Planning environments of hospital laboratories: An exploratory study

Aili Biriita Bertnum [0000-0003-3092-5760], Marco Semini and Jan Ola Strandhagen [0000-0003-3741-9000]

Department of Mechanical and Industrial Engineering,
Norwegian University of Science and Technology, 7491 Trondheim, Norway
{aili.b.bertnum,marco.semini,ola.strandhagen}@ntnu.no

Abstract. Hospital laboratories are facing challenges of increasing demand and limited budgets. Planning and control can improve resource utilization, reduce work-in-progress and shorten throughput times, but to achieve such benefits, there is a need for a strategic fit between the planning and control system and the unique planning environment of the hospital laboratory. Existing research on planning environments focuses mainly on manufacturing companies, whereas hospital laboratory planning environment research is scarce. The aim of the study is to characterize a hospital laboratory's planning environment based on an exploratory case study. The findings indicate an overall strategic fit of the case laboratory's planning environment, but a lack of strategic fit between large batch sizes and low set-up times. Hospital laboratory planning environment research must be further developed through multiple case studies, as hospital laboratories are different in service provision and organizational structure. This study increases knowledge on planning environments in hospital laboratories, and suggests topics for future research.

Keywords: Planning Environment, Service Operations, Hospital Laboratories.

1 Introduction

Test results from hospital laboratories are a vital support for physicians in decision making regarding a patient's health. Thus, hospital laboratory throughput time, also called turnaround time, is crucial to prevent delays in patient treatment [1]. With continuously increasing demand and limited budgets, hospital laboratories are facing a challenging future. They need to improve utilization of existing resources, while at the same time reduce work-in-progress and shorten throughput times. An appropriate planning and control system can support these objectives, but it requires the planning and control system to be aligned with the characteristics of the planning environment [2]. A lack of such a strategic fit will negatively affect performance [2].

Planning environments are company-specific, and its characterizing variables are typically related to the product, market and manufacturing of the specific company [3-5]. Most research related to planning environment and strategic fit takes a manufacturing point-of-view. Planning environment research in hospital laboratories, however, is

scarce. The aim of the study is, therefore, to characterize the planning environment of a hospital laboratory, which provides a starting point for the generation of knowledge on how to plan and control hospital laboratories.

A single and exploratory case study of a hospital laboratory department at a Scandinavian hospital was performed to achieve an in-depth understanding of its planning environment. The control model methodology has been used as a systematic approach to visualize and analyze the hospital laboratory's current production and logistics system [6]. Furthermore, Buer et al. [5] compiled existing manufacturing planning environment research into a framework for mapping planning environments, which has been used in this study to map the planning environment of the hospital laboratory.

The paper has the following structure. In section 2, relevant literature on planning environments is reviewed and common hospital laboratory planning and control challenges are introduced. In section 3, the hospital laboratory is described by the control model methodology and Buer et al. [5]'s planning environment mapping framework. The planning environment's strategic fit and its planning and control challenges is discussed in Section 4. The paper ends with suggestions for future research in Section 5.

2 Planning environments

Numerous authors have investigated manufacturing planning environment variables and categorizations. Hayes and Wheelwright [3] developed the product-process matrix, which is probably one of the most recognized frameworks for choosing manufacturing processes based on product and market characteristics. Manufacturing planning environment research is often based on the customer order decoupling point (CODP). E.g., Jonsson and Mattsson [4]'s four generic planning environments categorizations and Stavrulaki and Davis [7]'s further development of the product-process matrix, were based on the well-known CODPs: engineer to order (ETO), make to order (MTO), assemble to order (ATO) and make to stock (MTS).

Buer et al. [5] identified 30 planning environment variables from relevant literature and developed a framework for mapping planning environments in manufacturing companies. In the framework, the variables are grouped into three categories: product, market and manufacturing. Ranges of values are defined to each variable, which are sorted based on the CODPs. The framework reveals the company profiling, which can be used to assess the strategic fit of the product, market and manufacturing variables, where a lack of strategic fit provides the basis to evaluate planning and control related changes.

