanness /ramp-up relationship	Acc.	0.621	0.535	0.007	1.167
H_0:9.1	Experience >>>>>>> Agility /ramp-up relationship	Acc.	0.618	0.537	0.005	1.035
H_0:9.2	Size >>>>>>>>>>>> Agility /ramp-up relationship	Acc.	0.692	0.489	0.009	1.077
H_0:9.3	Ramp-ups no. >>>>> Agility /ramp-up relationship	Acc.	0.091	0.927	0.000	1.128
H_0:9.4	Newness >>>>>>>> Agility /ramp-up relationship	Acc.	1.068	0.286	0.021	1.061
H_0:9.5	Lifecycle >>>>>>>> Agility /ramp-up relationship	Acc.	0.179	0.858	0.001	1.102

As shown in the previous table, only nine null hypotheses were rejected and the rest of the null hypotheses were supported by the analysis. Figure 5.11 shows the model with only significant paths that indicate rejection of the related null hypothesis. The significant path between agile outbound logistics and product success was excluded, since it was related to a main hypothesis and not to a subsidiary one.

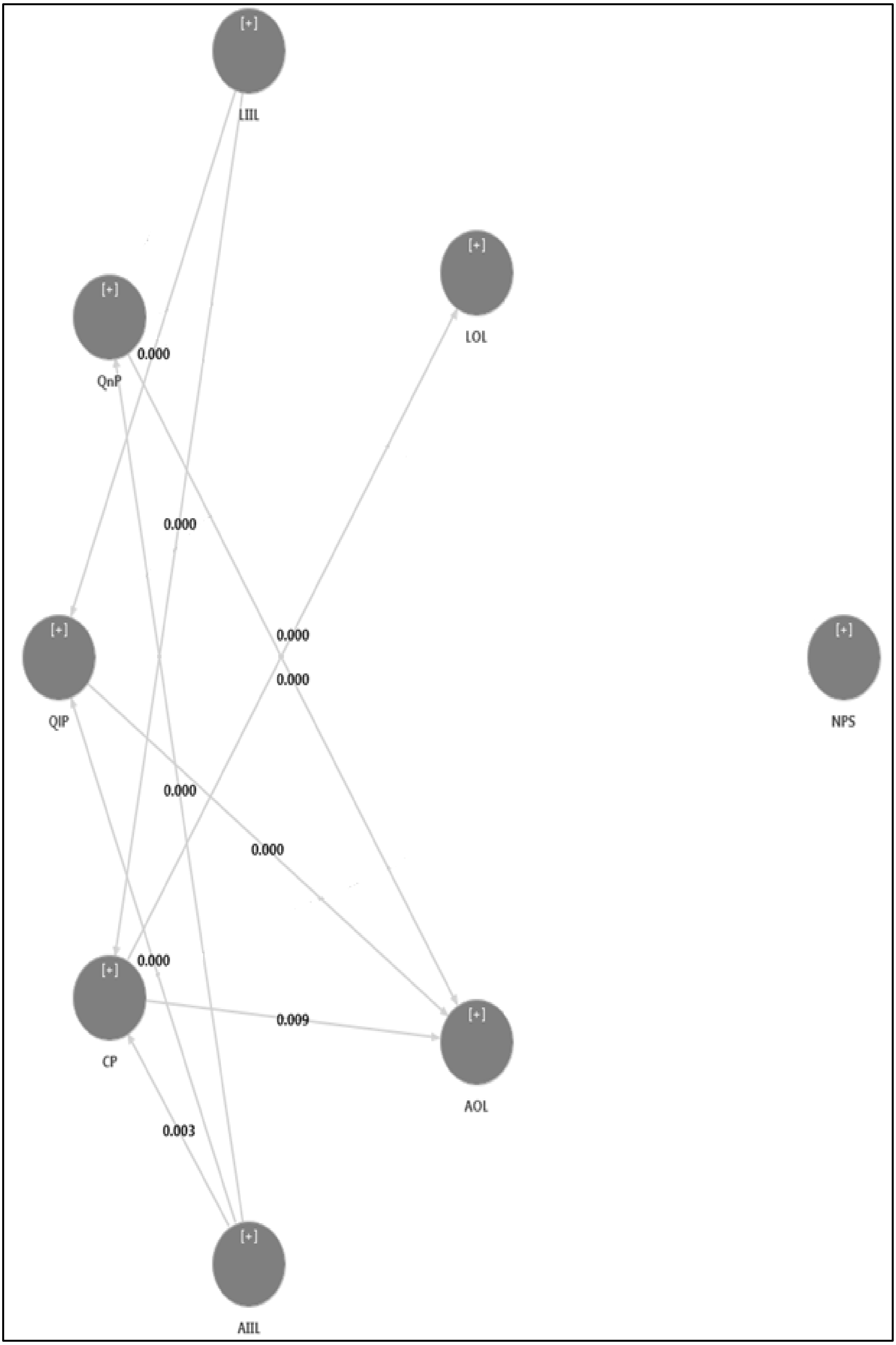


Figure 5.11: Significant path coefficients for the subsidiary hypotheses

CHAPTER 6

MIXED-STRATEGY INTRODUCTION

6.1. Introduction

As can be noted from the results of testing the research hypotheses, both lean and agile logistics significantly affect production performance during the ramp-up phase. The effect of variation in the logistics system’s leanness and agility levels on the composite ramp-up performance measure were investigated to test the proposed hypotheses. However, the three constructs constituting the ramp-up performance parameters do not have the same importance during the ramp-up phase.

Kontio and Haapasalo (2005), Lee and Matsuo (2012), Niroomand et al. (2014), and other researchers indicated that time reduction – and, hence, quantity performance enhancement – is the main focus during the ramp-up phase. Consequently, companies might be willing to enhance their quantity performance during production ramp-up even at the expense of lowering the cost – and sometimes quality – performance. However, in most cases, shortly after new product introduction, similar products will be introduced by competitors and the customers’ willingness to pay a premium price, due to the product’s novelty, will decrease dramatically. At this point, price rather than features can lead the customers' purchasing decision. Consequently, manufacturing firms have to change their production strategy to focus more on production cost reduction to be able to price their products competitively.

In this sense, manufacturing firms face the situation of switching their focus from time reduction (quantity performance enhancement) during the ramp-up phase to cost reduction (cost performance enhancement) during the steady-state phase. This phenomenon re-occurs with each new product development and introduction process. As mentioned previously, numerous organizational and environmental variables enforce more frequent re-occurrence of new product development, introduction, and ramp-up (see section 1.2).

In addition, the steady-state production process is followed by a production ramp-down phase (Schuh et al., 2005a), also called the product phase-out (Elbert, 2011) or production run-down phase (Milehamet al., 2004). The ramp-down phase takes place as the demand for the product drops. During this phase, cost control becomes even more important and is essential for the product's survival. As the operating revenues fall under the production variable costs, production shutdown should take place (McDonald and Siegel, 1985). Figure 6.1 illustrates how the manufacturing process's focus differs according to the different production lifecycle phases.

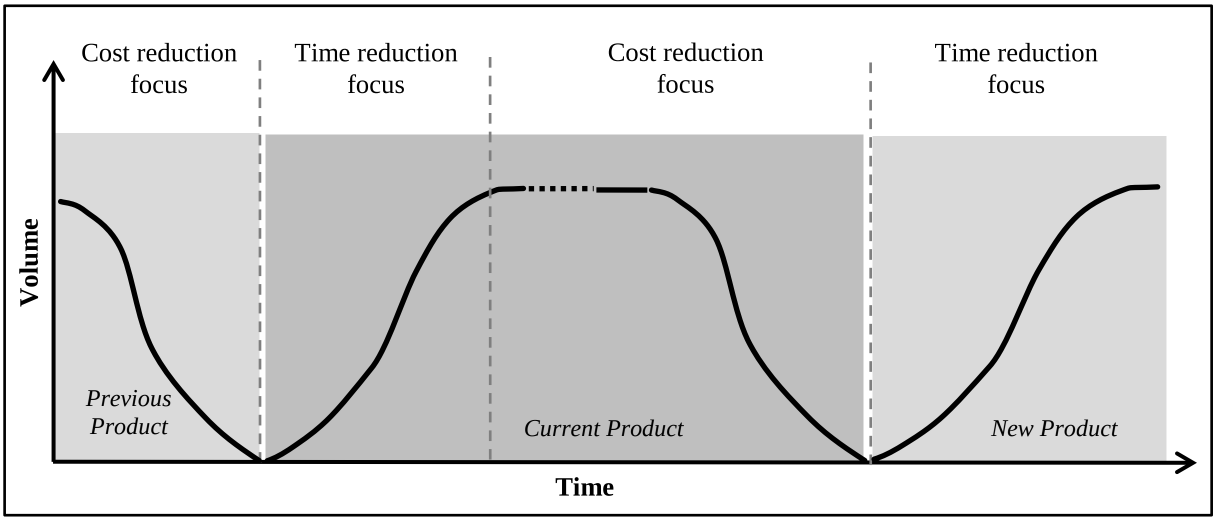


Figure 6.1: Production phases and focuses of performance outcomes

Leanness and agility play key roles in determining the quantity and cost performance levels. While leanness affects the cost performance significantly through waste elimination, the flexibility provided by an agile system positively affects the quantity-related – or time-related – performance. Whilst many researchers have assumed that systems that combine lean and agile concepts achieve the highest possible levels of both flexibility and cost control (see

Naylor et al., 1999; Christopher and Towill, 2000; Ilyas et al., 2008; Huang and Li, 2010), the pressing need for ramp-up's time reduction necessitates a higher flexibility level than can be provided by the composite (or leagile) systems proposed. Furthermore, the criticality of cost control during the steady-state and ramp-down production phases might require more rigorous application of the lean paradigm, especially in the ramp-down phase.

Consequently, this research proposes that employing different levels of leanness and agility – rather than one traded-off level – during different production phases might produce better overall lifecycle performance than using the lean system only, the agile system only, or even a fixed combined system. In serving this objective, the logistics part of the lean and agile systems was further investigated as part of an exploratory data analysis of the data collected to examine the role of lean and agile logistics during the ramp-up phase.

The relationships between each measure of the lean and agile logistics constructs and the ramp-up performance measures were analysed to determine which components are more desirable for quantity performance enhancement and which are more coveted for better cost performance. Basically, this analysis shows that agile logistics possessed a higher correlation with quantity performance, while lean logistics had a higher correlation with cost performance, as detailed in the coming sections.

Undoubtedly, reducing both the time-to-volume duration and the ramp-up cost simultaneously could be achieved, but to a certain traded-off level that produces the optimum levels of both time and cost that maximize the overall ramp-up performance or the overall success of the new product during the introductory period. However, taking the entire product lifecycle into account, this trade-off level might not be the best option; rather, varying levels of time and cost reduction might lead to higher product lifecycle performance.

6.2. Measures' Relationships

While all the performance indicators were investigated in testing the research hypotheses, only the time- and cost-related performance constructs will be considered now. Achieving the targeted levels of quality is a precondition for all the production phases. Führer (2008) mentioned the production of quality products as the main aim to consider in introducing new products. In addition, after the introductory period, lower quality level than expected will motivate the customer to switch to another producer. Furthermore, the effect of producing products with lower than the requisite quality level will be directly reflected in the time and cost performance indicators. Schmitt and Schmitt (2013), for example, mentioned the importance of quality issues for delays experienced in the ramp-up phase; quality issues will increase the costs of rework and scrap as well.

Similar to the proposed hypotheses, only the measures of inbound and intra logistics were investigated for their direct effects on time- and cost-related performance during ramp-up. In addition, the effect of outbound logistics measures was evaluated as mediators in the effect of ramp-up time and cost performance measures in the new product success indicators. In other words, outbound logistics' leanness and agility reflect how the quantity- and cost-related performances are translated into actual product success.

6.2.1. The Direct Effect

Table 6.1 provides a general view of the correlation values between the composite constructs of inbound and intra logistics' leanness and agility and the constructs of time and cost performance. As shown in the table, lean logistics' relationship with cost-related performance is more significant than its relation with quantity-related performance, and agile logistics' relationship with time-related performance is more significant than its relationship with cost-related performance, empirically supporting the previously proposed relationships.

Table 6.1: Correlation between lean and agile logistics and time and cost performance

		Quantity performance	Cost performance	Lean logistics	Agile logistics
Quantity performance	Pearson Correlation Sig. (2-tailed) N	1 56			
Cost performance	Pearson Correlation Sig. (2-tailed) N	0.053 0.696 56	1 56		
Lean logistics	Pearson Correlation Sig. (2-tailed) N	0.131 0.345 54	0.677** 0.000 54	1 54	
Agile logistics	Pearson Correlation Sig. (2-tailed) N	0.667** 0.000 54	- 0.112 0.420 54	0.161 0.249 53	1 54

** Correlation is significant at the 0.01 level (2-tailed)
Exclude missing (pairwise)

For a more detailed and comprehensive investigation of the relationship between the leanness of inbound and intra logistics measures and the ramp-up time and cost performance indicators, table 6.2 illustrates the correlation values for these measures and constructs. MRP was originally measured as an indicator of the existence of a push production and logistics system (Benton and Shin, 1998), which is considered as a negative indicator of leanness levels since a lean system should be based on a pull rather than a push philosophy. However, the level of standardization required by the lean system might legitimate the use of MRP techniques. Therefore, MRP failed to represent any clear pattern related to leanness levels. All the other measures of leanness in inbound and intra logistics showed strong positive relationships with the cost performance levels.

Table 6.2: Correlation between leanness and time and cost performance

Inbound logistics		Quantity	Cost	Intra logistics	Quantity	Cost
RM inventory levels	Pearson Correlation Sig. (2-tailed) N	0.153 0.265 55	0.702** 0.000 55	WIP inventory levels	0.108 0.430 56	0.775** 0.000 56
Supply–production synchronization	Pearson Correlation Sig. (2-tailed) N	0.146 0.283 56	0.449** 0.001 56	Standardization	0.064 0.637 56	0.310* 0.020 56
Material transportation costs	Pearson Correlation Sig. (2-tailed) N	- 0.082 0.547 56	0.715** 0.000 56	JIT	0.286* 0.033 56	0.288* 0.031 56
MRP (-)	Pearson Correlation Sig. (2-tailed) N	- 0.249 0.065 56	0.050 0.714 56	Kanban	0.163 0.230 56	0.305* 0.023 56
Supplier milk run	Pearson Correlation Sig. (2-tailed) N	0.061 0.655 56	0.315* 0.018 56	Cross-docking	0.191 0.164 55	0.454** 0.001 55

** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed)
Exclude missing (pairwise)

While some leanness–quantity performance correlation values had a minus sign, this sign is not a strong indicator since the relationships were statistically insignificant. Only JIT showed a positive and statistically significant (at the 0.05 level) relationship with quantity performance. The RM and WIP inventory levels in addition to the material transportation costs as compared with those of competitors can contribute the highest possible enhancement to production cost reduction. Except for MRP, inbound logistics activities are more influential in enhancing the cost performance during the ramp-up phase.

Similarly, table 6.3 shows the correlation values between the inbound and intra agile logistics and the time and cost performance indicators. All the agility measures were significantly (at the 0.01 level) correlated with the quantity performance levels. The special role of suppliers' flexibility and cooperation in enhancing the quantity performance during production ramp-up is quite straightforward. Li et al. (2014) and Ralston (2014) stressed the important role of suppliers' collaboration during ramp-up. Similarly, table 5.8 on page 110 illustrates the significant effect of material-related problems on ramp-up quantity performance, in terms of both the performance measured and the general evaluation provided.

Negative, but insignificant, relationships between the agility levels in inbound and intra logistics on the one hand and the ramp-up cost performance on the other were identified (except for employing an RMS). In other words, greater flexibility in the production system during the ramp-up phase can enhance quantity and time performance and is not related – if not negatively related – to cost performance. Such clear figures of a greater relationship between flexibility and time performance and between leanness and cost performance are not surprising and have frequently been supported in the theoretical and empirical literature.

Table 6.3: Correlation between agility and time and cost performance

Inbound logistics		Quantity	Cost	Intra logistics	Quantity	Cost
Supplier cooperation	Pearson Correlation	0.623**	- 0.109	Internal flexibility	0.470**	- 0.123
	Sig. (2-tailed)	0.000	0.423		0.000	0.370
	N	56	56		55	55
Producer–supplier IT link	Pearson Correlation	0.496**	- 0.008	Adaptability to change	0.454**	- 0.101
	Sig. (2-tailed)	0.000	0.954		0.000	0.459
	N	56	56		56	56
Supplier flexibility	Pearson Correlation	0.711**	- 0.137	Modular product design	0.412**	- 0.116
	Sig. (2-tailed)	0.000	0.313		0.002	0.394
	N	56	56		56	56
Vendor managed inventory	Pearson Correlation	0.486**	- 0.158	Reconfigurable manufacturing	0.452**	0.021
	Sig. (2-tailed)	0.000	0.250		0.000	0.878
	N	55	55		56	56

** Correlation is significant at the 0.01 level (2-tailed)
Exclude missing (pairwise)

Regarding the component measures of the internal flexibility construct, figure 6.2 shows their correlation values with the time and cost indicators. More flexibility in the machinery, the production system, the material handling system, or the tools and equipment is significantly and positively correlated with ramp-up quantity performance and negatively – but insignificantly – correlated with cost performance.

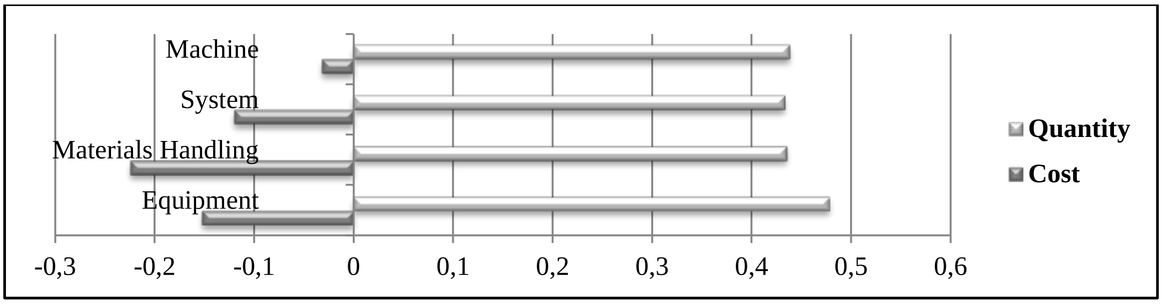


Figure 6.2: Internal flexibility measures' correlations with time and cost performance

Further support can be provided using the path analysis direct effect (equal to the path coefficient) histograms. As shown in figure 6.3, comparing the agile–quantity path with the lean–quantity path, and the agile–cost path with the lean–cost path, can simply and directly lead to the proposed idea that enhancing quantity performance during the production ramp-up phase and, hence, reducing the ramp-up time require more agility in the inbound and intra logistics activities.

