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HOSPITAL PROCESSES WITHIN AN INTEGRATED SYSTEM VIEW: A HYBRID SIMULATION APPROACH

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ABSTRACT

Processes in hospitals or in other healthcare institutions are usually analyzed and optimized isolated for enclosed organizations like single hospital wards or certain clinical pathways. However, many workflows should be considered in a broader scope in order to better represent the reality, i.e., in combination with other processes and in contexts of macro structures. Therefore, an integrated view is necessary which enables to combine different coherences. This can be achieved by hybrid simulation. In this case, processes can be modeled and simulated by discrete simulation techniques (i.e., DES or ABS) at the meso-level. However, holistic structures can be comfortably implemented using continuous methods (i.e., SD). This paper presents a theoretical approach that enables to consider reciprocal influences between processes and higher level entities, but also to combine hospital workflows with other subjects (e.g., ambulance vehicles).

1 INTRODUCTION

Improvements in healthcare delivery are important to master global challenges in future, which are particularly triggered by demographic changes and increasing costs. Hospital managers and those of other healthcare providers must solve many trade-off problems, i.e., a better service quality versus higher resource usage and operational costs. Process improvements performed by simulation and modeling (SaM) allow to better handle budgets and to increase the organizational performance prior to their cost-intensive real-world implementation. However, the success of such improvement processes crucially depends on the applied SaM method.

Process analysis by Business Process Modeling (BPM) plays a significant role in the management of companies or divisions (Giaglis 2001). This modeling technique enables to structure the process knowledge of single domain experts in common models that can be used as a basis for further discussions and studies. Together with simulation, BPM offers an efficient and comprehensive toolset for managers and other decision-makers (Harrison et al. 2007, Laguna and Marklund 2013, Weske 2012). This combination helps to detect bottlenecks and problems at an early stage, and to evaluate different scenarios and solutions prospectively. The main focus of process modeling is the (graphical) representation of different paths and process steps, but resources and organizational structures can also be considered. The process analysis aims to achieve an understanding of a certain process and to identify weaknesses and potential improvements (Rebuge and Ferreira 2012). Therewith, simulation is capable to calculate the expected outcome for both the currently existing process and for a prospectively adjusted process that does not exist yet. In this case, management decisions, especially at the strategic level, could be more objective by limiting biases of individual perceptions.

BPM and DES are primarily used for studies in the inpatient sector (Vera and Kuntz 2007), but they also can be applied in cases when abstract clinical pathways for certain diseases are evaluated. In recent time these methods receive a growing attention in situations where hospital services are reimbursed through flat-rate or fee-per-case charges, such as the Diagnosis Related Groups (DRGs). In this case, a hospital will receive a predefined and agreed reimbursement value for each patient. This value is dependent on diagnosis and not on the real costs of provided services. Consequently, hospitals are extremely interested to keep the costs per case below this value, but also to provide an adequate service quality in a competitive market. That means, process improvements have significant impacts on the operating result and organizational performance.

Process modeling is widely used and already established in hospitals across different application areas. On the one hand, the medical treatment process of a certain disease (i.e., clinical pathways) and thus the quality of care are in focus (Ronellenfitsch et al. 2012), on the other hand, the profitability is a major business target figure. In this case, e.g., the process structure can be modeled and underlaid with cost data. This approach serves as a basis for an activity based costing and enables to generate important information for an effective management (Öker and Özyapici 2013, Hada et al. 2014, Kaplan et al. 2014, Cannavacciuolo et al. 2015). However, the prospective analysis of processes and their realization in practice vary considerably. Furthermore, such techniques are often not used holistically, but rather for specific diseases or for a particular hospital ward. One reason is, that experts investigate their research scope focusing on one particular disease (Akhavadan 2016), henceforth, the willingness to model *foreign* processes does not exist. Another reason is, that in economic evaluations cost centers are mostly considered in separate studies (Ibrahim et al. 2014).

