Modelling and Simulation of clinical processes by the example of the "acute coronary syndrome"

K. Eisentraut*, F. Richter**

* Department of Medical Informatics, Technical University, Ilmenau, Germany
** Medical Solutions, Siemens AG, Erlangen, Germany

katja.eisentraut@tu-ilmenau.de

Abstract: In the health service a comprehensive instruction for each illness, which illness needs which diagnostics and which therapies, exists. The acute coronary syndrome represents such a clinical process. In the available paper this clinical process from medical view is arranged. In order to be able to model afterwards this clinical process, the necessary process structures must be put on such as systems, modules or primitives in using the MLDesigner. Subsequently, a model can be produced from the individual structures. The compiled model is evaluated in the connection according to criteria of modelling. Friendliness, correctness, reusability by model elements or the possibility of structuring are estimated. The developed simulation model can be used after completion for the analysis of the process of the acute coronary syndrome, in order to determine bottlenecks and dependence between individual process steps. Subsequently, it applies to find out by resources increase in the individual bottlenecks, which increase is useful for the minimization of the total waiting period of the patient.

Introduction

In the today's time also the health service is affected by the savings obligations. For this reason everyday processes must be analyzed and optimized, in order to be able to uncover and repair gaps in systems and to save funds. To the analysis existing medical process cycles in a hospital are seized and illustrated in a model. This model can be used afterwards for estimation on the basis of criteria of the modelling and simulation, in order to uncover weak points in the sequence of events in hospital. The won informations can be consulted to improve the analyzed sequence. In the following one the modelling and simulation by the example of the clinical process of "acute coronary syndrome" are represented using the software "MLDesigner".

Materials and Methods

With the clinical picture of the acute coronary syndrome (ACS) life-threatening situations develop, in which suddenly a decreased blood circulation of the heart muscle arises. The heart is provided with blood and nutrients by coronary vessels. By deposits of lime, cholesterol or blood platelet parts of coronary vessels can be narrowed or occluded.

The acute coronary syndrome can have different effects for the patient. The consequences of an inefficient supply are individually different and reach from angina pectoris via the cardiac infarction to sudden cardiac death. The patient must be diagnosed with suspicion of ACS as fast as possible followed by the corresponding therapy. The electrocardiography is part of the diagnostics. Further blood tests of the patient are taken and specific parameters are determined. From this statements about the accurate localization and the extent of the heart illness can be met. If an acute coronary syndrome is diagnosed, afterwards a cardiac catheterization is arranged. A tube is led across the bloodstream to the heart. With the help of a camera the physician can determine the severity level of the illness.

A local narrowed blodd vessel can be widened with a balloon angioplasty and additionally stabilizied by a metal lattice (so-called Stent). This is accomplished during the cardiac catheterization. If an extension of the blood vessel is not possible, the bypass operation is set as therapy. The obstructed part of the vessel is spanned, so that the blood circulation is re-established. If this therapy doesn't promise a success, only an artificial heart and waiting for a heart transplantation remain for the patient.

The process begins with the admission of the patient to the emergency admission, the diagnostics and following therapy of which are provided as models with the MLDesigner.

The MLDesigner is a variously usable software with a stout coupling between modeling and simulation. There is the possibility of modeling followed by simulating complex processes as well as systems of the regulation and control theory. The individual models can be developed, worked on, visualized and checked for modelling errors, as for example a missing connection between two modules.

Handling the MLDesigner requires the knowledge of the following terms: The smallest elements form the *primitives*. The user can choose a necessary primitive out of numerous libraries. If he doesn't find a correct one the programming in C++ is also possible. For a hierarchical layout of a model the *modules* can be used. These can be built up from other modules, primitives or a combination from modules and primitives. For the production of a functional simulation model the use of a *system* is necessary because only systems can be executed by the MLDesigner. In order to receive a structured storage of the created primitives, modules and systems, a library is recommended to put on. Here all model components can be put down.

ISSN: 1727-1983 © 2005 IFMBE

After a library and a system were put on, it can be started with the creation of the necessary modules on system level. The necessary modules depend on the expiration of the clinical process, which is to be modeled. On system level the clinical process of the ACS is illustrated.

