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# Knowledge Modeling for Performance Measurement of Built Environment

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**ABSTRACT**

Buildings undergo frequent changes, but very little is known about the effect of these changes on building's performance. As a case study, an underground station in the Netherlands is considered. In May 2000 a questionnaire regarding the perception of *public safety* and *comfort* at Rijswijk underground train station was developed and distributed. In total 246 responses were used for knowledge modeling. Knowledge modeling was done using a neuro-fuzzy system, and sensitivity analysis was used to elicit knowledge from the knowledge base.

Before July 2006 some design changes followed. In July 2006 the same questionnaire was handed out to measure the effect of the changes. In this paper, first a brief description of the station and of the studied aspects is provided. Thereafter, the results from the year 2000 and 2006 will be compared and the effect of the changes on the overall perception of public safety and comfort will be highlighted.

**Keywords: Knowledge modeling, Neuro-fuzzy system, Sensitivity analysis, Performance measure.**

## 1. RESEARCH BACKGROUND

Buildings undergo frequent changes. Either the delivered performance of a building is not satisfactory, and therefore the improvements are necessary for satisfactory use, or a building's user has changed a user and therefore a set of new requirements appeared. In this work we deal with the first case, since many buildings fail to meet the required performance and after a short period of utilization are subject to 'improvements'. Unfortunately, many projects and issues related to their successful or unsuccessful use remain hidden knowledge available only to a few directly involved or affected by it. This slows down the learning curve of the building industry. The first issue is that the evaluation of a building in use happens rarely. Secondly, when the changes happen, those are again *ad hoc* without comprihensive consideration of the possible effects of these changes. A little is known beforehand whether a decision made was a correct one and whether by changing perhaps another aspect a more desirable effect could be achieved. And finaly, after a change is made, there is no systematic method for establishing the effect of change on building performance.

As a case study, an underground train station in the Netherlands is considered. Rijswijk train station is a so-called linear station, meaning that there is only one train level without any interchange areas. The main entrance is located on a large square, and the only visible aspect that suggests the presence of a train station (Piramideplein) is the glass pyramid (*figure 1.1*). The other entrance is at Churchilllaan, and its sides are also made out of glass to provide enough daylight at the entrance (*figure 1.2*). The station is situated in a quiet area of Rijswijk, with mainly housing and offices nearby. Although the large shopping center is close to the station, this station remains isolated, with a few visitors during day and night time, with the exception of the rush hours (Durmisevic, 2002).

**Figure 1.1 and 1.2** Main entrance (left) and second entrance (right)

The train platforms are very long, and the two entrances mentioned earlier are placed at the far ends of the platforms (*figure 1.3 and 1.4*).

**Figure 1.3 and 1.4** Entrance to the platform (left) and a view of the train platform (right)

In May 2000 a questionnaire regarding the perception of public safety and comfort at Rijswijk underground train station was developed and distributed. In total, after consistency and data quality analysis, 246 responses were used for knowledge modeling. In 2004/2005 some design changes followed. These changes were:

- placement of additional artificial lighting at underground train platforms (to increase the overall lighting);
- placement of safety fences next to the stairways (to avoid accidents if one uses the elevators placed behind the stairs);
- placement of hand-supports on the original benches at train platforms (mainly to discourage homeless people from sleeping on the benches).

Next to these changes it is also important to note that:

- due to poor drainage the station had frequent problems with unpleasant odour, and numerous stains on the walls and floor appeared; both of these issues were not the case in 2000;
- the number of trains (especially fast trains) passing through the station increased as well in 2006, and further increase of train traffic can be expected in the future;
- in 2000 the trains stopped close to the main entrance (Piramideplein) and in 2006 the trains stoped in the middle, between two exits, meaning that no matter which entrance was used quite a long distance must be walked before reaching a place where the train actually stopped;
- a shop (small supermarket) in the main entrance of the station reduced its opening hours; in 2000 the shop was open until 10 pm and was open also during the weekend, while in 2006 the shop was open until 6 pm and was closed on Sunday;
- changes happened in the surrounding as well; the main library building moved from the Piramideplein entrance to the Churchilllaan entrance and additional buildings were built next to the Churchilllaan entrance (offices, hotel and an apartment building). Next to the Piramideplein entrance some housing blocks were demolished to make place for new housing (this is still under construction).

