IMPROVED DENTAL SERVICES WITH PROCESS MODELLING

Research full-length paper

Track N°12

Halonen, Raija, University of Oulu, Oulu, Finland, raija.halonen@oulu.fi

Martikainen, Olli, Service Innovation Research Institute, Helsinki, Finland, olli.martikainen@pfu.fi

Räsänen, Sari, Minutor Oy, Tampere, Finland, sari.rasanen@minutor.fi

Uusi-Pietilä, Mika, Minutor Oy, Tampere, Finland, mika.uusi-pietila@minutor.fi

Abstract

This paper presents empirical attestations regarding improving service processes in dental health care. The trigger for the study was the need to improve information use in the case organisation. The existing process and its possible improvements were modelled, and mathematical analysis software was used to calculate the improvement in productivity. The project of building the modelling and analysis software took more than 10 years from the service provider, and several development versions of the software were built and various software engineering problems had to be solved before the current solutions were obtained.

This paper reveals also challenges in the case. It confirms that service process improvements can be implemented systematically in co-operation with consultants and the health care personnel. Empirical data was collected via observations and interviews, and automatic data collection was also utilized. Both the personnel and customers were included in the data collection. The first analysis showed that the existing resources were close to optimal. The case verifies that when resources and costs are kept constant in the service, the improvements represent examples of total factor productivity growth. Overall, the case reveals an example of a successful productivity improvement based on available information and a new way of working.

Keywords: Data collection, Business process improvement, Dental care process, Healthcare process, Multimethod approach.

1 Introduction

The purpose of the paper was to analyse how to apply process modelling, when healthcare organisations want to improve their service processes with the help of information systems. Business process management and further business process improvement are discussed in several studies (see e.g. van der Aalst, 2013; Partington et al., 2015). However, most studies are artificial, and final evaluation and measurement remain unfinished. Moreover, after the estimated or recommended improvements have been implemented, the organisations have no longer been interested in evaluating whether the solutions were productive or not.

Business process improvement is particularly an issue in the service sector, as the share of services is growing in the Western countries. For example, in Finland the share of services is nowadays over 70% of the gross domestic product, as noted by the World Bank. Many service improvements can be considered as cases with total factor productivity growth, which has been reported as the major source of productivity already by Solow (1957). In practice, this means that new ways of working are needed.

In this current case, an empirical study to carry out one process improvement was realized, when a dental clinic (YoungTeeth) wanted to improve its services. The problem of YoungTeeth was that in the dental services offered to the customers there was almost 10% of no-show in customer arrivals. The employees had recognised, that their business process was not as productive as it could have been based on their expertise and professional experience. YoungTeeth also wanted concrete models for a new process, called multi-room dental service, that could be implemented in new facilities.

A service consultant (called BestPro in this paper) was hired, and it used a partner (called MathModeler in this paper). BestPro is a private company, which works with customers who want to improve their services. MathModeler is a company, which develops measurement techniques and analytic modelling tools for service productivity improvement.

At YoungTeeth, the patients were children and adolescents (aged 8–17), and the personnel consisted of dentists, dental hygienists, dental nurses, and receptionists. The improvement project was startedby analysing the proposed new processes and the existing process, and it was continued by seeking potential ways to enhance the process. Finally , the new process was implemented, analysed, and evaluated.

Productivity has been in the focus of work improvement since the 1920s, and huge developments have taken place , from refined work practices and punch cards to the LEAN and Six Sigma approaches (Furterer, 2014). Ten years ago, Botta-Genoulaz and Millet pointed out the challenges in integrating functions in a service context. These included the differing importance of material flows and labour acts in manufacturing and service companies. Today, the main concern of companies is to reduce costs by making processes to be more efficient. (Botta-Genoulaz and Millet, 2006.)

There is pressure to improve functions in the healthcare sector, and its challenges have now been studied for decades (Wolff and Harmon, 2014; Rohleder et al., 2011). It is known, that in the healthcare sector the variety of tasks is broad and the symptoms of issues of importance arise for several reasons (Bose, 2003). In healthcare several professions work in teams, but the research on multi-professional teams is relatively new (Halonen et al., 2011). Furthermore, the public sector has not recognized improvements enabled by services as a source of productivity (Martikainen et al., 2011).

In this study, we wanted to identify the challenges experienced by a service provider, when improving service processes in healthcare, specifically in dental care. Our approach was empirical and multi-methodical. We analysed the actions taken during a development project, which was based on innovations developed over more than 10 years.

The paper also describes the various problems and solutions that finally led to the process improvement and enabled its evaluation in the case environment. Special emphasis is put on the evaluation and measurement, which are often not given further attention in the research.