An overall view containing bordering influences typically does not exist. In particular, different related processes in the same institution and even the broader environment of the hospital should be considered when analyzing a system. For example, if a patient requires an imaging examination, the radiology department usually interacts with other medical wards during a treatment process. The same also occurs in other supporting processes like laboratory tests or occupancy management. Ideally, the whole hospital organization should be considered, but without over-complicating a model. Going one step further, even external influences can affect a considered process, i.e., the surrounding population structure, economical factors, political influences, or technological developments. Using BPM and DES, a modeler has to represent the whole environmental complexity by very detailed process models. However, in most cases it is sufficient to represent less important influences by more abstract or aggregated models. In this paper we present a hybrid simulation approach that allows to develop detailed process models by discrete simulation techniques using Discrete-Event Simulation (DES) and Agent-Based Simulation (ABS), as well as to represent the process environment and bordering processes by more abstract high level System Dynamics (SD) models.

2 RELATED WORK

The scope of this paper is particularly related to the following three topics: modeling of hospital processes, healthcare simulations in general, and the hybrid simulation technique. There are numerous academic publications that are focusing on these topics.

As previously described, BPM is used to develop process models for hospitals and other healthcare institutions. Fitzgerald and Dadich (2009) discussed how process simulation can be applied in order to identify potential improvements and perform optimizations in hospital workflows. Another paper which has been introduced by Mathew and Mansharamani (2012) presents a review of tools and techniques focusing on BPM. In particular, the use of the Business Process Model Notation (BPMN) and its shortcomings are discussed as well as the applicability of DES in this context is mentioned.

In general, applying SaM techniques in healthcare is not new. There are already many example success stories where established simulation methods have been used to represent healthcare structures. Gunal (2012) introduced a guide for building simulation models for hospitals. In this article the author describes important conceptual modeling steps within the context of healthcare, but also a comparison between different simulation paradigms (i.e., DES, ABS, and SD). Brailsford (2007) presented an interesting tutorial about advances and challenges in healthcare simulation modeling. This paper describes a possible categorization of healthcare models and classifies available examples in three different levels of abstraction. Finally, Gaba (2007) introduced two possible visions for simulation in healthcare. The first one describes a successfully achieved integration of simulation in healthcare studies until the year 2025, while the second scenario refers to a more pessimistic view, where only few aspects have been realized until the same year.

Probably the most related topic for this paper is hybrid simulation. This technique received a considerable attention over the last years, due to its flexibility and an increasingly improved tool support. In particular, this observation can be supported by the growing number of publications at the Winter Simulation Conference (WSC) focusing on hybrid simulation technique and its application in different domains. While in 2011 only few papers have been presented in different tracks, there is already a separate full track bringing together different presentations around the area of hybrid simulation. Heath et al. (2011) presented an interesting discussion focusing on cross-paradigm modeling. The authors considered different configurations of DES, ABS, and SD in order to describe their advantages and problems during the model building process. Additionally, Brailsford et al. (2013) reviewed the use of hybrid simulation for healthcare and social care. A first generic framework for hybrid simulations in healthcare has been introduced by Chahal (2009). This work particularly describes how to use SD and DES conjointly from a conceptual perspective. A further paper which has been accompanied by a panel discussion at the WSC 2015 has been presented by Mustafee et al. (2015). It generally presents definitions, challenges, and benefits of hybrid simulation, but also its applicability in healthcare. Djanatliev and German (2013) focused on hybrid simulation for prospective health technology assessments combining DES, ABS, and SD in common models. Moreover, an approach has been presented to generate agents dynamically from SD models, and other inter-paradigm connections within the scope of healthcare decision-support (Djanatliev 2015). Finally, we investigated some work to step forward towards a guide for hybrid simulation modeling and proposed four levels to develop modular hybrid models in healthcare (Djanatliev and German 2015).

3 HOSPITAL PROCESSES WITHIN AN INTEGRATED SYSTEM VIEW

Hospital processes are often analyzed isolated for single hospital wards, or for certain clinical pathways. In most cases, different stakeholders are working together in order to find the most suitable process structure representing specified processes. A main challenge during this procedure is to find a common language between all participants within an interdisciplinary context. BPM is appropriate to collect the process knowledge of domain experts and to present it in a standardized manner.

