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Automated Decision-Making
- Examples from Practice

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ABSTRACT

Full automation and real robotization require some kind of build-in intelligence. Automation requires in this way automatic decision-making, based on some kind of artificial intelligence tool. The Department of Construction Management at the Technical University of Denmark has for a number of years been heavily involved in developing this kind of tools in close collaboration with the construction industry in Denmark. Many different types of technologies have been used. This paper will only focus on tools based on simple, standard neural network software for PC's, software affordable to industry and easy to use by the manager himself. Five examples will be given, indicating, among other things, that the technology in some cases seems to have potential of producing valuable results for managing real life construction activities.

1. INTRODUCTION

Full automation and real robotization require some kind of build-in intelligence. The fully automated system must know what to do, when a number of different situations occur. Being automated, the system has no human to consult. It must consult it's own embedded intelligence. That's the reason for the close interrelation between automation and automatic decision-making based on some kind of artificial intelligence tool. This can be an expert system, a neural network, etc embedded in the control environment of the automated object, offering high quality decisions in it's own narrow problem area.

The Department of Construction Management at the Technical University of Denmark has for a number of years been heavily involved in developing tools of this kind, and most of the tools have been developed in close collaboration with the construction industry in Denmark. The tools developed have been different expert systems, knowledge-based systems and neural networks, each designed to offer decision support to a specific type of problem.

This paper will only describe a very small segment of these tools, as the paper will only focus on the latest and probably the most promising technology: neural networks. Only neural networks based on simple, standard software (Brainmaker Professional from California Scientific Software) for standard PC's - affordable to industry and easy to use by the construction manager himself - will be covered.

The paper will give a short introduction to the technology, describe five cases from practice, and finally offer some general conclusions on the potential to the construction industry of this kind of technology.

2. BACKPROPAGATION NEURAL NETWORKS

The human brain is made up of billions of cells called neurons. Each of these cells is like a very small computer with extremely limited capacity - yet, connected together, these cells form the most intelligent system known. Neural networks are a class of computer systems formed from simulated neurons, connected to each other in a network simulating the way, that we believe the brain's neurons are connected.

The networks in this study are based on the so called feedforward, backpropagation algorithm. In this algorithm learning is simulated in much the same way, as we think people learn, by examples and repetition -

association. It is not programmed by rules etc, but it is trained - that is, when the network sees an input A, or something like it, it responds with output B, or something like it. When a neural network is being trained, it is presented input-output pairs - facts. The output portion of a fact is called a training pattern.

Each time an input is presented, the network sends back an answer of, what it thinks the output should be. If it's wrong, the network makes corrections to itself. The program goes through the list of facts, presenting each fact once in turn and making corrections as necessary. When the entire list of facts has been presented, the program starts over at the beginning of the list. This training process is repeated until the network gets all the facts correct, if possible. Having obtained a hopefully good training pattern, the neural network is ready to help forecast future outcomes represented by actual sets of input values.

The neurons in the program are organized into layers. Figure no 1 shows an example.