The different functions in healthcare systems, such as hospital laboratories, provide various healthcare services. To the best of our knowledge, there exists no planning environment framework from a service operations-perspective, such as Buer et al. [5]. However, Wikner et al. [8] introduced two additional service operations decoupling points. The customer adaptation decoupling point (CADP) marks where the service is adapted to a specific customer. The customer contact decoupling point (CCDP) refers to the type of customer contact, either front-office, back-office or a combination.

Nguyen et al. [9] mapped the planning environment of three outpatient departments in Danish hospitals, revealing large differences in patient requirements, patient flow

and resource availability. While hospital laboratories have no patient contact, they are, like outpatient departments, highly different in service provision and organizational structure. Laboratories can be centralized with the ability to analyze all incoming samples, or decentralized where each unit is responsible for a specific analysis field [1]. E.g., microbiological laboratories identify microscopic organisms in biological samples, whereas pharmacological laboratories detect the share of drugs and medicine.

Several planning and control challenges are present in hospital laboratories. An unbalanced workload is common due to the unpredictable nature of accidents and illnesses, which makes it challenging to balance demand and supply [10]. Batch-based processing is also common in hospital laboratories, due to large material costs, among other. Large batches often cause prolonged processing times, and may lead to a specific operation only being performed once a day. Thus, samples coming in after the operation has been run, would have to wait until the next day to be processed [11]. In addition, machine-based operations with long durations are often being run during the night, which causes a one-day delay for all test results [12].

3 Case study

The case study involves a pharmacological laboratory department at a large Scandinavian hospital, offering analyses of the share of drugs, medicine and other substances in biological samples, such as blood and urine. Emergency preparedness around the clock for samples requiring immediate analysis is also offered, but is usually a negligible disruption due to its low occurrence. The product, market and customers of the case laboratory are described in section 3.1. The production processes and logistics are described in section 3.2, and visualized as an AS-IS control model in Fig. 1.

3.1 Product, markets and customers

The case laboratory delivers test results, which contains verified and interpreted information from the analysis of the biological sample. Test results are often used to detect drug and alcohol misuse, or to assess the effect of a medicine in patient treatment. The laboratory is able to analyze almost 300 substances. Several substances can be analyzed by one analysis method, and will be further described in section 3.2.

Approximately 200 000 biological samples are delivered to the case laboratory on a yearly basis. More than 40% of the demand concerns drug analysis, which is usually performed in urine samples because of its longer drug tracking time, compared to blood samples. Analysis of Vitamin D and medicine make up approximately 25% and 20% of the demand, respectively. These analyses are usually done in blood and serum samples for higher accuracies of substance share. The remaining 15% of demand concern many specialized and low demand substances, including forensic examinations with higher requirements to quality and traceability.

Seasonal variations are observed, such as an increase in demand in advance of public holidays. In addition, weekly variations in incoming samples are common due to the postal service operating from Monday to Friday. This results in least incoming samples

on Monday and most incoming samples on Tuesday. However, the seasonal and weekly variations do not impose a need for extra capacity.

The customers are the health professionals requesting the analysis of one or several substances, and supplying the biological sample. The patient, on the other hand, is both the end customer and the provider of this raw material. There are three main customer types: health professionals from the hospital itself, local healthcare institutions and regional healthcare institutions. They are differentiated by geographical distance, sample transportation mean and ordering system, and will be further described in section 3.2.

3.2 Production and logistics

The production and logistics activities are visualized in Fig. 1, and are further described. Hospital orderlies collect and deliver samples from the hospital and local healthcare institutions twice a day. Samples from regional healthcare institutions are delivered daily by mail due to the geographical distance, which prolongs delivery time with 1-3 days. In the receive process, samples are coupled with the corresponding order. It defines the case laboratory's CODP, best characterized as ATO as chemicals are ready-mixed, but the analysis is postponed until a sample with an order is in place. Paper-based orders from local and regional healthcare institutions are delivered with the samples, and are manually registered into the laboratory information system (LIS). Electronic orders from the hospital and a few local healthcare institutions are collected from the shared information system (XIS). Samples coming from the hospital are ready-registered, while other samples are manually registered into LIS. Adaptations to customer orders happen already in the registration process and presents the CADP.