Depending on the question to be answered there are many situations where it is not sufficient to develop models of specialized processes only. Often there are direct or indirect connections to other wards within the same hospital or even to other hospitals and institutions. For example, a treatment process can start within an ambulance vehicle and continues in the hospital. For a moment it does not seem to be challenging, but the complexity gets clearer, if one considers different possible combinations of treatment processes for single vehicles and different hospitals. In general, several internal and external influences can crucially affect the considered processes. This is why an isolated analysis of hospital processes is insufficient, rather they have to be evaluated within an integrated system view.

3.1 Structuring Hospital Processes

Before focusing on a broader scope, we particularly set the focus on hospital processes and describe how they can be structured. First, business processes will be outlined generally, thereafter, a mapping to hospital processes will be given.

3.1.1 The Nature of Business Processes

A business process can be described as a sequence of single activities that run consecutively to achieve overall objectives. Such objectives are usually oriented to customer needs and to the current market situation. The value chain can only run unobstructed, if all involved persons and equipment items have been previously coordinated. The better this coordination works, the more efficient procedures can be expected. The implemented processes, seen as one entity, can be characterized as a function, transforming a given input into a measurable output. In this case activities lead to an added value; a key aspect of business processes (Greiling et al. 2004).

A business process can be subdivided into different hierarchical levels: the top level represents the primary process including business objectives and the most important process groups. It can be divided into smaller sub-processes hierarchically. The number of levels that a primary process is divided into differs from company to company, or from project to project. Furthermore, it depends on the complexity of the main process, and on the question, how useful is an additional level for organization and controlling of the work routine. The benefit of different levels is to get an overview as well as a higher transparency of detailed work. In particular, the top level enables a comprehensive global control. Value creation is often the main aim at this management level. In contrast, sub-processes at the lowest level represent the most detailed view on a process. Additionally, there are various supporting processes that run parallel to the considered business process and are not directly involved in the value chain. They are not generating directly measurable benefits for the customer, however, they are nevertheless indispensable for a realistic evaluation. For example, the human resources department is not involved in the production process, but it is relevant for recruiting qualified staff. Within an end-to-end business process all activities and resources are included which are required to achieve value creation, from the first steps to the final realization, and it comprise both the value added and the supporting processes (Bergsmann 2012).

The success of an institution crucially depends on its operational performance and management. Thus, a constant monitoring and performance evaluation of its procedures is required. In this context, the process management plays an essential role and represents a link between the strategic and the operative management. The aim of process management is to combine knowledge, skills, tools, and techniques in order to achieve the targeted outcome. Furthermore, it includes continuous redesigns, strategic planning, monitoring and managing of business processes. In particular, continuous adaptations and improvements are necessary to ensure a persistent and high organizational performance. Finally, the aim of process management is to make processes more effective, efficient and flexible.

3.1.2 Business Process Management in Hospitals

In order to apply the idea of process management in the inpatient sector, the following factors have to be considered. In contrast to an industrial production process where products are located in the center, humans are the most important instances of service delivery in healthcare. Thus, various needs of individuals and other sensitivities of patients have to be respected.

The primary process of healthcare provision in hospitals usually includes various medical disciplines. For example, the emergency department is often initially involved in the treatment process of hospitals. Moreover, established medical disciplines like the internal medicine or the cardiac medicine can come along. Additionally, the nursing staff and other professionals have to be considered in the overall process. Thus, the functional organization of a hospital and a high medical specialization makes process structuring very complex and more challenging. In particular, the process manager must put increased efforts in coordination to achieve a more efficient and appropriate structure. As presented in Figure 1, a possible structure of primary processes in hospitals contains the following steps: admission, diagnose, therapy, post-treatment, and finally the discharge process (Hessel 2003).

