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ONLINE SIMULATION OF PEDESTRIAN FLOW IN PUBLIC BUILDINGS

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ABSTRACT

Online simulation of pedestrian flow in public buildings is a new tool which can be especially useful for improving the aspects of safety and short-term planning in the phase of organizing and operating large public buildings. These might be places such as a train station, an airport or a shopping center. This paper provides an insight into the different concepts of pedestrian flow simulation. Special emphasis is placed on explaining the mesoscopic approach as applied to the area of traffic simulation. This approach is transferred to the context of analyzing and predicting the pedestrian flow. A first prototypical implementation of a simulation supported control center is briefly presented, also.

1 INTRODUCTION

Shopping centers, train stations, airports and many other buildings and facilities are getting bigger and bigger and attract more and more people. These crowds have to be routed through the buildings in an efficient manner. Nowadays, besides the most important aspect of safety in the study of pedestrian flow in public buildings, other issues such as service level, comfort, advertising and short-term planning deserve closer attention.

The shape of a particular building has much to do with congestion and crowding and in this context the simulation of pedestrians as a tool of building design and long term planning is not new.

Much effort is put into counting the people at all imaginable places and transitions in the buildings and later into analyzing and evaluating the collected data. This, however, always happens offline and in retrospection on the things that have taken place already.

In summary, it can be said that until now, after the designing- and building-process, there is almost no simulation support in the subsequent phases of operating and organizing such large public buildings with high amounts of visitors in the form of pedestrians inside of them. This study, however, could greatly improve the above mentioned aspects of safety and short-term planning.

After a short project description in section 2, this paper will take a look at the different approaches known to be used to simulate pedestrian flow. Considering the various disadvantages of conventional methods section 4 describes the mesoscopic approach which is new to this particular topic but already know from the area of traffic simulation. Section 5 and 6 will shortly describe the integration of such a simulation into an existing infrastructure on the basis of a prototypical example. An outlook is given in section 7.

2 PROJECT DESCRIPTION

The goal of the project was to prototypically develop a simulation supported control center to observe and control the flow of pedestrians in large public buildings and facilities.

The simulation part should be embedded seamlessly and invisible. Invisible in the way that a potential control center user would not have to parameterize and start the simulation job. Furthermore, there should be no elaborate import and analyzing of the simulation output. As a matter of fact, the control center user should not even take notice of detail that there is constantly some kind of simulation support working in the background.

The main goal is to implement a so-called early-warning system which should foresee and advise about short-term problems regarding the respective flow of people in the near future.

The proposed workflow of the system looks as follows:

1. Simulation based prognoses of the prospective states and possible problems in the flow pedestrians.
2. Automatically generated notifications if predefined thresholds and limits are exceeded.
3. Selection of measures to proactively work against those possible problems in order to prevent them from happening.

4. Simulation based evaluation of the selected measures.
5. Execution of the selected measures.
6. Periodically, with a cycle time of 5 minutes, start the workflow with the simulation all over again.

There are different requirements that have to be fulfilled during the course of the project. As mentioned above, first developed as a standalone application, the system should later be integrated into an existing information system. The existing control center is a web-based geographic information system (GIS). The IT environment is given and has to be used. For each simulation run the model shall be initialized with real and up-to-date data and schedules. One of the main concerns is the run-time behavior of the simulation model and the result of that is the demand for short simulation computing times.

3 CONCEPTS FOR SIMULATION OF PEDESTRIAN FLOW

Simulation of pedestrian flow plays an important role in the project. The topic of modeling of pedestrian streams is not new and has been done for many years (Fruin 1971) and (Navin 1969). The previous focus was on modeling pedestrian streams in urban environments. In these earlier studies, the aim was to determine the dimension the parameters of walkways. Later the scope was extended to the field of emergency (Matsushita 1993). In the 90's the simulation of pedestrian streams was integrated in the simulation of intermodal transport facilities (Brill 1997). Nowadays, there exist quite a few different approaches for modeling pedestrian streams. Some of most important ones will be explained in the following section.

Macroscopic modeling approach: Models of this category describe pedestrian flows with differential equations. The approach is based on the idea that the movement of pedestrians can be handled analogous to fluids and gases. (Schreckenberg 2002, Helbing 1997).

Entity-based microscopic modeling approach: In this category every pedestrian is an entity in the model. Entities flow through a queuing system and their behavior is described with stochastic functions in general. This approach is very often applied to emergency scenarios with pedestrians.