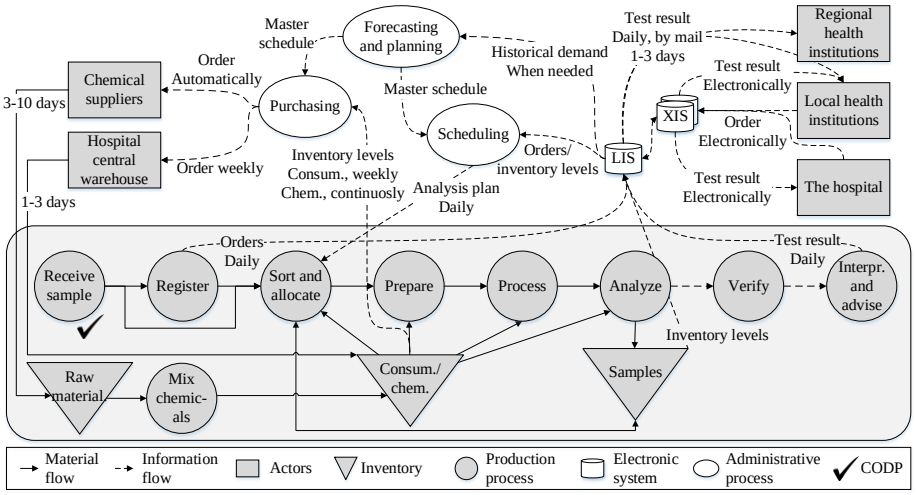

Fig. 1. AS-IS control model of the hospital laboratory department

Both new arrivals and stored samples are sorted and allocated into racks specifying the analysis method, which is decided by the analysis plan. Samples not being processed on the day of arrival are placed in inventory. There are strict storage requirements due

to the limited sample shelf life. E.g., some samples need to be frozen to prevent the substance from evaporating. Thereafter, the samples are prepared, entailing small operations, such as moving the biological material into the correct tube when delivered in the wrong tube, dividing the biological material into several tubes when several analysis methods are required, and centrifuging blood into serum. The samples are then processed into analyzable tests, entailing pipetting, evaporation, dissolving, adding chemicals, heat-treating, or a combination, specified by the analysis method. Processing takes place in various manual-labored workstations, and semi-automated machines and robots, which require manual sample transportation as well as manual machine refill.

The analyzable tests are pipetted onto plates and placed into the analysis machines. The samples are stored for a given period in case there is a need to redo the analysis. The analysis machines are programmed based on the analysis plan at the end of the workday. It takes 5 minutes to analyze a single sample, and the analysis time increases correspondingly with the batch size. The next morning, the analysis machines are emptied and cleaned. Bioengineers verify the analysis by checking if the test results are within the reference values. A doctor is responsible for interpreting the results, and can also give advices regarding adjustments to or change of medicine. Then, the test result is sent to the customer, either electronically through XIS, or paper-based by mail. The CCDP constitute a mix of front-office activities, e.g., test result reporting and consultation, and back-office activities, e.g. procuring materials and preparing for analysis.

The customers place call-off orders based on the cyclic master schedule, which states the analysis methods to be run on a given day. This schedule is based on factors such as historical demand, test result urgency and samples' shelf lives. Around 60 analysis methods are run on a regular basis. Low demand and medium demand analyses are run twice a month and twice a week, respectively, in batches of 10 to 20 samples, and high demand analyses are run daily in 2-3 batches of 100 samples. The workday starts with making a daily analysis plan stating the final schedule of analysis methods. Analyses should be performed to schedule, as test results are used in patient treatment. Yet, for cost reduction reasons, postponement is considered when the batch size requirement for running the analysis is not met, given that the samples' shelf lives allow for it. Analyses can also be run earlier than scheduled if the batch size requirement is met, or if there is a need for a faster delivery of the test result.