2 Earlier Knowledge

The role of information systems as accelerators in improving healthcare services has already been recognised for several years now (Juntunen and Halonen, 2012). Likewise, the role of services in the economy has been growing for many decades, and new innovations are needed to enable new services and solutions that can be utilized by customers, and in order to add value for service providers (Chesborough and Spohrer, 2006). On the other hand, Mucheleka and Halonen (2015) questioned if the potential of improved healthcare services and lower costs caused by innovations in using available information, has received enough interest in the information systems research so far. As an example, a Japanese study used wearable sensors in order to provide correct and trustworthy information to improve service processes. The study verified that the efficiency of services can be improved when there is reliable information about the routines and processes (Fukuhara et al., 2014).

Improvements in business productivity and services can be carried out without extensive changes in the use of technology. Rather, the focus should be put on organisational changes, as detailed in a study of work life improvement (Cumming et al., 2013). However, without committed organisational support the proposed processes are at risk of being dismissed despite their cost-effective nature (Halonen et al., 2014).

Landesman et al. (2010) introduced an electronic solution that enables efficient reporting, and they pointed out its safety and reliability benefits that lead to business process improvement. In the early 2000s, Reijers and Mansar (2005) analysed best practices in business process redesign using heuristic rules. They emphasised the mechanics of the processes under study, instead of behavioural or change management issues. In the analysis, a potential model for an evaluation framework consisting of four dimensions (cost, flexibility, quality, and time) was presented. However, Reijers and Mansar (2005) did not apply it themselves, but reported other researchers' work. Based on their overview, they proposed further studies to be conducted in order to determine best practices that would provide the desired results in terms of cost and time reduction or quality and flexibility improvement.

Based on the findings of three separate evaluations, Radnor (2011) suggested that the main factors in successful business process improvements include understanding the process and system views, the customer view, and the data and engaging the staff. Radnor (2011) analysed LEAN implementation in the study and concludes that one should also consider infrastructure and behavioral and cultural elements in improvement efforts. Likewise, Pourshahid et al. (2012) highlighted different aspects to be considered when seeking ways to improve business processes. They introduce a framework with several aspects, such as monitoring the process under improvement. In particular, they list processes, business goals, performance models (key performance indicators or KPIs), constraints, and even redesign patterns (for process improvement) to provide a more comprehensive framework.

A lot has happened since business improvement in healthcare was based on controlling the work hours of employees (Landesman et al., 2010). Business processes in healthcare are described as highly dynamic, complex, multi-disciplinary, and ad-hoc in nature, and they should be improved in terms of cost, time, quality, and flexibility (Wood and de Menezes, 2011; Rebuge and Ferreira, 2012). However, despite the popularity of research on business processes in healthcare, the focus has mainly been on solving a particular problem related to health and analysing event logs with the help of process mining (Mans, Schonenberg, Song, van der Aalst and Bakker, 2008) rather than on process improvement in general (see Blum et al., 2008).

Petersen et al. (2010) presented a modelling exercise to enable an information system implementation in healthcare. They list five steps to create a functional model: 1) preparation for data collection and workshops, 2) conducting workshops, 3) synthesising data from the workshops, 4) creating a preliminary model and presenting it in a follow-up workshop, and 5) refining the model. Step 3 is divided into three parts: a description of how things are originally done, ideas about how healthcare professionals would like things to happen in the future, and some of the challenges faced by healthcare professionals with the original practice.

Halonen et al. (2014) analysed two different cases from the healthcare sector with the aim of finding ways to improve service processes. Based on their study, the modelling of process improvements is crucial. Without existing applicable process models, the building of a new process from scratch requires the involvement of several experts, which is difficult, expensive, and time-consuming. In addition, the role of committed management is crucial to enable successful implementation of the new process.

To analyse business processes in healthcare, Rebuge and Ferreira (2012) proposed a methodology that consists of six tasks: the preparation of an event log, log inspection, control flow analysis, performance analysis, organisational analysis, and the transfer of the results. In the methodology, special attention is paid to techniques that can handle features in healthcare processes, including infrequent behaviour and process variants. Rebuge and Ferreira (2012) applied the sequence clustering minimum spanning tree approach in their study and believe that the proposed methodology can provide insight into healthcare processes and their performance. Furthermore, detailed insights into clinical pressures in relation to the quality of patient health and fiscal pressures in relation to hospital budgets can be gained by analysing processes (Partington et al., 2015).

So far, the research data acquired from the healthcare environment has not been truly satisfactory. For example, data from live work settings, such as gynaecological oncology (Mans et al., 2008), hospital emergency service (Rebuge and Ferreira, 2012), and laparoscopic surgery (Blum et al., 2008), has revealed that the quality of the real-time logs are often noisy or incomplete (Bose et al., 2013).