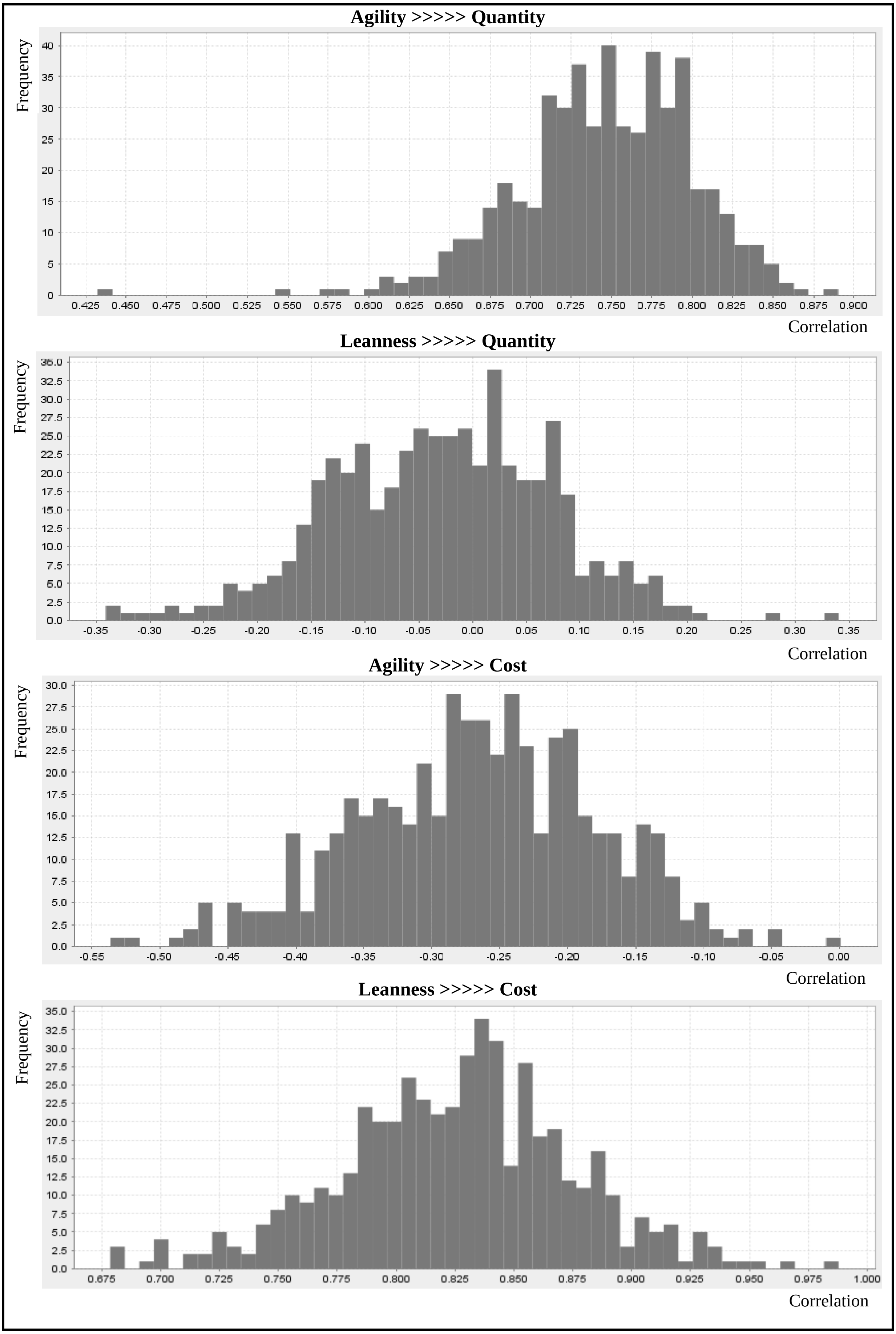


Figure 6.3: Correlation histograms for leanness and agility levels with quantity and cost performance

6.2.2. The Mediating Effect

To examine the role of outbound logistics in mediating the relationship between quantity and cost performance on the one hand and new product success on the other, the model shown in figure 6.4 was developed. The constructs of inbound and intra logistics were removed to explore any possible change in the relationship between ramp-up performance and product success from the patterns noted in chapter 5.

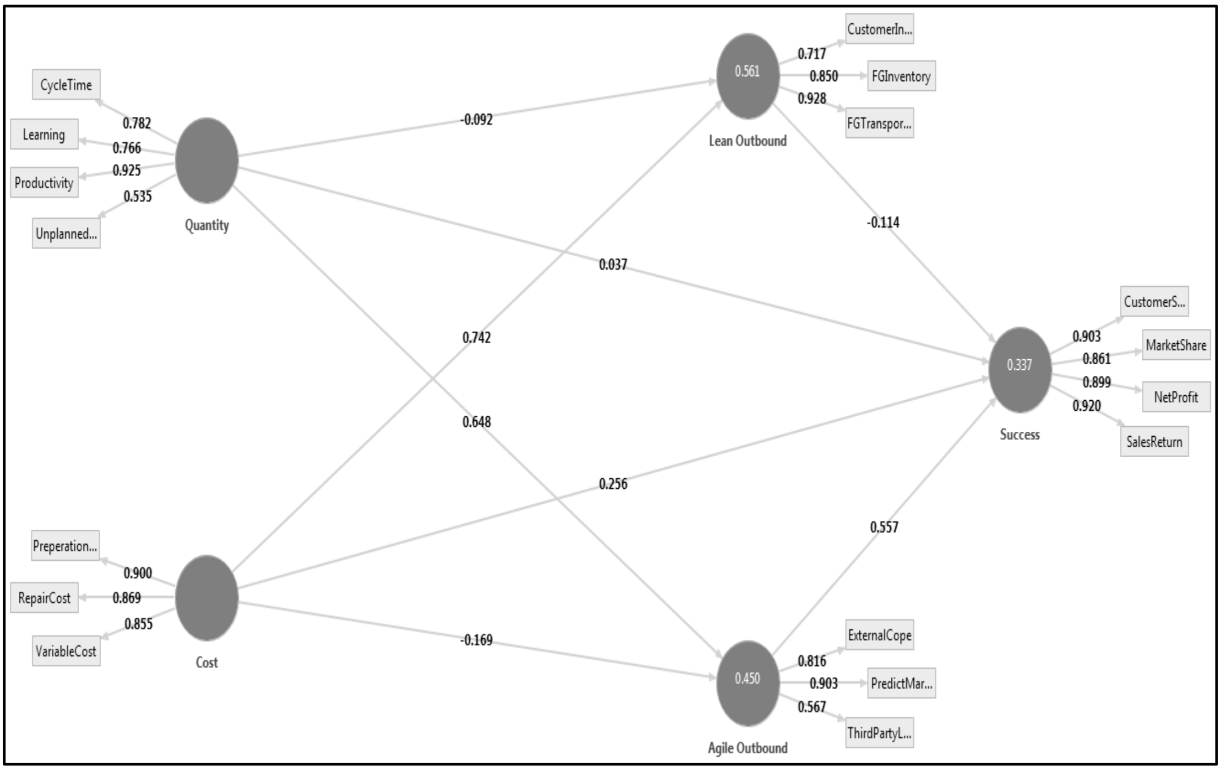


Figure 6.4: Path coefficients for examining outbound logistics' role

While the Cronbach's alpha for the agile outbound logistics was lower than 0.070, the 3PL measure was not removed, since the ρ_c value was acceptable (0.814 for agile outbound logistics). The AVE and VIF values for all the constructs were also acceptable. Figure A.6 in appendix 3 illustrates the p values for all the paths in figure 6.4. Since no significant relationships were found between quantity performance and success or between cost performance and success, no mediating effects were expected for lean or agile outbound logistics.

However, this analysis revealed a significant effect for cost performance on lean outbound logistics and for quantity performance on agile outbound logistics. In addition, a significant direct effect for the agility of outbound logistics on the new product success levels was identified with a path coefficient equal to 0.557. On the other hand, lean outbound logistics seemed to have no significant effect on new product success.

6.3. Logistics, Production, and the Lifecycle

As can be noted from the correlation values shown in the previous section, more agility in the inbound and intra logistics activities contributes to higher quantity performance, while more leanness is preferable for cost performance improvement. Figure 6.5 illustrates these relationships and the corresponding trend lines.

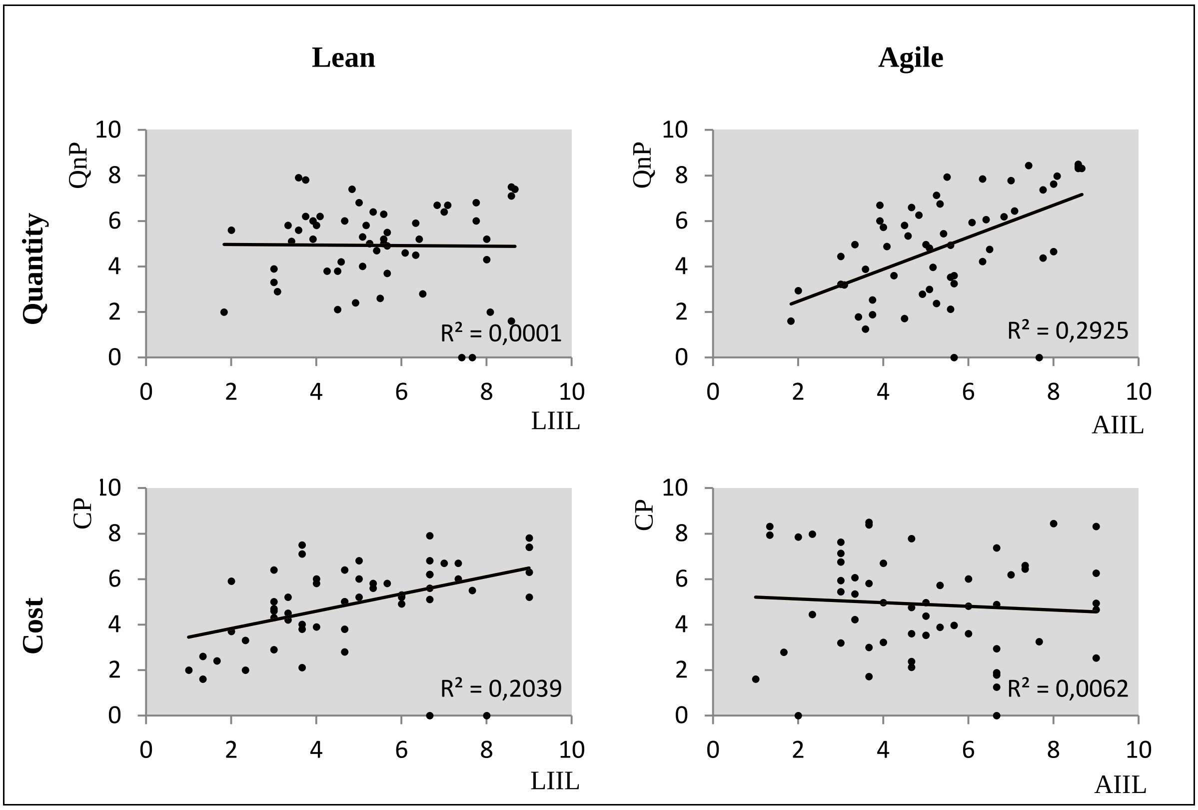


Figure 6.5: Correlation charts for leanness, agility, quantity, and cost

While the cost performance data used in this analysis pertain to the ramp-up phase, similar relationships between leanness and cost performance are expected to continue during the steady-state and production ramp-down phases. Considering the production ramp-up phase, which is the main focus of the current research, the use of agile logistics is highly recommended. However, the use of a certain logistical strategy cannot be separated from the production system, and the ramp-up phase cannot be isolated from the other production phases. Instead, the production system and the entire product lifecycle should be considered. The overall profitability during the entire product lifecycle should be the main focus, rather than the profitability during the ramp-up phase, the steady-state phase, or the ramp-down phase separately. While in this chapter different levels of leanness and agility are proposed based on the lifecycle phase, chapter 7 provides further support for this idea and discusses the product lifecycle issues in more details. In addition, the involvement of production will be discussed thoroughly in the following sections.

6.4. Literature Support

Many researchers have stressed the importance of time reduction during the ramp-up phase (e.g. Terwiesch and Bohn, 2001; Doltsinis et al., 2013; Winter et al., 2014). Bohn and Terwiesch (1999) stated that ramp-up management is intended to speed up learning and that, by the end of this phase, cost becomes the main decision criterion. Pufall et al. (2007) mentioned the limited impact of cost during the ramp-up phase compared with the lost sales that could result from delays. In addition, Ramasesh et al. (2010) mentioned the possible benefits of being the ‘first mover’ in the market, including the relative ease of market share gaining, less price pressure, better experience curve effects, higher buyer switching costs, and deterrence of late entrants. Hansen (2013) indicated the consequences of poor performance during the ramp-up phase using the ‘Apple iPhone 5’ example, when the available quantities were sold out during the opening weekend and sales of 1 million extra units were missed. The response was a 1.4% decrease in the stock price.

Scholz-Reiter et al. (2007) discussed the interdependency existing between the factors affecting ramp-up and the phase goals. In addition to the high demand experienced during production ramp-up due to the novelty of the product and the willingness of the customer to pay a premium price, another increase in the demand might follow the ramp-up period because of the reduced sales from the company’s old products, as well as those of competitors (Li et al., 2014). Hence, reducing the ramp-up time and lead time gains additional importance for manufacturers (Li et al., 2003).

Mason-Jones et al. (2000a) used the terms market qualifier and market winner to highlight the differences between leanness and agility and mentioned the importance of leanness when cost is the market winner and the need for agility when the market winner is the service level (see figure 6.6). Although Mason-Jones et al. (2000a) distinguished between service levels and lead time, many other authors (e.g. Ray and Jewkes, 2004) have mentioned the importance of lead time reduction as a service. In this sense, reducing the ramp-up time – by the means of agility – is at the core of customer service enhancement.

The flexibility advantage that an agile system has over a lean system has also been strongly supported in the literature. A lean system provides some levels of flexibility, but it prevents the development of extra flexibility that might be required in a dynamic workplace. Paixão and Marlow (2003) highlighted this fact considering the port operations environment. Kisperska-Moron and de Haan (2011) clarified the importance of agility to competing in a volatile environment and explained that ‘overly expensive’ agility is undesirable in mature markets, in which leanness becomes the right decision. The urgent need for agility during the ramp-up phase was discussed by Niroomand et al. (2012), Li et al. (2014), and other authors.

	Market Qualifier	**Market Winner**
Leanness	Quality Lead time Service level	Cost
Agility	Quality Cost Lead time	Service level

Figure 6.6: Leanness, agility, qualifier, and winner matrix according to Mason-Jones et al. (2000a)

The inverse relationship between flexibility and cost, on which the proposed model is based, has also been supported in the literature. Hayes and Pisano (1996) illustrated the extra costs incurred due to the acquisition of greater flexibility, as shown in figure 6.7.

As shown in the previous figure, and as frequently discussed in the literature, the flexibility of a manufacturing system has been attached to the production of a wide variety of products. However, when a single product is considered, flexibility is also required according to the variation in the demand, customers’ preferences, the technology used, and many other variables. In addition, the trade-off between time and cost performance and goals has frequently been discussed in the project management literature (see Atkinson, 1999; Yang, 2005; Tareghian and Taheri, 2006).

6.5. Applicability

The idea of changing the production strategy during the product lifecycle has already been investigated in the literature. In an early work, Hayes and Wheelwright (1979) discussed the importance of aligning the production process and the product lifecycle stage. Ramasesh et al. (2010) mentioned the mixed-process strategy, in which a flexible process is used in the early lifecycle stages and a dedicated process is used later to gain cost economies. In addition, Jaikumar and Bohn (1992) considered the importance of developing a dynamic approach to operations characterized by continuous change and instability. Basse et al. (2014b) emphasized the importance of designing a manufacturing system that is scalable and able to match changes during production ramp-up. Furthermore, Ramasesh et al. (2010) explained the first-mover advantage gained by companies that switch early to a low unit-cost process.

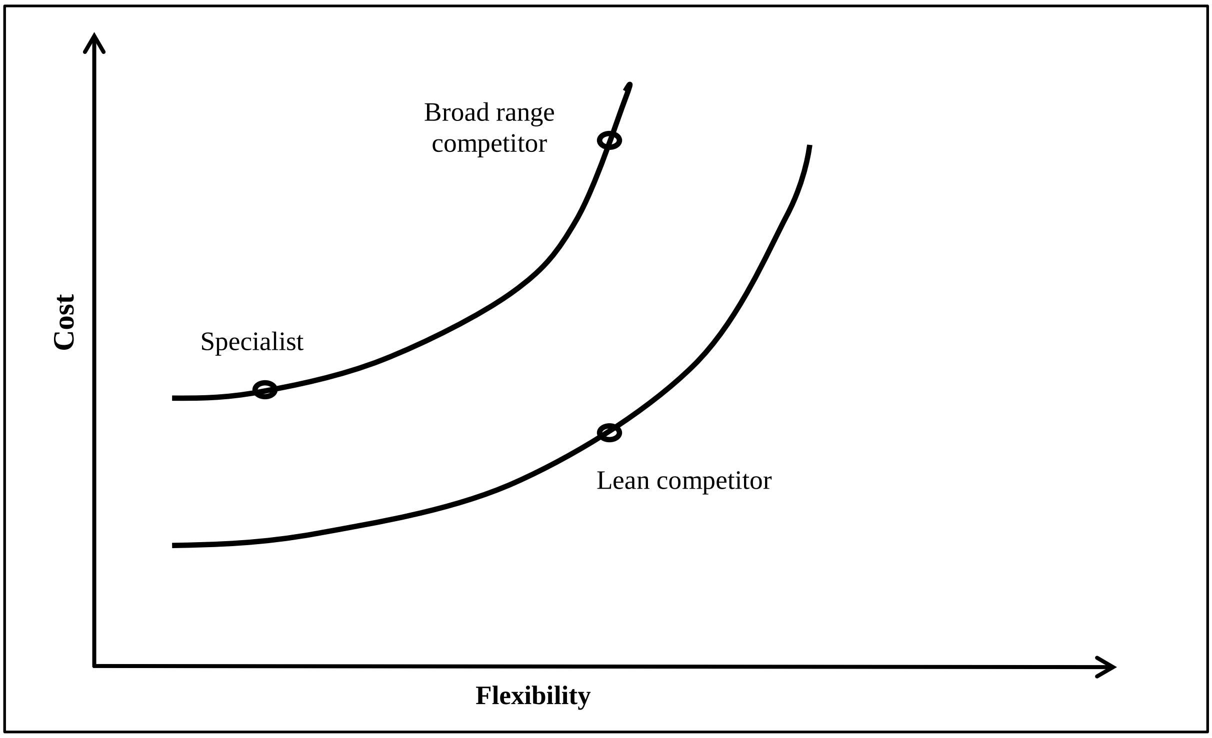


Figure 6.7: Production system’s cost–flexibility relationships according to Hayes and Pisano (1996)

Meyer (2007) mentioned that investing more assets in the ramp-up process is subject to the magnitude of returns expected from this investment. Figure 6.8 illustrates the relationship between assets investment and projected returns and mentions the alternative strategies when the expected returns are not enough to cover the resources invested. These strategies include leveraging the existing production line rather than investing in a new one, using outsourcing through a contract manufacturer, or sharing a flexible scale-up line. Similarly, Cantamessa and Valentini (2000) stressed the importance of trading off the two options of enhancing capacity – and incurring higher costs – and losing part of the expected demand.

Different options might be considered to apply the concept of switching between lean and agile production systems during different product lifecycle phases, including the use of reconfigurable manufacturing systems (Mehrabi et al., 2000; Elmaraghy, 2005; Niroomand et al., 2014), using outsourcing and contract manufacturers (Plambeck and Taylor, 2005), and the use of a specialized agile manufacturing plant (Meyer, 2007).

Niroomand et al. (2014) explained how a reconfigurable manufacturing system combines the advantages of both a dedicated manufacturing system and a flexible manufacturing system and provides a mechanism to trade off production volume and variety. A reconfigurable manufacturing system provides customized flexibility to adapt to variation on demand within a short time period (Elmaraghy, 2005); the main evaluation parameter for the agility level of the RMS is the length of the reconfiguration period and the ramp-up phase (Niroomand et al., 2014).

