Chapter 1.

Introduction

"We have many orders on hand that are already late. As such, only when a customer starts complaining about late delivery, his order is put on our top priority list."

"Tight delivery dates urge us to start assembling orders that can only be partly finished, as all required components have not been delivered yet by our suppliers. But sometimes we can proceed by using the components reserved for other orders."

"We do not know whether our planned processing times are realistic. Often these times are established based on experience and we do not track our actual processing times."

These statements demonstrate the practical situation we encountered in the make-to-order (MTO) industry in the Netherlands. Although the need for high logistical performance (for example, on-time delivery) to remain competitive is unquestionable for these companies, the actually performance achieved in practice leaves many opportunities for improvements regarding production planning and control (PPC). In our opinion the statements show that the PPC challenges these companies are confronted with are not served by implementing advanced and detailed scheduling systems. In contrast, simple and more robust PPC approaches would most likely provide a better starting point for improvements.

This PhD thesis has its origin in a body of knowledge that has been developed on such a simple and robust PPC concept, called workload control (WLC), at the university of Groningen (see, for example, Land, 2004; Henrich, 2005). WLC is regarded as the most suitable PPC concept for many companies in the MTO industry (Stevenson et al., 2005). The core of the WLC concept consists of controlled release of customer orders to the shop floor, while maintaining an order pool prior to release to buffer against the many uncertainties involved with MTO companies. By keeping the queues of orders on the shop floor at an acceptable level, throughput times are controlled and delivery dates can be met (Kingsman and Hendry, 2002).

WLC has received considerable attention for decades. It started with a handful of early implementations of WLC in the eighties/early nineties (see, for example, Bertrand and Wortmann, 1981; Bechte, 1988; Wiendahl et al., 1992). Based on these early results

the concept has been extended and tested in numerous simulation studies during the last two decades (see, for example, Melnyk et al., 1991; Salegna and Park, 1996; Perona and Portioli, 1998; Hendry et al., 1998; van Ooijen, 1998; Fredendall et al., 2009; Thürer et al., 2010b). Also research at the University of Groningen contributed to this topic (see, for example, Land and Gaalman, 1998; Oosterman et al., 2000; Henrich et al., 2006). As a body of theoretical knowledge has been developed on WLC, a logical next step would be to bring this knowledge back to the practical situation for which it is ultimately developed. However, contemporary empirical research on WLC is relatively scarce and many authors regard it as one of the future challenges (Gaalman and Perona, 2002; Stevenson et al., 2005). Only recently attempts have been made to investigate the WLC concept in practice (see, for example, Stevenson, 2006; Hendry et al., 2008; Stevenson and Silva, 2008). These qualitative empirical studies revealed many valuable implementation issues that can be used to foster the applicability of the concept in practice and to the development of more elaborate WLC theory.

This PhD thesis also contributes to this issue. In contrast to contemporary qualitative empirical studies that mainly focus on implementation issues derived from WLC implementations, we focus on the effects of WLC on performance in practice. More specific this PhD thesis aims to further develop WLC theory by fostering understanding of and improving the functioning of WLC in practice. For this purpose quantitative logistical data were collected, supplemented with qualitative data. The data result from a research project subsidized by the European Union in which several long-term studies have been carried out in MTO companies. The focus in all studies was to support the companies improving their logistical performance with the help of the WLC concept, meanwhile contributing to scientific knowledge on the functioning of WLC. To identify the functioning of WLC, a first step was to gain in-depth insights into the effects of the current way that companies executed PPC preceding any changes. As most companies did not gather all relevant quantitative logistical data, starting point was to implement a bar code scanning system recording data on the progress of orders. After a start-up period, order progress data were being collected for several months. A diagnosis on the collected data was carried out and the results and potential improvement opportunities were discussed with company staff. Changes were implemented based on WLC theory, which often resulted in significant improvements regarding logistical performance during the post-change measurements. Thus, besides that the research projects focused on retrieving insights regarding WLC theory, also the managerial relevance of the research project is undeniable.

1.1. Research themes

As indicated by its title, *workload control* and *diagnosis* are the key elements of this thesis. We derive theoretical insights regarding the functioning of WLC, insights resulting from the execution of empirical projects. We apply WLC in order to understand how the concept behaves in practice, and use the empirical results to contribute to improving the theory on WLC (see cycle 2 in Figure 1.1). This cycle of theory development is one of the main themes in this thesis. However, to gain insights into the functioning of WLC requires that links between PPC decisions and resulting logistical performance can be identified in practice. It calls for a comprehensive and structured diagnosis of observed logistical performance to determine the influence of specific PPC decisions. The need to fill the gaps that we identified in research on diagnosis led to an additional theme in this thesis, focusing on *diagnosing* logistical performance (see 1 in Figure 1.1). We will elaborate concisely on the two resulting research themes.