Cellular Automata based microscopic modeling approach: In this approach the area under study is represented by a uniform grid of cells with local states depending on a set of rules, which describe the behavior of the pedestrians. These rules compute the state of a particular cell as a function of its previous state and the states of the adjacent cells (Blue 1998) and (Dijkstra 2000).

Multi-agent based microscopic modeling: The main components of this approach are agents and objects in the surrounding environment. Pedestrians are typically one kind of object and the environment is the physical area of the system including all the other objects. Pedestrians are characterized by their behavior in response to their environmental conditions and their neighboring agents' status (Jiang 1999).

Compared with the requirements of our project, each of these mentioned approaches has certain disadvantages. Macroscopic models are very useful in the simulation of physical movement of pedestrians in "large" streams. The computing times of microscopic models with thousands of pedestrians are very high for the simulation. However, the simulation in the project has to be executed in a very short time. This means the response time has to be very small.

Still, there is another reason for rejecting this quite common microscopic approach. Of course, the relevant outputs we need can be calculated with models of this category but for this particular project the input data and parameters of pedestrians can not be provided at the necessary level of detail.

The result of preliminary investigation was that the existing approaches in the modeling of pedestrian flows could not be used for our application scenario. So a decision was made to use a new approach which is some kind of a mixture of the macroscopic and the microscopic approach.

4 ON-LINE SIMULATION OF MESOSCOPIC PEDESTRIANS FLOW MODELS

4.1 Mesoscopic Modeling of Pedestrian Flow

The world of traffic modeling simulation has a lot of analogies to the modeling of pedestrian flows. Additionally, to the above mentioned approaches in this world exists an additional modeling category, the mesoscopic approach (Florian 2001). Figure 1 shows the classification of the mesoscopic approach in relation to the others. The mesoscopic category does not focus on single vehicles but it focus on groups of vehicles in an identical environment. For example, there is the same speed for all vehicles in the same section of the road and this could be considered a group.

The idea of grouping individuals was transformed to our mesoscopic pedestrian flow model. That means we do not model a single pedestrian but we use groups of pedestrians and every group has its own rules of behavior. The flow of a single pedestrian is integrated into a flow of pedestrian groups. This simplification is valid because one of the main interesting results from the simulation model is not the state of a single person but the number of persons in a particular area at time t.

The main components of our model are groups of pedestrians and an abstract network to represent the environment (see Figure 2). The groups are moving through the network. The network consists of nodes and links. Nodes are subdivided into sources, sinks and storages. Sources generate and sinks respectively destroy groups. Both of

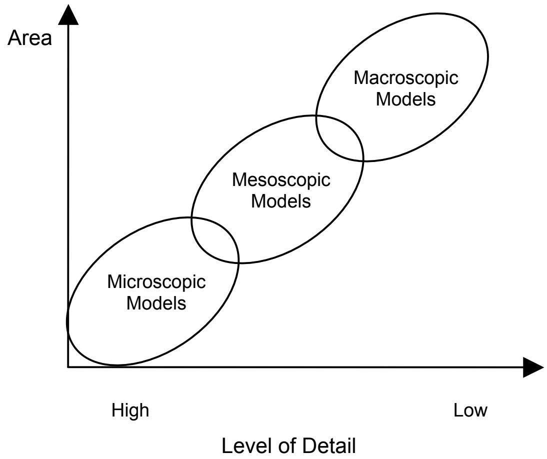


Figure 1: Relations of Traffic Modeling Approaches

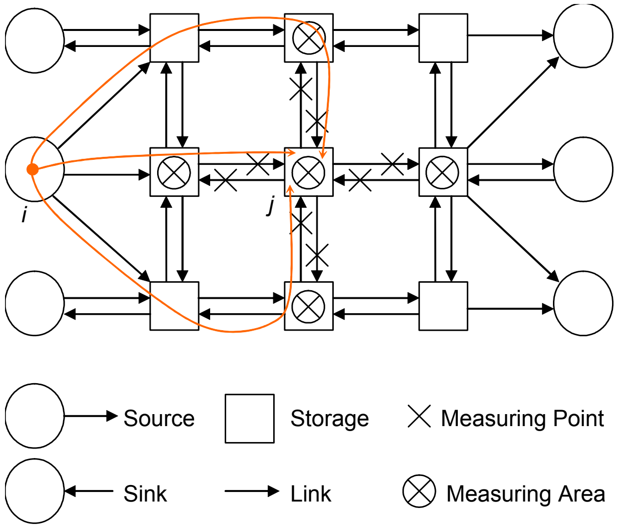


Figure 2: Abstract Network for Modeling Pedestrian Flow

these elements are boarder nodes of the network and they do not advance the pedestrian flow. Links describe the connections between the nodes.