3 The Research Method

The development project originated with the understanding of designing and evaluating service process improvements (see Martikainen and Halonen, 2011), and comparing these improvements to the original service processes. This was facilitated by MathModeler. This led to solving several software engineering problems. The work took more than 10 years, as the first modelling tools originated in 2006 and the latest results were from 2016.

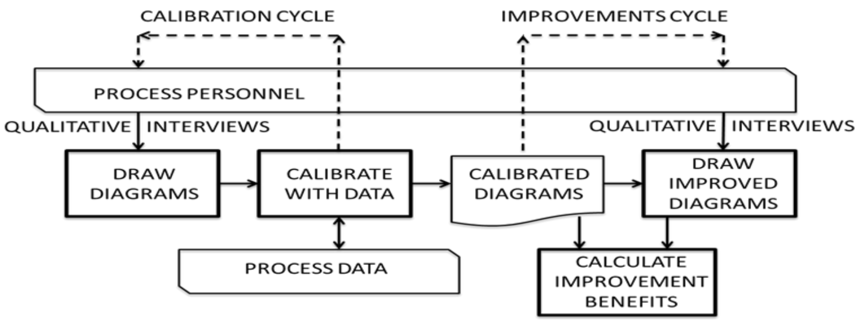

Figure 1. The four analysis steps of MAT to evaluate service benefits.

The main tool, the Modelling and Analysis Toolset (MAT), uses a multi-method approach and requires several different views of the target. MAT analyses work process changes with respect to 1) logical process diagrams, 2) performance, and 3) cost.

The benefits of the process changes are expressed as relative performance improvement and cost improvements compared to the original process model.

The evaluation of the process changes consists of four steps (Fig. 1): draw original diagrams corresponding to the original process model, calibrate the model with data, draw improved diagrams corresponding to model changes, and calculate improvement benefits from the changed models. The steps are explained in the next paragraphs.

3.1 Draw Diagrams

The first step is to draw logical process diagrams to describe the workflow in phases. This is done together with the employees using semi-structured interviews with the aim of producing a cognitive description of the work processes. Several descriptive models and graphical editors are available for documenting this step. The process model can be formally expressed as a tuple of process diagram elements (see Formula 1).

3.2 Calibrate the Model

The second step is the analysis of the process performance (Formula 2) and costs (Formula 3). The variables used in MAT are activities or tasks (A_i), related resources (R_k), groups of resources: teams and serving in activities, customers (E) served, customer arrival intensities (λ_i) in the system, routing probabilities (ρ_{ij}) of customers between activities, service times in activities (T_i), population sizes (N_i), and costs of resources (C_{RK}).

Formulas (1), (2), and (3) define their interrelations.

$$M = (A_i, E_p, \pi_{\iota\varphi}, T_{pi}, S_{mi}, R_{km}, C_{Rk}, C_{Aj}) \quad (1)$$

$$(\rho_\iota, \rho_{\kappa\iota}, \rho_{\mu\iota}, W_i, N_p, N_i, N_{pi}, X_{mi}) = G(\lambda_{\pi\iota}, R_k, M) \text{ and } R_k \geq \Sigma_{mi} R_{km} X_{mi} \quad (2)$$

$$(C_F, C_V) = F(\rho_i, \rho_{ki}, W_i, M) \quad (3)$$

The performance-related output variables are calculated from input variables using an extended queuing network solution for model M denoted by G and the cost analysis solution using a function denoted by F. The extended queuing network solution is based on optimal fractional allocations of resources to the teams (Naumov and Martikainen, 2011). This extended solution G provides the maximum throughput of the system (Denning, 2009). Table 1 lists the input variables, and Table 2 lists the output variables in the case of an open queuing network.

Input variables		***Output variables***	
Activities or tasks	A_i	Customer time in activity	W_i
Customer classes	E_p	Customers p in system	N_p
Routing probabilities of class p customers	π_{ij}	Customers in activity i	N_i
Service time of customers of class p in activity A_i	T_{pi}	Customers of type p in activity i	N_{pi}
Arrival intensity of customers of class p in A_i	λ_{pi}	Utilisation of activity	ρ_ι
Amount of resources of type k	R_k	Utilisation of resources of type k in activity i	$\rho_{\kappa\iota}$
Service rate of team m in activity i	S_m	Utilisation of team m in activity i	ρ_m
Amount of resources k needed in team m	R_{km}	Number of teams m allocated in activity i	X_m
Resource k cost in time	C_{Rk}	Fixed costs	C_F
Activity I other costs	CA_i	Variable costs	C_V

Table 1. Input variables and output variables.

