Using Stocks and Flows Diagrams to Understand Business Process Behavior

Timo Itälä
Aalto University

Mika Helenius
Aalto University

Business Process Modeling has traditionally focused on the activities and logic of how work is carried out. This is depicted through modeling notations like BPMN, which illustrate the sequence of activities, performers, and possible paths for each process instance. However, when measuring the performance of an organization and its processes, the aggregation of results from individual instances is often necessary. Unfortunately, these flows are not always smooth, as they may encounter variations, delays, accumulations, and other issues that can hinder expected performance levels. Therefore, understanding the behavior of business processes over time is crucial for improvement efforts. This paper demonstrates the use of stocks and flows diagrams for modeling business processes and simulating their behavior over time. Simulations aid in identifying critical points, removing bottlenecks, and enhancing overall process performance. We begin with a brief introduction to modeling business processes using stocks and flows diagrams, followed by a real-life case study in the healthcare sector, where stocks and flows models and simulations were employed to identify and resolve a problem.

Keywords: business process behavior, stocks and flows diagrams, business process simulation

INTRODUCTION

Organizational performance improvement initiatives often focus in improving, redesigning or re-engineering business processes (Hammer & Champy, 1993). Modeling the As-Is business processes, looking for problems and opportunities for improvements and then modeling and implementing, often automating the To-Be business processes are the normal steps in the improvement initiatives (Smith & Fingar, 2006). Modeling of business process is typically concerned of the *logic* of the processes. Davenport gives a following definition: "A business process is simply a structured set of activities designed to produce a specific output for a particular customer or market. It implies a strong emphasis on *how* work is done within an organization, in contrast to a product´s focus on *what*. A process is thus a specific ordering of work activities across time and place, with a beginning and end and clearly identified inputs and outputs, a structure for action". (Davenport, 1993). That is reflected in the modeling notations like BPMN (Business Process Modeling Notation) which show the sequence of activites, their performers and the different paths individual business process instances can take (OMG, 2013). Business Process Management with help of Business Process Modeling languages and techniques has probably been one of the most important management practices in the last 20 years in improving the organizational performance.

However, how the performance of the organization is measured is typically over some period of time. From that angle we can say that the results of the business processes are aggregations of the flow over time of single business process instances. Many organizations use Data Warehousing and Business Intelligence to measure, report, analyse and sometimes predict the aggregated results of their business processes like sales, orders, deliveries, revenue streams and many other variables.(Kimball, 1996). Those - important-numbers look at the outcomes of the business processes but do not give much help in trying to find out how to improve their performance. Instead, we argue that because the flows produce the results we need to observe and look at the very flows inside the business processes and understand their behavior over time as one important angle in our improvement initiatives

When trying to model the behavior inside the business process we come to a difficult question: which notation to use? Here we quote Albert Einstein, who said: **"Whether you can observe a thing or not depends on the theory which you use. It is the theory which decides what can be observed."** Most often used swimlane type business process models are not very intuitive in trying to visualize behavior over time. One natural choice for modeling the behavior of the flows inside the business processes are Stocks and Flows models which are known from the field of System Dynamics (Forrester, 1961). The Stocks and Flows models of the business processes are also suitable for computer simulations. They help in understanding the behavior of the stocks and flows over time. Simulations also help in finding the critical points to remove bottlenecks and improve the overall performance of the processes. Chapter 2 of this paper gives a short introduction in using stocks and flows for modeling behavior over time of a simple business process. Chapter 3 explains a real case where stocks and flows models and simulations helped us to reveal the underlying problems and find improvements to the business processes. Chapter 4 discusses about the usefulness of stocks and flows diagrams in business process modeling and chapter 5 draws the conclusions.

STOCKS AND FLOWS

The most basic visual model of a business process according to Davenport is shown in figure 1.