A storage represents an area and this node can delay the pedestrian flow. Storages are basically internal resources in the environment which are used by pedestrians. Entrances and exits are two types of resources. They have a limited capacity for throughput of moving pedestrians. For example, a moving staircase has a smaller capacity of pedestrians per minute than a large door. Pedestrians can be delayed on these resources.

A station is another type of internal resource. This component is used for representing server processes, e.g., pedestrians have to pass a check-in facility where they have to show their tickets. Stations are characterized by their throughput (capacity) and they can advance the pedestrian flow too.

The behavior of a pedestrian group is always related to a storage. Every group has its own way through the storage. Inside a storage old groups can be split and new groups can be formed. The group "flows" through the different internal resources. Delays occur during the movement from one resource to another and during passing stations.

The calculation of moving time for one group between two resources works as follows. The group has to move from start resource *i* to the destination resource *j*. A distribution function determines probabilities for the moving time. The simulation time t is divided into k equidistant time intervals Δt. An example of such a distribution function is given in Figure 3.

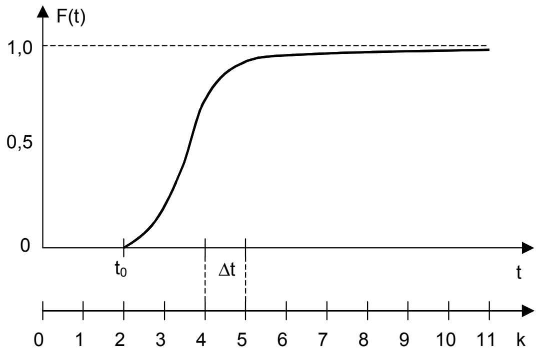


Figure 3: Distribution Function for the Moving Time

As mentioned before, the primary objective of the simulation model is to determine the quantity of pedestrians inside storages. The quantity q of the j-th storage at the end of the k-th time step is

$$q_{j,k} = q_{j,k-1} + inp_{j,k} - out_{j,k}\,, \tag{1}$$

where *inp* is the number of pedestrians that have arrived and *out* the number of pedestrians that have left.

The number of pedestrians that have arrived, *inp,* at storage j is

$$inp_{j,k} = \sum_{i\in I_j} inp_{i\to j,k}\,, \tag{2}$$

where $inp_{i\to j,k}$ is the quantity of pedestrians which arrive at the end of the k-th time step from other storages i on storage j. The quantity $out_{j,k}$ of pedestrians that have left is calculated in the same way.

Figure 4 demonstrates the calculation for the number of arrived pedestrians on storage j. There are three different arriving groups. Each group starts at different times from storage *i*.

The simulation model calculates at every time-step the quantity of pedestrians in every storage. Generally, the time-step is variable but for this case it is 60 seconds. Figure 5 shows the model of a very simple example. There are two different train tracks where pedestrian arrive.

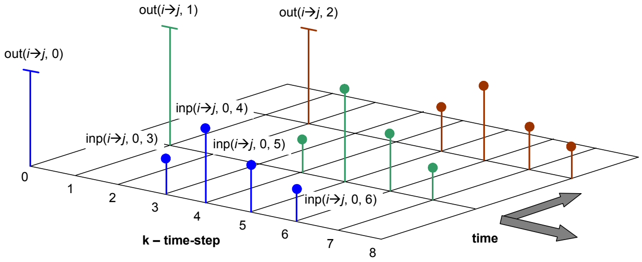


Figure 4: Calculation of Arriving Pedestrians

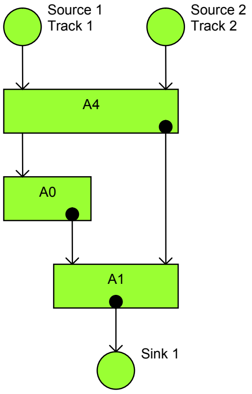


Figure 5: Simple Example of a Train Station

The arrival times are taken from predefined time tables. Pedestrians flow through the storages A4, A0 or A1 and finally leave the model in the sink. In these storages the delay is not only affected by moving times but also by the integrated stations that are marked as black circles in Figure 5. The calculated quantity of pedestrians (called Number of Pax) in these three storages during a forecasting horizon of 60 minutes is shown in Figure 6. The station inside storage A4 has a service rate of 20 Pedestrian per minute.