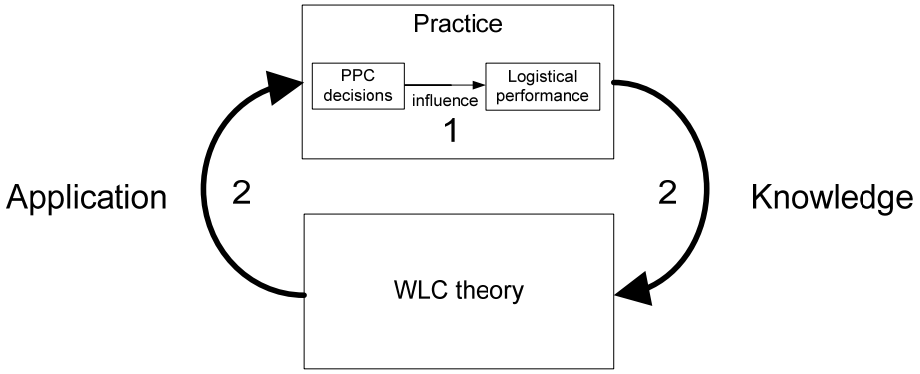

Figure 1.1. Two main research themes.

Research theme 1: To improve the diagnosis of logistical performance

The first research theme of the PhD thesis focuses on diagnosing logistical performance and to attribute causes to underlying PPC decisions. More specifically, we focus on delivery reliability performance, which is often regarded as one of the main logistic performance objectives (see, for example, Slack et al., 2010). To understand the influence of WLC, as aimed for in the second research theme, diagnosing delivery reliability performance is a recurring necessity, both before and after WLC–based changes.

To support the diagnosis, a key diagram available in WLC literature is the throughput diagram (Wiendahl, 1995). In chapter 2 we will show how this tool can help to

diagnose the influence of individual PPC decisions on the average lateness. Furthermore, we indicated a need for support to diagnose the influence of PPC decisions on another important delivery reliability performance criterion, the variance of lateness. This notion has led to the development of a new supportive instrument in this research, the order progress diagram, which is the main topic in chapter 2.

Both throughput diagrams and order progress diagrams are extensively used during the company projects. However, a diagnosis also requires a structured search process in order to determine the most influencing PPC decisions on logistical performance in practice. For this purpose chapter 3 discusses the development of a diagnosis framework which structures the diagnosis process step-by-step from performance to underlying PPC decisions. The framework combines both insights from general problem solving literature and from domain specific literature on delivery reliability determinants related to PPC. The use of the framework is exemplified for three case companies, which show that the framework enables to detect a variety of causes underlying delivery reliability problems regarding PPC. As such, it provides a good starting point for taking appropriate improvement actions.

Research theme 2: To understand and improve the functioning of WLC in practice

The second research theme focuses on the functioning of WLC in a practical setting. For this purpose throughput diagrams and the newly developed order progress diagrams are used to support diagnosing the observed changes in performance after using WLC. An issue frequently emerging from the diagnosis originated from the dynamic circumstances to which companies were exposed. One of the companies, in which these dynamics were especially prevalent, clearly revealed the inability of the WLC concept to deal with extreme dynamics. The issue of dynamics is researched in chapter 4, identifying and classifying the key issues in a dynamic setting when WLC is being used to control logistical performance.

Finally, chapter 5 focuses on extending the applicability area of the WLC concept. The limited capability of WLC to control order progress in manufacturing situations with long and assembly type routings is known from literature (see, for example, Bertrand and van de Wakker, 2002; Henrich et al., 2004). One of the case studies provided the opportunity for an in-depth study of a complex job shop. The analysis of the PPC approach taken by this case company provided the opportunity to gain insights into potential improvement opportunities for WLC. It resulted in a number of

proposed adaptations to the WLC concept in order to extend the applicability area of WLC to these complex job shops.

1.2. Methodology

In all chapters data from companies participating in the long term empirical research studies were used. In total ten long term empirical studies have been carried out. This section starts by discussing the case selection criteria and procedure for all companies participating in the research project. In this thesis not all cases are used. For each chapter making use of the cases, selection criteria for the cases and chapter-specific approaches are discussed in 1.2.2.

