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Summary. This paper presents the validation of an office utilisation model for the research project called "User Simulation of Space Utilisation (USSU)". The result of this research is a system that can be used for analysing and evaluating the space utilisation of a building for any given organisation. A system for building usage simulation that produces data about activities of members of an organisation can substantially improve the relevance and performance of building simulation tools. This is relevant for engineering domains as well as for architects to evaluate the performance of a building design. For a thorough evaluation of the system an experiment was executed for assessing its predictive quality in the context of a real building, organisation and actual human behaviour; this experiment was executed using RFID technology. The result of the experiment was observed data about the space utilisation of the selected organisation. This data set was compared with the space utilisation predicted by the USSU system to evaluate the simulation model. The validation of USSU showed that there were no significant differences between the predicated and observed activity behaviour. As a consequence, the output of USSU is considered to be valid.

1 Introduction

Activity and location schedules are input for office utilisation simulations. These schedules however, are often assumptions rather than based on measured observations and resulting descriptive and predicting models. Thus, the results of such simulation systems are tentative at best and may often be misleading. Therefore, a more advanced scheduling method is needed that adequately represents real-life complexity of human activity and location schedules. The main objective of the research project User Simulation of Space Utilisation (USSU) was to develop a system that can be applied for analysing and evaluating the space utilisation of a building for any given organisation. The system generates activity schedules that provide a representation of human activities that are executed in building spaces. An activity schedule not only describes which activities are performed and at which location, but also the route that is followed between the locations of these activities. These activity schedules are a source of dynamic input data for building usage simulation tools. Reliable data on human movement is scarce. It is valuable input for several research areas. For instance, the relevance and performance of building simulation tools like indoor climate simulations or working conditions assessments will substantially improve when realistic input data is applied. If reliable human movement models can be created, then these models can not only be used to analyse existing situations, but also to simulate new building designs taking the digital design as input. This is also relevant for architects to evaluate the performance of a building design.

USSU models the scheduling behaviour of employees following their heuristics. The proposed scheduling method is not producing schedules for planning purposes based on an optimisation method. Neither, does the scheduling method try to find the optimum activity schedule for instance with regard to the priority of its activities. The goal of the scheduling method is to mimic the behaviour of real human beings when scheduling activities [1].

USSU serves as a pre-processor for other simulation systems that need real-life data about the location of persons at a specific time, such as indoor climate calculations, evacuation simulations and working condition assessment simulations. The underlying model integrates activity modelling and workflow modelling constrained by spatial conditions of a building [2]. The combination of these two methods provides a solid basis that ensures process consistency, inclusion of individual (re)scheduling behaviour and allows execution in compressed time intervals. With this model, space utilisation can be simulated at a high level of realism instead of make assumptions as usual in many building simulation systems. This is possible through the incorporation of human activities as they are executed in real life, split up into skeleton activities (i.e. workflow dependent activities) and intermediate activities (i.e. social and/or physiological activities). Scheduling of activities is executed under bounded rationality. Persons are only aware of their own agenda which evolves in compressed time.

The scheduling method can accommodate real-life complex organisational structures and maintains consistency between the activity schedules. Most existing approaches to model activity schedules assume an individual-based decision making process. These models do not take into account the interaction between individuals. A special feature of the USSU system is the incorporation of interactions between activities (e.g. meetings). The interaction between activities contributes significantly to the realism of the activity schedules.

The final step in this project was to validate the system. For a thorough evaluation of the system an experiment was performed using RFID technology. The goal of this experiment was to collect data for assessing the predictive quality of USSU in the context of a real building, organisation and actual human behaviour. The experiment resulted in observed data about the actual space utilisation of a chosen organisation. The observed data was compared with the space utilisation predicted by USSU to evaluate its predictive quality. This paper focuses on the validation approach and observation method selected with regard to the validation of USSU.