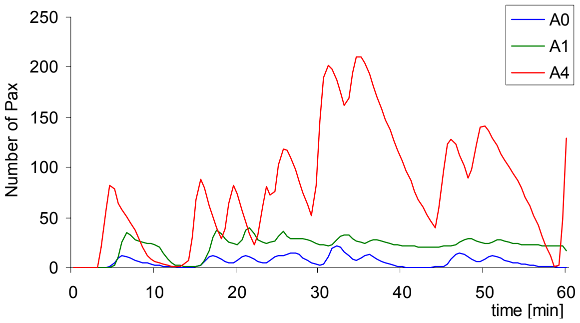


Figure 6: Example 1: A4 - 20 Pedestrians/min

Figure 7 shows another result of the simulation. The same model with exactly the same settings as before was used - the only thing that was changed is the service rate of the station in storage A4. It was increased from 20 Pedestrians/min to 40 Pedestrians/min. Obviously the storage A0 is not affected at all.

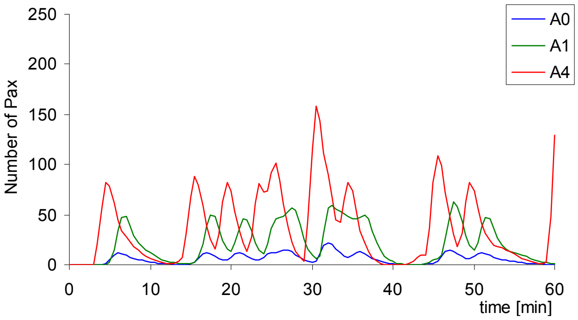


Figure 7: Example 2: A4 - 40 Pedestrians/min

4.2 On-Line Simulation

The simulation model is integrated into a decision support system. The model has to predict the state of the real system in near future times. If simulated outputs cross predefined thresholds then the decision system has to react. Possible crossings of the predefined and storage specific thresholds in future will be detected and the decision system can react in a proactive manner by generating and sending out notifications to the control center.

Naturally, the accuracy of the prediction decreases with an increasing forecasting horizon (see Figure 8).

This support system has to react to current changes in the real world and on changes that have been predicted by the simulation model. (See Figure 9)

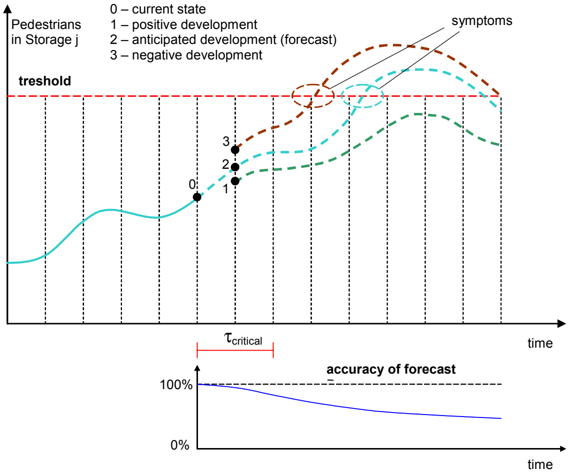


Figure 8: The Character of Forecasting with a Decreasing Accuracy

In addition, the control center including the simulation part has to work under real-time conditions. The given framework of the control center with a decision support system imposes special requirements for the simulation model so that it can be integrated into this framework. The workflow has already been described very shortly in section 2 and is now illustrated in some more detail in Figure 9.