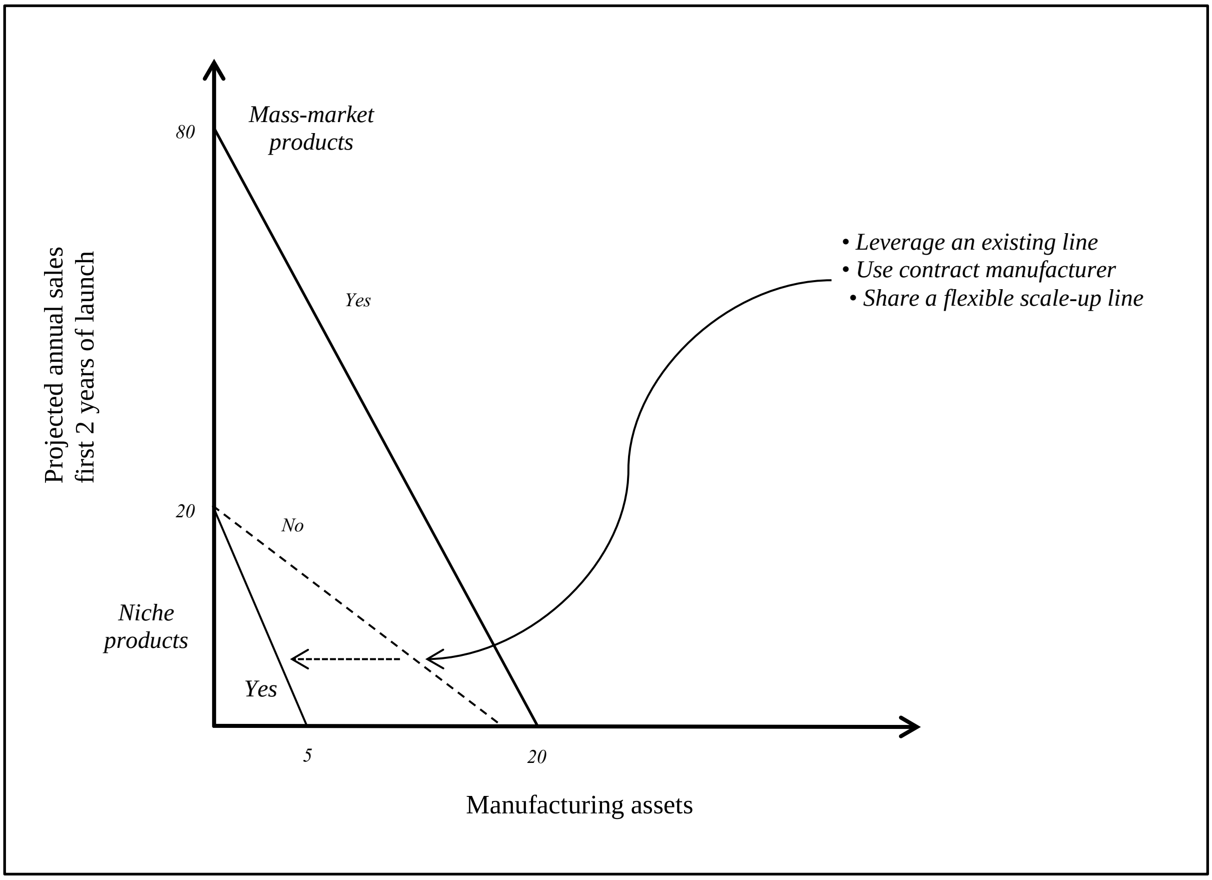


Figure 6.8: Ramp-up asset requirements, projected returns, and strategies according to Meyer (2007)

6.5.1. Developing a Ramp-Up Facility

Another important option for applying the proposed model is to construct a special ramp-up facility characterized by the maximum rate of agility in terms of the manufacturing system and the logistics system as well. All ramp-ups are carried out in the ramp-up facility (see figure 6.9). The viability of constructing such a facility might depend on many factors, including the type of product, innovation levels and number of ramp-ups, severity of the competition, nature of the demand, and many other factors. Ramasesh et al. (2010) illustrated how critical and sensitive the decision on switching the production system is from one strategy to another. The development of a specialized flexible ramp-up facility might be significantly beneficial in such a situation.

While agility is more supportive of ramp-up time reduction, and leanness is more desirable during the steady-state and ramp-down phases, the switch between the two paradigms requires extensive analysis for the production system, the nature of demand, the lifecycle price trend, the accompanying costs, the investment required, and the opportunity cost. An ad hoc comprehensive strategy is required to implement the model proposed.

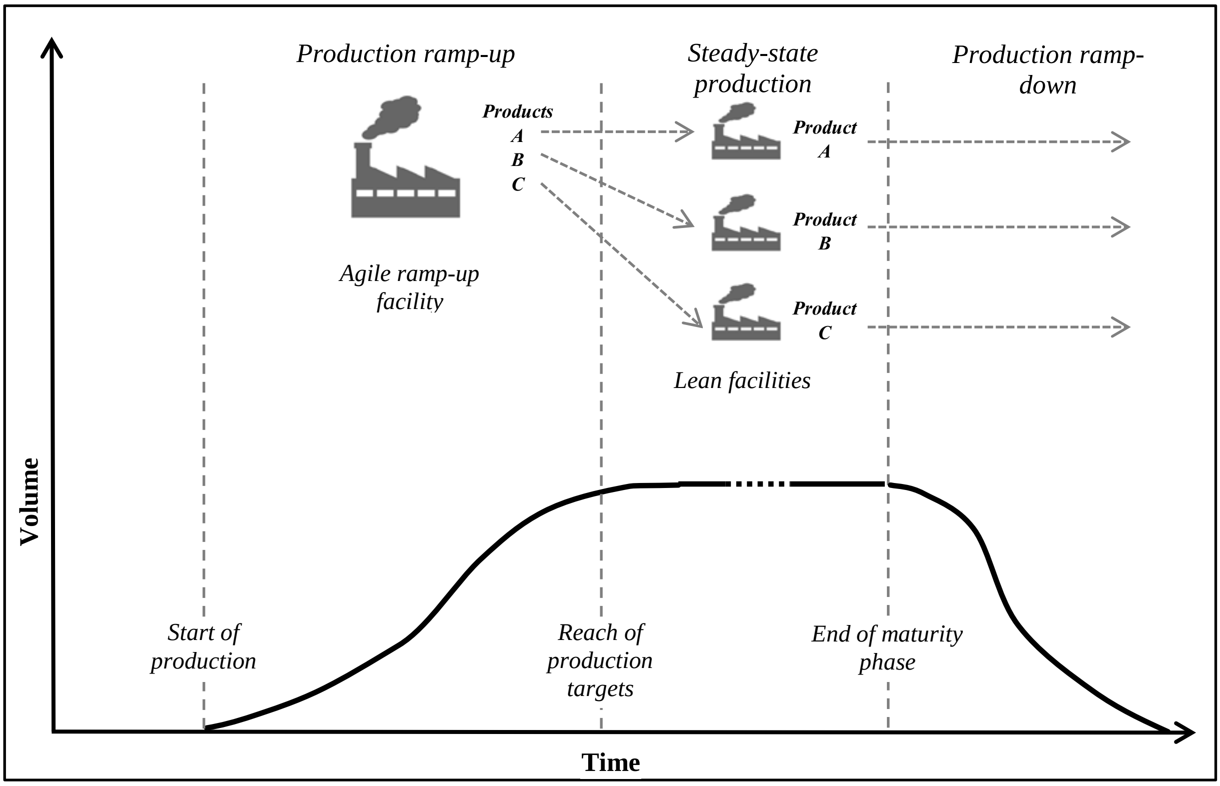


Figure 6.9: Specialized agile ramp-up facility

CHAPTER 7

LIFECYCLE PROFITABILITY COMPARISON

7.1. Introduction

The model presented in the previous chapter proposed more enabling for agile tools during the production ramp-up phase and more enabling for lean tools during the steady-state and ramp-down production phases. Further validation of this model is required. This can be achieved through an investigation of the effect of using the proposed system on the overall lifecycle performance and comparing the proposed system performance with the fully lean system, the fully agile system, and the leagile system. For this purpose, the results of the statistical analysis were used to evaluate the possible enhancement of time performance using agile logistics and the possible enhancement of cost performance using lean logistics. The magnitude of enhancement was utilized as an input to analyse the lifecycle performance in terms of overall profitability.

The effects of the different dimensions should be considered, including the product type, the competitive rivalry, the price trends, the demand nature, the expected lifecycle length, the profit margins, and many other factors. Mathematical tools were utilized to imitate the lifecycle cumulative productivity of each scenario applied and to evaluate the limitations of each scenario according to different products' types and characteristics.

7.2. Product Lifecycle Analysis Considerations

To analyse the profitability over different product lifecycle stages, many factors should be considered, including the demand curve, the price curve, and the lifecycle cost trends. The lifecycle stages were connected to different production phases (see figure 7.1). Production ramp-up is considered to take place during the introduction and growth stages of the lifecycle, steady-state production is considered to be within the maturity stage, and ramp-down should be started with the decline phase of the cycle.

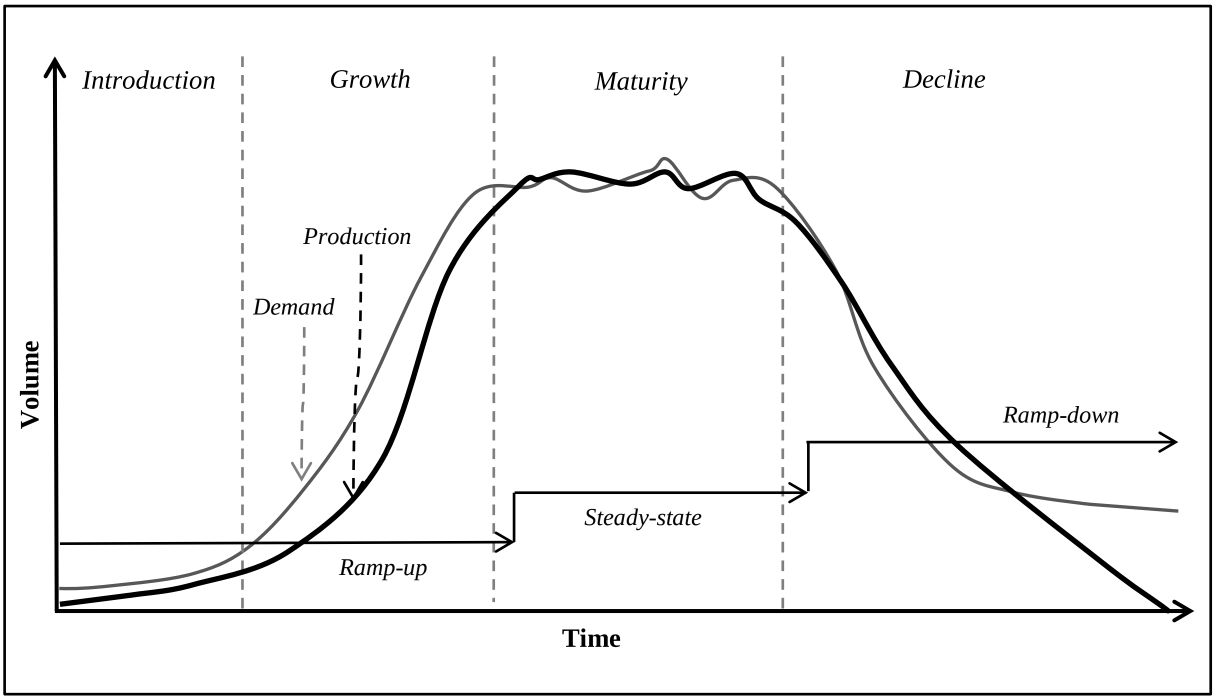


Figure 7.1: Demand and production during different product lifecycle stages

However, this is not the case for all types of products. In addition, different manufacturers might experience different combinations of product and production lifecycles. For example, considering the research conducted by Haller et al. (2003) and Sturm et al. (2003) in the wafer fabrication industry, the entire product lifecycle can consist of ramp-up and ramp-down phases only without experiencing a steady-state production phase.

The analysis of the product lifecycle has frequently been considered in the literature to support a variety of purposes, including evaluating the production strategy (Hayes and Pisano, 1996; Luna and Aguilar-Savén, 2004), evaluating the stages' characteristics (Chang and Chang, 2003), exploring the price trends (Lilien and Yoon, 1988; Melser and Syed, 2014), analysing the lifecycle cost (Asiedu and Gu, 1998; Kleyner and Sandborn, 2008; Folgado et al., 2010), and analysing the lifecycle inventory (Suh and Huppes, 2005; Hsueh, 2011).

7.2.1. Lifecycle Demand

Ramasesh et al. (2010) mentioned that most researchers agreed about the general shape of the lifecycle demand (as shown in figure 7.1), which starts from an initial demand greater than zero and increases slightly during the introduction stage, then a sharp increase distinguishes the growth stage, followed by a constantly declining demand indicating the final stage of the product lifecycle. However, the author indicated that the uncertainty surrounding new product success requires the consideration of different possible demand curves (see figure 7.2).

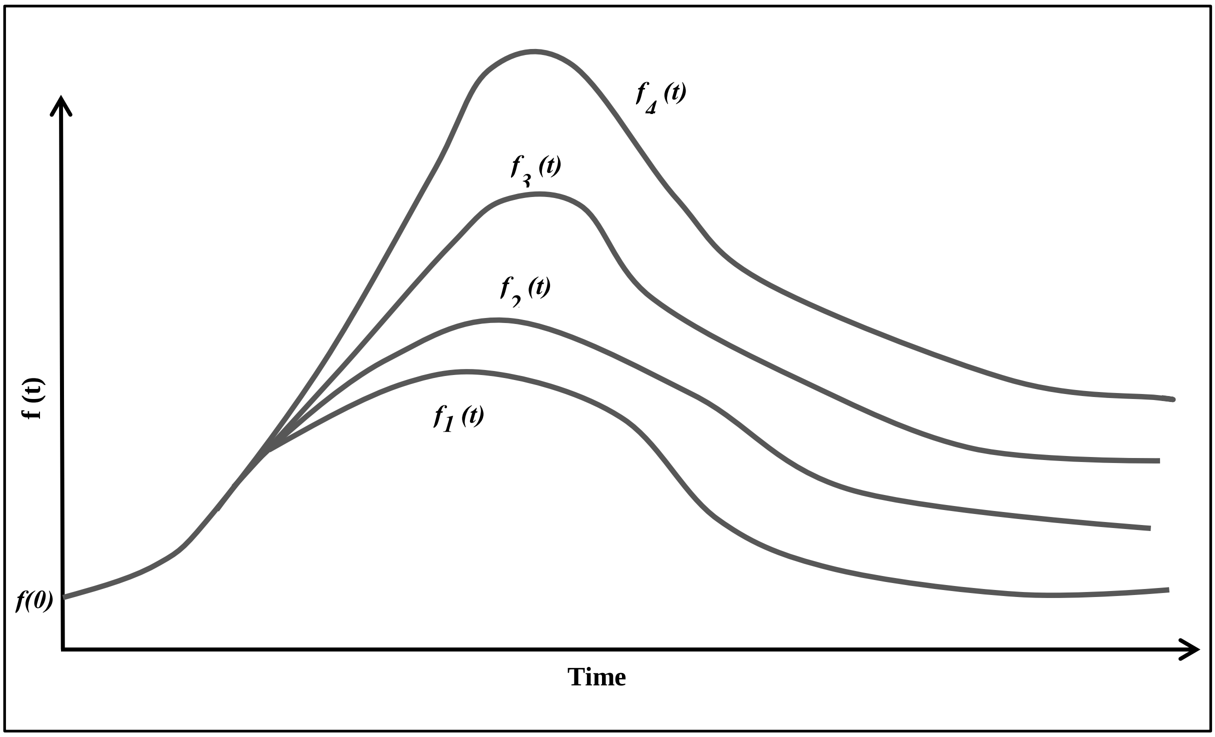


Figure 7.2: Different demand curves due to product success uncertainty according to Ramasesh et al. (2010)

To model the lifecycle demand mathematically, the approach followed by Hsueh (2011) was used. In this approach, the total demand was calculated through a separate equation for each lifecycle stage that reflects the agreed-upon demand trends during each stage; considering the different time periods (t) shown in figure 7.3, the following equations were used:

- Introduction stage: $d_i = v_1 + b_1 t \qquad v_1 > 0,\ b_1 > 0$
- Growth stage: $d_g = v_2 + b_2 t \qquad b_2 > b_1,\ v_2 = v_1 + (b_1 - b_2)t_1$
- Maturity stage: $d_m = v_3 \qquad v_3 = v_2 + b_2 t_2$
- Decline stage: $d_d = v_4 - b_4 t \qquad b_4 > 0,\ b_4 = \frac{v_3}{(T - t_3)},\ v_4 = b_4 T$

- Demand according to time period (t):

$$d(t) = \begin{cases} v_1 + b_1 t & 0 \le t \le t_1 \\ v_2 + b_2 t & t_1 \le t \le t_2 \\ v_3 & t_2 \le t \le t_3 \\ v_4 - b_4 t & t_3 \le t \le T \end{cases}$$

- Total lifecycle demand:

$$D = \int_{0}^{t_1} (v_1 + b_1 t) + \int_{t_1}^{t_2} (v_1 + b_2 t) + \int_{t_2}^{t_3} (v_3) + \int_{t_3}^{T} (v_4 - b_4 t) \qquad \textbf{(1)}$$

where: a_1 is the initial demand at time $t = 0$

$b_1, b_2, b_3, and\ b_4$ are the demand growth factor during the introduction, growth, maturity and decline stages respectively

D is the total lifecycle demand

T is the lifecycle length

7.2.2. Lifecycle Production

Considering the demand functions during different lifecycle stages, the production function can be divided into two sections. The first one includes the ramp-up curve and the second moves with the demand function. Once the production curve reaches the demand level at a certain time point, only the required quantities will be produced thereafter (see figure 7.3). Different observations to describe the ramp-up curve are available in the literature, including the power curve observed by Risse (2003) in the automobile industry, in which the effective capacity (ec) – or production volume – is expressed as follows:

$$ec = \alpha \cdot t^{\beta} \qquad \textbf{(2)}$$

where α and β are parameters to identify the steepness of the ramp-up curve’s slope. Hansen (2013) provided a sigmoid function to describe an s-shaped ramp-up curve as follows:

$$ec = \frac{tc}{(1 + c \cdot e^{-b \cdot t})} \quad \textbf{(3)}$$

where tc represents the targeted capacity and c and b are parameters that determine the slope of the ramp-up curve. Alternatively, Glock et al. (2012) used an exponential formula to represent the ramp-up curve as follows:

$$ec = sc + c_{ir} \cdot (1 - e^{-t/\delta}) \quad \textbf{(4)}$$

where sc represents the starting capacity, c_{ir} is the increase rate for effective capacity, and the δ value determines the rate of capacity increase.