FIGURE 1
A BUSINESS PROCESS

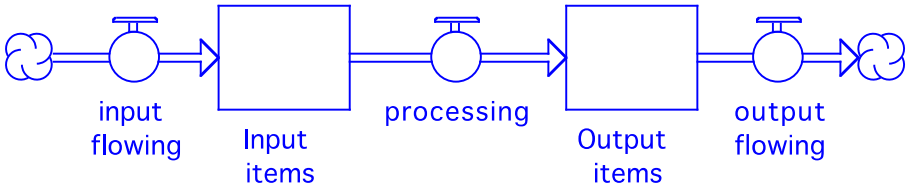
The common method for modeling business processes is based on the activities, the flow of work from one task to next. Typical visual model is the swimlane and its many variants, BPMN perhaps most widely used. Business processes consist of tasks and their sequence, logic for branching the sequence based on rules and conditions and actor who carry out the tasks. The swimlane represents all the different paths what one process instance can take. But when we are interested in behavior of the aggregation of the business process instances over time the swimlanes do not give much help. Input to the process usually is not evenly distributed over time. The flow of tasks as input items may have fluctuations and variations, backlog of work may be accumulating and other phenomena may occur that have consequences on how the process will produce its output.

To understand how the flow of input will affect the output we turn the same business process model into very high-level diagram of stocks and flows. We map the business process concept "a task" into the stocks and flows concept "an item".

We start with identifying the first stock. The stock represents an accumulation of some entity. Input items (tasks) waiting to be processed is the obvious choice for the first stock. A stock is visualised with a

rectangle, which has a noun as a name. A stock is represented by the value of a corresponding variable like number of input items. The value represents always the size of the stock in some point of time. That value can be changed only by a flow. A flow can be an inflow, which will increase the stock. A flow can also be an outflow, which will decrease the stock. A flow is visualised by an arrow and valve in the middle of it. The value assigned to a flow represents the rate of change of the respective stock over time, like processed input items per hour. Figure 2 shows previous diagram using stocks and flows notation.

FIGURE 2
STOCKS AND FLOWS DIAGRAM



In the diagram we have input items (tasks) flowing in and accumulating to wait for processing. Here the business process concept "an activity" is mapped to the stocks and flows concept "flow". The flow "processing" will deplete the stock and move finished items into accumulation of output items. The flow input starts from a cloud and the flow output ends in a cloud. Those are how we set boundaries in our model and are not interested what lies outside in those clouds.

Stocks and Flows Diagrams are useful in simulating the behavior over time of the model. Flows can be affected by information of the level of stocks and other factors, which create feedback loops and can make the process behavior non-linear. There is some literature about modeling the business processes using swimlanes and Stocks and Flows diagrams (An & Jeng, 2005). In the next chapter we show a real life example of modeling using Stocks and Flows diagrams and how simulation of the model helped to understand the business process problems, which were not easily seen from swimlane models.

CASE HOSPITAL

Situation and Need for Improvement

This case is from a central hospital in Western Finland. It offers full range of healthcare services like inpatient and outpatient services, operations theatre, emergency services, diagnostics, laboratory etc. It has about 400 000 visits per year, 1000 beds and around 60 departments.

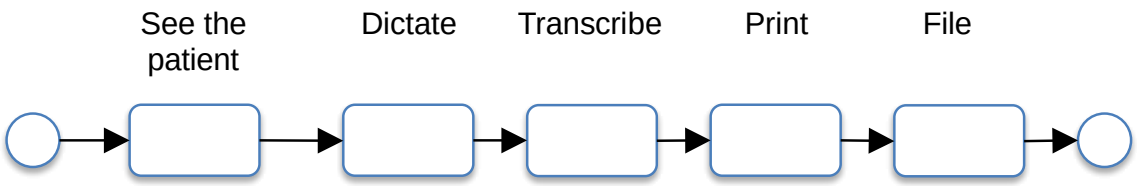
The hospital, like most hospitals, has a practice that the doctors dictate the medical records, observations, statements and other documents, which then are transcribed by the secretaries. The situation in our case hospital was that the technology for recording the dictations on magnetic tape was coming to its end of life phase. It was being replaced by digital recording equipment and software for dictations and transcriptions. At the same time the possibilities for improvements in managing the transcriptions could be discussed more broadly.

One problem in this case was that some departments had long delays in getting the dictations transcribed. That was causing problems in the next steps of the care when the medical records were not available from the previous step. That problem was coming more visible when the hospital had introduced a new regional information system which enabled the doctors in health care centres look into the medical records from the hospital. The management of the hospital had initiated an improvement effort to reduce the delays and shorten the time to get the medical records transcribed.

Swimlane Diagram of As-Is Business Process

We started with modeling the as-is business process. We interviewed several doctors, nurses and secretaries on different departments. A very simple model of the activities is shown in figure 3.