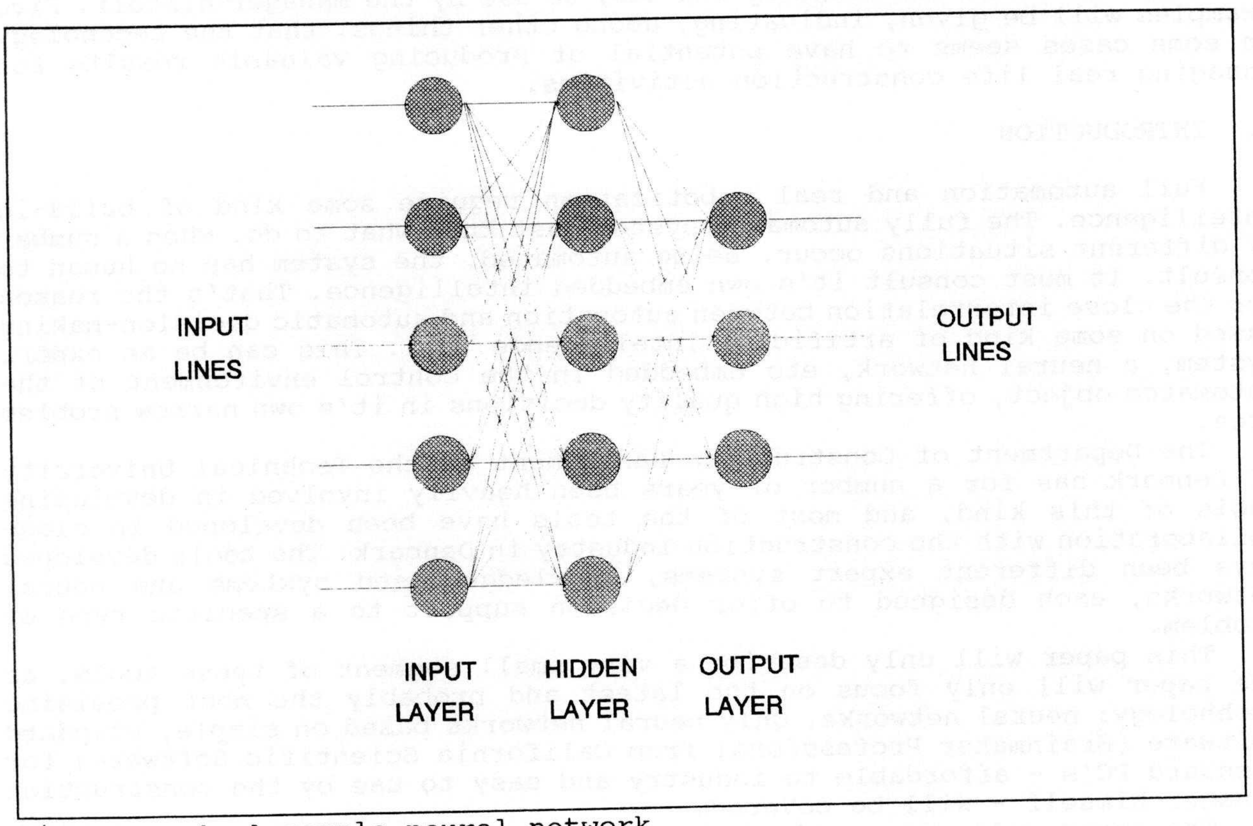

Figure no 1: A sample neural network.

The neurons are organized in three types of layers, an input layer (representing the input facts), one or more so called hidden layers, and the output layer with the facts, we are training the network to forecast. The example in figure no 1 shows a network with five input neurons, five hidden neurons in one layer, and three output neurons. The lines interrelating the neurons show, how the neurons are connected into a network, and how information flows between neurons. In this feedforward algorithm information flows only from left to right.

The function in the program of a single neuron is illustrated in figure no 2.

The box represents a single neuron. It is receiving an arbitrary number of inputs, in the example 5 inputs. Neurons send a single output to the rest of the network. This is represented by the outgoing line labeled output.

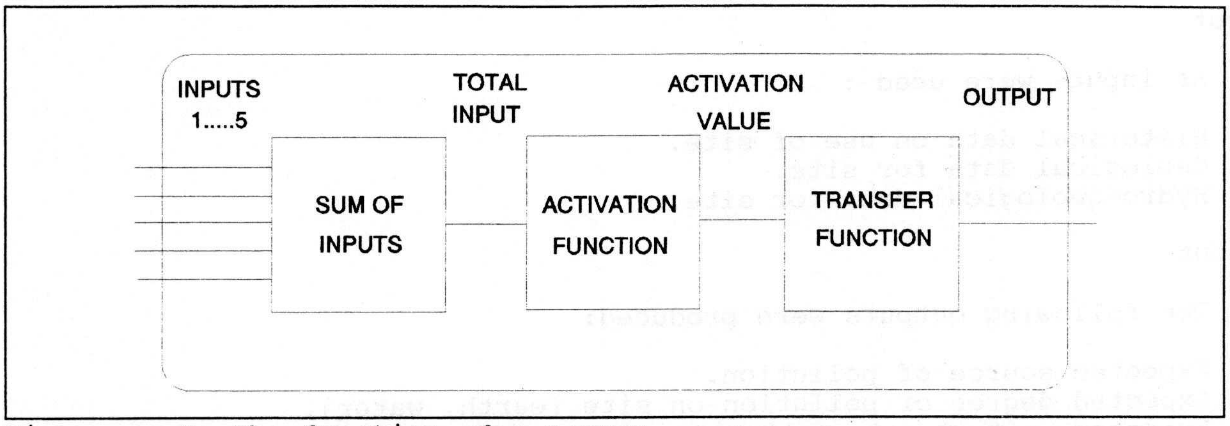

Figure no 2: The function of a neuron.