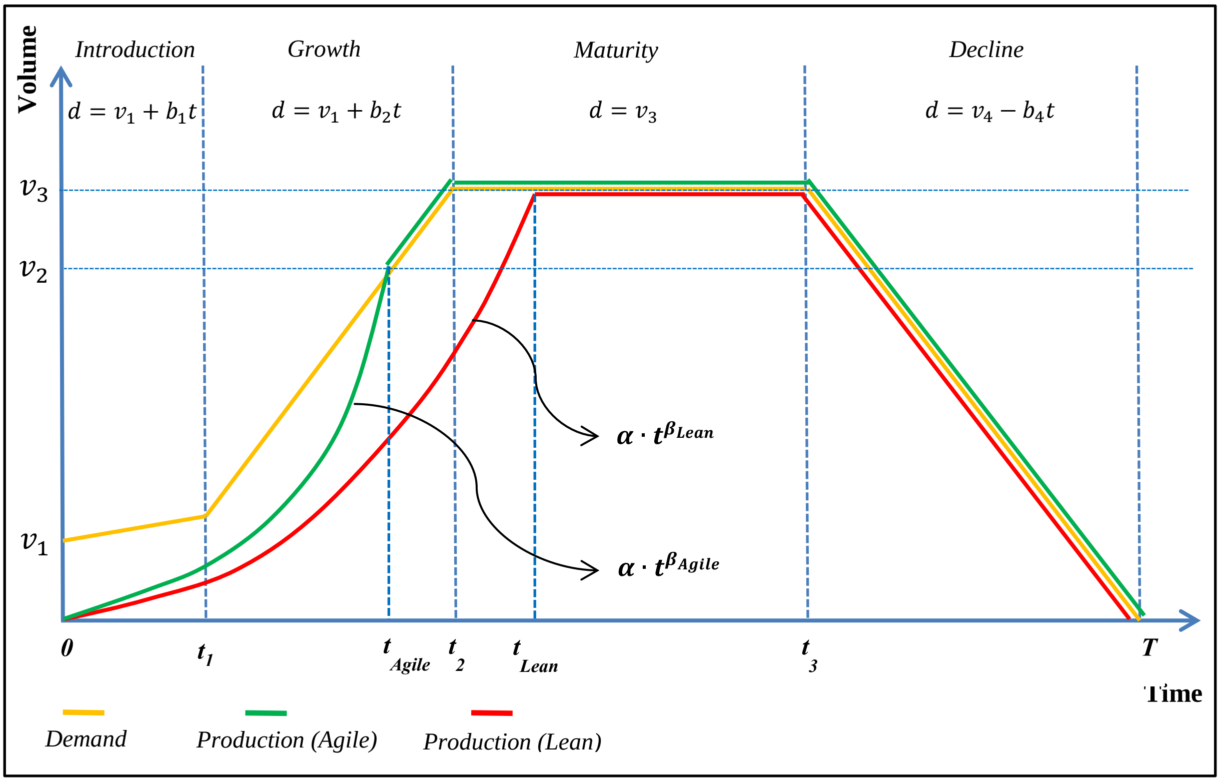


Figure 7.3: Demand, agile production, and lean production curves

This research considered the power function (equation number 2) to represent the ramp-up curve. The enhancement level during the ramp-up phase due to the use of an agile logistics system depends on many factors: (1) the contribution of logistics to the ramp-up performance should be identified and (2) the R^2 value’s change due to the enhanced agility of the logistical system should be evaluated. Hierarchical linear regression was utilized to evaluate the enhancement of quantity performance during the ramp-up phase that can be produced through the use of an agile logistics system. Table 7.1 shows the R^2 change using the hierarchical regression procedure, in which quantity performance is the dependent variable and lean and agile logistics are entered as independent variables, starting with lean logistics and followed by agile logistics.

Table 7.1: Hierarchical regression for quantity performance and lean and agile logistics

Model	$\boldsymbol{R}$	$\boldsymbol{R^2}$	**Adjusted $\boldsymbol{R^2}$**	**St. error of the estimate**	**Change statistics**				
					R^2 change	**F change**	**df1**	**df2**	**Sig. F change**
1	**0.508**	**0.258**	**0.081**	**1.680**	**0.258**	**1.458**	**10**	**42**	**0.189**
2	**0.876**	**0.767**	**0.664**	**1.046**	**0.509**	**9.291**	**8**	**34**	**0.000**

While the R^2 change was as high as 50%, this does not imply that using an agile system will enhance the quantity performance by 50%. Using the path analysis again and considering a model that includes only lean logistics, agile logistics, quantity performance, and agile performance (figure 7.4), only 0.535 instead of 0.767 of the variation in quantity performance can be explained through the variation in lean and agile logistics. In addition, the total effect of logistics among other variables that can affect ramp-up requires further investigation. However, a 20% enhancement due to the use of agile logistics can be confidently proposed.

7.2.3. Lifecycle Profitability

In addition to the demand and production curves, the cost and price trends over the lifecycle are required to compare different scenarios in terms of lifecycle profitability. Melser and Syed (2014) showed that the price curve over the product lifecycle differs according to the product type. The change in products' price over the lifecycle depends greatly on the price elasticity of demand (Lilien and Yoon, 1988).

For simplicity, the price was considered as a declaiming function of time. Figure 7.5 shows that different product types might lose different percentages of their initial price (P_i). Electronics, for example, might lose a significant percentage of their prices compared with other products, which might keep the same price or even gain a price premium, such as in the case of medicines and cigarettes. The price curve will be represented using the following equation:

$$P(t) = a_p t + b_p \qquad b_p > 0, a_b < 0 \tag{5}$$

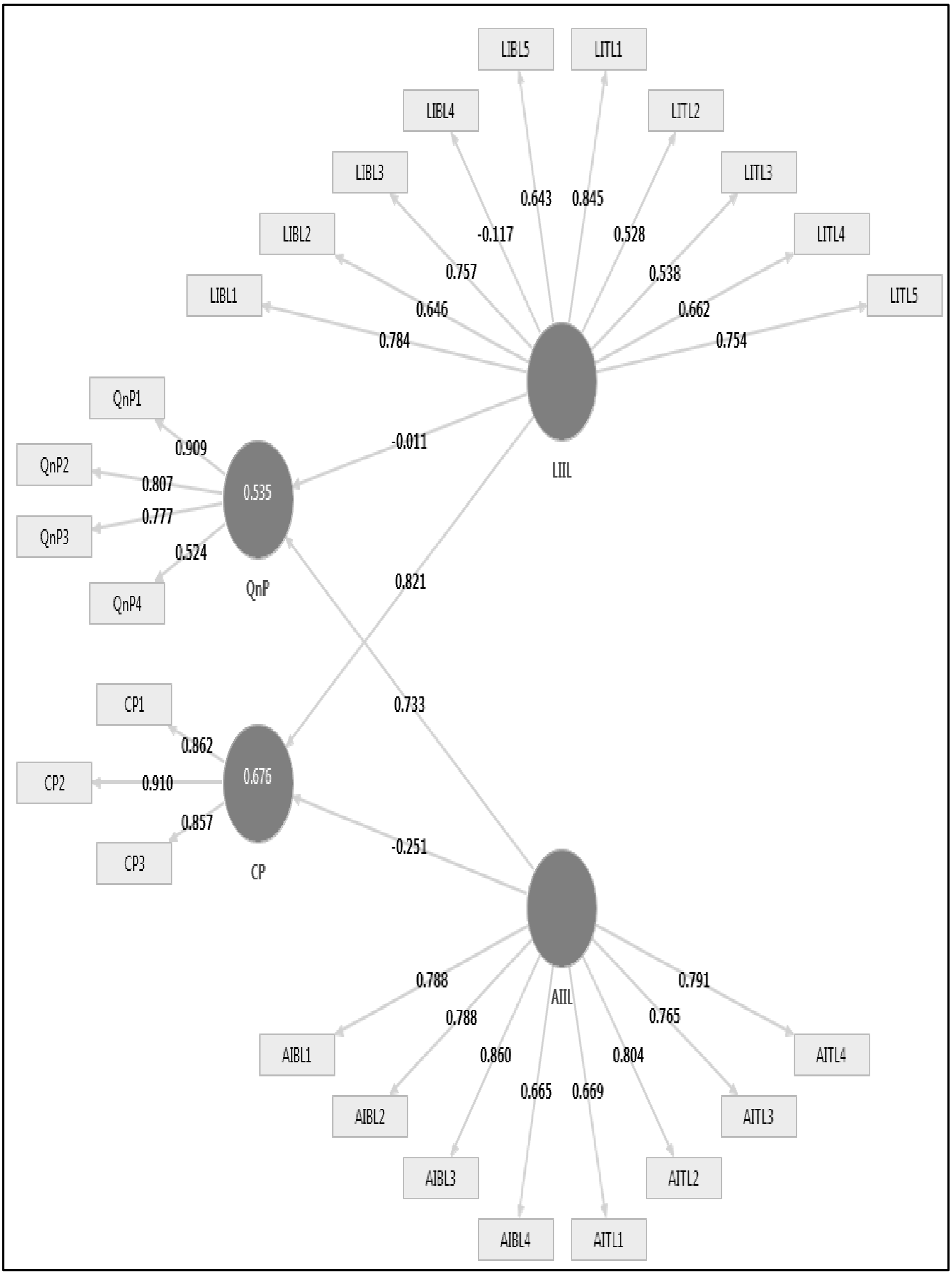


Figure 7.4: Path model for quantity, cost, leanness, and agility

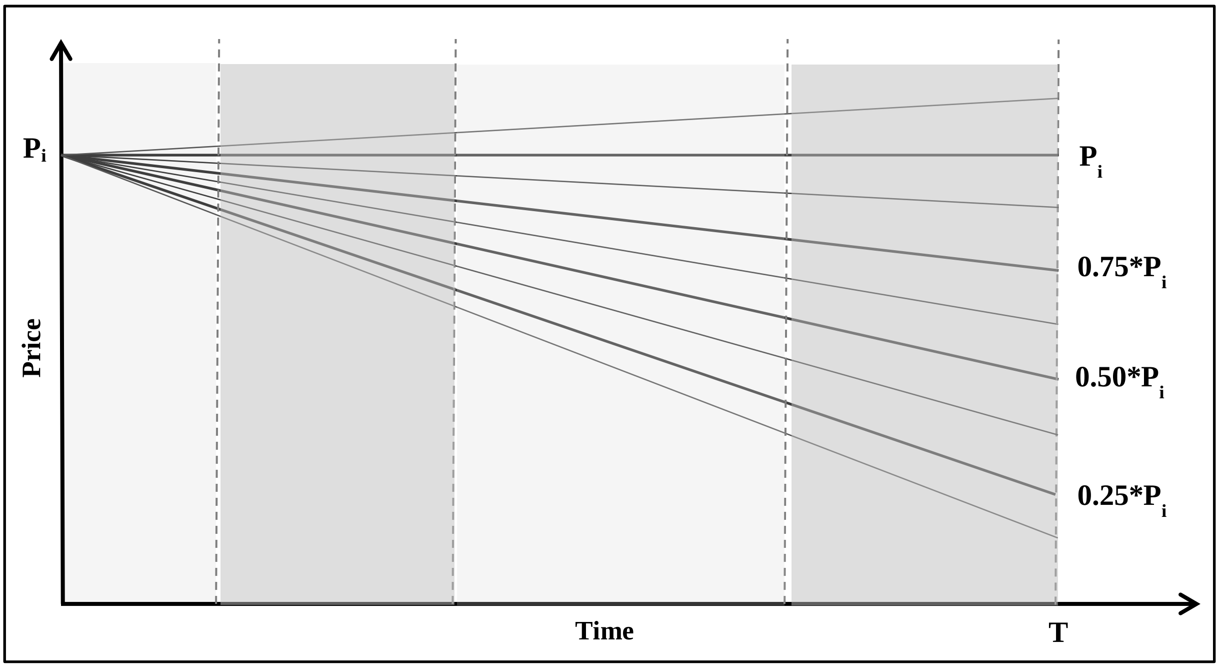


Figure 7.5: Different price trends according to product type and price elasticity

The product lifecycle cost depends on many factors, including the volume of production, since higher production rates provide the advantage of greater economies of scale, resulting in a lower per-unit price. Moreover, the cost decreases with time due to the effect of experience and learning curves. However, only the cost variation resulting from employing different leanness and agility combinations will be considered. Other factors will affect all the scenarios in similar directions.

To evaluate the possible enhancement in cost performance due to higher levels of leanness, the R^2 change should be considered. Table 7.2 shows the results of a hierarchical regression model in which cost performance was set as the dependent variable and agility and leanness were entered into the model starting with agile logistics and followed by lean logistics. The results indicated significant opportunities for cost reduction using a leaner logistics system with an R^2 change with a value of 0.575.

Table 7.2: Hierarchical regression for cost performance and agile and lean logistics

Model	***R***	**R^2**	**Adjusted R^2**	**St. error of the estimate**	**Change statistics**				
					R^2 change	***F* change**	**df1**	**df2**	**Sig. F change**
1	**0.487**	**0.237**	**0.098**	**2.054**	**0.237**	**1.707**	**8**	**44**	**0.124**
2	**0.901**	**0.812**	**0.713**	**1.160**	**0.575**	**10.406**	**10**	**34**	**0.000**

7.3. Profitability Calculations

Three scenarios were compared with the proposed mixed system: lifecycle lean, lifecycle agile, and lifecycle leagile. In all the cases, once the ramped-up production touches the demand curve, only the demanded quantity will be produced. Consequently, the production – or sales, since all production is proposed to be sold – over the lifecycle can be divided into two sections, ramp-up and demand, as follows:

Production for the lean scenario:

$$P_{lean}(t) = \begin{cases} \alpha_{lean} t^{\beta_{lean}} & 0 \le t \le t_{lean} \\ d(t) & t \ge t_{lean} \end{cases} \tag{6}$$

Production for the agile scenario:

$$P_{agile}(t) = \begin{cases} \alpha_{agile} t^{\beta_{agile}} & 0 \le t \le t_{agile} \\ d(t) & t \ge t_{agile} \end{cases} \tag{7}$$

The quantity produced during different stages of the product lifecycle, in addition to the related costs and prices, was used to calculate the lifecycle profitability for each scenario. For the lifecycle lean scenario, the per-unit profitability was calculated by:

$$UP_{lean}(t) = a_p t + b_p - C_{lean} b_p > 0, \qquad a_p < 0 \tag{8}$$

where UP is the per-unit profitability and C_{lean} is the per-unit cost of using the lean system. The profitability equation during different periods in the case of the lean system $(Profit_{lean})$ is calculated by:

$$Profit(t)_{lean} = \left(a_p t + b_p - C_{lean}\right) \begin{cases} \alpha_{lean} t^{\beta_{lean}} & 0 \le t \le t_{lean}, & \alpha_{lean} > 0, \ \ \beta_{lean} > 1 \\ v_{3,} & t_{lean} \le t \le t_{3,} & v_3 = v_2 + b_2 t_2 \\ v_4 - b_4 t, & t_3 \le t \le T, & b_4 > 0, v_4 = v_3 + b_4 t_3 \end{cases} \tag{9}$$

$$Profit(t)_{lean} = \begin{cases} a_p \alpha_{lean} t^{\beta_{lean}+1} + b_p \alpha_{lean} t^{\beta_{lean}} - c_{lean} \alpha_{lean} t^{\beta_{lean}} \\ v_3 a_p t + v_3 b_p - v_3 c_{lean} \\ \left(v_4 a_p - b_4 b_p + b_4 c_{lean}\right) t + v_4 b_p - v_4 c_{lean} - b_4 a_p t^2 \end{cases} \tag{10}$$

The total lifecycle profitability using the lean system (TP_{lean}) equals:

$$TP_{lean} = \int_0^{t_{lean}} \left(a_p \alpha_{lean} t^{\beta_{lean}+1} + \left(b_p \alpha_{lean} - C_{lean}\alpha_{lean}\right) t^{\beta_{lean}}\right) dt + \int_{t_{lean}}^{t_3} \left(v_3 a_p t + v_3 b_p - v_3 C_{lean}\right) dt + \int_{t_3}^{T} \left(\left(v_4 a_p - b_4 b_p + b_4 C_{lean}\right) t + v_4 b_p - v_4 C_{lean} - b_4 a_p t^2\right) dt \qquad \textbf{(11)}$$

$$TP_{lean} = \frac{a_p \alpha_{lean} {t_{lean}}^{\beta_{lean}+2}}{\beta_{lean}+2} + \frac{\left(b_p \alpha_{lean} - C_{lean}\alpha_{lean}\right) {t_{lean}}^{\beta_{lean}+1}}{\beta_{lean}+1} + \frac{v_3 a_p - 2v_4 a_p + 2b_4 b_p - 2b_4 c_{lean} {t_3}^2}{2} + \left(v_3 b_p - v_3 C_{lean} - v_4 b_p + v_4 C_{lean}\right) t_3 - \frac{v_3 a_p {t_2}^2}{2} - \left(v_3 b_p - v_3 C_{lean}\right) t_2 + \left(v_4 a_p - b_4 b_p + b_4 C_{lean}\right) T^2 + \left(v_4 b_p - v_4 C_{lean}\right) T - \frac{b_4 a_p T^3}{3} + \frac{b_4 a_p {t_3}^3}{3} \qquad \textbf{(12)}$$

Similarly, considering equation (7), the total lifecycle profit for the agile scenario can be calculated as follows:

$$UP_{agile}(t) = a_p t + b_p - C_{agile} \qquad b_p > 0, \qquad a_p < 0 \qquad \textbf{(13)}$$

where UP_{agile} is the per-unit profit using the agile system and C_{agile} is the per-unit cost using the agile system. The profitability equation in different lifecycle stages using the agile system ($Profit_{agile}$) was calculated by:

$$Profit(t)_{agile} = \left(a_p t + b_p - C_{agile}\right) \begin{cases} \alpha_{agile} t^{\beta_{agile}} & 0 \le t \le t_{agile}, \alpha_{agile} > 0, \quad \beta_{agile} > 1 \\ v_2 + b_2 t & t_{agile} \le t \le t_{2,} b_2 > 0, v_2 = v_1 + (b_1 - b_2) t_1 \\ v_3 & t_2 \le t \le t_{3,} v_3 = v_2 + b_2 t_2 \\ v_4 - b_4 t & t_3 \le t \le T, > 0, \quad v_4 = v_3 + b_4 t_3 \end{cases} \qquad \textbf{(14)}$$

$$Profit(t)_{agile} = \begin{cases} a_p t . \alpha_{agile} t^{\beta_{agile}} + b_p . \alpha_{agile} t^{\beta_{agile}} - C_{agile} . \alpha_{agile} t^{\beta_{agile}} \\ v_2 a_p t + v_2 b_p - v_2 C_{agile} + b_2 t \left(a_p t + b_p - C_{agile}\right) \\ v_3 a_p t + v_3 b_p - v_3 C_{agile} \\ v_4 a_p t + v_4 b_p - v_4 C_{agile} - b_4 t \left(a_p t + b_p - C_{agile}\right) \end{cases} \qquad \textbf{(15)}$$

The total lifecycle profitability using the agile system (TP_{agile}) equals:

$$TP_{agile} = \int_0^{t_{agile}} \left(a_p \alpha_{agile} t^{\beta_{agile}+1} + \left(b_p \alpha_{agile} - C_{agile}\alpha_{agile}\right) t^{\beta_{agile}}\right) dt + \int_{t_{agile}}^{t_2} \left(\left(v_2 a_p + b_2 b_p - b_2 C_{agile}\right) t + v_2 b_p - v_2 C_{agile} + b_2 a_p t^2\right) dt + \int_{t_2}^{t_3} \left(v_3 a_p t + v_3 b_p - v_3 C_{agile}\right) dt + \int_{t_3}^{T} \left(\left(v_4 a_p - b_4 b_p + b_4 C_{agile}\right) t + v_4 b_p - v_4 C_{agile} - b_4 a_p t^2\right) dt \qquad \textbf{(16)}$$

$$TP_{agile} = \frac{a_p \alpha_{agile} t_{agile}{}^{\beta_{agile}+2}}{\beta_{agile}+2} + \frac{(b_p \alpha_{agile} - C_{agile} \alpha_{agile}) t_{agile}{}^{\beta_{agile}+1}}{\beta_{agile}+1} + \frac{(v_2 a_p + b_2 b_p - b_2 C_{agile} - v_3 a_p) t_2{}^2}{2} + (v_2 b_p - v_2 C_{agile} - v_3 b_p + v_3 C_{agile}) t_2 + \frac{b_2 a_p t_2{}^3}{3} - \frac{(v_2 a_p + b_2 b_p - b_2 c_{agile}) t_{agile}{}^2}{2} - (v_2 b_p - v_2 c_{agile}) t_{agile} - \frac{b_2 a_p t_{agile}{}^3}{3} + \left(\frac{v_3 a_p}{2} - v_4 a_p + b_4 b_p - b_4 C_{agile}\right) t_3{}^2 + (v_3 b_p - v_3 C_{agile} - v_4 b_p + v_4 C_{agile}) t_3 + (v_4 a_p - b_4 b_p + b_4 C_{agile}) T^2 + (v_4 b_p - v_4 C_{agile}) T - \frac{b_4 a_p T^3}{3} + \frac{b_4 a_p t_3{}^3}{3} \quad \textbf{(17)}$$

Similar calculations were made to determine the profitability of the third scenario, which represents the leagile system, combining leanness and agility, to provide a traded off level of flexibility and leanness. In this scenario, the cost enhancement was calculated as an average level between the lean and the agile system and the time performance enhancement was also considered as an average between leanness and agility. The cost was considered to be an average between the lean and the agile system, and the enhancement in the production curve was also calculated as an average between the lean and the agile system. The equations were omitted to eliminate unnecessary repetition.

