((MODYPLAN)) - Early-Stage Hospital Simulation with Emphasis on Cross-Clinical Treatment Chains

Gabriel Wurzer[1], Wolfgang E. Lorenz[1], Matthias Rössler [1], Irene Hafner[1], Niki Popper[2], and Barbara Glock[2]

[1]Vienna University of Technology
Vienna, Austria
{firstname.lastname}@tuwien.ac.at

[2]DWH Simulation Services
Vienna, Austria
{firstname.lastname}@dwh.at

ABSTRACT
Health trusts are aiming to consolidate the clinical landscape: The provision of medical services, now handled by individual clinics, is to be transformed such that the patient volume can be redirected between different specialized service providers. As implication, hospital planning needs to embrace the subject of cross-clinical development rather than looking at each facility in isolation. In this context, we have been developing ((MODYPLAN)), a cross-clinical simulation for early-stage architectural planning. Our software takes the patient volume as input and redirects it to different facilities, each one having a different spatial layouts and treatment capacity. As outputs, we obtain the utilization and occupancy of each service unit on which we can base further analysis concerning bottlenecks. Furthermore, different configurations of the clinical landscape can be compared, facilitating a multi-faceted discussion among stakeholders (clinical providers, their staff and patients). As audience, we target hospital administration, architects and process designers preparing or working on tenders. Such an *early* application of cross-clinical simulation is, to the best of our knowledge, yet unprecedented.

Author Keywords
Hospital planning; cross-clinical simulation; early-stage planning; service provisioning; resource utilization.

INTRODUCTION
Medical service provision is planned both *regionally* (strategic planning of a clinical region) as well as *locally* (hospital planning concerning a single clinic). The goal is to adapt the capacities of medical service units in accordance with the needed future demand. Physically, this may be accomplished through (1.) building, refurbishing or closing clinics and (2.) transferring departments to specialized facilities, leading to strong cooperation in a clinical region. But how to evaluate which of these measures should be taken? In this paper, we seek to answer this question through whole-building simulation based upon the patient schedules and the preliminary building layout. In more detail, we

- give a short overview of the whole-building simulation approach which we use, which is aimed at early-stage planning conducted by architects and organizational planners (see Background),
- define which options exist when developing a clinical region both from a building as well as from an organizational viewpoint (see Options for Clinical Development),
- outline how these options can be represented and quantified in our simulation (see Representing and Simulating Planning Options).

To be fair, we have so far not applied these concepts in an actual planning process: The implementation of our software is just finishing and we are transitioning to a phase where we have first customer shipments of the alpha version. Instead of a case study, we thus give a discussion of our idea (see Discussion) before concluding.

RELATED WORK
We use an Agent-Based Simulation (ABS) model in which each agent visits a sequence of functional units (FUs) – spaces having a finite capacity and defined spatial scale (e.g. examination room, medical department or whole clinic, depending on the type of simulation study). The choice of ABS is motivated by the ease of interacting with the environment (i.e. the spatial program consisting of FUs and circulative system). We have no “behavioral” aspect in our implementation as other authors do [1,2]. Omitting the reference to space, we could also have used DES [3] or even Petri Nets [4], however, we chose not to do so for being able to reason spatially (e.g. also for adjacency planning conducted as extra module of the development of our software [5]).

Within ABS, our approach can be seen as *schedule-based simulation* where each entry of the schedule is exported from a Hospital Information System (HIS). Other approaches rely on questionnaires for obtaining this information, e.g. Tabak in his Ph.D. thesis “User Simulation of Space Utilisation” [6]. Regardless of whether an automatic or manual surveying technique was used, the gathered data can be used to generate fictional schedules reproducing the same characteristics. Goldstein et al. [7] have called this extrapolative approach “schedule-calibrated”, where a future activity can be based on the past schedule. We have a similar possibility for generation,

SimAUD 2015, April 12 - 15, 2015, Alexandria, VA, USA

based on often-reoccurring "standard schedules" in which we can leave out certain activities according to probabilities (see Background).

BACKGROUND

Our paper buildings upon a previously published description of our simulation model [8], which we wish to summarize briefly before returning to the scope of cross-clinical simulation.