2 Validation approach

For the validation of USSU a specific existing organisation and a building was used, namely two chairs in our Faculty which are located on the same floor. The validity of USSU was determined by comparing predicted space utilisation with observed space utilisation. Activity schedules predicted by the USSU prototype were compared with activity schedules observed in the real world. To assess the validity of the system the predicted space utilisation was compared with the observed space utilisation on a set of performance indicators, so-called criterion variables. These criterion variables (e.g. the usage of facilities or movement behaviour of employees) specify the aspects on which the comparison of the observed and predicted activity schedules was performed. The values of the criterion variables were derived from both the predicted and observed activity behaviour of all employees. The following criterion variables were chosen:

- Zone utilisation.
- Mean walking distance of employees.

These criterion variables are discussed below.

2.1 Criterion variables

The first criterion variable relates to the amount of time a zone on the test floor is used during a working day, either observed in the real world or simulated using USSU. The zone utilisation is a proportion of the total simulated or observed time. It is calculated by dividing the total time a zone is used by the total simulated or observed time. In formula:

$$P_x = \frac{T_x^{zone}}{T_s}, \quad T_x^{zone} = \sum_{i=1}^{n_x} \Delta T_{a_{x,i}} \qquad (1 \,\&\, 2)$$

where:

P_x	is utilisation of zone x for an average working day
T_x^{zone}	is total time zone x is used during simulation/observation
T_s	is total simulated or observed time
$a_{x,i}$	is activity a_i using zone x
$\Delta T_{a_{x,i}}$	is duration of activity $a_{x,i}$
n_x	is total number of activities using zone x

The second criterion variable examines the movement behaviour of employees. The activity schedule of an employee reveals the required movement behaviour as a result of its activities. First the total walking distance for all simulated or observed days is calculated as follows:

$$W_e^{total} = \sum_{i=1}^{m} W_e^{day}, \quad W_e^{day} = \sum_{i=1}^{n-1} L_{[a_{e,i}, a_{e,i+1}]} \qquad (3 \,\&\, 4)$$

where:

W_e^{total}	is total walking distance of employee e for all work days
W_e^{day}	is total walking distance of employee e for one work day
m	is total number of simulated or observed working days
$L_{[a_{e,i}, a_{e,i+1}]}$	is length of route between location of activity $a_{e,i}$ and location of activity $a_{e,i+1}$
n	is number of activities in the activity schedule for a work day

Next, the mean walking distance of an employee on a work day is calculated:

$$W_e^{mean} = \frac{W_e^{total}}{m} \tag{5}$$

where:

W_e^{mean} is mean walking distance of employee e for a working day

2.2 Goodness-of-fit

The goodness-of-fit was measured using a combination of the following two tests, namely:

- Student's *t*-test for paired samples combined with a correlation coefficient determination.
- Variability test.

Although, the variability test is not a standard statistical test it gives further insight in the differences between the observed and predicted sets of data. The smaller the variability is (i.e. the closer it gets to zero) the better the match between the two data sets, e.g. the observed and predicted activity behaviour. The variability can be calculated using the following formula:

$$v^2 = \frac{\sum_{i=1}^{n} (s_{c,i} - o_{c,i})^2}{n} \tag{6}$$

where:

v^2 is variability

$s_{c,i}$ is predicted value i of the criterion variable c

$o_{c,i}$ is observed value i of the criterion variable c

n is the number of observations

3 Observation method - RFID

A relative new technology called RFID (Radio Frequency Identification) could be the key for a non obtrusive way of collecting data about human movement and activity behaviour. Using this system, participants only have to carry a small device and the RFID system automatically registers their movements. During the observation period participants themselves do not have to perform any additional actions besides performing their normal activity behaviour. Due to the passive nature of this system the behaviour of people is only influenced in a limited manner and probably only the most in the beginning of the experiment. This system results in observed data about the daily movement behaviour with a relative high degree of precision.

An RFID system consists of readers and tags. An RFID tag is a device which can be remotely accessed to retrieve data stored in its chip. Each tag is equipped with an antenna to receive and respond to radio-frequency queries from an RFID reader. There are two types of RFID tags: passive and active tags. Passive tags do not have an internal power supply; the power required to transmit a response is induced through the incoming radio-frequency signal. These tags can only be read out from short distances (up to several meters). However the active tags can have a read distance of up to several hundreds of meters. Therefore these tags are equipped with an internal power source. An active RFID tag will send out a signal for example every 1.5 seconds. The battery of these tags last up to 5 years. In this experiment the active tags were applied in combination with a number of readers. Currently, RFID technology is used by some Dutch organisations for access control and as a means of working hours registration, but up to now never on the detailed level as it was used in this experiment.