The model M includes the process components and the variables of the calibrated diagrams. The function G is the extended solution of the queuing network representing the process or processes involved. Usually, G is an algorithm that cannot be given in a closed form. The function F simply calculates the costs based on the resource utilisations and customer delays that are obtained from G. In Table 1, the variables are given in the case where the model M is an open queuing network.

The performance analysis consists of solving the function G for the model M and the variables □pi and R_{km} in Formula (2). The resources, such as employees and equipment, are classified as resource types R_k and assigned in teams R_k to the activities they are capable of completing. Based on the teams, the optimal resource distribution over the activities with the boundary condition $R_k \geq \Sigma_{mi} R_{km}X_{mi}$ of Formula (2) can be calculated, and we denote this optimal solution as G. The calculation reveals, for example, the optimal allocation of resources to teams that can be assigned the activities. The resource distribution of the original and improved process models can now be compared and the improvements in resource utilisation levels analysed. The joint use of resources specified for the teams and the optimisation algorithm included enables the analysis of externalities caused by resource sharing. For instance, an improvement in one process releases resources that can be moved to other processes in the organisation.

In the cost analysis, the fixed costs (C_F) in the processes are related to the costs of the fixed resources and to the fixed quality costs and fixed risk costs. The variable costs (C_V) of the processes are related to the product of the utilisation, the cost per time unit of the variable resources involved, as well as to the waiting costs, quality costs, and risk costs that depend on the load of the system. In Formula 3 and in the corresponding input variables, we have left out explicit quality and waiting costs for the sake of simplicity. The cost function F divided by the number of service transactions and calculated as a function of load represents the average variable cost curve generated by the production function of the system.

When the processes are analysed using model M and functions G and F, the modelling results can be calibrated using the process performance data of the real process. The calibration means the comparison of existing real process performance statistics to the corresponding results given by the analysis tools. If the calibration does not succeed, iterative interviews are needed to correct the process diagrams and their variables. This results in better insight regarding the process behaviour. In some cases, experimenting with the process variables, such as “incorrect delays” or possible “hidden work times”, is necessary to reveal and correct the factors that prevent successful calibration. This is the calibration cycle (Fig. 1). Only after successful calibration can the possible process changes be modelled and their effects analysed.

3.3 Draw Improved Diagrams

After the original calibrated process diagrams have been created, new process diagrams taking into account the process changes can be sketched. The improved diagrams are drawn as before using qualitative interviews where the possible improvements are analysed. This procedure is called the improvements cycle (Fig. 1). Let us denote two possible improved models of M as M1 and M2.

3.4 Calculate Model Change Benefits

Before comparing the original and improved models, the function G must be solved for each of the models. If resources in teams are used, then the optimal function G can be obtained for the models. Let us denote the resulting variables of the solution $G(\lambda_{pi0}, R_k, M)$ of Formula (2) using the following notation: $\lambda_{pi} = \underline{G}(\lambda_{pi0}, R_k, M)(\lambda_{pi})$.

The service level obtained by a customer class p in model M can be expressed as the throughput □pi for some activity i. The service level or throughput improvement of model M1 compared to model M can be calculated from (4):

$$\Delta\lambda_{pi} = \underline{G}(\lambda_{pi0}, R_k, M_1)(\lambda_{pi}) - \underline{G}(\lambda_{pi0}, R_k, M)(\lambda_{pi}). \quad (4)$$

We obtain the resource improvements $\Delta R_k = R_k - \underline{R}_k$ related to a constant service level λ_{pi} from (5):

$$\underline{G}(\lambda_i, R_k, M)(\lambda_{pi}) = \underline{G}(\lambda_i, \underline{R}_k, M_1)(\lambda_{pi}). \quad (5)$$

The utilisation improvement of resources in activity i related to a constant service level λ_{pi} can be calculated from (6):

$$\Delta\rho_i = \underline{G}\ (\lambda_{pi0}, R_k, M_1)\ (\rho_i) - \underline{G}\ (\lambda_{pi0}, R_k, M)(\rho_i). \qquad (6)$$

Similar formulas can be written for other variable improvements by keeping some reference variables as constants. The development of MAT has changed over the past years in terms of its logic, programming tools, and equipment. The current version of MAT provides realistic and verifiable results and was being used in the current case of YoungTeeth.

4 The Case Problem

To carry out its dental service improvement YoungTeeth chose BestPro to be its partner. In addition to BestPro and its partner MathModeler, researchers were involved in the improvement project, that was established to carry out the actions. The improvement project consisted of five main steps:

1) Modelling the existing service process and its possible improvements. Data gathering was supported by automatic measurement.

2) The conversion of the process models to the MAT tool.

3) Analysis of the possible process improvements by MAT.

4) The expression of the analysis results in an applicable format (Excel charts).