In July 2006 the same questionnaire was handed out. In total 303 questionnaires were used for knowledge modeling. The determinants which are identified to be most presumably related to comfort are given in *table 1.1* and those related to safety are presented in *table 1.2* (Durmisevic et al., 2001a). During knowledge modeling these dimensions are studied together so that the unexpected relationships between all aspects are taken care of as well.

**Table 1.1** Aspects related to comfort (25 aspects).

| Attractiveness | Wayfinding | Daylight | Physiological |
|---|---|---|---|
| color | to the station | pleasantness | noise |
| material | in station | orientation | temperature winter |
| spatial proportions | placement signs | | temperature summer |
| furniture | number of signs | | draft entrance |
| maintenance | | | draft platforms |
| spaciousness entrance | | | ventilation entrance |
| platform length | | | ventilation platforms |
| platform width | | | |
| platform height | | | |
| pleasantness train plat. | | | |
| pleasantness entrance | | | |
| | | | |

**Table 1.2** Aspects related to safety (11 aspects).

| Overview | Escape | Lighting | Presence of people |
|---|---|---|---|
| Pillars and overview | possibilities | entrance | public control |
| entrance | distances | train platform | few people daytime |
| train platform | | dark areas | few people night |
| | | | safety in surrounding |

Further in the text, a brief description of knowledge modeling will be given followed by cross-data analysis.

## 2. KNOWLEDGE MODELING

As it can be seen in *table 1.1* and *1.2* the data at hand is qualitative. This implies that special techniques, able to deal with the 'soft' data, are required. In this work a combination of an Artificial Neural Network and Fuzzy Logic is applied for knowledge modeling. This needs some further explanation.

In a complex information environment, to establish the complete fuzzy rules dealing with the knowledge base is a formidable task. To alleviate the problem, the knowledge base can be formed in a distributed and structured form by means of learning so that the structure so formed represents the fuzzy expert system altogether with the consistent rules in any complexity. Here the main task for consistent rules is to carry them out by means of a learning process, which should be specially designed for this purpose. The accomplishment of this structure can be achieved by means of a network operating with fuzzy computational units. Such structure can be a radial basis function network (RBFN). The general characteristics of such network are rather diverse and comprehensive with sound mathematical foundations. On one side they can be considered as multivariable multifunctional approximators using basis functions (Broomhead and Lowe, 1988) with functional interpolation and extrapolation capabilities. On the other side they are equivalent to fuzzy logic systems under some lenient conditions (Roger, 1990; Hunt, 1998). Due to these properties, conversely fuzzy logic systems can be used as universal approximators (Kosko, 1994; Wang, 1994). The general structure of a RBFN is shown in *figure 1.5*.

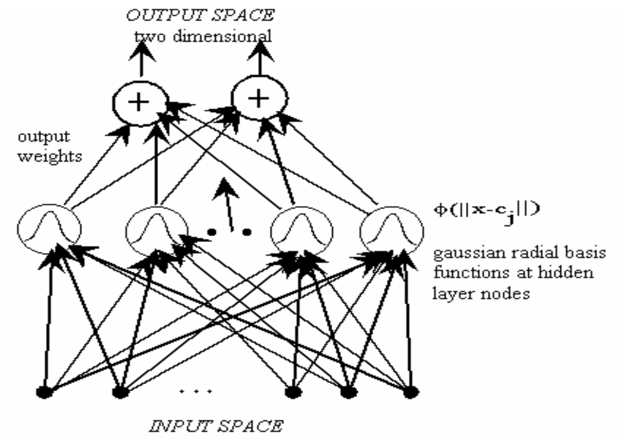


**Figure 1.5** Radial basis function networks for knowledge modeling

Without loss of generality, the number of outputs in the network can be extended to a multi-output case. This is the case with an example explained later in this paper, where there are two dimensions at the output space (comfort and public safety). The network architecture consists of an input layer, a hidden layer and an output layer. The hidden layer consists of a set of radial basis functions as nodes. Each node has a parameter vector **c** defining a cluster center dimension which is equal to the input vector. The hidden layer node calculates the Euclidean distance between the center and the network's input vector. The distance calculated is used to determine the radial base function output. Conventionally, all the radial basis functions in the hidden layer nodes are the same type and usually gaussian. The response of the output layer node(s) can be seen as a map $f: R^n \rightarrow R$, of the form