All employees working on the test floor were asked to participate in the RFID experiment. Roughly 50 employees are officially located on this floor. In the end 37 persons accepted the request. Each person was asked to wear a RFID tag for a period of 3 months. On the office floor 16 receivers were installed. The placement of readers was such that the real movement behaviour of the employees could be tracked throughout the whole floor.

In 46 days the RFID system recorded about 360,000 events; each event relates to one of the 37 participants entering or leaving one of the RFID zones. These events had a total duration of more than 32,000 hour.

When the data collected in the RFID experiment was compared with the predicted space utilisation attention had to be paid to the way in which the activity behaviour is collected. Although the USSU system predicts space utilisation on the level of (parts of) building spaces, in the RFID experiment the space utilisation was observed on level of sets of spaces, called zones. The main reason for this was that it proved to be too costly to equip each space with an RFID reader. To be able to compare the observed space utilisation with the predicted space utilisation, the predicted data had to be aggregated to allow for comparison and hence model validation.

4 Validation results

This section discusses the results of the validation. First the results of the validation with regard to the zone utilisation criterion variable are discussed. Then, the validation results related to the second criterion variable (i.e. movement behaviour of employees) are treated.

4.1 Zone utilisation

Table 1 indicates a strong correlation between the predicted usage of zones (USSU) and the observed usage of zones (RFID); this result is significant at 0.05 level. As a consequence, it was allowed to perform a paired samples *t*-test. The paired samples *t*-test for the zone utilisation shows a powerful outcome (Table 1). Consequently, the null hypothesis could not be rejected. In other words, there were no significant differences between the predicted (USSU) and observed (RFID) usage of zones. This rather strong outcome of the *t*-test was further emphasised by the variability test. The results of this test also indicate negligible differences between the USSU and RFID data sets with regard to the utilisation of zones.

Table 1. Validation results for the usage of zones.

Criterion variable	Correlation coefficient		Paired-samples *t*-test		Variability	
	r-value	*P*	*t*-value	*P*	value	std. dev.
Zone utilisation	0.77	0.01	0.00	1.00	0.00	0.00

4.2 Employees

Not only did the RFID tracking system store the amount of time an individual was in a certain zone, it also stored the routes which were followed between the RFID zones. This meant that the data collected in the RFID experiment could also be used to validate USSU on the level of human movement behaviour, in particular the mean walking distance per employee.

Table 2 shows the correlation coefficient between the USSU and RFID data sets in relation to the mean walking distance. The correlation coefficient was significant and indicated a strong link between the two data sets. The results of the paired samples *t*-test for the mean walking distance were significant (Table 2). This meant that for this criterion variable the null hypothesis could not be rejected. With regard to the mean walking distance there were no significant differences between the two data sets. Finally, the variability test also suggests only minor differences between the two data sets with regard to movement behaviour (Table 2).

Table 2. Validation results for movement behaviour of employees.

Criterion variable	Correlation coefficient		Paired-samples *t*-test		Variability	
	r-value	*P*	*t*-value	*P*	value	std. dev.
Time percentage	0.70	0.04	1.62	0.14	0.05	0.08

5 Discussion

The validation of USSU showed that there were no significant differences between the predicted and observed activity behaviour. This is further emphasised by that fact that all statistical tests (i.e. Student's *t*-test, correlation coefficient and variability test) supported each other and pointed in the same direction. As a consequence, the output of USSU is considered to be valid. In other words, USSU can be used to accurately predict the space utilisation of an organisation (at least when applied within the limitations set for this project).

RFID technology allows for a non obtrusive way of collecting data about human movement. Participants of the experiment only had to carry a small RFID tag, for instance in their wallet, and the RFID system automatically registered their movements using a number of strategically placed readers. The RFID system made it possible to track the movements of all participants across the floor and thereby collecting data about the real movement behaviour of the participants.

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