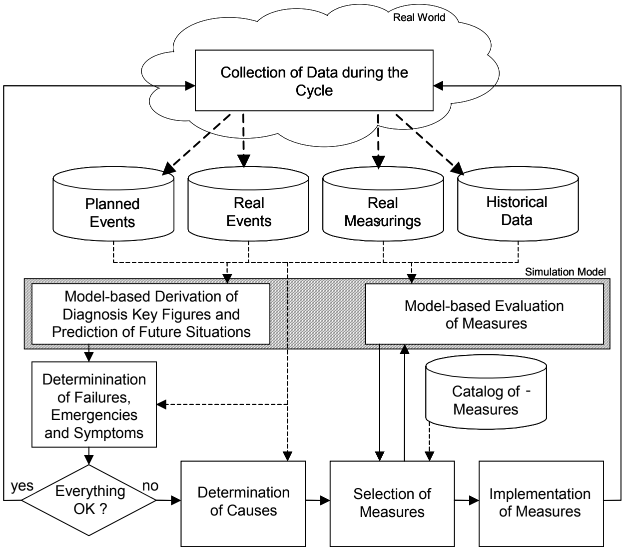


Figure 9: Model-Based Decision Support System

The simulation model must be connected on-line with the real world. This means every time the simulation starts, (see also section 5) the model must be initialized with the currents state of the real system. The second requirement is that the results of the simulation have to be obtained before a deadline occurs. The simulation engine must be fast enough to deliver the results in a short period of time so that the results can be used inside the decision process. Simulation models that fulfill these requirements are classified as on-line simulation models (Davis 1998). A typical application area for on-line simulation, some times called real-time simulation, is proactive decision support for scheduling problems in manufacturing systems (Gupta 2002, Chong 2002, and Glinsky 2002).

The simulation model must be connected with three different on-line and one off-line data sources. The first on-line data source is from actual measured data. This data will be recognized by special sensors. These sensors deliver real-time data about the intensity of pedestrian streams and the quantity of pedestrians in dedicated areas. This data will be used for initiating the simulation model.

The second on-line data source reflects scheduled events which influencing the pedestrian flow. Examples for such data are time tables with arriving times of trains or shift schedules for capacities of resources. This data are necessary for running the simulation and it will be updated by an information system. The third on-line data source are real-time events which have occurred but the effects have not been detected by the sensors. The following situation is an example for such events. A train arrived at the platform, pedestrians started their walk but the sensor is placed at the end of the walkway. The model has to consider these pedestrians although the sensors did not detect these pedestrians yet. The last data source, which has off-line character, offers historical information about behaviors of pedestrians in the respective the real system.

5 INTEGRATION OF THE SIMULATION MODEL INTO THE SYSTEM

Since the framework of the surrounding environment as well as the strict requirements for integrating the simulation part into the existing system are set already there is little scope to implement this task.

As mentioned in section 2, the simulation part has to be embedded seamlessly and invisible. All the surrounding components read and write their data from a central database and the same approach was used to integrate the simulation.

All the necessary information to parameterize and start a simulation run comes from special tables in the database and the results are written back to the database (compare Figure 9). The results are the number of people in a certain storage over a period of time.

This information can than be used in different ways. The most obvious usage is to just display this information in a demonstrative manner. The numbers, which are available as raw data, could be presented in every imaginable way e.g. line charts, bar charts or table.

After a successful simulation run another control center component could go over the results and check whether certain predefined limits of the respective building areas are exceeded. Again, the necessary information is taken from the database and is therefore highly up-to-date. For example, a construction site in the building which has been propagated to the control center naturally decreased the available area in the respective neighborhood of the working area and also decreases the number of permitted persons in this area. If the component which checks the simulation results against the limits finds such a described exceeding it would use the communication component of the control center to generate and spread a notification message to the systems that are connected.

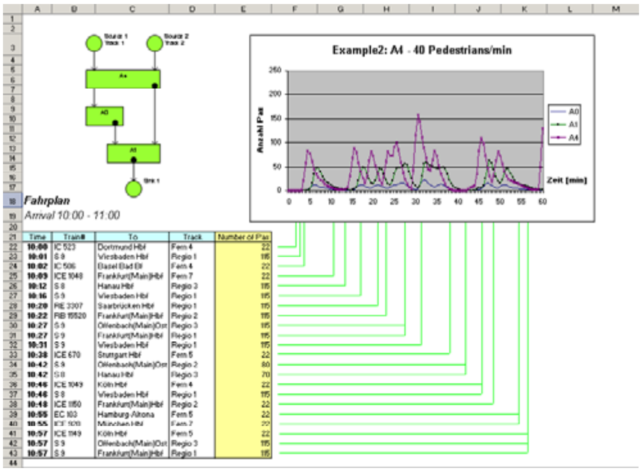
The above described application flow would periodically run. The time between two of these runs could be either constant or variable.

6 PROTOTYPICAL EXAMPLE

A prototype of the above described control center with an embedded online simulation of pedestrian flow in public buildings, which includes a mesoscopic simulation model has been set up at the Fraunhofer Institute of Magdeburg.

Currently the simulation model is implemented with VBA (Visual Basic for Application) in Microsoft Excel and all the necessary parameterization is done in Excel too (see Figure 10).