5) Choosing of the improvement action and its implementation. The process improvement was also verified by automatic measurement.

All the steps required several sub-tasks that included, for example, designing and building interfaces, converting data, solving mathematical problems, heavy calculation, and developing wireless process measurement.

According to the steps, the first challenge was to describe the existing process, which was to be improved. In this step, several modelling approaches were developed and tested; textual model input (FORTRAN 2007), forms to be filled in as input (Java 2009), graphical model input (Java, boxes and arrows drawn, 2010), and Excel were used as industrial standards for model input (2013), of which Excel appeared as most successful. The Excel models were of standard format and they were easy to be distributed between researchers and to be stored in a model database. This development task was carried out by MathModeler.

The second step was converting the new developed process models into the analysis tool MAT. The purpose of MAT was to calculate the benefits of the new process models compared to the original process model. The output of step one was converted to a textual model to be used as input for the mathematical analysis. The conversion was done using the implementation language in each case and the Visual Basic macros included in the Excel models. In Excel, the data analysis for calculation was included in macros with a graphical button.

The third step was the execution of the analysis by MAT. This in practice included novel mathematical features because the calculations had to be performed between the original and improved models. The development of new mathematical algorithms was also a challenging task. The development of the mathematical analysis software took place in 2003–2013. The long time period resulted from the complexity of the model development. In implementing the algorithms, FORTRAN and C++ software were used, and the conversion between the languages needed much more work than expected in the beginning.

The purpose of the fourth step was to show the results of the analysis in a format that is easy to understand by the researchers, who needed the results in their work. In practice, they wanted to use PowerPoint when reporting their findings. Therefore, the analysis reports were offered as CSV (Comma-separated Values) files that can be easily embedded into MS Excel and used in graphical charts for the PowerPoint reports.

The last step was to provide a solution that would automatically gather the process data. A wireless process measurement tool with radio beacons and mobile phones as data collectors was designed and developed in 2009–2014 to automate the data collection. Several prototypes were developed over the years, first to function on laptops, then to work on tablets, and finally to work on smart phones. Moreover, several patent applications were filed for this measurement data modelling and collection.

5 The Implementation

First, the original model is described. In Finland, both children and adolescents usually come to a hygienist who performs an oral health check. If the hygienist discovers tooth decay or some other health issue that necessitates diagnostics and treatment, the hygienist guides the patient to a dentist's practice. The patient needs to visit the dentist twice in order to obtain an understanding of the overall status of the his or her oral health. This has also been the practice at YoungTeeth.

Figure 2 shows the usual service process for the dental care of children and adolescents. The process step "Wait" means the time the patient needs to wait at reception (the queue), "Loss" means the number of patients who do not show up at reception ("no show"), "Recall" means the calling system, "hygcheck" means the oral health check performed by a hygienist, and "dentist" means the diagnosis made by a dentist.

The original model was compared to the MAT model using the received statistics. Because the statistics were heterogenic, the MAT results served to provide guidance only.

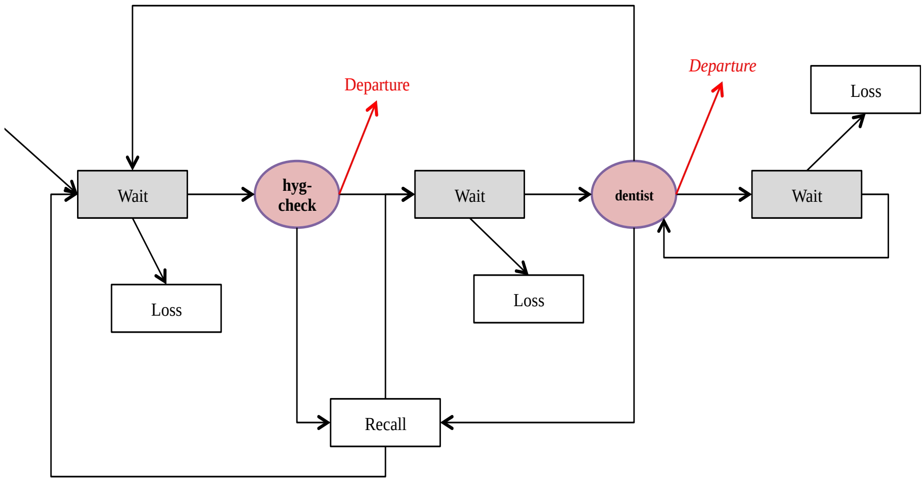

Figure 2. The original service model.

In addition, as it was noticed that the existing dental care software and statistics systems are not able to produce values for the process calculations, the numeric data was collected manually and in subsequent cases in an automatic manner.