Overview of our Simulation Model

Our model is based on individual schedules for each patient which are executed within the building layout. More precisely, a schedule in our terms is a sequence of FUs that a patient has to visit. These are spaces (see Figure 1a) - e.g. a single examination room, a department or a whole clinic, depending at the intended resolution of the simulation study. A FU can further be capacity-constrained, i.e. acting as resource of the simulation (e.g. examination room with 2 treatment places in Figure 1a). Exceeding this capacity leads to queue formation. The queuing strategy (e.g. FIFO, priority queuing such as in the form of a Manchester Triage) is specified separately, in the form of a *behavior* governing the FU.

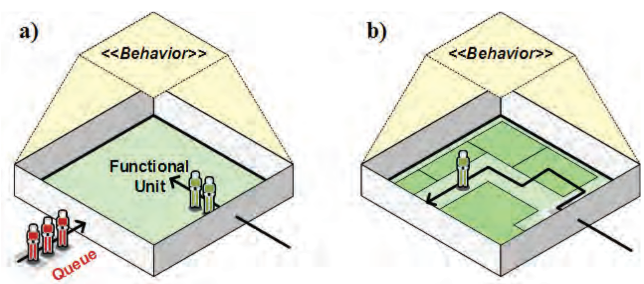


Figure 1. (a) FU of capacity 2 means that two agents may enter and all others have to queue. (b) FU consisting of nested sub-units, governed by a single overall behavior.

FUs can be nested to form a spatial hierarchy (FUs within FUs, see Figure 1b). A behavior controlling such a composite unit can be used to guide the passage of patients through its sub-units, allowing to model processes that are standardized (i.e. acting on a preset spatial configuration, e.g. for an operation area).

Outputs

Our simulation model measures three types of results,

1. the agent history in the form of FUs utilized and queued for; implicitly, this also gives the passage length of each individual patient (obtained through route computation between each two FUs on the way),
2. utilization of each FU (agents in the FU as well as queues before the FU),
3. occupancy (time spent within the FU, which is different from utilization for FUs that are not capacity-constrained, such as general waiting areas without seats).

Based on these factors measured in each simulation run, we can go on to compare the different options for clinical planning that are presented due course.

OPTIONS FOR CLINICAL DEVELOPMENT

Clinics have to be constantly adapted so as to keep track with the expected patient volume, which undergoes changes not only in numbers but as well in its characteristics (medical progress leading to changed treatment, and thus also to different schedules for each patient). An effect of this is that a FU may be over- or underutilized, as given in Figure 2a. More specifically, the capacity of a FU refers to physical entities such as chairs in a waiting area (see Figure 2b), which have a required area. In that example, overutilization would mean that there are not enough seats available in that area, but increasing the capacity of the FU may not be possible due to lack of extra space within the FU. Underutilization would mean that there are always seats free and thus space is wasted.

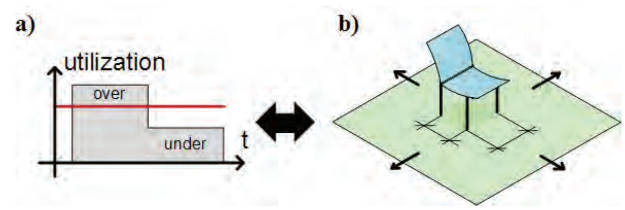


Figure 2. (a) Over- and underutilization of a FU. (b) Space requirements of a resource unit of a FU.

The core problem of how to extend or decrease the capacity of a FU, also acting on its space, is the main topic to be addressed by clinical planning. As we will see, measures in that context range from localized to regional options, which will be scrutinized in due course before coming to details of how we handle these cases using our combined simulation/planning tool, ((MODYPLAN)).

Local options

The simplest type of intervention is to adapt the capacity of a FU by adding or removing resources, which might entail building activities (changed arrangements of spaces, changed equipment, etc). Such an approach is usually called **refurbishment**, if the actual building structure is not changed. Another option would be to add a (temporary or permanent) structure to the building, which acts as an **extension**. One example for the latter are prefabricated surgery modules, which have recently become popular (minimal planning time, fixed costs for building and known running costs). By contrast, a **new building** requires a lengthy process for planning and building (typically 10 years, as by an own survey by the authors), based on requirements that try to predict the next 10 years after the building goes into operation. Given such an uncertainty in planning, **closing a clinic** and transferring the departments to the new building might not work as expected, since requirements and patient volumes might have changed in the mean time.