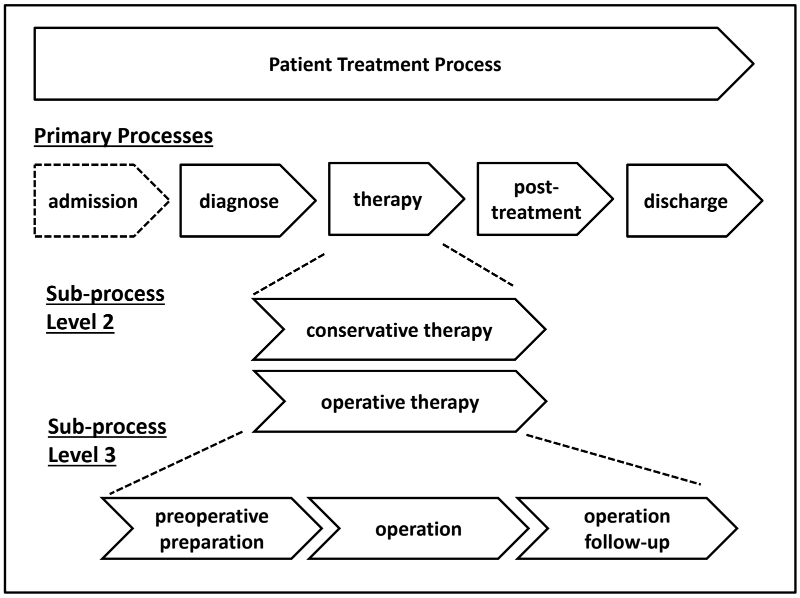

Figure 1: Structuring hospital processes. Based on Hessel (2003).

In this context specific success factors have to be mentioned. They are basically measured by three outcomes: time, costs and quality of care. These parameters constitute a triangle of independent items. The general goal of process management is henceforth an improvement of all three items. Hence, an optimized process ideally runs faster, at lower costs and produces an increasing quality of care. However, a simultaneous improvement is often pretty difficult, because each dimension can affect another one. Consequently, improvements of one parameter can lead to a deterioration of another one (negative correlation). For example, a faster process can save costs, but may lead to a decreased service quality. Therefore, it has to be checked how such dimensions interact within an individual setting. Generally speaking, an overall optimum of all parameters should be achieved.

3.2 Integrating Hospital Processes by Hybrid Simulation

As long as only discrete process steps have to be represented in optimization studies, BPM in combination with DES can be used. This modeling approach offers enough features to model processes with their special characteristics. Even more complex processes containing substructures can be built hierarchically in DES models. However, in this case all parts of the model are usually represented at a very low and detailed abstraction level, even for those sections that are less important in contrast to the considered process. In this case, high data requirements must be met and simulation can result in bad runtime performance. There are also many examples representing hospital processes at high abstraction levels. Using rates and continuous flows allow to represent a system of differential equations. In this case SD is appropriate to be applied. This approach requires less input data and usually results in excellent execution times, however, detailed coherences cannot be modeled.

3.2.1 Hybrid Simulation in Healthcare

In order to take advantages from all simulation techniques, a hybrid simulation approach can be applied. Furthermore, guidelines or best practices from existing case-studies shall be considered. In particular, a modular structure can help to achieve a sustainable model development and to reuse already validated components in different studies. As already mentioned, we distinct between the following four abstraction levels in healthcare models (Djanatliev and German 2015):

- **Holistic Level:** Also called macro-level or top-down view. For example, health system models, abstract disease models, global health economic models, as well as representations of demographic, or epidemiological changes. SD is most appropriate to be applied, but DES can be used to change SD parameters at discrete points.
- **Process Level:** Also called meso-level, or workflow perspective. In particular, representation of hospital processes and clinical pathways. Cohorts, or entities *without* an individual behavior are traversing predefined paths triggered by global instructions. Mostly modeled by the process-oriented Discrete-Event Simulation.
- **Individual Level:** Represents a micro-level perspective. More detailed entities can be represented at this level. In particular, agents which are following their own *active* behavior. An active behavior include primarily actions that have been initiated explicitly (e.g., taking medication, calling the doctor, ignoring symptoms). At this level the ABS is highly appropriate to be applied.
- **Internal Level:** In contrast to the micro-level, passive or background processes of agents can be represented at the internal-level. For example, person's internal body processes (i.e., gradual deterioration of organs). Due to a continuous matter and lacking detail data, SD is particularly used to model such processes.