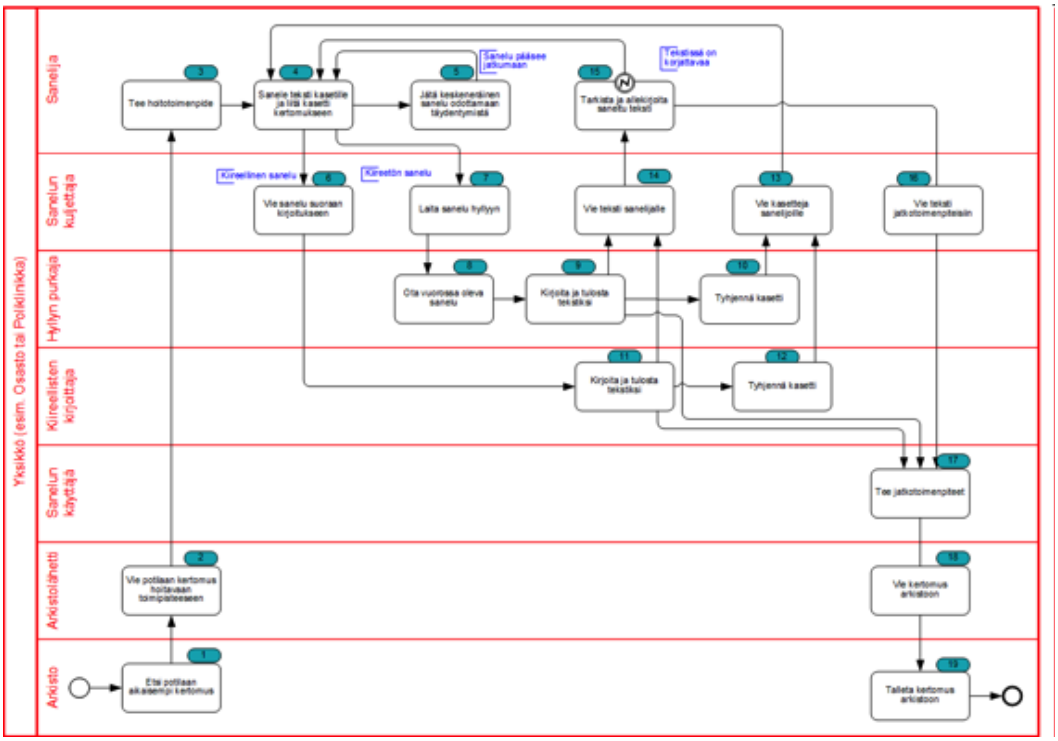
FIGURE 3
DICTATIONS AND TRANSCRIPTIONS



This simple model gave us an understanding of the flow of dictations but did not give understanding of the delays.

Then we modeled the as-is business process in Fig. 4 using swimlanes and BPMN 1.0 notation.

FIGURE 4
AS-IS BUSINESS PROCESS OF TRANSCRIBING



Unfortunately, the diagram text is in Finnish and also too small to read. Anyway, it is presented to give a flavour of a swimlane diagram. The swimlane model showed basically to paths for the transcriptions: normal path and an expedited path for urgent cases. The difference was that urgent dictations went directly to the transcriptionists whereas the normal dictations went first to the shelf of waiting dictations and from there to the transcriptionists.

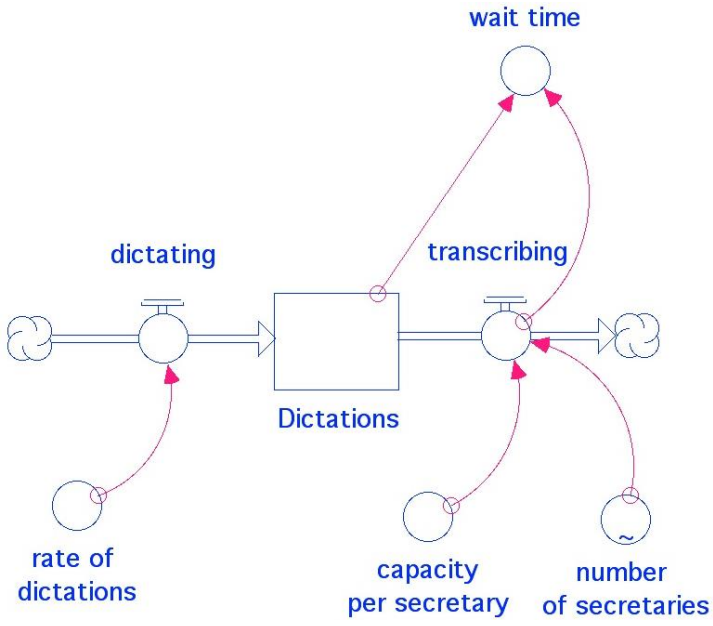
Every department in the hospital had their own shelves and own secretaries for transcribing their dictations. The secretary would take the next dictation from the shelf if there were no urgent dictations