Cross-clinical options

Forming highly-cooperating special clinics in which medical services are **concentrated** is a long-term trend in provision planning. From a practical standpoint, this means that departments are transferred and patients are redirected. The question of existing patient volume in the target clinic being merged with that of the old department needs to be investigated. The same goes for the coordination between the cooperating clinics. Electronic integration, physical interactions such as pick-up and delivery service and so on are central for ensuring the cooperation between the facilities.

REPRESENTING AND SIMULATING PLANNING OPTIONS

The aforementioned planning options are represented as follows in our tool:

- Refurbishments act as a change in capacity of a functional unit. We store the space requirements of each resource unit (see again Figure 2b) and complain if there is not enough space to accommodate the new capacity. The planner can then change the space of the FU to make that possible.
- Extensions of a clinic are new FUs giving additional capacity. The agents will use the extensions in parallel to pre-existing ones.
- For new buildings, we design a schema with the envisioned functional units but simulate with the given patient volume of the previous building. In that way, we can constrain the building such that it can handle the current patient flow. Changed departmental roles (e.g. a central A&E instead of two individual departments) need to be mapped manually by the planner in the input data.
- We do not explicitly handle the case of a clinic being closed and its departments transferred to a new building. However, one could set the capacities in the old clinic to 0 consecutively, thus simulating a gradual shift between old and new facility.
- For the cross-clinical cooperation between multiple clinics, we lay them out side-by-side and let a connecting functional unit with a specialized “transfer” behavior handle the simulated service integration (e.g. shuttle services, public transport). We do not currently simulate the flow of material (e.g. central kitchen serving to all clinics via cook-and-chill), since the emphasis lies on patients.

Using the schematic drawings gained in the above fashion, we get a tree of functional units in which our simulation steers agents through the clinical buildings (see Figure 3). As result of that computation, we store for each simulated scenario the resulting individual patient histories (paths taken, queues encountered and functional units utilized for an individual), space occupancy and functional unit utilization over time.

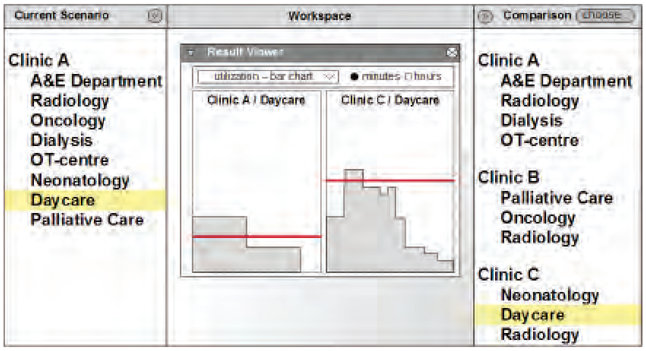
Figure 3. Screenshot of simulation during computation

The final step lies in a comparison of results obtained via the simulation, using a comparison as in Figure 4, either side-by-side or stacked, using occupancy or utilization of FUs as input. Analyzing a common functional unit in both scenarios gives a performance measure of both options. For example, transferring the Daycare unit shown in Figure 4a from Clinic A to Clinic C will entail a higher utilization for that unit, but only once exceed its capacity for a short period of time. The stacked occupancies shown in Figure 4b can give a measure of how busy two compared functional units will be in terms of patients being present (e.g. for non capacity-constrained areas). Furthermore, we offer a Gantt Chart showing relative utilization, color-coded to show under- and over-utilized units (Figure 4c). Also, the characteristics of the inhibiting patients can be shown aggregated by their type (e.g. walking/sitting/lying or other categorization dependent on the input data), and characterized further to show the duration of treatment so far, time spent queuing and time utilizing the functional unit (not shown in any Figure).