The last scenario represents the proposed system that switches between the agile and the lean system. The agile system is considered until the actual demand is matched and the lean system will be considered thereafter. The profit per unit of production was calculated as:

$$UP_{mixed}(t) = \begin{cases} a_p t + b_p - C_{agile} & t \le t_{agile} \\ a_p t + b_p - C_{lean} & t > t_{agile} \end{cases} \quad \textbf{(18)}$$

The profit over time periods (t) for the mixed system $Profit_{mixed}$ is:

$$Profit(t)_{mixed} = \begin{cases} (a_p t + b_p - C_{agile}) \alpha_{agile} t^{\beta_{agile}}, & 0 \le t \le t_{agile}, \alpha_{agile} > 0, \quad \beta_{agile} > 1 \\ (a_p t + b_p - C_{lean})(v_2 + b_2 t), & t_{agile} < t \le t_2, \quad b_2 > 0, v_2 = v_1 + (b_1 - b_2) t_1 \\ (a_p t + b_p - C_{lean}) v_3, & t_2 \le t \le t_3, v_3 = v_2 + b_2 t_2 \\ (a_p t + b_p - C_{lean})(v_4 - b_4 t), & t_3 \le t \le T, b_4 > 0, \quad v_4 = v_3 + b_4 t_3 \end{cases} \quad \textbf{(19)}$$

$$Profit(t)_{\mathrm{mixed}} = \begin{cases} a_p t . \alpha_{agile} t^{\beta_{agile}} + b_p . \alpha_{agile} t^{\beta_{agile}} - C_{agile} . \alpha_{agile} t^{\beta_{agile}} \\ v_2 a_p t + v_2 b_p - v_2 C_{lean} + b_2 t (a_p t + b_p - C_{lean}) \\ v_3 a_p t + v_3 b_p - v_3 C_{lean} \\ v_4 a_p t + v_4 b_p - v_4 C_{lean} - b_4 t \, (a_p t + b_p - C_{lean}) \end{cases} \quad \textbf{(20)}$$

The total lifecycle profit using this system (TP_{mixed}) can be calculated using the following equations:

$$TP_{mixed} = \int_0^{t_{agile}} \left(a_p \alpha_{agile} t^{\beta_{agile}+1} + \left(b_p \alpha_{agile} - C_{agile}\alpha_{agile}\right) t^{\beta_{agile}}\right) dt + \int_{t_{agile}}^{t_2} \left(\left(v_2 a_p + b_2 b_p - b_2 C_{lean}\right) t + v_2 b_p - v_2 C_{lean} + b_2 a_p t^2\right) dt + \int_{t_2}^{t_3} \left(v_3 a_p t + v_3 b_p - v_3 C_{lean}\right) dt + \int_{t_3}^{T} \left(\left(v_4 a_p - b_4 b_p + b_4 C_{lean}\right) t + v_4 b_p - v_4 C_{lean} - b_4 a_p t^2\right) dt \tag{21}$$

$$TP_{\text{mixed}} = \frac{a_p \alpha_{agile} t_{agile}{}^{\beta_{agile}+2}}{\beta_{agile}+2} + \frac{\left(b_p \alpha_{agile} - C_{agile}\alpha_{agile}\right) t_{agile}{}^{\beta_{agile}+1}}{\beta_{agile}+1} + \frac{\left(v_2 a_p + b_2 b_p - b_2 C_{lean} - v_3 a_p\right) t_2{}^2}{2} + \left(v_2 b_p - v_2 C_{lean} - v_3 b_p + v_3 C_{lean}\right) t_2 + \frac{b_2 a_p t_2{}^3}{3} - \frac{\left(v_2 a_p + b_2 b_p - b_2 C_{lean}\right) t_{agile+1}{}^2}{2} - \left(v_2 b_p - v_2 C_{lean}\right) t_{agile+1} - \frac{b_2 a_p t_{agile+1}{}^3}{3} + \left(\frac{v_3 a_p}{2} - v_4 a_p + b_4 b_p - b_4 C_{lean}\right) t_3{}^2 + \left(v_3 b_p - v_3 C_{lean} - v_4 b_p + v_4 C_{lean}\right) t_3 + \left(v_4 a_p - b_4 b_p + b_4 C_{lean}\right) T^2 + \left(v_4 b_p - v_4 C_{lean}\right) T - \frac{b_4 a_p T^3}{3} + \frac{b_4 a_p t_3{}^3}{3} \tag{22}$$

7.4. Comparison and Analysis

The aim of comparing different systems was not to reach a stable conclusion regarding which system is better. Rather, the magnitude of enhancement in the total lifecycle profitability produced using the mixed system under certain conditions was evaluated. The amount of enhancement provides an insight into the feasibility of investing resources in such a system. Different scenarios were compared using the following parameters:

- The introduction stage constitutes 20% of the total lifecycle.
- The growth stage constitutes 25% of the lifecycle.
- 30% of the lifecycle is consumed by the maturity stage.
- The decline stage lasts for 25% of the lifecycle length.
- The lifecycle length is given the value 100.
- The time required for the production system to reach the actual demand levels using the agile system is 15% less than in the case of using the lean system with $t_{agile} = 35 \; and \; t_{lean} = 50$.
- The cost saving using the lean system is as much as 20% with $C_{lean} = 2.5 \; and \; C_{agile} = 3$.

- Other parameters were proposed as follows: $v_1 = 10,\ b_1 = 0.1,\ \beta_{lean} = 1.1,$ $\beta_{agile}\ is\ 1\%\ higher\ than\ \beta_{lean}.$

Figure 7.6 represents the results obtained from comparing the cumulative lifecycle profitability for all the scenarios. Except for the proposed mixed system, the lean system will produce higher lifecycle profitability. However, around 4.046% of the total profit increase can be achieved using the mixed system. This percentage will increase as the lifecycle is shortened, the agility is enhanced, the initial price is increased, the product contribution is increased, or the leanness performance is decreased. Based on this level of enhancement, the evaluation of the investment decision will be more reliable.

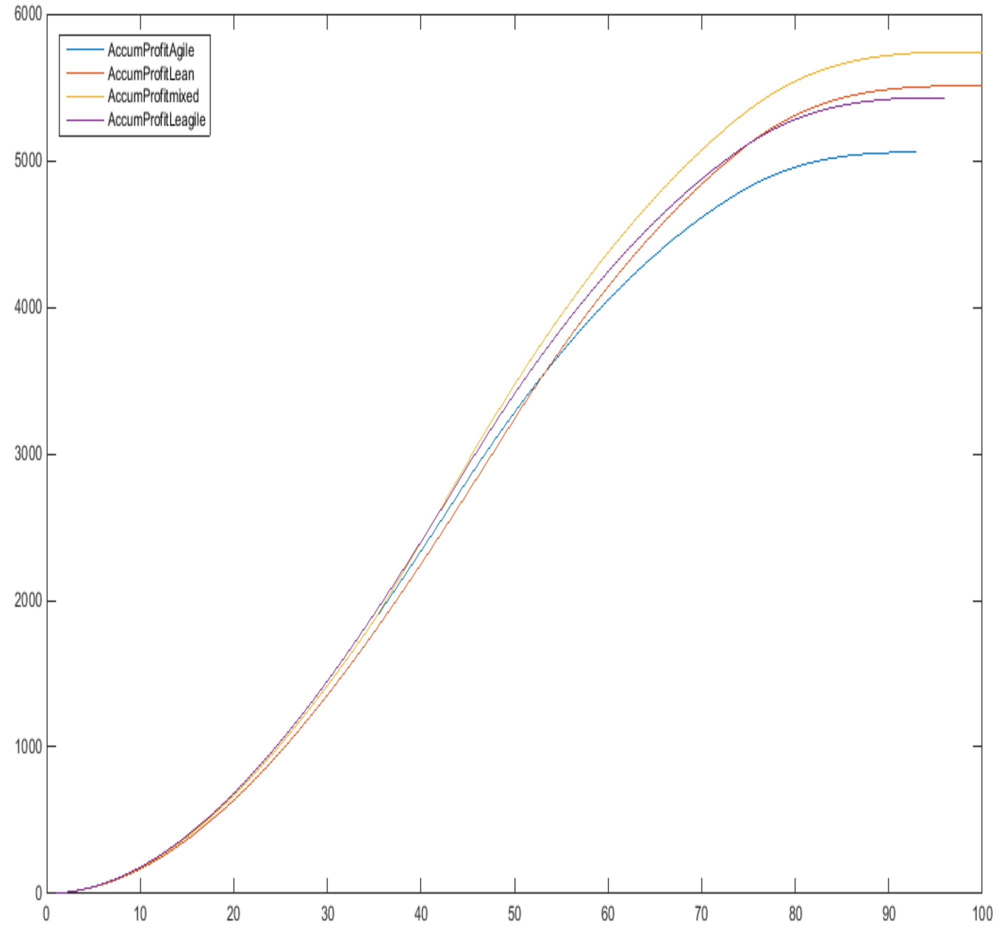


Figure 7.6: Cumulative profitability scenarios' comparison

CHAPTER 8

CONCLUSIONS, DISCUSSION, AND RECOMMENDATIONS

8.1. Introduction

In section 8.2 in this chapter, the final conclusions that integrate various research issues are presented, answers to the research questions are provided, and the attainment of the stated research objectives is evaluated. In addition, a discussion of the major points that manifest the contributions and additions of the research, as well as a comparison of the current research's findings and conclusions with similar research's findings, is presented in section 8.3. Comparing the results of similar research conducted in different environments or using different methodologies helps to explain possible variations and raises further research points.

The limitations of the research are discussed in section 8.4, with an attempt to self-criticize and evaluate the research quality and shed light on the mistakes made during the research to avoid similar procedures in subsequent research in this field. Finally, section 8.5 provides recommendations for researchers and practitioners to maximize the potential to benefit from the research's findings.

8.2. Conclusions

Researchers have agreed on the urgent need for empirical research on production ramp-up. Berg and Säfesten (2006) indicated the importance of considering the critical factors affecting production ramp-up in developing a comprehensive framework for ramp-up management. The scarcity of empirical research extends to the lean and agile logistics literature as well. Furthermore, Bowersox et al. (1999) mentioned that integrating logistics into the new product development process has not been considered in the logistics literature.

While the type of the relationship between ramp-up performance and logistics – as a general concept – has been determined and researched previously, the paradigms of lean and agile logistics have barely been touched. In addition, the relative magnitude of the effect that a specific logistics activity has on the ramp-up performance indicators provided in this research could be of particular importance for decision making. Under the constraints of limited resources that exist in almost every enterprise, the resources should be directed toward enhancing the processes that are likely to lead to the most preferable results. In this direction, the current research's results provide guidelines for the decision maker regarding which logistical tool to employ and in which activity to invest. For example, the statistical analysis revealed that WIP inventory and RM transportation are of special importance for ramp-up cost performance and that supplier collaboration is more relevant to ramp-up problems with machine and information flow sources.

Both lean and agile logistics were proved to have a statistically significant effect on the production performance during the ramp-up phase. A detailed analysis of each single measure's effect on the time and cost performance indicators led to the proposal that higher levels of logistics agility are required during the ramp-up phase, during which time reduction is the most important determinant of performance, and more logistical leanness is demanded during the steady-state and ramp-down production phases, in which cost reduction might play a critical role in the survival of the product. Switching from agile to lean (and sometimes backward) during different stages of the product lifecycle might enhance the overall lifecycle performance, success, and profitability.

While the theoretical literature has provided a sort of support for such a proposition, further validation was needed. Different scenarios were built to calculate the cumulative profit during the entire product lifecycle. The lean, agile, leagile, and mixed models were compared with each other. The results show that using a mixed model that switches between lean and agile paradigms produces the highest lifecycle profits. The use of this comparison, however, is subject to many factors, including the length of the product lifecycle, the price, the cost, the type of demand, the success of the product, and the length of each lifecycle stage, among other factors.

The applicability of the proposed model requires multifaceted research and analysis, since the logistics system cannot be separated from other divisions and activities, for which the proposed system might or might not be suitable. This preliminary model also requires further testing through multiple-case research in different environments and settings. As explained by Naim et al. (2010), exploratory research that constitutes the initial step in examining the validity and credibility of a model requires more research efforts to be validated and enhanced.

8.3. Discussion

In this section, some aspects of the research structure, steps, and procedures are supplementarily explained and discussed and the results are compared with the results of similar research to enhance their validity and to explain the variations appearing between current and future research.

8.3.1. Research Structure

Further explanation of some debatable points might be helpful for providing further support for the current research and potential guidelines for future research. Such points include the research stimulus, the variables investigated, the formulation and usability of the measurement tool, and the analytical tools utilized.

Research Variable Issues

While this research considered logistics activities for a focal company, two levels of integration (figure 8.1) should be considered: the internal integration with other organizational functions and the external integration through considering the entire supply chain. Logistical processes should be viewed in light of the overall strategy and logistics should be employed to support the achievement of the aggregate objectives of the company and of the supply chain. Jones et al. (1997) indicated that an attempt to optimize each part of the supply chain separately does not provide the optimal cost solution. They stressed the need to look at the sequence of activities, from the raw materials to the final customer.

A great deal of debate has taken place around the classification of many activities as being logistics or operations. Investigating the role of some logistics activities might seem –

to many researchers – like studying the effect of operation activities on operation performance. However, this overlapping is more apparent in the case of intra logistics than in the cases of inbound and – certainly – outbound logistics. However, considering a certain practice and techniques such as lean and agile tools might be more rational. Even concerning operations themselves, studying the role of lean manufacturing practices, for example, in the operational performance is highly acceptable.

The lean approach aims to eliminate waste resulting from no-value-added activities. This is related more to logistics than to production, since it is difficult to identify a manufacturing activity that adds no value to the product. In addition, many researchers have mentioned logistics activities as cost centres that add no value. Therefore, lean logistics actually represents the most crucial part of the lean manufacturing concept.

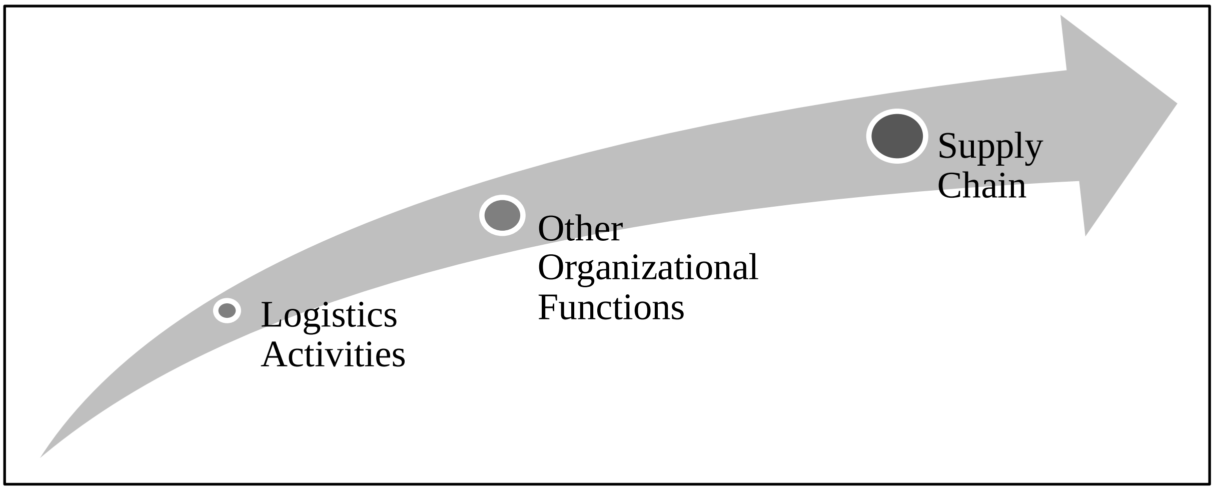


Figure 8.1: Model integration at the organizational and supply chain levels

Measurement Tool

The use of the three items of quantity, quality, and cost was sufficiently comprehensive and consistent with the general body of literature. The three dimensions of duration, which was measured by the quantity variable in the current research, quality, and cost accounted for most research efforts. Matta (2007) indicated that most research in the ramp-up field has concentrated on managing the ramp-up phase through investigating the factors affecting ramp-up's duration and its related costs or investigating issues related to reducing the duration through speeding up the enhancement of product quality. Witt (2006) used a similar approach to measure the outputs of the new product launch phase through time, cost, and quality dimensions.

While the ramp-up performance measurement tool used aims mainly to support the current research purposes, it can be modified to measure the ramp-up performance in a particular company. However, since the measurement method developed ignored adaptability issues, which are considered to be important for a successful measurement system (Ghalayini and Noble, 1996), the use of the proposed tool by a certain company should be preceded by adaptation to the company's internal and external environment. In addition, due to frequent target changes, the performance metrics should be periodically reviewed and updated (Doltsinis et al., 2013). Medori and Steeple (2000) proposed a framework for the auditing and updating of performance metrics.

Some variables were measured through questions that compared the ramp-up process with the steady-state production. Sometimes poor performance is not attributed to the special characteristics of the ramp-up process, but rather to factors that continue even after the ramp-up's end. Therefore, comparing some indicators and measuring them relative to the steady-state production might be helpful in analysing and understanding the study's results. Such a direction has been supported in the literature. Langowitz (1988), for example, measured output, quality, and delivery target achievement for both the new product and the existing product to clarify the deviation of the performance during the new product's initial manufacturing process.

Sampling

The focus on strictly defining the research population and sample arose from the desire to affirm that the sample is a representative one and that the results can be generalized to the entire population. However, this is not the exact case of the current research due to the numerous factors that make every system a unique one.

8.3.2. Results' Comparison

The effect of lean and/or agile logistics on ramp-up performance has never been empirically investigated. However, Bowersox et al. (1999) contributed a theoretical framework utilizing the 'effect-based' logistics – pull approach – for a lean product launch strategy. Pfohl and Buse (2000) indicated the importance of accelerating the learning process to reduce the ramp-up time. The authors concluded that the focus should be directed toward promoting the transfer of logistics-related knowledge.

Motivated by the lack of information regarding the design of logistics during the new product launch phase, Pfohl and Gareis (2000) studied the role of logistics, represented by the material flow and the logistics process, throughout the production run. The authors focused on the problems occurring and the issues of coordination between logistics and other chains, other phases, other projects, and other functions. They classified logistics into operative and administrative activities. Data were collected from 13 companies (4 auto manufacturers, 7 auto suppliers, and 2 other firms from different sectors) through a questionnaire. Selected results were presented because some questions were not answered.