1.2.1. Selection of case companies

Three main criteria apply for companies that could potentially participate in the EU subsidized research project. First, as WLC is especially developed for MTO companies (see, Stevenson et al., 2005), selected companies had to produce dominantly make-to-order products. Second, companies had to have relatively high capacity complexity as the focus on controlled release by WLC is especially useful for such companies. The latter criterion could, amongst others, be indicated by capacity restrictiveness, complex routing structures, or customers' pressure on short delivery times. Thirdly, the granted EU subside restricted the choice for companies. Only small-to-medium sized enterprises (SMEs) in specific regions in the northern part of the Netherlands could potentially participate in this research.

The selection process started with sending 346 mailings to manufacturing companies based on a database from the Chamber of Commerce. The mailings comprised companies in a wide variety of industries, located in the northern part of the Netherlands. Ten percent of these companies were interested and wanted to participate. Secondly, plant visits in twenty six companies were made to check their fit to the criteria described above. Nine companies were selected at that time. As one the research projects was cancelled in a premature stage, two additional companies were selected based on the same criteria during the research project in a second selection round. As such, in total ten companies in a wide variety of industries were selected to participate in the total EU subsidized research project.

1.2.2. Approaches in individual chapters

The companies participating in this research were used to foster understanding of and to improve the functioning of WLC in practice. Although all companies contributed to a

certain extent, this PhD thesis focuses on those companies which revealed relevant issues for further development of WLC theory. Unfortunately, our wish to execute a comparative study across all case companies could not be carried out, mainly due to data quality issues.

Chapter 2 focuses on developing a new diagnosis instrument, the order progress diagram. After specifying design criteria, the main focus of this chapter is on the capabilities of the developed instrument. The diagram was developed before the diagnoses in the ten long term empirical studies had been executed. The illustrative role of case material in this chapter allowed us to utilize available quantitative data from a pilot study in a company that complied with the selection criteria described in section 1.2.1.

Chapter 3 presents a new diagnosis framework regarding delivery reliability. The development of the framework finds its roots in general problem solving literature, combined with elements of domain specific literature on delivery reliability. Three case companies were used to illustrate the use of the developed diagnosis framework. We aimed to provide a rather complete picture of the diagnosis process. As such, cases were selected that provided insights into different problem areas as distinguished in the diagnosis framework.

Chapter 4 focuses on the behaviour of WLC in dynamic environments. A representative single case study (Yin, 1989) in a highly dynamic environment was chosen for this purpose. The detailed collection of quantitative data over time in combination with qualitative data from workshops allowed us to gain in-depth insights into how WLC behaved when confronted with these dynamics. The findings in this company can be seen a unique opportunity to observe the effects of dynamics on WLC over time so clearly. This makes the study in chapter 4 a so-called revelatory case in terms of Yin (1989). It enabled us to provide the pathway for further theoretical developments of WLC in dynamic environments.

Chapter 5 aims to provide insights into how WLC could be made suitable for complex job shops, which lie at the border of its applicability area. For this purpose a complex job shop is selected as a representative case (see, Yin, 1989). The case company did not make use of WLC. We aimed to learn from the company approach to achieve delivery performance and from the problems the company faced in realising this. The insights gained from this company could be classified as enlightening. The paper combines the analysis of the company approach with insights from theoretical studies on WLC to provide foundations for a new approach to PPC in complex job shops.

1.3. Thesis outline

The chapters of this thesis consist of four papers that are all related to one of the two main research themes. Chapters 2 until 5 each discuss one the papers, which can all also be read individually (see Figure 1.2).

Research theme 1

2. Soepenberg, G.D., Land, M.J., and Gaalman, G.J.C., 2008. The order progress diagram: A supportive tool for diagnosing delivery reliability performance in make-to-order companies. *International Journal of Production Economics*, 112 (1), 495-503.

3. Soepenberg, G.D., Land, M.J., and Gaalman, G.J.C., 2010. A framework for diagnosing delivery reliability of make-to-order companies. *International Journal of Production Research*, under review.

Research theme 2

4. Soepenberg, G.D., Land, M.J., and Gaalman, G.J.C., 2010. Workload control dynamics in practice. *International Journal of Production Research*, under review.

5. Soepenberg, G.D., Land, M.J., and Gaalman, G.J.C., 2010. Adapting workload control for complex job shops. *International Journal of Production Economics*, under review.

Figure 1.2. Papers within each research theme.

The papers are published or under review for journal publication at the time of finishing this thesis[1]. Finally, Chapter 6 provides the main conclusions from the thesis and discusses additional observations and insights gained from the empirical projects.

[1] All papers are presented in their published or submitted form. As such, individual chapters show some overlap.