Between all these levels different interactions from a logical and technical perspective can be considered. For example, demographic changes at the macro-level can affect the number of traversing entities in processes, but single steps in paths can reduce financial budgets at the macro-level. Another example is policy making in the healthcare sector. Global decisions can lead to process changes (e.g., regulatory changes lead to a necessity of additional steps for documentation) or different study results due to changed costs. From the technical point of view SD can be coupled with DES in this scenario. Five types of interaction can be applied in both directions, e.g., firing events in DES after exceeding threshold values in continuous modules (Djanatliev and German 2015). Further important connections exist between the micro-level and the internal-level. For example, taking medication at the micro-level can lead to a slower deterioration of organs at the internal-level, however, accruing disabilities at the internal-level can affect the agent's activity at the micro-level. In this case interactions between ABS and SD are required.

3.2.2 The Environment of Hospital Processes

As already stated, a considered process can be influenced by numerous factors. Some of them are depicted in Figure 2. In particular, various holistic and micro structures are affecting the considered processes. Typically, other intra-institutional workflows can, e.g., reduce the number of human and material resources, otherwise, investments in new resources can improve the process quality. Moreover, processes of other entities are also important to be considered. For example, external treatment procedures that have been started in ambulance vehicles and are continued within the hospital.

Similarly, a nearby located hospital can have increased numbers of arriving patients. In particular, demographic influences include population specific factors. Aging or an increasing population size are most representative examples therefore. Epidemiological influences particularly refer to disease-specific coherences, e.g., growing incidence rates leading to a higher bed occupancy. Political influences include decisions of governments and regulatory agencies. Appropriate examples are changes in the reimbursement catalog, and different legal requirements. Money flows at the holistic level, subventions and considerations of various budgets can be represented by economic influences. Technical factors particularly refer to new technical opportunities, or improved profits due to innovative cost-effective technologies. Going more in detail, individual influences can play a significant role. In this case agents representing patients can refuse to perform certain process steps, or forget to take important medications. Furthermore, wrong diagnostics

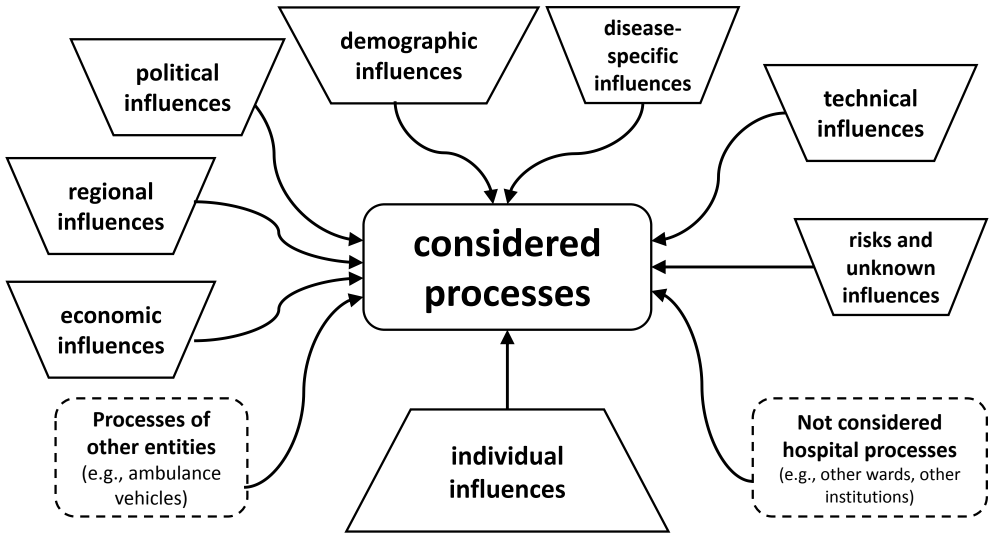

Figure 2: Hospital processes within an integrated system view.

and treatment decisions by the staff can affect the quality of considered processes. Finally, in many strategic studies risks and unknown influences have to be represented as well.