$$f(\mathbf{x}) = \Sigma\, w_i\, \Phi(||\mathbf{x} - \mathbf{c}_i||)^2$$

Here the summation is over the number of training data N. $\mathbf{c}_i$ (i=1,2,….N) is the i-th center which may be equal to the input vector $\mathbf{x}_i$ or may be determined in some other way. Once the basis function outputs are determined, the connection weights from hidden layer to the output are determined from a linear set of equations. As a result, accurate functional approximation is obtained. The complexity increases as the size of the training data increases. For a large data set, this may become unpractical, and therefore it is desirable to use limited number of hidden layer nodes in place of having a number equal to N.

The mathematical model employed is a multivariable functional approximation structured in a neuro-fuzzy knowledge representation form. The advantage of such structure is that the knowledge can be effectively modelled by such system with appropriate learning strategy.

Such a form is compatible with a fuzzy logic structure as the radial basis functions play the role of fuzzy membership functions (Cios et al., 1998) and the output is a fuzzy decision-making based on the soft (fuzzy) architectural design data. In particular, the machine learning method used is the orthogonal least squares (OLS) method (Chen et al., 1991), which is the essential requirement to use for machine learning in this particular knowledge modelling research (Durmisevic, et.al, 2001b).

Having finalized the knowledge modelling, the sensitivity analysis is carried out. The sensitivity analysis is a method used for determining the dependency of the output of a model on the information fed into the model. In other words, sensitivity analysis "studies the relationships between information flowing in and out of the model" (Saltelli, et. al., 2000). The method is well explained in the literature and therefore will not be further discussed in this paper, except the results obtained by sensitivity analysis.

## 3. CROSS-DATA ANALYSIS

As it has been earlier mentioned, the questionnaire dealt with aspects listed in *table 1.1* and *table 1.2* and the same questions were posed in 2000 and 2006 in order to observe the effect of change regarding the perception of public safety and comfort.  The data obtained from the questionnaires is separately modeled by neuro-fuzzy system. There are in total 36 aspects at the input level (table 1.1. and 1.2.) and two at the output level (public safety and comfort). The number of nodes used for the training is in both cases set to 80. The *figures 1.6* and *1.7* are the training results for the data obtained in 2006. For the purpose of model consistency, the knowledge modeling procedure was the same for the data obtained in 2000 and 2006. Some optimization of the training could be done, since there are rather few data for comfort for the range 0.9, and exclusion of 0.9 data sets for comfort could lead to better model performance and could decrease a model error.