waiting on her desk. Practically every department was working according to this model. However, this swimlane model did not help us to understand why some departments had long delays in getting dictations transcribed and others did not. So, we needed some other method to model the behavior of the transcription process so that we could find the cause for delays and differences between departments.

Stocks and Flows Diagram

Eventually there was a backlog of dictations accumulated and waiting for the transcription. A natural choice was next to look into the method of stocks and flows diagramming. A simplified model of the flow of dictations to transcriptions is shown in figure 5.

FIGURE 5
STOCKS AND FLOWS OF DICTATIONS AND TRANSCRIBING



An activity in the swimlane model is represented as a flow, for example transcribing the dictations. And the stocks – they are the dictations waiting to be transcribed. The activity – the flow- will empty the stock. The stocks, the accumulations of tasks waiting for the activity to start are not visible in the swimlane diagram. That is why a swimlane diagram does not naturally show the accumulation of the backlogs.

The model has one stock which is Dictations waiting to be transcribed. It has an inflow dictating and an outflow transcribing. When a new dictation arrives, it has to wait until all the previously arrived dictations have been transcribed. For example, if there are 30 dictations in the stock and the rate of transcriptions is 30 dictations / day, then the wait time for newly arrived dictation is one day until it will be transcribed.

For simulation purposes we added variables into so called converters in the model so that we can experiment how they affect the different behavior patterns. We added variables capacity per secretary and the number of secretaries so that we can try different scenarios. We also added variable wait time to show the results of simulation. We connected the converters into respective stocks and flows using arrows called connectors.

Simulating the Transcription Process

Recommended practice is to start simulation in a steady-state initial condition. So we started the simulation by setting the capacity per secretary into 30 dictations per day per secretary and number of

secretaries into three secretaries giving total capacity of 90 dictations per day. For the inflow we gave the same rate 90 dictations per day and for the initial value of the stock 10 dictations waiting to be transcribed. The simulation result showed that the model works: The wait time was10 dictations / 90 dictations per day resulting in 0.11 days steady wait time.

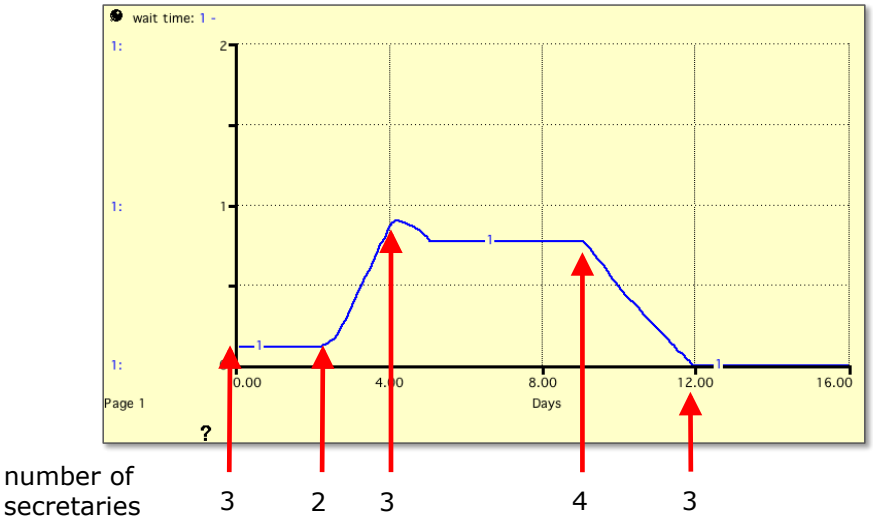
Then we made a small disturbance to cause the model out of balance to see how the process behaves. We set the number of secretaries into two for two days. The wait time got longer on those two days and came back to steady state after the secretary returned to work on day four. However, now the wait time was *permanently* longer than before the disturbance because the stock of dictations had increased during her absence. To adjust the wait time, we increased the number of secretaries into four on day nine for a couple of days. We saw the decrease of the wait time and finally the stock was emptied. We could set the number of secretaries back to three. The model was again in steady state and the wait time now remained zero.