3.3 Building Hybrid Models

Building hybrid models in this context is not a trivial task. There are many decisions that have to be made before. In particular, the main questions are usually, what kind of influences are important for a case-study, and what is the most appropriate level of detail. Another problem refers to implementation specific aspects. For example, how a running simulation can be realized and which software packages are sufficiently featured.

3.3.1 Conceptual Modeling

According to Robinson (2011), the conceptual modeling process is the most essential success factor of any simulation study. This kind of modeling usually does not depend on a simulation software and considers the problem from a domain perspective. An important aim is to collect important knowledge from domain experts in common non-formal specifications. We call them *Conceptual Domain Models (CDM)* (Djanatliev 2015). This structure must be understandable by all stakeholders (i.e., domain and simulation experts) and it helps to find a consensus about the level of detail and simulation objectives.

There are different options for building CDMs. On the one hand, it is possible to start by very detailed models and to aggregate fuzzy structures in holistic and high level models. Another possibility is to start by top-level models combining important influences at high levels and to zoom-in those parts that have to be considered in more detail. This approach is usually more preferable, as only necessary parts will be modeled in detail. An appropriate and slightly formal technique is the Casual-Loop-Diagrams (CLD). They allow to connect different entities by positive and negative influences and enable to transform a resulting diagram to executable SD models. Figure 3 shows an example of a CLD. Positive influences mean that changes of the source result in same directed changes of the target. For example, lower resources per person lead to a decreased service quality. However, the amount of changes is not necessarily the same. Negative influences mean that changes of the source contrarily affect the target.

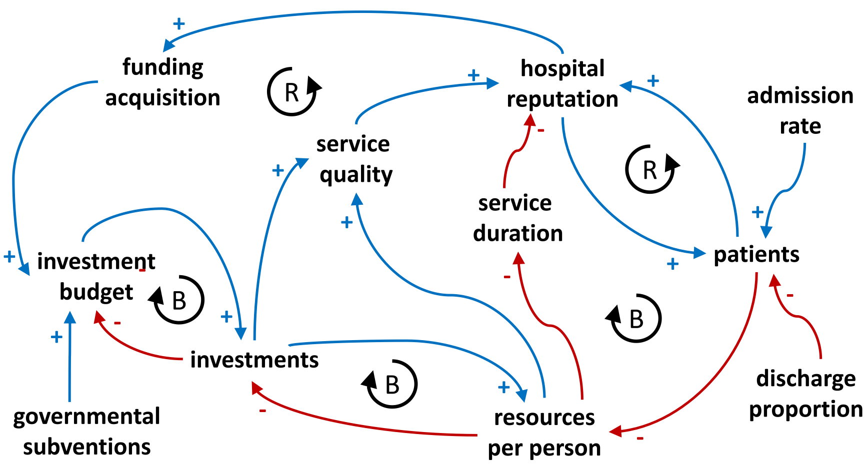

Figure 3: An example scenario modeled by a Casual-Loop-Diagram. Based on Djanatliev (2015).

3.3.2 Implementation of Case Studies by Hybrid Simulation

In context of this paper we suggest to follow neither the top-down approach, nor the bottom-up. In particular, following the previously presented four-level architecture, the focus has to be set on hospital processes at the meso-level. That means, DES can be used to build process models in detail. Thereafter, all required environmental influences have to be modeled around the considered process. SD can be used to represent abstract and holistic structures, such as population dynamics, or disease dynamics, but also for bordering hospital workflows that have not to be modeled in detail. ABS can be applied to represent the behavior of people, i.e., patients and the hospital staff at the micro-level. Figure 4 depicts a schematic scenario containing DES, SD, and ABS elements.