Differing from what the literature has frequently reported, the researched sample showed a moderate-to-high evaluation for ramp-up performance. Most of the research that reported insufficient or unsatisfactory ramp-up performance concentrated on the auto industry. The extremely high competition in this sector is reflected in higher targets and specifications. Higher targets for the ramp-up phase should be reflected in the perception of this phase’s outcomes. The potential negative effect of time-to-market on overall product quality mentioned by Carrillo and Franza (2006) should be extended to time-to-volume as well. However, the results of the statistical analysis showed a positive effect for both quantity and cost performance on quality performance, if only the three constructs were considered (see figure A.7 in appendix 3). If all the paths were considered, as in the model used to test the subsidiary hypotheses, the relationships were insignificant, as shown figure A.8 in appendix 3.

While some researchers have considered the switch from one process strategy to another during the product lifecycle, such a switch will not take place if a high level of uncertainty regarding product success or failure exists (Ramasesh et al., 2010). However, the proposed application method of using special and separate ramp-up and steady-state facilities might enhance this switching ability even with higher levels of uncertainty.

8.4. Limitations

The scarcity of research on ramp-up and – to a lesser extent – on lean and agile logistics, in addition to the preliminary nature of the proposed model of switching between the lean and agile paradigms, imposed some limitations on the current research.

Logistics in this research refers to the process of managing the two-directional movement and storage activities of inventory and related information and funds. Only one direction of inventory and information was considered in this research. Logistics, however, includes the reverse flow of inventory and information as well. Nonetheless, collecting data on backward logistics flows as well requires contributions from different entities, and perhaps different organizations, which might greatly complicate the data collection process and reduce the response rate dramatically. In addition, the consideration of information flows was limited to a few measures in the questionnaire. The funds flow was not investigated due to the reasons previously mentioned (section 2.2.2).

In addition, the management process mentioned in the definition includes the activities of planning, organizing, leading, and controlling. These components were not thoroughly distinguished and investigated. A greater focus on implementation dominated the research. However, the attempt to focus on implementation activities rather than on planning, leading, organizing, and controlling activities can be noted in the operation management literature. Furthermore, multidimensional-focused research investigating more than one managerial dimension is lacking.

While this research intensively utilized flexibility measures to capture levels of agility, some authors (e.g. Vokurka and Fliedner, 1998; Zhang and Sharifi, 2000) have argued that flexibility is only one component of agility along with other components, such as cost, quality, and dependability. Elkins et al. (2004) distinguished between agile and flexible manufacturing systems in the automotive industry.

The use of the frequency of occurrence of some ramp-up problems was not sufficiently representative of the severity of the problem. For example, a mismatch between the product design and the production process might occur only once for one ramp-up process but can hinder the entire ramp-up process. Repair, rework, and scrap costs were used to measure cost performance during production ramp-up; the reduction of these costs is one of the main goals of lean manufacturing practices. Therefore, these costs can be used to measure ramp-up and leanness levels alike.

The different levels of performance measurement proposed by many authors were not considered in the current research. Merchant (1961), Peklenik (1971), and Wiendahl Lutz (2002) supported the division of performance measurement into five levels that cover machine, cell, line, factory, and network. This five-level approach was employed by Hon (2005). The inclusion of all these levels requires a prolonged questionnaire that might substantially reduce the response rate. However, case studies – rather than survey research – are more suitable for investigating different levels of production performance.

The model, which proposed to employ lean and agile logistics during different production phases, was based on exploring the effects of leanness and agility on performance indicators during production ramp-up only. The results might vary if the performance indicators during the steady-state or ramp-down phases were included in the analysis. More comprehensive research efforts are required to verify the model proposed. In addition, the conventional models – which employ strategies other than lean, agile, or leagile strategies – were not included in the comparison.

8.5. Recommendations

The results and conclusions of this research should be reflected in particular contributions to the field investigated. Specific guidance and directions are introduced for both researchers and practitioners in the following two sections.

8.5.1. Recommendations for Researchers

Using the case study methodology to provide verification for the proposed model is worthy of consideration. Flynn et al. (1990) mentioned the importance of using multiple cases to verify theories. Koufteros (1999) indicated that exploratory studies' results serve as stepping stones for further analysis using confirmatory approaches. In addition, more investigation is required to explore the possible impact of the switching between lean and agile logistics on other functions in the manufacturing facility and on other partners in the supply chain. A need for survey research in the field of production ramp-up could be easily identified. Rungtusanatham et al. (2003) mentioned the general direction in the OPM literature toward conducting more survey research instead of the traditionally followed modelling-based approach that utilizes optimization or simulation methodologies. Furthermore, in the current research, only a single-product case was considered. The analysis of production systems with multi-product cases is an important field of research.

Outbound logistics takes place after the completion of the production process. Therefore, it is beyond the scope of this research. However, outbound logistics of the suppliers might affect production ramp-up. Furthermore, suppliers' level of leanness or agility could be indicative, but including this requires a closer view of operations and a multi-organizational analysis, thus necessitating different data collection and analysis tools, which constitute another worthy research point.

In addition, production ramp-up's pace, resulting quality, and costs can be researched as an independent variable contributing to the prediction of outbound logistics' performance. Studying this mediating role might be helpful in enhancing certain aspects of customer service, taking into consideration the major importance of distribution management for customer service and satisfaction. The developed measurement tool of ramp-up performance might be utilized for this purpose.

One problem in measuring the study variable was the overlapping between research variables. For example, ramp-up performance was measured through time-related variables, and high performance leads to reduced time-to-volume; however, the ability to reduce the manufacturing lead time was used by Merschmann and Thonemann (2011) to measure the supply chain flexibility. Additionally, setup time reduction will definitely contribute to ramp-up time reduction, but it has also frequently been considered as a lean tool (White et al., 1999; Cua et al., 2001; Ahmad et al., 2003; Li et al., 2005; Shah and Ward, 2007). Furthermore, the ability to launch new or revised products has been considered, by some authors (e.g. Duclos et al., 2003; Elkins et al., 2004), as an indicator of agility. Therefore, for researchers who consider ramp-up as part of the new product development process, the entire process performance indicating the agility levels of the system, organization, or the supply chain should be considered. In addition, Helo (2004) mentioned product mix flexibility as an indicator of agility and referred to the ability to change the expected lifecycle of a certain product; this also leads to the consideration of production ramp-up as part of building product mix flexibility.

Moving the production process from the ramp-up facility to the steady-state facility will require another ramp-up phase within the steady-state facility; this ‘second ramp-up phase’ requires more investigation and analysis.

8.5.2. Recommendations for Practitioners

The measurement tool used was designed to be general and applicable to multiple organizations operating in different environments. However, the design and implementation of a performance measurement system in a certain facility should be based on strategy (Goold, 1991; Kaplan and Norton, 1992; Bourne et al., 2000). Therefore, practitioners have to take into account the adaptation of the measurement tool to the specific strategy and environment of their organization. While the formation of the measurement tool considered common parameters and activities practised by almost every manufacturing company, a more detailed and company-specific tool might offer further advantages.

The following points can summarize the recommendations for practitioners regarding the data analysis results:

- Lean logistics is recommended when quality or cost performance has the highest priority or when all the performance indicators are equally important.
- Agile logistics is recommended as the importance of quantity performance enhancement increases.

- A mixed system, which switches from agility to leanness, should be evaluated according to different dimensions, including the product type, price, cost, contribution, demand, competition, industry, and environment.
- Multi-product cases and, hence, multi-ramp-ups should be considered in evaluating the feasibility of the mixed system proposed.

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APPENDICES

Appendix 1: Questionnaire Items

Firm:

Contact Information:

A- For multiple choice items, please highlight the number that represents the case for you, your firm and the product:

Respondent

1- Your job title or position

2- Experience
1 Less than 2 years
2 From 2 to less than 5 years
3 From 5 to less than 8 years
4 From 8 to less than 11 years
5 More than 11 years

Firm

3- Number of workers in the firm
1 Less than 50
2 From 50 to less than 250
3 From 250 to less than 500
4 From 500 to less than 1000
5 More than 1000

4- Country

5- Number of production ramp-ups experienced within the last 3 years

The product undergoes ramp-up process

6- Product type

7- Degree of product/process newness
***** more than one option can be chosen (for example, new product and new process)***
1 Slightly modified product
2 Significantly modified product
3 Completely new product
4 Production process slightly modified
5 Production process significantly modified
6 Completely new production process or new production facility

8- Estimated product lifecycle
1 Less than 6 months
2 From 6 months to less than 1 year
3 From 1 to less than 3 years
4 From 3 to less than 6 years
5 More than 6 years

B- Please highlight the number that represents your personal assessment for the following dimensions:

			Very Poor <<<								**>>> Excellent**		
9-	Actual to planned production rate during:	the initial stages of ramp-up	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
		the middle stages of ramp-up	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
		the final stages of ramp-up	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
10-	The ability to reduce production cycle time throughout the ramp-up period		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
11-	Employees' learning rate during the ramp-up period		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
12-	The match between material deliveries in term of quantity, quality and timing and the real needs of the manufacturing process		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
13-	Cooperation with suppliers		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
14-	The use of information technology to link the company with suppliers		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
15-	Suppliers' flexibility and ability to adapt to changes in material requirements in term of quality, quantity and timing		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
16-	The ability of the firm's internal logistics system to cope with changes in production mix		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
17-	The ability of the firm's logistics system to respond, with a cost efficient manner, to the changes in customers' orders in term of size, type or delivery time		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
18-	Firm's ability to predict market changes		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Please provide your overall assessment for:

		Very Poor <<<								**>>> Excellent**		
19-	Attainment of goals related to production volume during the ramp-up phase	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
20-	Attainment of time-related goals during the ramp-up phase	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
21-	Attainment of quality-related goals during the ramp-up phase	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
22-	Attainment of financial and cost-related goals during the ramp-up phase	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
23-	Overall ability of the logistics system to eliminate waste and save resources	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
24-	Overall flexibility of the logistics system	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Please provide your overall assessment for the success of the new product been ramped-up in term of:

		Very Poor <<<										>>> Excellent
25-	Sales return	0	1	2	3	4	5	6	7	8	9	10
26-	Net profit	0	1	2	3	4	5	6	7	8	9	10
27-	Market share	0	1	2	3	4	5	6	7	8	9	10
28-	Customer satisfaction	0	1	2	3	4	5	6	7	8	9	10

C- Please highlight the number that represents your personal assessment in the following dimensions:

		Very Low <<<										>>> Very High
29-	The proportion of defective products during the ramp-up	0	1	2	3	4	5	6	7	8	9	10
30-	The proportion of products returned by customers	0	1	2	3	4	5	6	7	8	9	10
31-	Acceptable deviation in quality level as compared to steady-state production	0	1	2	3	4	5	6	7	8	9	10
32-	Unit production cost during ramp-up as compared to steady-state production	0	1	2	3	4	5	6	7	8	9	10
33-	Costs incurred by preparing for the ramp-up process	0	1	2	3	4	5	6	7	8	9	10
34-	Repair, rework and scrap costs during ramp-up as compared to steady-state production	0	1	2	3	4	5	6	7	8	9	10
35-	Levels of: raw material inventory	0	1	2	3	4	5	6	7	8	9	10
	work in process (WIP) inventory	0	1	2	3	4	5	6	7	8	9	10
	finished goods inventory	0	1	2	3	4	5	6	7	8	9	10
36-	Materials' transportation costs compared to competitors	0	1	2	3	4	5	6	7	8	9	10
37-	Finished goods' transportation costs compared to competitors	0	1	2	3	4	5	6	7	8	9	10
38-	The degree of standardization and smoothing in materials and parts flow in the manufacturing process	0	1	2	3	4	5	6	7	8	9	10
39-	Levels of customer involvement	0	1	2	3	4	5	6	7	8	9	10
40-	Levels of flexibility provided by: the production machines	0	1	2	3	4	5	6	7	8	9	10
	the production system	0	1	2	3	4	5	6	7	8	9	10
	the material handling	0	1	2	3	4	5	6	7	8	9	10
	the production tools and equipment	0	1	2	3	4	5	6	7	8	9	10

D- Please mention the frequency of occurrences for the following situations during the ramp-up phase:

		Never <<<										>>> Very Often
41-	Unplanned stops in the production process	0	1	2	3	4	5	6	7	8	9	10
42-	Materials unavailable, defective, or does not match requirements	0	1	2	3	4	5	6	7	8	9	10
43-	Machines are not suitable for the new product	0	1	2	3	4	5	6	7	8	9	10
44-	Equipment or tools are unavailable or inappropriate	0	1	2	3	4	5	6	7	8	9	10
45-	Committing mistakes by production employees	0	1	2	3	4	5	6	7	8	9	10
46-	Mismatch between product design and production process	0	1	2	3	4	5	6	7	8	9	10
47-	Mistakes in product design	0	1	2	3	4	5	6	7	8	9	10
48-	Inappropriate technology was used	0	1	2	3	4	5	6	7	8	9	10
49-	Poor cooperation and coordination between production and other departments	0	1	2	3	4	5	6	7	8	9	10
50-	Poor flow of information	0	1	2	3	4	5	6	7	8	9	10

E- Please mention your evaluation for the application of the following tools (if used) in your firm:

		Not used	Used, and my evaluation is									
			Very Poor <<<									>>> Excellent
51-	Just in time (JIT)	0	1	2	3	4	5	6	7	8	9	10
52-	Kanban/pull system	0	1	2	3	4	5	6	7	8	9	10
53-	Lean warehousing/cross-docking	0	1	2	3	4	5	6	7	8	9	10
54-	Material requirement planning (MRP)	0	1	2	3	4	5	6	7	8	9	10
55-	Supplier milk run	0	1	2	3	4	5	6	7	8	9	10
56-	Modular product design	0	1	2	3	4	5	6	7	8	9	10
57-	Reconfigurable manufacturing system	0	1	2	3	4	5	6	7	8	9	10
58-	Vendor managed inventory (VMI)	0	1	2	3	4	5	6	7	8	9	10
59-	Third party logistics (3PL) in distribution	0	1	2	3	4	5	6	7	8	9	10

Appendix 2: Fragebogen Artikel

Firma:

Kontaktinformationen:

A- Persönliche Angaben:

Teilnehmer

1- Ihre Berufsbezeichnung oder Position

2- Arbeitserfahrung
1 Weniger als 2 Jahre **2** Von 2 bis weniger als 5 Jahre
3 Von 5 bis weniger als 8 Jahre **4** Von 8 bis weniger als 11 Jahre
5 Mehr als 11 Jahre

Firma

3- Mitarbeiterzahl
1 Weniger als 50 **2** Von 50 bis weniger als 250
3 Von 250 bis weniger als 500 **4** Von 500 bis weniger als 1000
5 Mehr als 1000

4- Land

5- Anzahl der durchgeführten Produktionsanläufe in den letzten 3 Jahren

Das Produkt in der Anlaufphase

6- Produkttyp

7- Innovationsgrad des Produktes/des Prozesses
***** Mehrfachauswahl möglich (zum Beispiel neue Produkte und neuer Prozess)***
1 Leicht modifiziertes Produkt **2** Deutlich modifiziertes Produkt
3 Komplett neuentwickeltes Produkt **4** Produktionsprozess leicht modifiziert
5 Produktionsprozess wesentlich verändert
6 Komplett neues Produktionsverfahren oder neue Produktionsstätte

8- Geschätzter Produktlebenszyklus
1 Weniger als 6 Monate **2** Von 6 Monaten bis unter 1 Jahr
3 Von 1 bis unter 3 Jahre **4** Von 3 bis unter 6 Jahren
5 Mehr als 6 Jahre

B- Bitte geben Sie Ihre persönliche Einschätzung für die folgenden Bereiche an:

			sehr schlecht <<<										>>> **sehr gut**
9-	Effektiv zu planende Produktionsrate während:	des Beginns des Produktionsanlaufs ----------------	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
		der mittleren Phase des Produktionsanlaufs -------	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
		der Abschlussphase des Produktionsanlaufs ------	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
10-	Die Möglichkeit, die Produktionsdurchlaufzeit während der gesamten Anlaufzeit zu reduzieren ---		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
11-	Die Lernrate der Mitarbeiter während der Anlaufphase --------------------------------		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
12-	Die Übereinstimmung zwischen Materiallieferungen und den tatsächlichen Anforderungen während des Herstellungsprozesses ------------------------------------		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
13-	Zusammenarbeit mit Lieferanten ---		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
14-	Die Verwendung von Informationstechnologie, für die Kommunikation des Unternehmens mit Lieferanten --		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
15-	Flexibilität des/der Lieferanten sowie die Möglichkeit sich auf Änderungen der Materialanforderungen (Qualität, Menge und Laufzeit) anzupassen ------------------		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
16-	Die Fähigkeit des internen Logistiksystems des Unternehmens, sich auf Veränderungen im Produktionsmix einzustellen ---------------------------------------		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
17-	Die Fähigkeit des Unternehmenslogistiksystems kosteneffizient auf die Veränderungen bei Kundenaufträgen (Größe, Art oder Lieferzeit) zu reagieren ---		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
18-	Die Möglichkeiten der Firma, künftige Marktveränderungen einzuschätzen --------		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

	Bitte geben Sie Ihre Gesamteinschätzung für folgende Aspekte an:	**sehr schlecht <<<**										**>>> sehr gut**
19-	Fähigkeit mengenbezogene Vorgaben während der Anlaufphase einzuhalten	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
20-	Fähigkeit zeitliche Vorgaben während der Anlaufphase einzuhalten	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
21-	Fähigkeit qualitätsbezogene Vorgaben während der Anlaufphase einzuhalten	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
22-	Fähigkeit finanzielle/kostenbezogene Vorgaben während der Anlaufphase einzuhalten	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
23-	Fähigkeit des Unternehmenslogistiksystems, Ressourcenverschwendung zu vermeiden bzw. Ressourcen zu sparen	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
24-	Persönliche Einschätzung zur Flexibilität des Unternehmenslogistiksystems	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

	Bitte geben Sie Ihre Gesamteinschätzung für folgende Kenngrößen eines neuen bereits angelaufenen Produktsan:	**sehr schlecht <<<**										**>>> sehr gut**
25-	Umsatzrendite neuer Produkte	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
26-	Nettogewinn neuer Produkte	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
27-	Marktanteil neuer Produkte	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
28-	Kundenzufriedenheit bei neuen Produkten	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

C- Bitte geben Sie Ihre persönliche Einschätzung für die folgenden Bereiche an:

			sehr gering <<<										**>>> sehr hoch**
29-	Anteil von defekten Produkten während der Produktionsanlaufphase		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
30-	Anteil an Produktreklamationen durch den Kunden während der Produktionsanlaufphase		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
31-	Akzeptierte Qualitätsabweichungen während der Produktionsanlaufphase im Vergleich zum Dauerbetrieb		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
32-	Produkteinzelkosten während der Produktionsanlaufphase im Vergleich zum Dauerbetrieb		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
33-	Vorbereitungskosten während der Produktionsanlaufphase		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
34-	Reparatur-, Nachbearbeitungs- und Abfallentsorgungskosten während der Produktionsanlaufphase im Vergleich zum Dauerbetrieb		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
35-	Höhe des Lagerbestandes von	Produktionsausgangsstoffen	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
		Unfertigen Produkte	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
		fertiger Produkte	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
36-	Transportkosten von Produktausgangsstoffen im Vergleich mit Wettbewerbern		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
37-	Transportkosten von fertigen Produkten im Vergleich mit Wettbewerbern		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
38-	Standardisierungs- und Glättungsgrad beim Material- und Warenfluss während des Fertigungsprozesses		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
39-	Einbindung des Kunden in den Produktionsprozess		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
40-	Flexibilitätsgrad	der Produktionsmaschinen	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
		des Produktionssystems	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
		beim Materialfluss	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
		bei Produktionswerkzeugen und Ausrüstung	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