Inventory levels of consumables and equipment are manually checked once a week. The order frequency is controlled by a reorder point and order-up-to system, given the demand, delivery lead-time and storage capacity of each item. Consumables and equipment constitute 50% of the total material supply, delivered from the hospital's central warehouse with a lead-time of 1-3 days. Chemicals constitute the other half of material supply, and are controlled by an automatic stock replenishment system tracking the actual usage of each chemical. Chemicals are delivered from chemical suppliers all over the world, with a lead-time of 3-10 days. High consumption materials have deliveries weekly, e.g. disposable gloves, pipettes and certain gas types. Materials with a very low consumption, such as machine parts can be ordered as seldom as every second year.

The summary of the product, market and manufacturing variables of the case laboratory's planning environment is provided in Table 1. The planning environment is characterized based on Buer et al. [5]'s mapping framework for manufacturing companies.

Table 1. The planning environment of the pharmacological laboratory department

	Variables	Values			
Product	CODP	ETO	MTO	**ATO**	MTS
	Level of customization	Fully customer specific	**Allows some specifications**		None
	Product variety	High	**Medium**		Low
	BOM complexity	<5 levels	3-5 levels	1-2 levels, several items	**1-2 levels, few items**
	Data accuracy	Low	Medium		**High**
	Level of process planning	None	Partial process planning		**Fully designed process**
Market	P/D ratio	<1	1		**>1**
	Demand type	Customer order allocation	Calculated requirements		**Forecast**
	Demand source	Customer order		**Stock replenishment order**	
	Volume/frequency (per year)	Few large customer orders	Several customer orders with large quantities	Large number of customer orders with medium quantities	**Frequent call-offs based on delivery schedules**
	Customer demand frequency	Unique	Block-wise or sporadic	**Regular**	Steady (continuous)
	Time distributed demand	**Annual figure**		Time distributed	
	Demand characteristics	Dependent		**Independent**	
	Type of procurement ordering	Order by order procurement		**Order releases from a delivery agreement**	
	Inventory accur.	Low	Medium		**High**
Manufacturing	Mfg. mix	Mixed products		**Homogenous products**	
	Shop floor layout	Fixed-position	**Functional**	**Cell**	Product
	Production type	Single unit production	**Small series**	**Serial production**	Mass production
	Throughput time	Years	Months	**Weeks**	**Days**	Hours
	Major operations	High	Medium		**Low**
	Batch size	Equal to customer order quantities	**Small, equal to one week of demand**	**Medium, equal to a few weeks of demand**	Large, equal to a month's demand or more
	Production order repetition freq.	Non-repetitive production	Production with infrequent repetition		**Production with frequent repetition**
	Fluctuations of capacity req.	High	Medium		**Low**
	Planning points	High	**Medium**		Low
	Set-up times	**Low**	Medium		High
	Sequencing dependency	None	**Low**	Medium	High
	Part flow	One-piece flow	Overlapped	Lot-wise	**Bulk (batch)**
	Material flow complexity	High	**Medium**		Low
	Capacity flex.	**High**	Medium		Low
	Load flexibility	High	**Medium**		Low

4 Discussion

The planning environment of companies often falls rather homogeneously within one of the four CODPs, which indicates a strategic fit between product, market, and manufacturing variables [5]. The case laboratory resembles manufacturing companies, with functional entities performing specific tasks that combined make up the final product. Its planning environment has many values within ATO, the case laboratory's CODP, and MTS (see Table 1), indicating an overall strategic fit. However, some variables deviate as well, which can have a negative effect on performance [1]. E.g., low set-up times and high capacity flexibility are usually associated with ETO or MTO companies.

The case study is in agreement with the literature inasmuch as unpredictable demand and unbalanced workload present hospital laboratory-related planning and control challenges. The case study further points out large varieties of both incoming raw materials and analysis methods, as well as limited sample shelf lives. However, a mismatch is identified between the case study's batch sizes and batch-based part flow on one hand, and low set-up times and high capacity flexibility on the other hand (see Table 1). Large batch sizes give longer processing times, which is especially true for the analysis process in the case study. A single sample takes 5 minutes to analyze, whereas a batch of 100 samples will correspondingly take more than 8 hours to analyze. Nighttime analysis itself delays the test result delivery with one day [12].