DISCUSSION

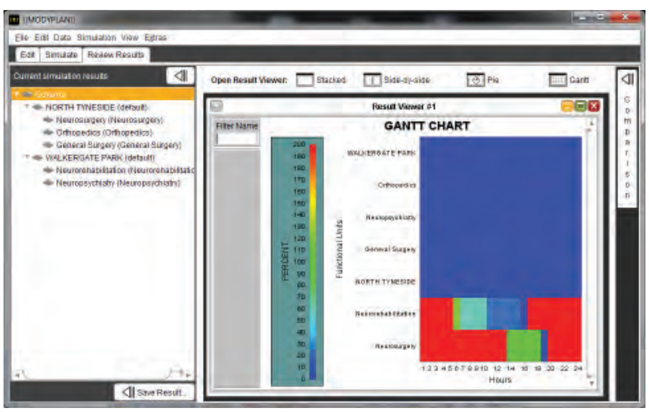
The presented concept for comparing two clinical configurations lacks an assessment of an “overall fitness”. However, we argue that the design of healthcare facilities cannot be summarized easily; the planner has to go through each department and analyze the impact of chosen planning options for the patient before being able to decide for one over the other scenario. In the future, we will add more evaluation options apart from the purely resource-based ones - adjacencies of functional units, usage of the circulation immediately come to mind - so that we can compare also the form of the building and with that the viability of a concept for the staff (short ways, compare the two building types in Figure 5). Another necessary addition to the model is the inclusion of staff schedules to back the capacities of FUs. Such functionality would certainly need to include specialized logic for legal constraints in the respective national context, which we have so far avoided.

Likewise, material supply and disposal logistics forms another area for extension of the model which we will conduct in the future.



(a) Sketch: Comparing one unit in two scenarios

(b) Screenshot: Stacked consecutive units



(c) Gantt Chart showing relative utilization in percent (red: over-utilized, green: utilized 100%, blue: underutilized)

Figure 4. Visualizing and comparing outputs

CONCLUSIONS

In this paper, we have presented ((MODYPLAN)), a schedule-based simulation model that focuses on comparing different building concepts, especially dealing with cross-clinical development options (medical service provision in cooperating clinics) in addition to the common practice of refurbishments and adaptation of clinics. The context of our approach lies within early planning, i.e. during competitions or as means to quickly build up and compare a number building concepts for later refinement. The early application of simulation within hospital planning makes our approach unique, valuable for architects and organizational planners.

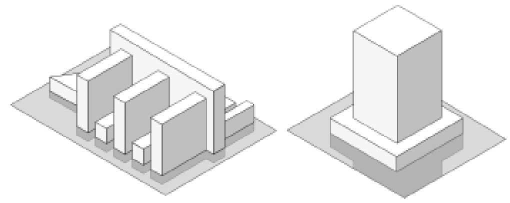


Figure 5. Future Work - comparing building types

ACKNOWLEDGMENTS

We want to thank the Technology Agency of the City of Vienna (ZIT), a subsidiary of the Vienna Business Agency for supporting us on the project Modular Dynamic Planning and Simulation for Health Care Facilities - ((MODYPLAN)).

REFERENCES

1. Padgham, L., Scerri, D., Jayatilleke, G., and Hickmott, S., Integrating BDI Reasoning into Agent-Based Modelling and Simulation, *Proc. WSC 2011*, WSC (2011), 345-356.
2. Simeone, D., and Kalay, Y.E. An Event-Based Model to Simulate Human Behaviour in Built Environments, *Proc. of eCAADe 2012*, eCAADe (2012), 525-532.
3. Günal, M.M., and Pidd, M. Discrete event simulation for performance modelling in health care: a review of the literature, Journal of Simulation, 4 (2010), 42-51.
4. Salimifard, K., Hosseini, S.Y., and Moradi, M.S. Improving Emergency Department Processes Using Coloured Petri Nets, *Proc. of the International Workshop on Modeling and Business Environments 2013*, CEUR-WS.org, 989 (2013), 335-349.
5. Lorenz, W.E., and Bicher, M. Adjacency in Hospital Planning, Proc. of MathMod 2015, IFACOnline (2015), 6 pages. http://publik.tuwien.ac.at/files/PubDat_237766.pdf.
6. Tabak, V. *User Simulation of Space Utilisation*. PhD. Thesis, TU Eindhoven, 2008.
7. Goldstein, R., Tessier, A., and Khan, A. Schedule-Calibrated Occupant Behavior Simulation, *Proc. SimAUD 2010*, SCS (2010), 3-10.
8. Wurzer, G., Lorenz, W.E., Rößler, M., Hafner, I., Glock, B., Bruckner, M. and Popper, N. MODYPLAN: Early-Stage Hospital Simulation based on Treatment Chains, *Proc. MathMod 2015*, IFAC Online Paper Archive, http://publik.tuwien.ac.at/files/PubDat_237765.pdf