Next, the first calculations are described. YoungTeeth had been developing different dentist practice models for the dental care of children and adolescents over the years. A work group at YoungTeeth proposed a multi-room dental service model to be implemented in new clinics and facilities. In principle, in this multi-room dental service model dental hygienists consult dentists if special expertise is needed. Thus, depending on the specific situation, either the hygienist or the dentist defines the diagnosis and creates the treatment plan for the patient. The general idea of this multi-room dental service is that the patients get an oral health diagnosis and treatment plan by the dentist during one visit to the clinic instead of two visits, which has so far been the common procedure at dental clinics. The hypothetical proposed service model was converted to the mathematical process that was used as a basis for the MAT method.

As illustrated in Figure 3, the model consisted of six process steps: Hygcheckmap, Dentist1, Xray, Dentist2, Specialist, and Care.

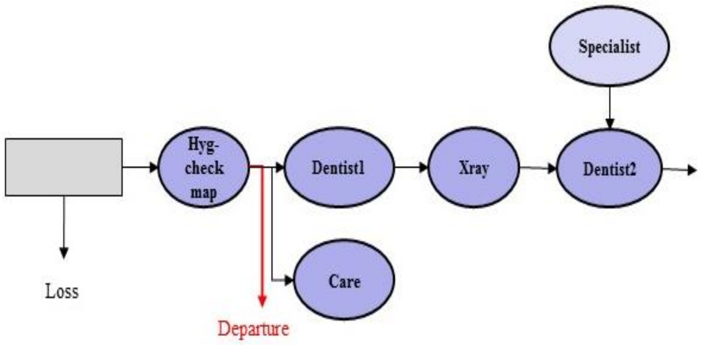

Figure 3. The proposed model.

First, after a customer has arrived at the reception, she then proceeds to have an oral health check by a dental hygienist with the help of a dental assistant (Hygcheckmap). If no further action is needed, the customer leaves the premises (Departure). The dentist is called for (Dentist 1) only if needed. The dentist (optionally) orders X-rays to be taken by the hygienist or the assistant (Xray). The dentist then analyses the pictures and creates a treatment plan with the help of the hygienist or the assistant (Dentist2).

At this point, the hygienist or the assistant, depending which one is free, prepares the treatment room for the next customer. If the dentist notices that the customer needs orthodontic treatment, she calls for an orthodontic specialist (Specialist). Sometimes, children do not remember to come to the dentist or their parents do not remember to cancel the appointment; this is illustrated as “Loss” in Figure 3.

If the customer does not need to consult the dentist, the dental hygienist draws up the treatment plan (Hygcheckmap). In addition, it was planned that the assistant provides group-level dental health information for customers (Care).

To determine the optimal process, different kinds of models were analysed using the MAT method, varying the amount of resources, skills of the resources, and treatment times. From these calculations it was estimated that the optimal process organisation would consist of four dental hygienists (and therefore four service rooms), one dentist, five assistants (one responsible for the health information), and one orthodontic specialist (which is needed for about 5% of the time). In this case, all the resources were evenly used and about 40–48 customers could be cared for. Similar results were obtained in the model where the dentist was able to make decisions about the need for orthodontic treatment.

These calculations showed that the model was sensitive to the amount of personnel and therefore there should be a standby system if someone fell ill. In addition, if the treatment required a longer time, the waiting times increased. The calculations also revealed that if an oral health condition was worse than average and therefore required the dentist’s attention, the delay increased. It was also noticed that this model would require new teams and working methods, and that this might be problematic.

The pilot phase was as follows. The information from the first calculations was analysed and the optimal process was decided to be piloted in a real environment. The modified model (see Fig. 4) was piloted in the spring of 2014 for 10 days. In addition to the model, the call system (how to invite children to the clinic) was tested. In this pilot, there was no reserve personnel for hygienists or assistants, and therefore it was possible to see what happened if someone fell ill. Two customer segments were separated for MAT calculations: those who did not need to consult the dentist (Hygcheck III) and those who did (Hygcheck I, Dentist and Hygcheck II). In the model, the customer arrived for the oral health check to be performed by the hygienist and the assistant (HygcheckI). The dentist was then called if needed (Dentist). After the dentist’s visit, the hygienist and assistant finished the care (HygcheckII). If the dentist was not needed, the hygienist and the assistant created a treatment plan (Hygcheck III). After the care, there was a voluntary health information session held by the assistant (Preventio). The model consisted of one dentist, four hygienists, four assistants, one assistant guiding the customers to the right rooms, and one assistant offering the voluntary health information session. The statistics and treatment times were recorded during the pilot days.

During these 10 pilot days, six different cases were identified. The cases differed from each other by the calling system, available resources, or available specialized dentist (orthodontic specialist or not).