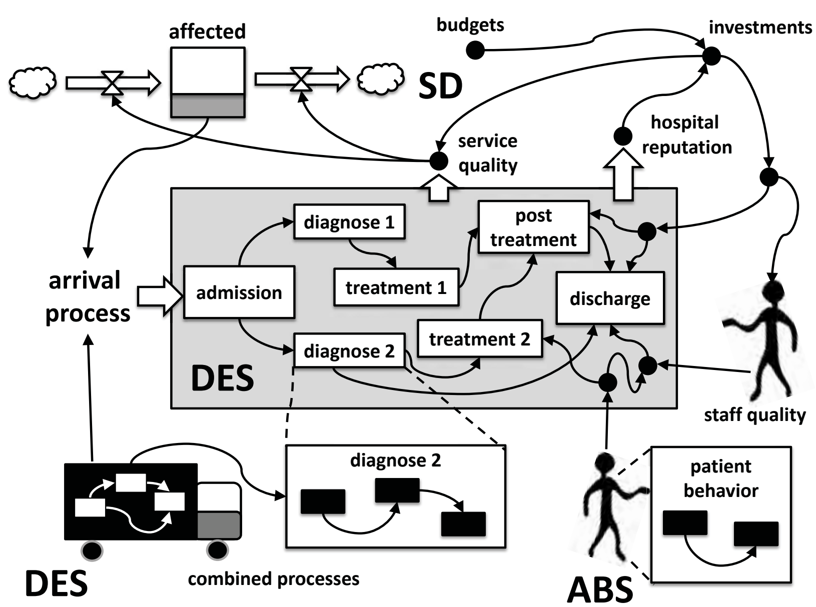

Figure 4: Combining processes, holistic structures and detailed agent behavior.

Building executable models in this context requires a powerful tool support. In particular, a suitable software package must enable to develop models using SD, DES, or ABS in a common environment. There are a lot of tools that can be applied to develop models referring to one of the relevant simulation techniques. Some packages have extension features to establish connections to other tools (Heath et al. 2011). This may be sufficient to develop simple integrated hospital models, as particularly DES is set in focus. However, in more complex scenarios and studies representing a more integrated system view, a powerful software package is required that enables to use all three simulation paradigms equally. AnyLogic (AnyLogic 2016) is a multi-method simulation software that flexibly allows to use different simulation techniques in one common simulation environment. Moreover, this tool contains libraries and other pre-implemented components for model developments in certain domains (e.g., manufacturing, road simulations). The possibility to add own Java code makes this package more powerful particularly when modeling complex structures. Another feature is the possibility to develop own modules hierarchically and to define interfaces for a sustainable usage. In our previous work, we presented how dynamic process libraries can be built in order to comfortably change internal processes of institutions or vehicles without reimplementing similar modules in each component (Djanatliev 2015).

Due to the just presented reasons, we decided to use this tool, though the license costs are pretty high, even for an academic usage. It should be mentioned that we did not performed a structured tool evaluation within the scope of this work, so there are probably also other tools that can fulfill the requirements as well. Figure 5 shows a very small illustrative extract of our first stroke hybrid model. At the left hand side a statechart is depicted describing the behavior of an affected person. After recognizing the disease a person can ignore symptoms or calls the emergency department.