Some inputs may be excitatory, some inhibitory, why the inputs are combined into a signed single value, called the total value. The total value is processed by an activation function, and the activation value produced. This is finally passed through the transfer function, which produces the neuron output.

3. CASES FROM PRACTICE

This part of the paper will be devoted to a description of five different models developed in collaboration with the construction industry in Denmark. The description will include neural networks designed for the following problem areas:

* Analyzing polluted sites: source of pollution, degree of pollution, effect of pollution, cost of testing and cleaning-up the site.
* Competitive bidding: forecasting the low bid in a bidding situation.
* Effective quality assurance: precast concrete components factory forecasts daily quality assurance scheme based on actual mix of products.
* Forecasting the total volume of work in a consulting company: making 6-months forecasts based on general and company-specific parameters.
* Forecasting earnings in a consulting company on specific jobs.

None of the models described is yet in daily use in the companies.

3.1 Polluted Sites

Objective

Polluted sites is an ever increasing problem all over the world, also in Denmark. The model is intended to analyze sites, which for a number of years have been used for gas stations, predicting the pollution expected on the site.

Client

The net was developed in collaboration with some of the major gas companies represented in Denmark.

Data

Reliable data was very scares even with several companies involved. Only 25 cases was documented so well, that they were used in the analysis.

Input

As inputs were used :

Historical data on use of site.
Geological data for site.
Hydro-geological data for site.

Output

The following outputs were produced:

Expected source of pollution.
Expected degree of pollution on site (earth, water).
Expected effect of pollution from site (groundwater, recipient, surface).
Expected cost of re-establishing the site (cost of inspection and testing, cost of cleaning-up).

Results

The model was tested on five test cases randomly selected, and not included in the training process. The model was able to predict correctly the percentage of the outcomes indicated below, within the stated limits of accuracy.

Source of pollution:	60%	+/-20%
Degree of pollution on site:		
Earth	80%	+/-27%
Water	60%	+/-40%
Water if earth pollution known	100%	+/-20%
Effect of pollution:		
Groundwater	60%	+/-40%
Groundwater if pollution earth known	80%	+/-33%
Groundwater if pollution earth and water known	80%	+/-5%
Recipient	40%	+/-40%
Recipient if pollution earth known	100%	+/-30%
Recipient if pollution earth and water known	80%	+/-20%
Surface		
Surface if pollution earth known	100%	+/-20%
Cost of:		
Inspection and testing	80%	+/-30%
Cleaning-up	100%	+/-20%

Conclusion

Only a very crude model was developed based on rather few historical cases. Testing this model in real life showed:

* Data set is much too small to build a reliable net, forecasting all factors with a reasonable degree of certainty.
* Even the crude neural network produces rather good estimates of cost of re-establishing the site.
* The tests also indicate that given more training data, it seems to be possible to construct really useful nets.

Further information

Reference no 5 in the list of references contains a detailed description of the study.

3.2 Competitive Bidding

Objective

A standard research topic in construction has for a number of years attempted to produce mathematical models to provide an optimal bidding strategy for a construction company. Probably, it all started with Friedman, reference no 3. He developed a statistical model for optimum bidding behavior based on data collected on potential competitors. The number, and the identity of the competitor was essential in his model. Later Broemser, reference no 2, used regression analyses to forecast the low bid in a construction bidding situation. In later years, many other authors have written extensively about this problem, see as an example Parker reference no 8.

The bidding situation might be seen as a typical pattern-matching problem, suitable for the neural network technology.

The objective of this study is to do so, and compare the results with the results using traditional procedures.

Client

This is the only study reported on in this paper, which was not conducted with an industrial client.

Data

In Broemser (1968) we find a complete data set for a US contractor, and a fully documented regression analyses of the data presented. In our study we will use the same data set as Broemser.

Broemser collected data on 76 bid situations, showing: number of competitors (NUM), the company's estimated cost of the job (COST), the estimated percent of work not subcontracted (NOT_S), the estimated job duration (DUR), and the lowest competitor's bid as a percent of the company's cost estimate (LOW).