All these models were analysed using the MAT method. The analysis showed that even though there were six different cases, still all the customers were treated during the day. The calling system or a missing hygienist did not affect the process because the team formed a system. The personnel took care of the customers and helped each other if someone was late. Thus, the practical solution showed that the customers could be called to the clinic without beforehand explicitly naming rooms and hygienists. In addition, there was no room-related pressure in terms of how many patients should be treated per day.

The analysis also revealed that empty time slots (customers, who did not show up at the clinic) acted as buffers. During the empty slots, the hygienists were working with the next patients called for the other hygienists or with a patient, who had already arrived. This also showed that the team worked as a system; they did not care how the customers were called in.

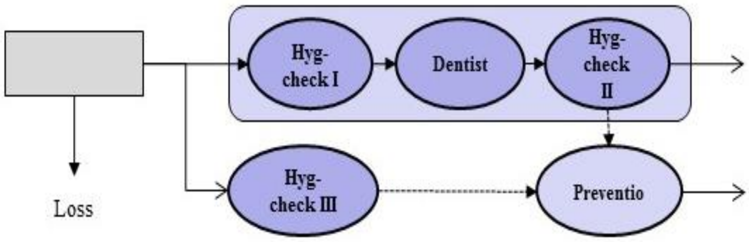

Figure 4. The pilot model.

During the pilot, customer feedback was also collected. It appeared that negative feedback was not related to the piloted process model, but to the dental care in general. The customers liked the dental service, the professional personnel, and the multi-room model. About 49% of the customers gave a rating of 9 (with ratings from 4 to 10) and 25% gave a rating of 10. The parents were happy that typically only one visit was needed instead of two, which used to be the case earlier.

In addition, the dentists' work days were monitored and measured. The results showed that the work days differed a lot at the clinic. This was due to the different work habits of the dentists and the types of customers. The average dentist's automatically measured treatment time was the same as the time measured manually. However, this part of the case will be reported in later papers.

The follow-up of the developed model was performed in the winter of 2014 at three different locations. The process was similar to the pilot except that a voluntary prevention information session was not offered. In addition, there was no assistant to guide the customers to the right rooms, as was the case in the pilot. The statistics and customer and personnel feedback were collected. The models were analysed using the MAT method (Fig. 1). The calculations showed that the workload was lower than expected when one dental hygienist was ill and there was no deputy. The calculations were made using the treatment times collected from the pilot and therefore they were only directive in nature. After the personnel feedback and the discussion with the personnel, it was recognised that the working time was used for things other than clinic work or customer-related work/taking care of the patients at the clinic. This "unproductive" work included answering the phone, guiding the customers to the right rooms (as there was no assistant to do that), learning the new model, learning to work together with colleagues and the team, and learning the routines at the clinic.

The customer feedback was again very positive; half of the customers (50%) gave a rating of 9 and 23% gave a rating of 10 (rating from 4 to 10). The customers liked the service and the new multi-room model. The negative feedback again concerned the dental care in general and the long waiting times.

This follow-up gave deeper insight of how the new model could optimally run. The MAT calculations showed where the process was not working properly and it also guided for the search for answers. In the pilot phase, the calculations indicated that the employees were working as a system, and in the follow-up the calculations showed, that the time that should have been used for customer care was spent on unproductive work. Both findings were essential information when putting the model into production.

After analysing the follow-up phase and the automatically collected data, the improvement project results were listed to be used in the future. The analysis suggested that the environment of the dental clinic should be modified to facilitate the potential productivity improvements. In addition, the work process should be discussed between the professionals, and the clinic environment should be made familiar to all personnel. Because the working pace was effective and busy, breaks and patient appointments should be scheduled. In addition to the working environment, the process improvement pointed to a need to improve other information systems as well. For example, improved logging in on separate workstations was needed to avoid waiting for a turn to update customer and dental information.

6 Discussion

The purpose of the this paper was to report how to apply process modelling when healthcare organisations want to improve their service processes. The research problem was solved by determining what kind of challenges arise when a service provider (in this case a dental clinic called YoungTeeth) decides to improve its services. In order to do this, the service provider hired a professional company (BestPro) that offered services relating to business process improvement. This company had a partner called MathModeler that by the time of the study already had significant experience in developing mathematical models and evaluations related to process improvement cases.

As reported in the literature (van der Aalst, 2013; Furterer, 2014), business process improvement has interested researchers for many years. However, most cases are reported without paying attention to the measured output (see also Mucheleka and Halonen, 2015) or to which specific improvement has been the focus, such as algorithms, procedures, or tools. The current study focused on the service process at a dental clinic (YoungTeeth), and the output was measured and evaluated using a tool developed by MathModeler.