D- Bitte geben Sie die Häufigkeit des Auftretens folgender Situationen während der Hochlaufphase an:

		Niemals <<<										**>>> Sehr häufig**
41-	Ungeplante Produktionsstillstände	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
42-	Fehlendes, defektes oder unpassendes Material	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
43-	Ungeeignete Fertigungsmaschinen bei neuen Produkten	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
44-	Nicht vorhandene oder ungeeignete Ausrüstung	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
45-	Fehler durch die Mitarbeiter bei der Ausführung	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
46-	Abweichungen zwischen Produktentwicklung und Produktionsprozess	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
47-	Fehler bei der Produktentwicklung	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
48-	Einsatz ungeeigneter Technologie	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
49-	Defizite bei der Kooperation zwischen Produktion und anderen Abteilungen	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
50-	Defizite im Informationsfluss	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

E- Bitte geben Sie Ihre Bewertung für die Anwendung der folgenden Tools (falls verwendet) in Ihrer Firma an:

		nicht verwendet	**Bewertung, falls verwendet** **sehr schlecht** <<<									>>> **sehr gut**
51-	Just in time (JIT) --	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
52-	Kanban/pull system --	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
53-	Lean warehousing/cross-docking ---	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
54-	Material requirement planning (MRP) --	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
55-	Supplier milk run ---	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
56-	Modulare Produktentwicklung ---	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
57-	Rekonfigurierbares Fertigungssystem ---	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
58-	Vendor managed inventory (VMI) ---	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
59-	Drittanbieterlogistik (3PL) in distribution --	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Appendix 3: Path Analysis Figures

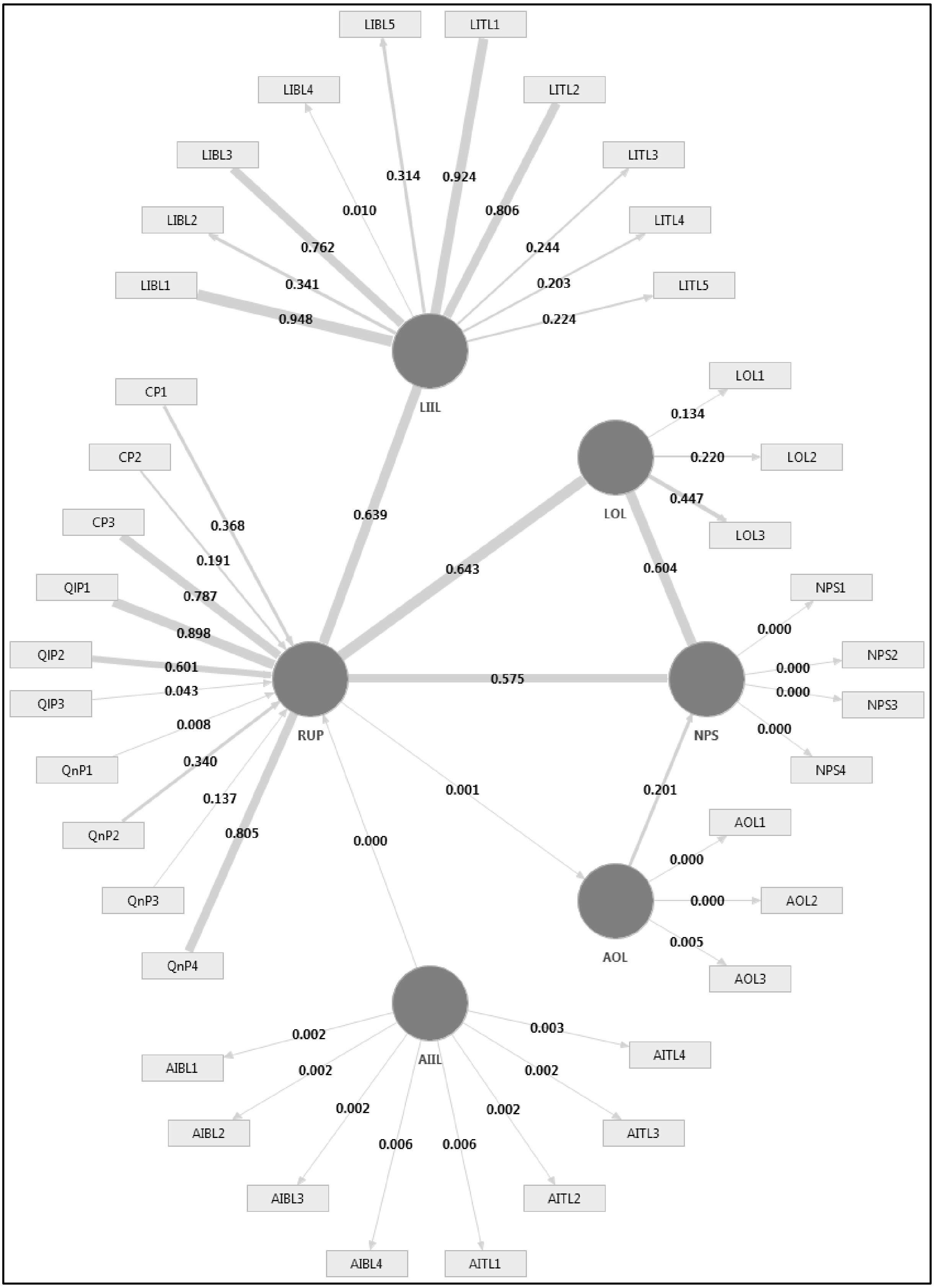

Figure A.1: p values for the path analysis results with ramp-up as a first-order formative variable

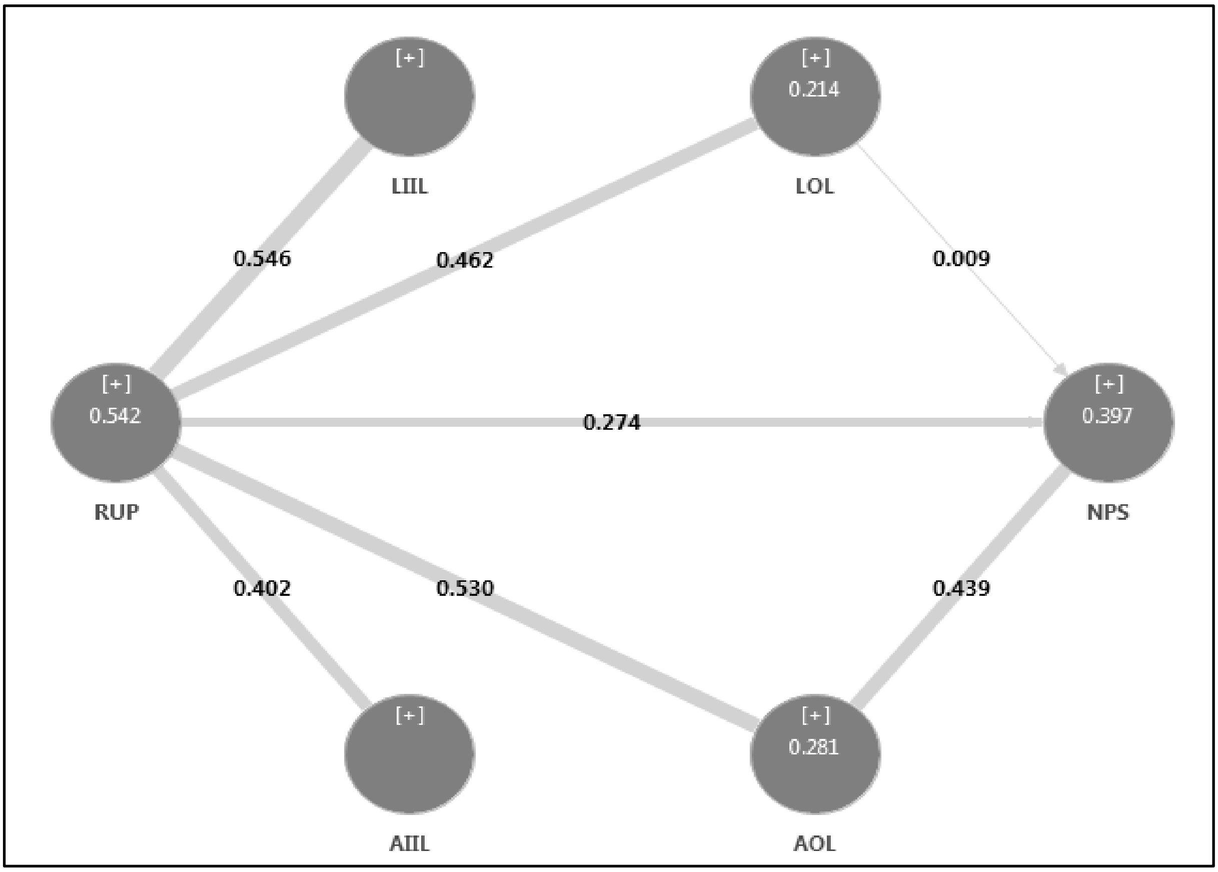

Figure A.2: Results of the path analysis for scenario 3

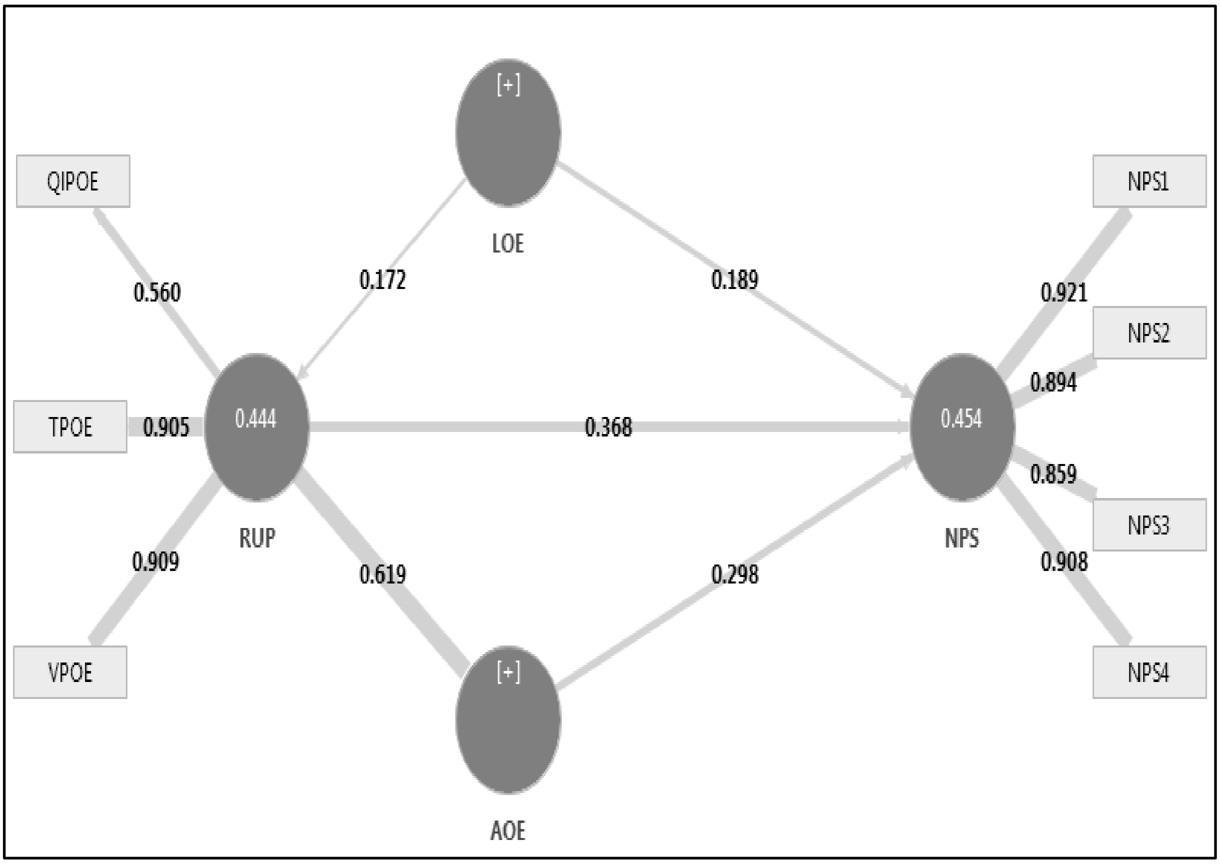

Figure A.3: Results of the path analysis for scenario 4 after removing the cost evaluation indicator