After the model on system level is provided, the necessary functions must be developed regarding a later simulation in the form of modules or primitives. For this it is necessary to convert the medical and the system-oriented details. The hospital everyday life presupposes waiting rooms with a limited capacity for many stations within a process. In order to be able to accomplish a simulation, fictitious patient data are necessary, which are read in over files. The received data during the simulation are collected in a data structure and completed in the course of the simulation. In order to be able to evaluate the data after finish the simulation the data have stored in a file. So it is possible to destine the total length of stay and the total waiting period. Since no real-life numbers are present, the stays are indicated in each process step with a Poisson distribution around a average value. The number of available resources (nurse in admission, physician and devices to the diagnostics, physician to the therapy, physician/nurse for discharge) are defined in each case. To the announcement of simulation results the model contains additional modules, which realize the display output. The simulation model has the following appearance on system level:

Figur 1: Simulation model

The simulation model created with the MLDesigner can be examined now according to criteria of modeling. For this the following factors are consulted: the *user-friendliness*, which gives somebody information about the creation, deletion and storage of models. The *structuring* of the model represents a further factor. Here are statements concerning the clearness and hierarchy representations. The *comprehensibility* of a model forms the third factor. Here it applies to answer questions about the model documentation. A further important factor represents the *correctness* of the model. Can the MLDesigner detect errors in the model? Also the possibility of *validation* of models is important. The adaptation of existing models is determined. For the creation of individual models a set of modules and primitives are put on. The possibility of *reuse* is considered to examine it as last factor. These results are represented in detail in Results.

After the analysis of the provided model this can be used for simulation. The developed data are evaluated afterwards. After evaluation weak points can be identified and be tried out in a further simulation after adjustment of the model. This procedure points at the same time the large advantage out of the simulation. Because only here changes in the process can be made and examined on success, before they are converted in the hospital.

Results

With the MLDesigner it is possible to visualize and simulate the clinical process of the acute coronary syndrome. In order to reach visualization, the necessary modules and systems are to be provided and put down in a library. The provided model can be analyzed to the criteria of modeling.

The creation of systems, modules or primitives is straightforward because the realization is supplied over one mask only. For deletion the user can choose between two possibilities. It can decide whether it would like to delete only the reference on a module for example or the complete module. With the deletion of the entire module this is not completely removed, but put down into a trash. The user can delete these then if necessary and remove contents irreparably. Each erasing process is to be confirmed by the user over a safety inquiry. Thus unwanted erasing processes can be broken off. The user-friendliness covers further easy training and usability of the MLDesigner. The screen is very clearly developed. The windows for parameterizing, for the production of the models or for the administration of the data structures are if necessary fade outable, so that the available screen width can be adapted.

The structuring of the models forms the second criteria. A very good structuring of the model is possible by use of several hierarchy levels.

The comprehensibility of the created models can be achieved by means of the documentation. To everyone module or primitive provides can statements about the function assigned directly. If the user liked to experience the meaning of a module, it can be able to be indicated these directly with the help of the mouse, without reading thick documentation file.

The correctness of a model represents an important factor. Because only correctly provided models permit also correct statements about functionality. The modeler is responsible for the contentwise correctness of a model. The MLDesigner cannot determine whether a module is placed in the entire model on the correct place. But the MLDesigner gives the information about the sematically correctness of the model. For example it is examined whether all contained modules and primitives are correctly connected with the neighbour.

If errors in the model are discovered, the user gets these informations over a written and graphical report.

If an already finished model must later be adapted to new requirements, the validation is located in the center. The MLDesigner makes it for the user possible to modify all provided models. Additional modules can be inserted into a model or existing modules against new be exchanged. Validating of the models is always possible in all model levels.

A further interesting factor is the reusability of modules and primitives. Individual modules as for example the realization waiting rooms occur in the universal model more than once. The re-use is problematically, if two components possess the same structure however different parameter values. Then a re-use is not possible, since a module, which is twice inserted use the model, in both cases gets identical parameter values. The MLDesigner doesn't make it possible to insert different parameter values into reused modules. So the reusability is strongly reduced by model components within a model regarding the simulation.