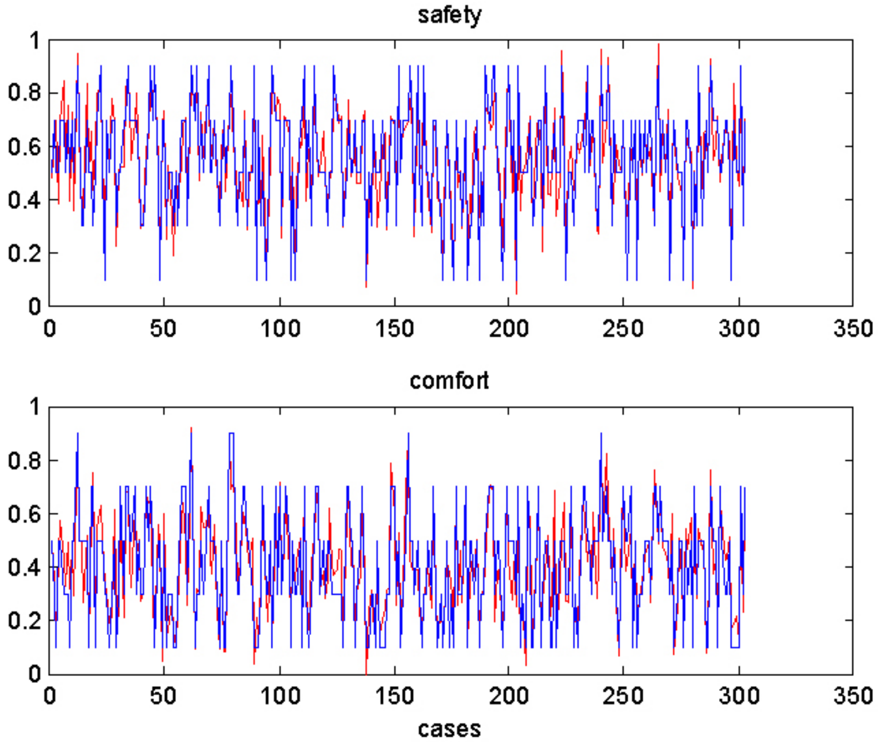


**Figure 1.6 and 1.7** The training results for range 0.1-0.9 with 80 hidden nodes

Using the established knowledge model the relative dependency of the input variables on comfort and public safety is identified by means of sensitivity analysis (Bhatti, 2000). Here, based on the knowledge model, the gradients of comfort and public safety with respect to each variable in the input space are computed. As was earlier mentioned, the sensitivity analysis is a method used for determining the dependency of the output of a model on the information fed into the model. The 36 aspects represented in *figures 1.8* and *1.9* correspond to aspects list in *table 1.1* and *1.2*. In *figures 1.8* and *1.9*, the variables are listed on the 'x' axis, and the actual numerical readings are given on the 'y' axis. Comparing two figures, the obvious change of the priorities can be observed for different year periods.

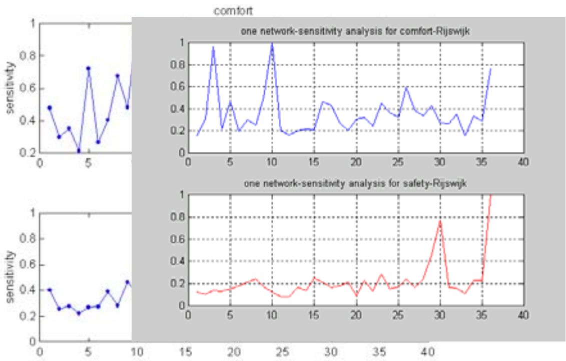


**Figure 1.8 and 1.9** The sensitivity analysis for comfort and public safety (left figure are the results of year 2006 and the right figure are from 2000)

The *table 1.3* shows the hierarchical order for the first five most sensitive aspects to safety and *table 1.4* to comfort.

**Table 1.3** The hierarchical order of sensitivity analysis results for safety for Rijswijk station for the year 2000 and 2006

| **Hierarchical order 2000 for safety** | **Hierarchical order 2006 for safety** |
|---|---|
| 1.safety in surrounding | 1. safety in surrounding |
| 2.few people during night | 2. pleasentness daylight |
| 3.few people daytime | 3. few people daytime |
| 4.ventilation of entrance | 4. placement of direction boards |
| 5. number of signboards | 5. noise |

**Table 1.4** The hierarchical order of sensitivity analysis results for comfort for Rijswijk station for the year 2000 and 2006

| **Hierarchical order 2000 for comfort** | **Hierarchical order 2006 for comfort** |
|---|---|
| 1. pleasantness train platform | 1. pleasantness train platform |
| 2. spatial proportions | 2. maintenance |
| 3. safety in surrounding | 3. platform width |
| 4. overview of entrance area | 4. placement of direction boards |
| 5. platform height | 5. pleasentness daylight |

Based on the results of sensitivity analysis, and the comparison of the average grades for the year 2000 and 2006, it is possible to measure the effects of changes on the performance regarding public safety and comfort.

The changes had an effect on both public safety and comfort. The respondents were asked to answer one question in the questionnaire about how safe they felt at the station. In *Table 1.5,* the general perception of public safety of all respondents is given.

**Table 1.5** Perception of public safety in 2000 and in 2006

| | **Rijswijk 2000** | **Rijswijk 2006** |
|---|---|---|
| Very unsafe | 7,6% | 6,8% |
| Unsafe | 14,9% | 14,0% |
| Neutral | 35,7% | 34,0% |
| Reasonably safe | 32,5% | 35,0% |
| Very safe | 9,2% | 10,0% |

The perception and feeling of one's comfort in an underground station can be influenced by the built environment as well. The respondents were also asked to answer a question about how pleasant or unpleasant they felt at the station. In *table 1.6* the general perception of comfort of all the respondents is presented.