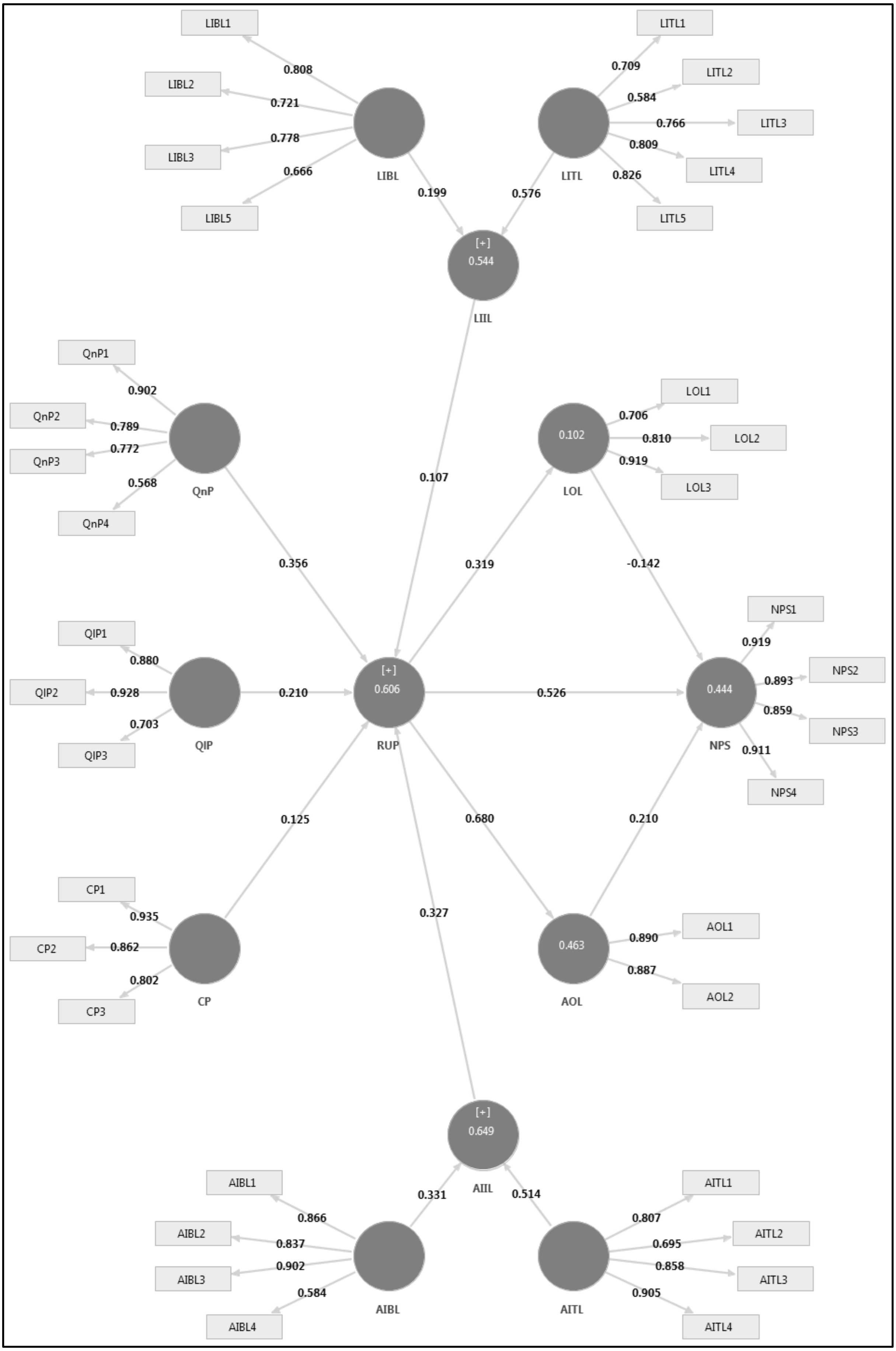

Figure A.4: Results of the path analysis for scenario 5

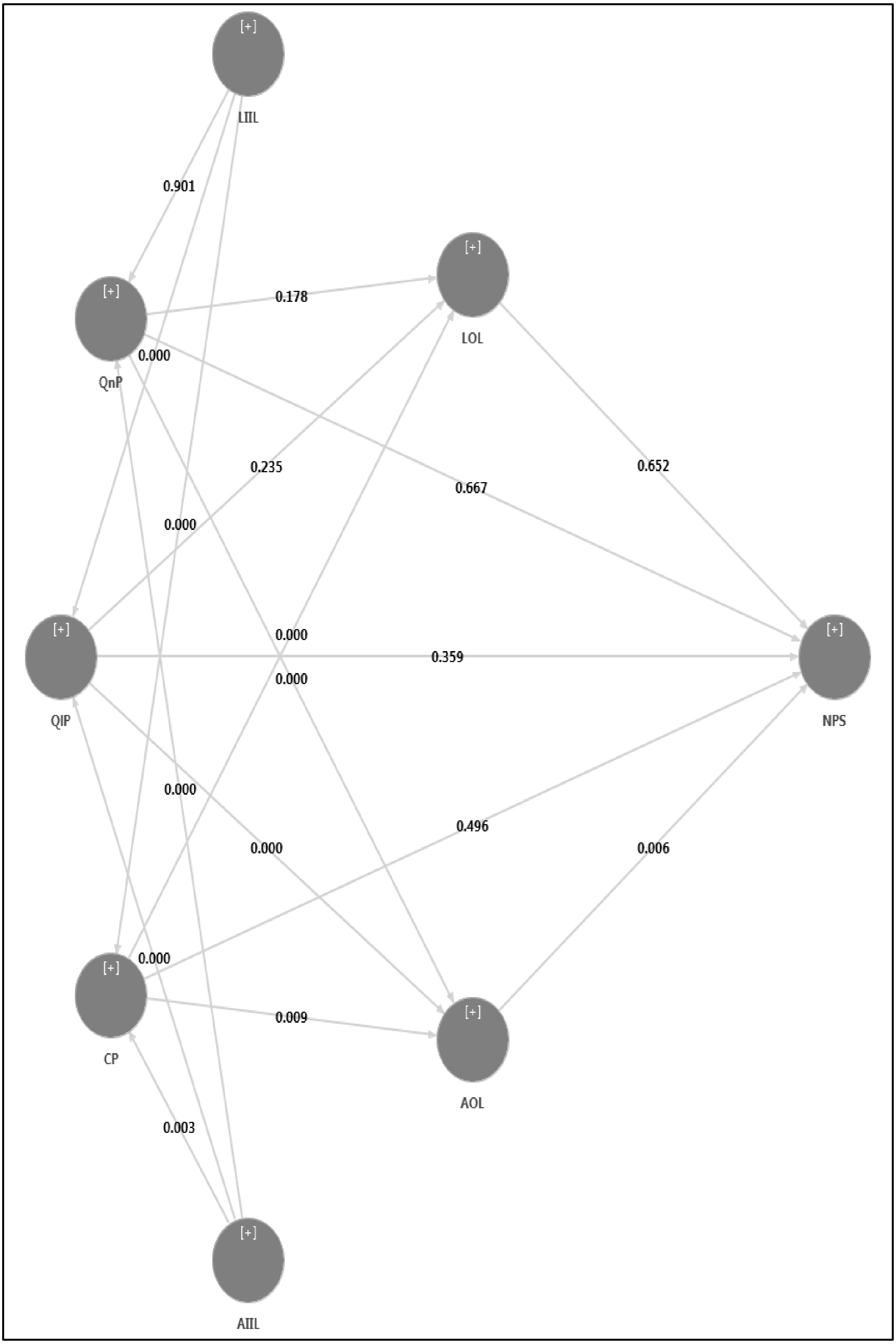

Figure A.5: Sub-hypotheses path analysis with p values

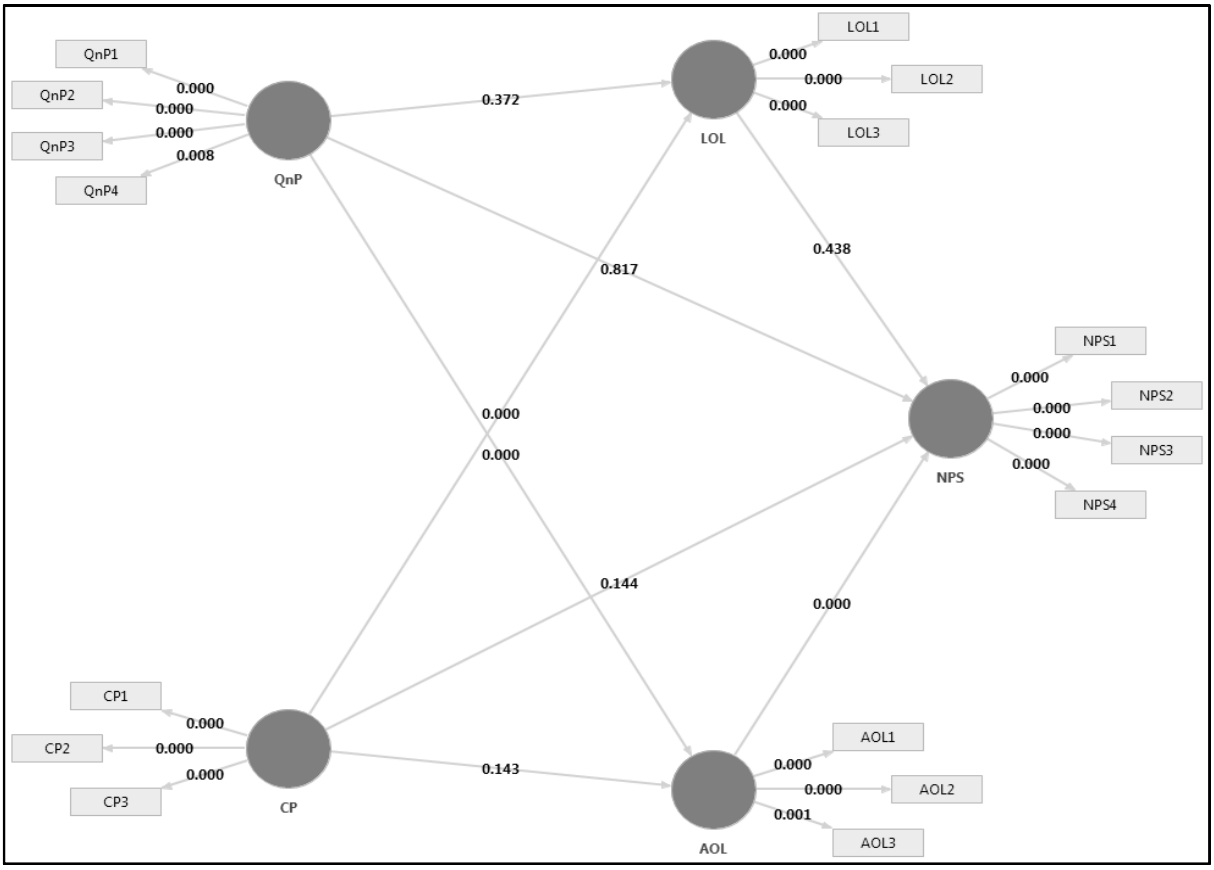

Figure A.6: p values for path analysis in the model examining outbound logistics role

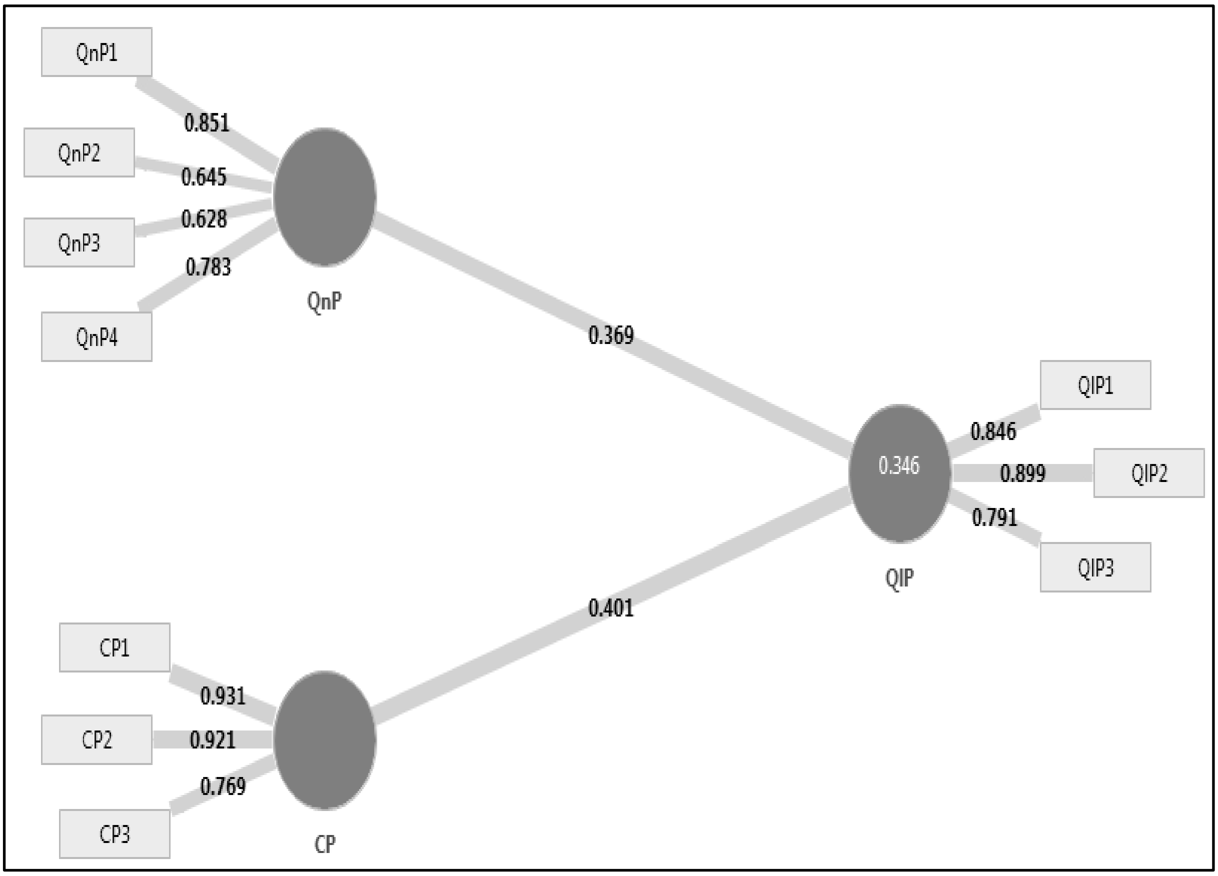

Figure A.7: Path analysis considering only quantity, quality, and cost performance

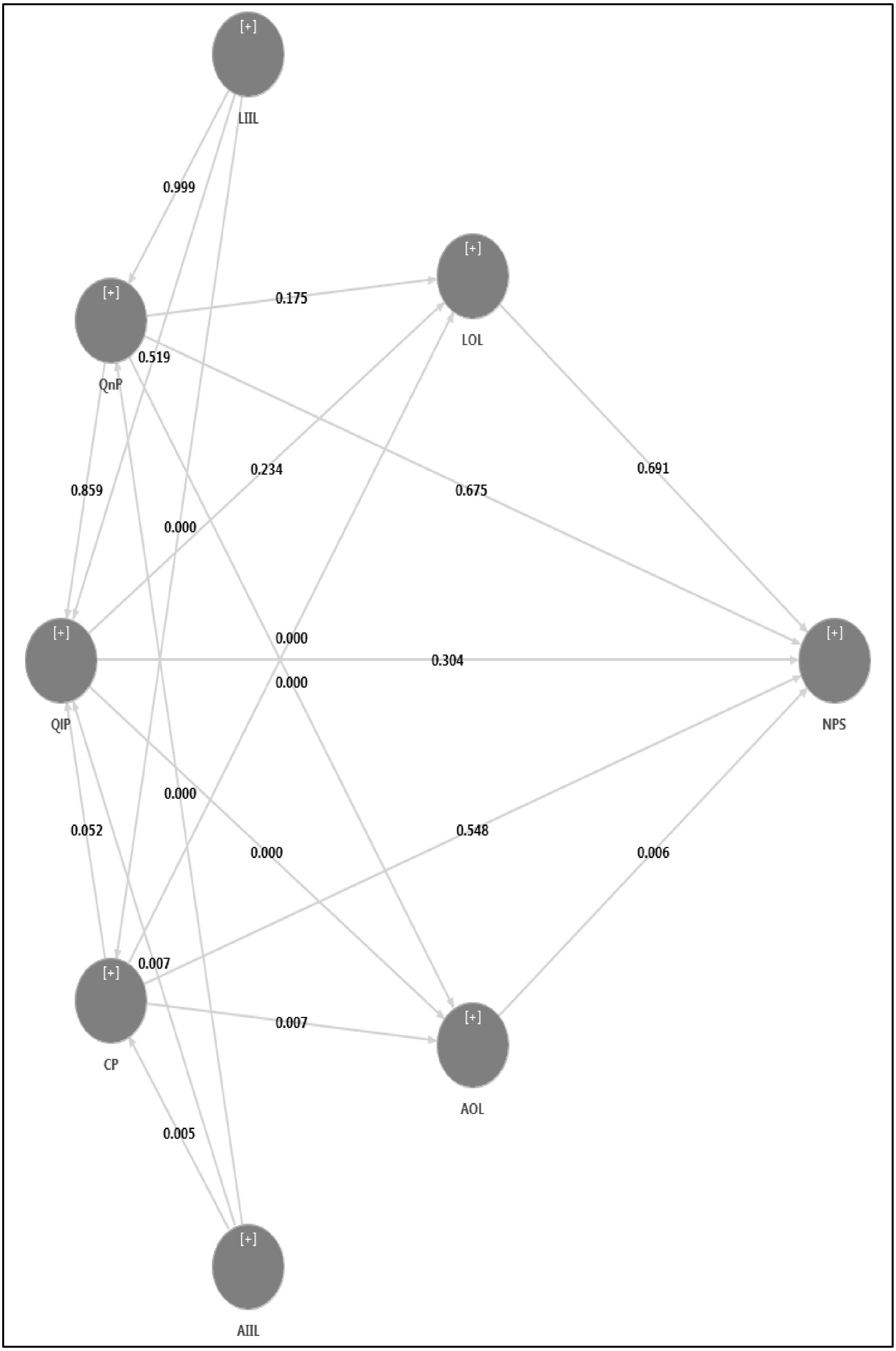

Figure A.8: *p* values show insignificant effect for quantity and cost on quality performance

Appendix 4: Calculated Score of the Latent Variables

Table A.1: The calculated values for the latent variables used in scenarios 2 and 3

Case number	A						B					
	Ramp-up's problems not considered						Ramp-up's problems considered					
	Agile inbound and intra	Agile inbound and intra	Ramp-up performance	Product success	Lean outbound	Agile outbound	Agile inbound and intra	Agile inbound and intra	Ramp-up performance	Product success	Lean outbound	Agile outbound
1	0.538	0.356	0.758	0.510	0.510	1.013	0.557	0.431	0.961	0.511	0.502	1.023
2	-1.103	-1.771	-1.525	-1.919	-2.090	-1.816	-1.093	-1.617	-2.011	-1.920	-2.090	-1.811
3	-0.067	0.494	2.122	-0.605	0.790	0.037	-0.061	0.986	1.981	-0.605	0.779	0.035
4	1.628	1.649	0.751	0.817	1.289	1.197	1.621	1.547	1.308	0.818	1.293	1.192
5	1.175	1.307	1.341	0.803	0.759	0.953	1.193	1.564	1.286	0.800	0.758	0.945
6	0.121	-0.683	1.757	0.827	0.330	0.684	0.109	-0.552	1.450	0.828	0.331	0.692
7	-1.302	-0.337	0.242	-0.615	-0.033	-1.348	-1.315	-0.067	-0.393	-0.615	-0.032	-1.343
8	-0.609	0.116	1.054	0.055	-0.158	0.301	-0.601	0.155	1.307	0.055	-0.160	0.308
9	1.327	0.652	-0.844	1.670	-1.190	1.481	1.323	0.604	-1.372	1.671	-1.192	1.491
10	0.376	-1.260	-1.109	0.640	-0.603	0.281	0.402	-1.300	-1.594	0.640	-0.601	0.282
11	1.574	1.525	2.498	1.814	1.726	0.953	1.573	1.516	2.125	1.813	1.727	0.945
12	-0.398	-1.237	-1.593	-0.793	-0.686	0.037	-0.427	-1.267	-1.713	-0.792	-0.687	0.035
13	-0.892	-1.563	0.009	-1.047	0.340	-0.003	-0.891	-1.484	-0.469	-1.049	0.346	-0.018
14	-1.703	-2.026	-2.629	-2.330	-1.199	-1.368	-1.702	-1.969	-2.176	-2.330	-1.200	-1.369
15	1.629	1.502	1.902	1.239	0.908	1.461	1.621	1.361	1.504	1.236	0.908	1.465
16	-1.576	0.785	-0.032	-0.323	-0.035	-1.328	-1.575	0.698	-0.668	-0.326	-0.040	-1.317
17	1.574	-2.050	-0.214	0.827	-1.421	1.685	1.565	-2.049	0.038	0.828	-1.420	1.686
18	-1.264	1.482	-0.123	-1.765	1.139	-1.592	-1.265	1.700	-0.966	-1.765	1.135	-1.590
19	1.371	-1.547	-0.815	0.415	-1.288	0.993	1.370	-1.550	0.092	0.422	-1.285	0.997
20	1.414	-1.872	0.057	1.249	-2.231	0.953	1.405	-1.913	0.107	1.248	-2.232	0.945
21	-0.354	0.362	0.659	-0.476	-1.148	-0.024	-0.360	0.447	0.072	-0.476	-1.142	-0.044
22	0.791	0.710	0.286	0.357	1.445	1.013	0.799	0.558	0.612	0.356	1.442	1.023
23	-0.113	0.163	-0.125	-0.779	-0.331	0.261	-0.116	0.305	-0.762	-0.780	-0.331	0.256
24	1.317	-0.532	0.530	-0.615	-0.843	1.441	1.313	-0.516	-0.032	-0.615	-0.844	1.439
25	-1.186	0.239	-1.421	-0.745	0.114	-1.816	-1.186	0.135	-0.732	-0.744	0.110	-1.811
26	-1.832	1.536	-0.040	0.817	1.280	-1.124	-1.816	1.415	0.120	0.816	1.278	-1.122
27	-1.584	-1.664	-1.449	-0.745	-1.207	-1.124	-1.582	-1.541	-1.836	-0.744	-1.207	-1.122
28	0.790	0.363	-0.079	0.099	-0.843	0.458	0.801	0.290	-0.163	0.098	-0.844	0.477
29	-1.422	-0.021	-0.948	-0.462	-0.406	-1.592	-1.434	0.064	-0.969	-0.463	-0.410	-1.590
30	-0.638	0.042	0.017	0.055	-0.613	0.525	-0.629	0.065	0.919	0.055	-0.616	0.529
31	-0.938	-0.579	-1.158	0.664	0.240	-1.124	-0.951	-0.561	-0.746	0.663	0.246	-1.122
32	0.402	1.261	1.204	0.535	2.082	-0.431	0.388	1.064	0.764	0.535	2.083	-0.433
33	0.077	-0.263	-0.769	0.664	-0.413	-1.144	0.070	-0.221	0.051	0.661	-0.409	-1.148
34	0.132	-0.521	-0.750	-1.344	-0.041	0.281	0.131	-0.475	-0.584	-1.343	-0.039	0.282
35	0.363	0.314	0.498	0.793	-0.976	0.281	0.377	0.374	0.629	0.792	-0.979	0.282
36	-0.525	-0.779	-0.287	-1.741	0.538	-1.368	-0.550	-0.867	-1.361	-1.741	0.545	-1.369
37	0.831	0.841	0.241	0.817	0.991	1.257	0.848	0.955	0.549	0.818	0.994	1.271
38	-0.902	0.039	0.114	-0.615	0.397	-1.348	-0.902	-0.085	0.333	-0.615	0.403	-1.343
39	0.614	0.772	1.166	-0.333	-0.182	0.261	0.610	0.649	0.849	-0.332	-0.181	0.256
40	0.496	0.772	0.985	-0.180	-0.190	0.017	0.492	0.649	0.788	-0.179	-0.189	0.009
41	1.577	1.388	0.751	0.817	-0.182	1.197	1.579	1.253	1.044	0.818	-0.181	1.192
42	1.303	0.961	0.584	0.260	0.694	0.525	1.303	0.798	0.158	0.263	0.694	0.529
43	-1.656	0.041	0.172	0.827	0.263	-0.431	-1.660	0.067	0.242	0.828	0.260	-0.433
44	-0.308	0.781	-0.028	-0.615	1.875	-1.144	-0.330	0.945	0.427	-0.615	1.876	-1.148
45	-0.984	-0.725	-1.270	0.055	-1.058	0.086	-0.976	-0.542	-0.743	0.055	-1.057	0.084
46	0.959	-0.353	-0.068	1.670	-0.843	0.281	0.963	-0.166	0.306	1.671	-0.844	0.282
47	-0.292	-1.262	-0.298	0.640	0.041	-1.368	-0.300	-1.361	-1.338	0.640	0.039	-1.369
48	0.031	0.728	0.557	1.814	-0.630	1.257	0.061	0.889	0.676	1.813	-0.616	1.271
49	-0.179	0.435	-1.041	-0.793	1.131	-1.348	-0.189	0.113	0.106	-0.792	1.128	-1.343
50	-0.092	0.779	0.806	-1.047	2.082	0.261	-0.100	0.801	0.800	1.049	2.083	0.256
51	0.354	-0.243	-0.560	-2.330	-0.115	0.017	0.344	-0.500	0.065	-2.330	-0.110	0.009
52	0.481	-0.110	-0.235	1.239	-0.041	1.197	0.477	-0.009	0.721	1.236	-0.039	1.192
53	-0.428	0.292	0.351	-0.323	0.138	0.301	-0.412	0.191	0.004	-0.326	0.132	0.308
54	0.411	-1.058	-0.954	-0.040	-1.504	0.301	0.411	-1.452	-0.826	-0.040	-1.506	0.308
55	-0.555	0.343	0.127	0.085	0.834	0.017	-0.538	0.257	-0.270	0.087	0.837	0.009
56	-0.754	-0.573	-1.175	-0.490	0.546	-0.452	-0.742	-0.779	-0.869	-0.488	0.552	-0.459