As a response to the research problem, the multi-method approach of MAT (see Fig. 1), with all the mathematical formulas and algorithms included, appeared to reveal a functional solution for the case organisation. The proposed service process (see Fig. 3) was analysed and evaluated, and MAT revealed that the dental service process structure had to be changed, if increased productivity was sought. This is in line with Wolf and Harmon (2014), who reported on increased investing in better coordination and management of process work. On the other hand, Petersen et al. (2010) highlighted the importance of a preliminary model and how it should be refined along the improvement actions. In our case, the calculations illustrated that the optimal process would include four dental hygienists (and therefore four service rooms), one dentist, five assistants (one responsible for the health information session) and one orthodontic specialist (which needed 5% of the time). Similar results were obtained for the model where the dentist was able to make decisions about orthodontic treatment, and so making a consultation with the specialist unnecessary.

Based on the calculations, the model (Fig. 4) was piloted for 10 days. The process was monitored, and measurement data was collected and analysed for future use. According to the MAT analysis, the work load was not extensive. However, the hygienists felt that the days were heavier than usual. This might be because the lighter work tasks, such as cleaning and organising, were performed by the assistant instead of the hygienists. The task variation was minimized and therefore the service work might have been experienced as heavier than usual. It was also recognized that the dentist was able to do some paperwork during the work day. It was estimated that the direct salary costs associated with the improved service decreased about 26% compared to the situation before the improvement.

The results showed that the customers were pleased with the changes. Almost all (about 99%) stated that it was very good that the children also received a consultation with the dentist (if needed) during the same one visit and did not need to return for other appointments later on.

The most important finding was that the employees started to work as a team, as a system. This finding led to changes in the customer calling system and to a new way of thinking. In this multi-room service model, the outcome (in this case the successful treatment of patients) is the result of the efforts of the whole team and not just of the individual hygienists or the dentist.

Employee satisfaction was mirrored in the commitment of the employer, and the proposed changes designed in collaboration were implemented with success. The role of commitment is significant, as reported in an earlier research (see e.g. Halonen et al., 2014). Because the customer feedback was so positive and the short financial evaluation showed savings, this multi-room service model was proposed to be taken in production. However, it was highlighted that also the feedback from the personnel had to be taken into account, as they felt the work days were heavier than previously.

In the follow-up, the model was evaluated again. The MAT calculations showed the points and phases where the process was not working properly, and guided the search for answers. The calculations indicated that the time that should have been used for customer care was spent on unproductive work. This was because the new process was in production for the first time. Multiple practical considerations and small details were recorded and listed for future reference. Even though these small details might feel irrelevant they were seen as very important from the standpoint of having a fluent process; when a large number of customers are being treated in a day, all things must function fluently.

Contrary to the review by van der Aalst (2013), who stated that it is often impossible to compare different approaches due to the lack of experiments, our study allowed the comparison of three different processes adopted at YoungTeeth. Our study confirms that by using proper modelling tools, such as MAT, it is possible, and it can be recommended to pilot improved processes before extensive changes are implemented in organisations. The study also proposes that MAT could be evaluated in a similar way to the 20 use cases discussed by van der Aalst (2013).

7 Conclusions

Besides a positive result in the form of recorded satisfaction with the improved process, the study revealed several challenges in the implementation project that provided both practical and theoretical implications. First, the long time spent developing the algorithms required for the tool (MAT) caused problems related to engineering and mathematics, especially in terms of optimizing processes with multi-resource teams. Second, due to the background of the participating partners in the process improvement, the models had to be presented in a way that enabled understanding for all involved parties. Third, the process modelling and improvement requires the involvement of the process personnel and the organisation’s management. In practice, the LEAN approach was seen as a positive way to create this involvement. The analytical tools, such as MAT, help in comparing the benefits of different improvement options.

Because the object was to improve service process (see Wood and de Menezez, 2011), it was important to monitor satisfaction. Therefore, it was recommended to collect customer feedback regularly. In addition, it was important to monitor how the released working hours were spent instead of only noting the decrease in the hours in the phases. The personnel feedback was considered valuable and it helped to understand how the new process was functioning in production.

The same multi-room dental service model was also recommended to be implemented for other customer segments, such as adult customers. New implementations will produce new scientific knowledge serving audiences from both information processing science and process improvement.

The case organisation was committed to improving its service processes, and the commitment was seen in the active collaboration with BestPro and MathModeler. More research is needed to determine how the case organisation implements the proposed changes.

Further studies are needed to determine if the applied multi-method approach of MAT is effective in larger healthcare environments, as the current study was carried out in one dental clinic. In addition, the model should be tested in environments with more versatile professions representing several disciplines, such as software engineering in international business projects, instead of only one, such as dental medicine.

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