According to a recent study of a hospital laboratory, reducing nighttime analysis, balancing the workload, and increasing the number of batches can result in a 20% reduction of throughput time [12]. It is also found that increasing the frequency of operations, even from once to twice a day, can largely reduce throughput times [11]. The case laboratory runs large batch sizes due to high fixed batch-related costs, such as expensive materials. However, the low set-up times should make it possible to reduce the batch sizes, as well as increase the number of batches and analysis frequency. It will result in a more balanced workload, and have a large impact on the case laboratory's throughput time and performance.

5 Conclusion

Planning and control can improve resource utilization, reduce work-in-progress and shorten throughput times in hospital laboratories, but it is important to have a strategic fit with the planning environment. Existing research on hospital laboratory planning environment is scarce, and there exists no known service operations framework for mapping planning environments. Therefore, this study characterized a hospital laboratory's planning environment with a mapping framework for manufacturing companies. The findings indicate an overall strategic fit of the case laboratory's planning environment, but a lack of strategic fit between large batch sizes and low set-up times. The low set-up times present an improvement possibility inasmuch as they allow processing in small batches.

A limitation of this study is the use of a single case, which makes it difficult to generalize the findings to other hospital laboratory types. We suggest executing multiple

case studies to compare planning environments of different hospital laboratory types. This study also revealed a lack of a framework for mapping planning environments in service operations, which also presents a future research topic.

Acknowledgements. This research received funding from the strategic research area NTNU Health in 2020 at NTNU, Norwegian University of Science and Technology. We also want to acknowledge the case hospital laboratory taking part in this study.

References

1. Dolci, A., Giavarina, D., Pasqualetti, S., Szóke, D., and Panteghini, M., Total laboratory automation: Do stat tests still matter? Clinical Biochemistry 50, 605-611 (2017).
2. Berry, W.L. and Hill, T., Linking systems to strategy. International Journal of Operations & Production Management 12(10), 3-15 (1992).
3. Hayes, R.H. and Wheelwright, S.C., Restoring our Competitive Edge: Competing Through Manufacturing. Wiley, New York (1984).
4. Jonsson, P. and Mattsson, S.-A., The implications of fit between planning environments and manufacturing planning and control methods. International Journal of Operations & Production Management 23(8), 872-900 (2003).
5. Buer, S.-V., Strandhagen, J.W., Strandhagen, J.O., and Alfnes, E., Strategic Fit of Planning Environments: Towards an Integrated Framework. in International Conference on Information Systems, Logistics and Supply Chain. Springer, (2016).
6. Strandhagen, J.O. and Skarlo, T., A Manufacturing Business Process Reengineering Method: Design and Redesign of a Production Control Model, in Re-engineering the Enterprise. Springer, Boston, USA, 187-198 (1995).
7. Stavrulaki, E. and Davis, M., Aligning products with supply chain processes and strategy. The International Journal of Logistics Management (2010).
8. Wikner, J., Yang, B., Yang, Y., and Williams, S.J., Decoupling thinking in service operations: a case in healthcare delivery system design. Production Planning & Control 28(5), 387-397 (2017).
9. Nguyen, V.T., Sommer, A.F., Steger-Jensen, K., and Hvolby, H.H., Hospital Planning Environment Variables Applied in Practice: A Multiple Danish Case Study. in IFIP International Conference on Advances in Production Management Systems. Ajaccio, France: Springer, (2014).
10. Leeftink, A.G., Boucherie, R.J., Hans, E.W., Verdaasdonk, M.A.M., Vliegen, I.M.H., and Van Diest, P.J., Predicting turnaround time reductions of the diagnostic track in the histopathology laboratory using mathematical modelling. Journal of Clinical Pathology 69(9), 793-800 (2016).
11. Hewer, E., Hammer, C., Fricke-Vetsch, D., Baumann, C., Perren, A., and Schmitt, A.M., Implementation of a 'lean'cytopathology service: towards routine same-day reporting. Journal of Clinical Pathology 71(5), 395-401 (2018).
12. Leeftink, A.G., Boucherie, R.J., Hans, E.W., Verdaasdonk, M.A.M., Vliegen, I.M.H., and van Diest, P.J., Batch scheduling in the histopathology laboratory. Flexible Services and Manufacturing Journal 30, 171-197 (2018).