After a successful simulations run the results are taken and imported into a Microsoft Access database. This database is the foundation for the control center shown in Figure 11. This control center is a web-based GIS platform where the CAD (computer-aided design) files of a building are accessible through the web browser. All the standard



Fahrplan

Arrival 10:00 - 11:00

Time	Train#	To	Track	Number of Pax
10:00	IC 523	Dortmund Hbf	Fern 4	22
10:01	S 9	Wiesbaden Hbf	Regio 1	115
10:02	IC 506	Basel Bad Bf	Fern 4	22
10:09	ICE 1048	Frankfurt(Main)Hbf	Fern 7	22
10:12	S 8	Hanau Hbf	Regio 3	115
10:16	S 9	Wiesbaden Hbf	Regio 1	115
10:20	RE 3307	Saarbrücken Hbf	Regio 1	115
10:22	RB 15520	Frankfurt(Main)Hbf	Regio 2	115
10:27	S 9	Offenbach(Main)Ost	Regio 3	115
10:27	S 9	Frankfurt(Main)Hbf	Regio 1	115
10:31	S 9	Wiesbaden Hbf	Regio 1	115
10:38	ICE 670	Stuttgart Hbf	Fern 5	22
10:42	S 9	Offenbach(Main)Ost	Regio 2	80
10:42	S 8	Hanau Hbf	Regio 3	70
10:46	ICE 1049	Köln Hbf	Fern 4	22
10:46	S 8	Wiesbaden Hbf	Regio 1	115
10:48	ICE 1150	Frankfurt(Main)Hbf	Regio 2	22
10:55	EC 103	Hamburg-Altona	Fern 5	22
10:55	ICE 920	München Hbf	Fern 7	22
10:57	ICE 1149	Köln Hbf	Fern 5	22
10:57	S 9	Offenbach(Main)Ost	Regio 3	115
10:57	S 9	Frankfurt(Main)Hbf	Regio 1	115

Figure 10: Standalone Simulation Model

CAD functionality such as zoom, pan and select is available. Different layers, that usually show different thematically separated parts of the building structure and layout, can be turned on and off.

According to the simulation results and additional information about the different area accessible to pedestrians the layers can then be colorized. With the help of a colorized time table, illustrated on the very right in Figure 11, the user can now select a certain time of the forecast horizon and can then see the forecasted state of the respective rooms and areas in the building. Instead of showing just plain numbers or diagrams we decided to use the color scheme of a traffic light – here: red, yellow and green. In the prototype, quite obviously, green means that the density of people or pedestrians in the respective area is within normal limits. Yellow means that is this number is above average and respectively the color red means that a predefined threshold for the number of people in this area has been exceeded. This will also result in a notification message and in reality the workflow illustrated in Figure 9 would start in order to trigger special measures to prevent these possible future problems from happening.

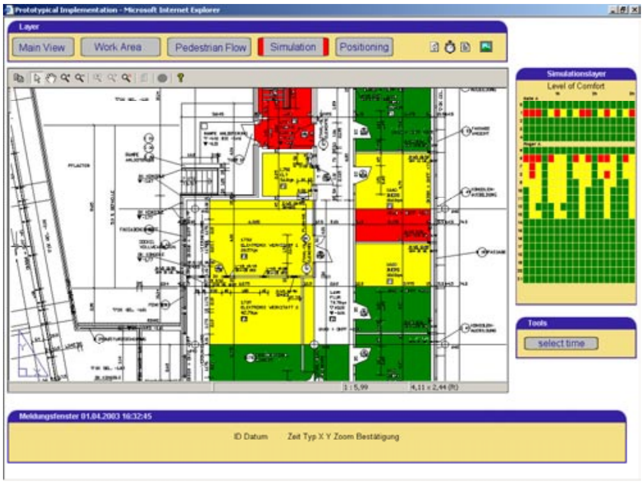


Figure 11: Web-Based Control Center with the Activated Simulation Layer

7 OUTLOOK

The paper has discussed the use of mesoscopic on-line simulation of pedestrian flows inside a control system. The workflow for this task covers six sub-processes. The computer based support for theses sub-process is not yet complete and in the current stage of the prototype there are still a lot of data import- and export-functions that need manual intervention. The next task in the project will be to extend the computer support and to create a smoother integration of the stand alone simulation.

Another future task will be the integration of portable user devices called PDA (production data acquisition) into the system. The decision system will be extended to such wireless devices and the simulation results have be specially prepared and formatted for this task.

Finally the experiences gained from the work on this particular project have to be generalized so that the approach of mesoscopic on-line simulation of pedestrian flows can be used and transferred to other projects which are related to controlling pedestrian flows in public buildings.

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