The simulation was carried out using iThink 10 software. The simulation parameters were following:

Dictations(t) = Dictations(t - dt) + (dictating - transcribing) * dt
INIT: Dictations = 10
INFLOWS: dictating = Rate of dictations
OUTFLOWS: transcribing = capacity per secretary*number of_secretaries
capacity per_secretary = 30
number_of_secretaries = GRAPH(TIME,NUMBER)
(1.00, 3.00), (2.00, 3.00), (3.00, 2.00), (4.00, 2.00), (5.00, 3.00), (6.00, 3.00), (7.00, 3.00), (8.00, 3.00), (9.00, 3.00), (10.0, 4.00), (11.0, 4.00), (12.0, 4.00), (13.0, 3.00), (14.0, 3.00), (15.0, 3.00), (16.0, 3.00)
rate of dictations = 90
wait time = Dictations/Transcribing

The results of the simulation are shown graphically in Figure 6.

FIGURE 6
SIMULATION RESULTS



When we showed and explained the results of the simulation a lively discussion started. How in a case of one secretary´s sick leave resources could be borrowed from some other departments so that the stock of waiting dictations would not increase too much? How could we share the workload so that if some departments have extra resources in some point in time, they could help other departments who have heavy workload? As process modelers we understood that just looking at the swimlane diagrams this discussion

would not have started. Stock and flows model brought new insight in understanding the behavior of the business process and helped in trying to find new solutions to the problem at hand.

Looking at the Processes on the Hospital Level

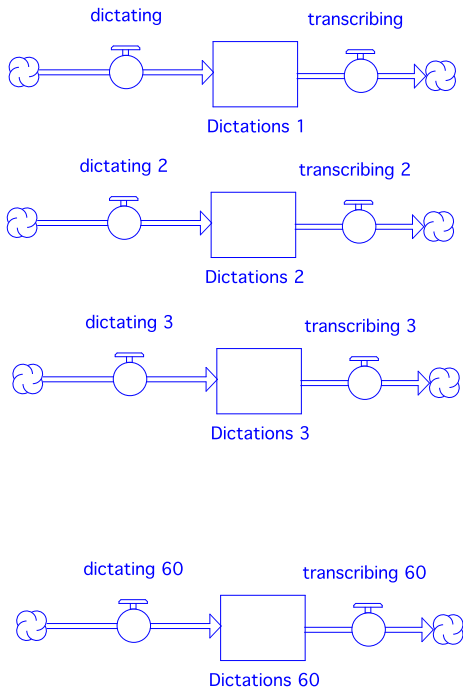
We continued our modeling and turned our attention to hospital level, which is shown in figure 7.

During the interviews we observed two departments, which did not seem to have backlogs of dictations waiting for transcription. We started to investigate what is different with these departments compared to the other departments. The departments were the emergency department and the operations rooms department. The patients stay at these departments only for a short period of time and soon are moved to the next department. The receiving departments have a requirement that the medical records need to follow the patient at the time of transfer. So, the doctors will dictate and the secretaries will transcribe the medical records immediately. If there is a backlog of dictations accumulating then secretaries from other departments can be borrowed for transcription. But these two departments were an exception in the policy that departments do not share their secretaries even in case that some departments would have a need for additional resources and some other departments would have extra resources available at that moment.

We started to see the underlying problem.

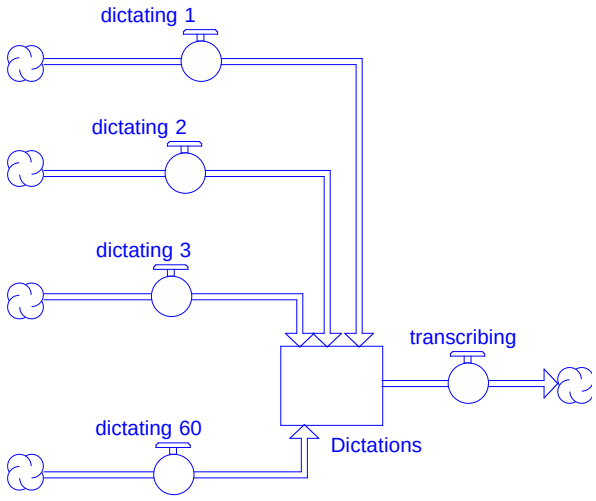
On departmental level even small variations in workload or capacity can easily disturb a steady state and cause the backlog start to build up. For example, department with two secretaries will have its capacity dropped in half if one of the secretaries is sick.