The simulation can start after setting all necessary parameters. In first simulations the question about existing bottlenecks had to be answered within the examined clinical process. For this the number of patients in connection with the point of arrival time of the read in patient data was examined. On the total waiting period the point of arrival time and the already present patients have a large influence. More patients at the same time or with very small distance have to wait longer time. The following illustration represents this connection. The diagram shows that the temporal distance is important to total waiting time for each patient. With a arriving distance of ten minutes the total waiting period sinks distinct.

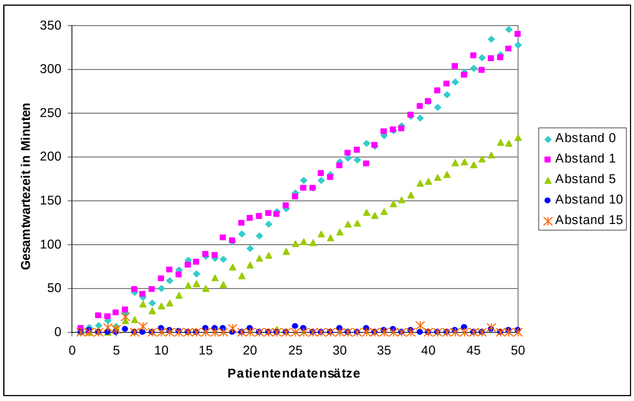

Figure 2: Connection point of arrival time and temporal distance between arriving patients

After a clear connection between point of arrival time and number of patients is recognizable, it applies to find out, in which process steps the relatively high waiting periods is accruing. Therefor patients with a temporal distance of one minute will be determined.

In the following illustration the waiting periods in dependency on the process steps are posed.

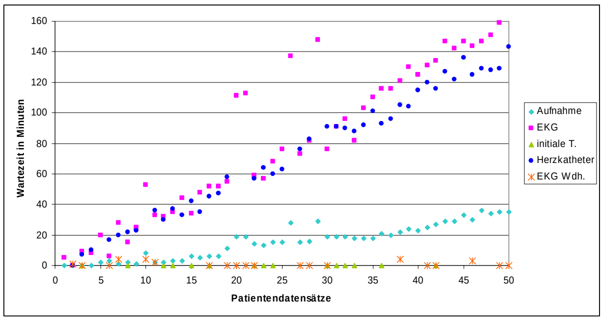

Figure 3: Waiting periods in the individual process steps

As bottlenecks the following process steps can be defined from Figure 3: ECG, cardiac catheter and admission. The admission is passed by all patients. The average investigation duration in step ECG was assumed with five minutes. This is the reason why succeeding patients must wait before the investigation. The waiting before cardiac catheter has two causes. On the one hand the average investigation and treatment time are here set with ten minutes, on the other hand there are two different ways by the simulation model, in order to arrive at the cardiac catheter.

The temporal distance of one minute of two patients is unrealistic, however the effects in available resources can be very well analyzed here. Since for patients with acute coronary syndrome each minute of waiting period can have partial life-threatening effects, it applies to minimize the waiting periods of the patients. For this reason the increase of available resources in each process step is to be considered. If two nurses are responsible for admission the waiting period have to sink. Likewise a resources increase in the process steps ECG and cardiac catheter is examined, since these form the bottlenecks of the system. The following simulations for the investigation of the use of a resource increase was accomplished with 50 patients. Each resource combination was simulated, in order to find the optimal constellation out regarding the smallest waiting periods.