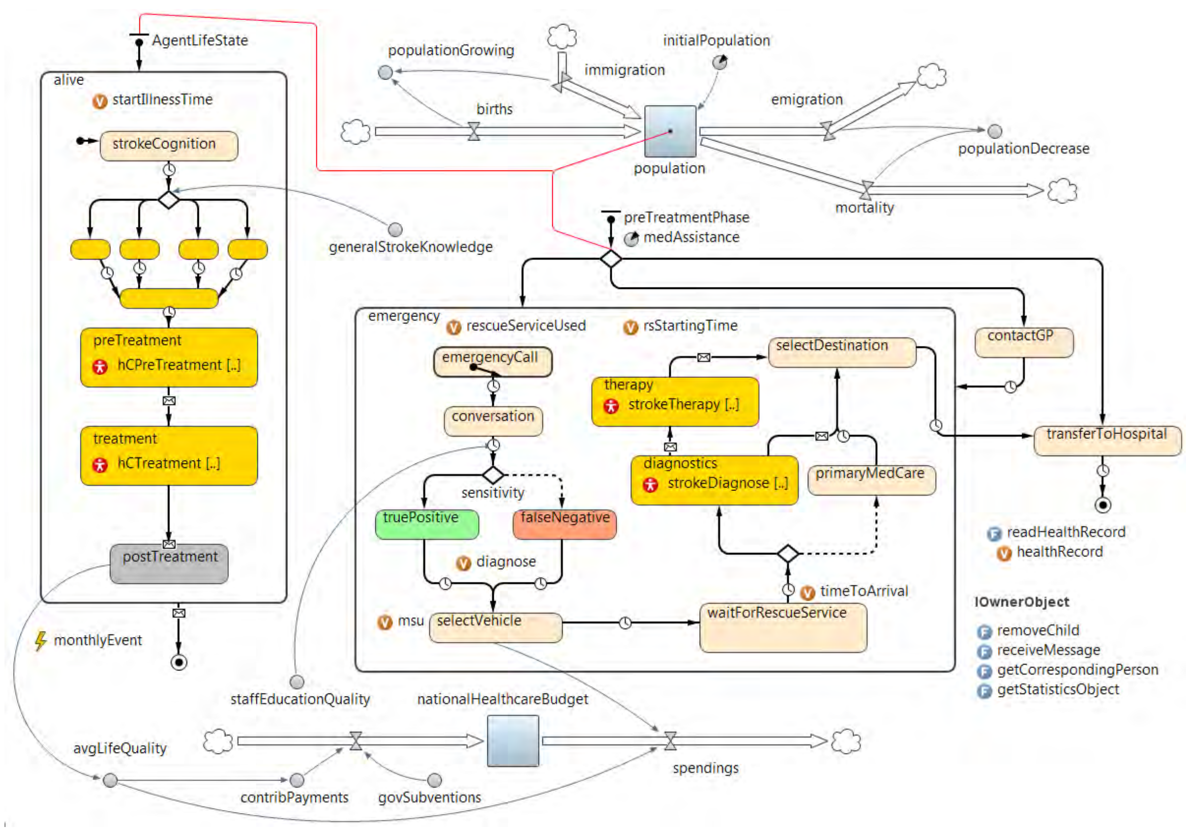

Figure 5: A small illustrative extract of our first stroke hybrid model.

In the latter case the pre-treatment process from the right hand side will be started. Both processes affect the presented SD models and can be affected by them. For example the population and disease dynamics influence the number of emergency calls. The more cases are identified, the more costs will be produced. In this case, global budgets will be changed which can result in less financial resources for staff education and other important investments. Finally, the better outcome hospital processes produce, the more healthy contributors are available.

4 CONCLUSIONS

Hospital processes are usually analyzed independently for single wards or for certain clinical pathways. However, there is a need to put such workflows in a broader view in order to perform long-term evaluations from a strategic perspective. Various internal or external influences have to be regarded. In particular, the following high level influences can affect hospital processes: demographic, epidemiological, economic, technical, political, regional, and further unknown processes as well as risks. Moreover, bordering workflows can also affect a considered process. For example, a treatment begins in an ambulance vehicle and will be continued in the hospital. Finally, individual influences including the behavior of patients and the hospital staff must be considered. In this case a patient can, e.g., refuse certain process steps, or forget to take medications. Wrong treatment decisions and a slow work progress is an example of how the behavior of single physicians can affect the quality of hospital workflows.

In this paper we discussed from a theoretical perspective how hospital processes can be structured and how they can be generally considered within an integrated system view. Furthermore, we proposed a hybrid simulation approach that can be applied at four different abstraction levels. In this context DES is used to represent processes, ABS and state charts are applied to consider individual behavior at the micro-level, and SD allows to model abstract and continuous structures. We particularly suggested to begin by process models at the meso-level and thereafter to enrich them by the surrounding process environment. As this paper particularly focuses on theoretical aspects, the focus of future papers in this context should be set to example case studies referring to the applicability of the presented theoretical basis.

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