FIGURE 7
TRANSCRIPTIONS ON EVERY DEPARTMENT



Based on this understanding we started to think about the potential solution. If we could share the resources on hospital level then it would be very unlikely that half of the capacity would be lost because of sick leaves. In other words, the variations have *relatively* smaller effect on hospital level compared to departmental level. That led us to the solution of having one hospital level flow of transcriptions instead of 60 flows on departmental level. Figure 8 shows that idea.

FIGURE 8
COMBINED FLOW OF TRANSCRIPTIONS



Implementation of a New Flow Structure

The idea of one flow of transcriptions was much discussed and the necessary changes considered. The changes were needed in all areas of an Enterprise Architecture: Business Processes, Information, Applications and Technology. In addition to that also policies and accounting practices needed changes.

We will discuss them briefly:

- Technology: New technology using digital dictation machines resulting into audio files made it possible that transcribing was not any more limited to certain physical location. Also typing the medical records directly into electronic format made it possible to share the medical records and print them out where needed. So, in our case the technological requirements for the changes were already in place.
- Applications: We would need an application to keep track of the dictations which are made by doctors and which are waiting to be transcribed. That application would distribute dictations to the available secretaries and keep track of work in progress and work completed.
- Information: Identification of the digital files and assigning them to the right patient need to be solved. Dictations in the physical recording cassettes were always carried within the folders of respective patient´s paper records. An application was needed to manage identification of the files and assigning the to the right patients.
- Business processes: New business processes for dictations and transcriptions using the new electronic devices and the above mentioned application was needed. That was later modeled using BPMN business process models.
- Policies: Perhaps biggest and most time-consuming change was how to enable the work flow across organizational boundaries. The accounting practices in the hospital were based as departments being cost centers. Some shared services were internally invoiced from the cost centers. But sharing secretaries and invoicing that work between departments would be too complicated and cause too much administrative effort. It was then decided to set up a separate unit for transcriptions and collect needed secretarial resources into that unit which would then offer its services to the departments and make the internal accounting very simplified.

Another Accumulation in the Doctors' Memory

The interviews with the secretaries of the departments had also revealed that sometimes the backlog of dictations started to accumulate even when all the secretaries were at work. It turned out that the doctors

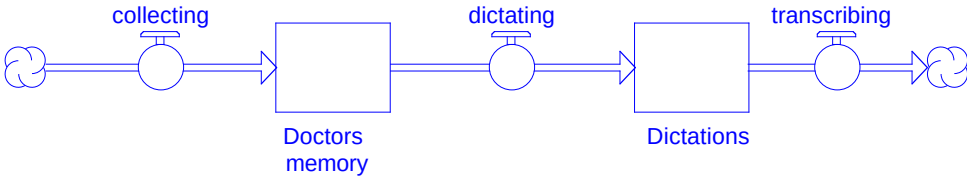
had different practices in how they organised their work. Some doctors would dictate the medical records immediately after the visit of the patient. But some doctors would see all the patients during the day and only in the end of the day dictate their medical records. And then there were some doctors who would do the dictations of several days in one go. We modeled the stocks and flows diagram of this observation. The model showed us that initially we had made too tight boundaries to our model to be able to see all the causes for the backlogs.

In the model there is another stock, which is in the *doctors' memory*. The extended model is shown in figure 9.

The first stock is made up of the medical records waiting to be dictated. That stock has an inflow when doctor is working with patients and *collecting* information, which need to be dictated. And the outflow is the dictations made by the doctor. If the doctor dictates two days of accumulation of medical records will that cause a pulse in the inflow of the stock of dictations waiting to be transcribed. The next dictation from some other doctor would have to wait for the accumulation from the previous doctor to be cleared.

Another policy change was made requiring the doctors to do the dictations as soon as possible, latest within the same day. Changes were also made in their work schedules etc. but in this paper, we do not go into those details. The point is that it is important to choose the boundaries of the stocks and flows diagram so that all relevant aspects become visible and are considered.