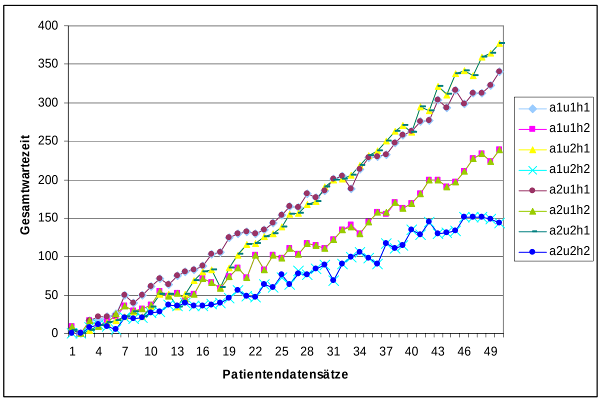

Figure 4: all possible combinations of additional resources

ISSN: 1727-1983

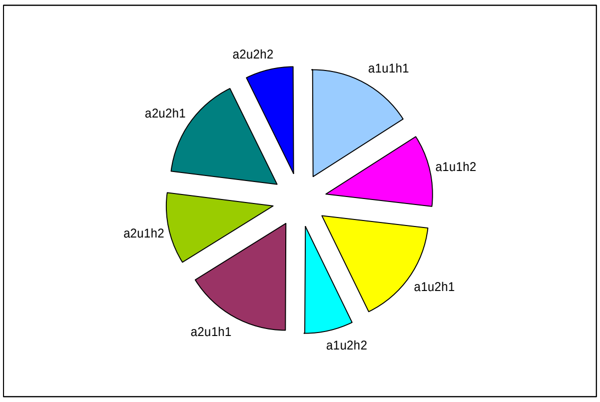

Figure 5: average total waiting periods for each resource combination

The legend in Figure 4 and in Figure 5 contains the different combination options of resource admission (a), ECG (u) and cardiac catheter (h) with the associated color coding. Figure 5 contains the average total waiting period of the 50 simulated patients for each resource combination. From both representations it is recognized that there are clear differences in the total waiting period depending upon resource combination. It comes out from the compositions clearly that those doubling of resources ECG and cardiac catheter cause a clear profit on total waiting period. However additional nurse resources don't contribute considerably to the minimization of the total waiting period, so that a doubling brings no large use here in relation to the necessary expenditure.

Conclusions

The won realizations from this work show that the MLDesigner can be used for the modelling and the simulation of a clinical process. The elements needed for the modelling are to be put on problem-free and uncomplicatedly over a uniform mask. If the necessary modules and primitives are put on, a model in form of a system can be developed. If adjustments at the model are to be made at a later time, problem-free the modules or primitives can be removed or by others replaced. If modules or primitives are to be used several times in a model, it can come to problems with a following simulation. In a module if a parameter is set, it is occupied at the same time in all other copies of the module with this value. However for example two waiting rooms with same structure are to be used however different capacity in a model, its own module must be produced for each waiting room. This is unfavourable during a structure of model. Better it would be to let decide the user whether he would like to insert the same module or a new module with identical structure and parameter set into its model.

The implemented simulation could be implemented in the next step with realistic instead of fictitious data and times. Subsequently, the possibility of a comparison between both results is given. It is however improbable that further bottlenecks exist in the model. As a consequence the cognitions can be used for further investigations.

The simulation focus lay in this case on the time in interaction with available resources. Further investigations could follow here, which analyze for example the increase of resources from cost view. For this realistic costs of investigations and treatments would have to be available. These results could be confronted afterwards to the additional costs of further personnel and devices, in order to judge whether a resources increase is not only worthwhile itself from the temporal aspect.

Finally it must be referred that in this simulation model only patients with a uniform illness, the acute coronary syndrome, in the emergency admission arrive. The fact that within fewer minutes several patients with this diagnosis arrive is quite improbable. Therefore considerations can be met, as this simulation model can be arranged more realistic. For example the process step investigation could be extended and be determined afterwards on the basis the diagnosis posed the further procedure. Likewise the arriving patients could be assigned automatically to the different priorities, from which the urgency of a fast treatment results on the basis the symptoms. This procedure shows a more realistic emergency admission.

References

[1] Eisentraut, Katja: Abbildung und Simulation eines klinischen Prozesses mit dem MLDesigner am Beispiel des akuten Koronarsyndroms; 2004

ISSN: 1727-1983 © 2005 IFMBE