**Table 1.6** Perception of comfort in 2000 and in 2006

| | **Rijswijk 2000** | **Rijswijk 2006** |
|---|---|---|
| Very unpleasant | 6,8% | 20,3% |
| Unpleasant | 15,7% | 27,7% |
| Neutral | 37,8% | 33,4% |
| Reasonably pleasant | 34,5% | 16,3% |
| Very pleasant | 5,2% | 2,25 |

The *figure 1.10* gives the average grades for public safety and comfort. Comparing the average grades, a 10% increase in the perception of public safety is observed while at the same time a 10% decrease in the perception of comfort is observed.

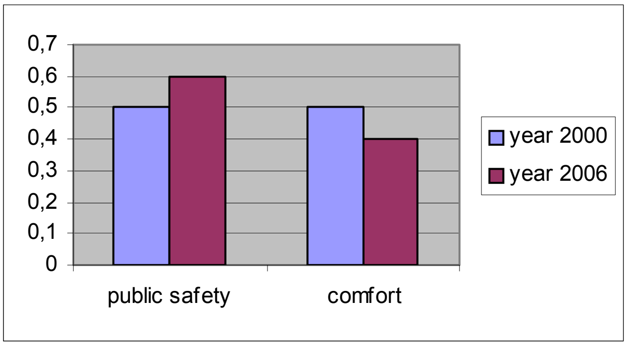


**Figure 1.10** The average grade for public safety and comfort for the year 2000 and 2006

A better evaluation of public safety in 2006 is most presumably due to the accumulated effect. The aspects which were changed were in the top 9 most sensitive aspects which came out as a result of the study in 2000. There were changes/improvements in the surrounding of the station, which was and still remains the most sensitive aspect to public safety. Aspect of safety fence was 6th in the hierarchical order of sensitivity analysis, which was also considerably improved. And finally, the lighting condition at the station was changed, which was on the 9th place in the hierarchical order.

On the other hand, none of the aspects related to comfort were significantly improved. Many aspects related to comfort received mainly lower grade in 2006 than in 2000. The main drawback was the maintenance issue related to drainage problem and bad odor at the station. Not much was done to improve the pleasantness of the train platform, except the improved lighting condition. The study showed that this aspect had more effect on the perception of public safety than comfort. Major drawbacks of comfort related issues are the ventilation of the platforms, use of color and materials, long walking distance from trains to exits, the insufficient amount of direction boards and their incorrect positioning.

## 4. CONCLUSIONS

The neuro-fuzzy structures are well-known and used in engineering and applied sciences, since they are especially suitable for data from exact sciences. In contrast to that, the data from soft sciences, including architectural data as well are mostly linguistic and intuitive rather than exact. In this respect, the approach employed presents novelties in two aspects. Firstly, considering the linguistic nature of the architectural data, fuzzy logic techniques are invoked. Secondly, knowledge is modeled by machine learning methods so that the complex data is structured automatically without use of domain knowledge explicitly. Domain knowledge plays an important role in providing the underlying information, which is subject to modeling. Such a model is supposed to be generic and robust enough for design in the domain of concern.

Using neuro-fuzzy system together with the sensitivity analysis showed to be a good indicator of the ‘weak points’ in the buildings and also provide means to measure the effect of change on the building performance taking into account the presence of all other aspects at the same time. It is difficult to imagine how the change of one aspect can affect the performance and perception of other aspects in the model. The methodology explained in this paper shows a way to better understand the effect of changes and to approach the ‘improvements’ in a more responsible way.

The end results are two knowledge models (for 2000 and 2006) that provide an integral perception of underground station in terms of comfort and public safety. The knowledge models enable us to conduct a cross-examination of sensitivity analysis results so as to be able to understand how a change of one aspect influences the total perception of space, but also to discover whether a change of one aspect has a contradictory effect.

The results could eventually lead towards the improvement of performance standards which are related to user requirements regarding underground train stations. The methodology is developed for underground space perception but can be easily applied to any domain of built environment where user perception is of great importance, like for example healthcare environments. Such methodology helps to keep track of changes during the building's life-span. Furthermore it speeds up the learning process of the building industry regarding user perception of the built environments.

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