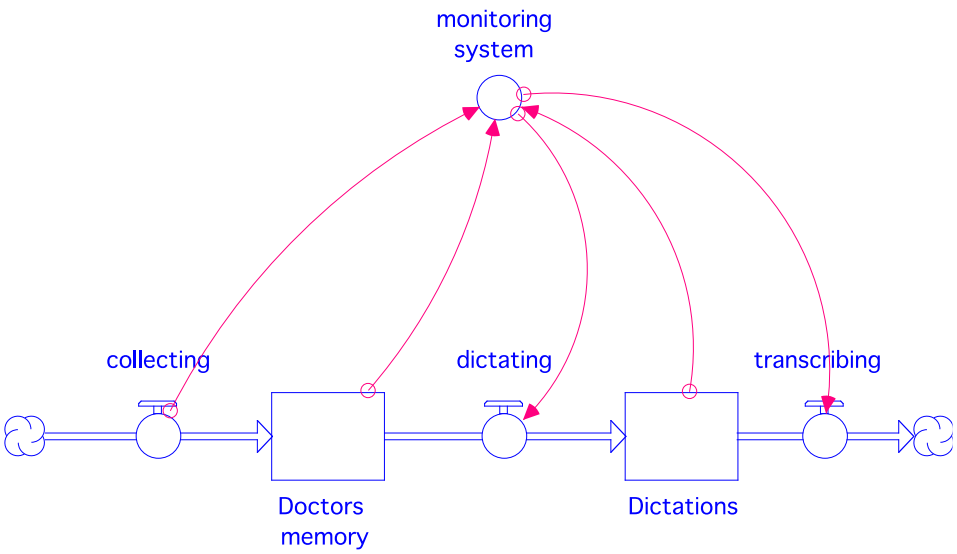
FIGURE 9
ACCUMULATION IN THE DOCTOR´S MEMORY



How to Monitor the Flows

Extending the boundaries to include the flow of patients visiting the doctors required also the functionality of the application to monitor the dictations. It would keep track of the visits for doctors and accumulation of the medical records, which needed to be dictated. The application could kindly remind the doctors to do the dictations. The idea of that application is shown in figure 10.

FIGURE 10
MONITORING THE FLOWS



Also, that application could be used for giving early indication that eventual backlog would be accumulating if the number of visits and the amount of medical record what they would generate exceeds the available transcription capacity of the secretaries. Additional secretaries could be called in duty to prevent or remove the backlog before it would cause major delays.

Experiences

The changes were implemented. Now in the hospital there is a transcription centre with about 25 secretaries transcribing all dictations from the departments. The goal of maximum 5 days delay in transcription of the dictations was achieved after two years of implementing the changes.

DISCUSSION AND CONCLUSIONS

Using stocks and flows diagrams to model and analyse business processes in addition to widely used work flow models helps us to point out problems and opportunities what otherwise would probably remain undetected. The stocks and flows diagrams enable us to:

- Identify the bottlenecks in the business process flows and find alternatives how to widen the bottlenecks for example by increasing parallel processing or speeding up individual activities.
- Understand the effects of the distribution profiles of incoming tasks and how to be prepared in case of bursts to assign resources timely so that accumulations will not build up and cause delays in the downstream flow
- Avoid accumulations by trying to keep the inflows as steady as possible
- Design an information system for monitoring the stocks and adjust the flows to prevent the accumulations to grow too much
- Give factual input for discussions of potential changes in organizational policies and practices, which are needed to enable organizational changes.

In the discussions with the hospital participants, it was said that visualisation and seeing the behavior in live greatly helps our cognitive capabilities in understanding how business processes behave over time.

One important aspect is the adoption of digital dictations, which made it possible to physically separate the transcription from the department where the doctor made the dictation. If the original manual, department level workflow had been left unchanged the reasons for delays had still been causing problems.

It was beneficial for the organization to have a high level view to the business process and understanding the underlying reasons for the behavior of the processes.

Comparing workflow diagrams (swimlanes) and stock and flow diagrams we can say that when we want to understand how work gets done, we use swimlanes. When we want to understand how the flows behave over time we use stocks and flows diagrams. They help us to identify the potential problems or opportunities and find the solutions.

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