Input

Broemser discussed important factors competitors will consider, when they determine their percent markup on a job bid. He concludes, that the work not subcontracted would affect the bid, that is the ratio of the estimated cost to do our portion of the work to our estimated total cost to be important (reflected by variables: NOT_S, NOT_S^{-1} and NOT_S^{2}). He also concludes, that it's logical, that a contractor's markup will depend on the size and the intensity of the job. These would be, in a sense, surrogate measures of risk to the contractor. Further discussions result, that these can be measured by variables as: DUR^{-2}, DUR^{-1}, $(DUR/COST)^{-1}$, $(DUR/COST)^{2}$ and $COST^{-2}$.

Broemser uses these 8 variables in his regression analysis and finds a good fit. In some nets we used Broemser's raw data, in some the 8 variables mentioned, and finally in some cases a combination of both sets of data.

Output

As Broemser we use lowest competitor's bid to our cost (LOW) as output.

Results

Using the combined data set showed the best training pattern. The final net has therefor 11 input neurons, 11 hidden neurons and 1 output neuron.

After 15 hours and approximately 1,200,000 training cycles the network was able to forecast 66 out of 68 cases within +/-10%.

Testing 8 new cases resulted in a correct prediction of the percentage stated below, within the indicated limits of accuracy:

75%	+/-40%
38%	+/-10%
12%	+/-5%

The number of bidders showed some, but minor, impact on the low bid. The results showed a positive correlation between number of bidders and the low bid.

Conclusion

The study indicates:

* That it is a rather simple problem to model the bidding situation, and study bidding behavior with a commercially available software.
* The study also showed, that machine learning even on fast modern equipment, and even for a simple problem, like the one tested, can be very slow.
* We must also realize, that the model is not able to produce results with an accuracy needed for practical purposes.
* In this case traditional methods probably produce better forecasts.
* Our analysis supports Friedman's assumption, that the number of bidders are of importance for the low bid, contrary to Broemser's own analysis of the data. But it is alarming to observe, that an increase in the number of competitors has a positive impact on the output value, which means, that increasing the number of bidders, increases the expected low bid, contradicting with all economic theory!

Further information

Reference no 4 in the list of references contains detailed information on the study.

3.3 Quality Assurance

Objective

Effective quality assurance is becoming an increasingly important issue. The objective of this study is to assist management in planning the daily quality assurance scheme in a factory for concrete components. It is believed, that there is a coherence between actual daily mix of products and likelihood of production errors, indicating that a neural network approach might be a suitable technology to plan, which elements to inspect, for obtaining an optimal balance between cost of errors and cost of inspections. We will do so by constructing a network, which can be run for each component produced, predicting the likelihood of production errors in this specific component.

Client

The study was made in cooperation with the biggest concrete components producer in Denmark.

Data

As most companies in the stationary industry, the components factory had a well established tradition for collection production data - a good starting point for applying a neural network approach! The study is based on data on the production of 550 components but more data are available.

Input

The input specifies the characteristics for the component being tested. These are:

Type of component.
Components are often produced in series, specify placing in series.
Component thickness, with, height, area, weight.
Types of concrete mixes used in component.
Number of different concrete mixes in the component.
Minutes to cast.
Day of the week to be produced.
Specify other components produced the same day.

A total of 41 input data specify the component and the actual circumstances of production.

Output

The output predicts, if an error in the component should be expected, or not. It was not possible to predict the type of error expected.

Results

Many different net structures were tested. The training and ability to predict was very dependant on the actual net structure. The final net had 41 input neurons, one hidden layer with 20 neurons, and 2 output neurons. It was trained with 494 cases, and training stopped after 47 iterations.

55 cases, not included in the data used for training, were randomly selected for testing. The final test showed the result:

100%   +/-5%

Conclusions

This study indicates that:

* It seems possible to construct a model for controlling quality assurance in a concrete components factory.
* Good quality data are essential to the success of the model.
* It is important to study a range of different net structures, as the result depends heavily on this choice.

Further information

Reference no 1 in the list of references contains a detailed description of this study.

3.4 Forecasting Volume of Work in Consulting Company

Objective

Practice shows, that it's very difficult, even within a short horizon, to predict the total volume of work in a typical consulting company in

Denmark, as supply of contracts varies very much.

The objective of this study is to construct a neural network, able to help predict total volume of work in 6 months, based on recent trends in macro-economic parameters, and company specific parameters as volume of work, level of acquisition activities etc.

Client

The model was developed in collaboration with one of the largest engineering consulting firms in Denmark.

Data

Even in this rather big organization, it was difficult to establish a good data set for the company related data on volume of work, level of acquisition activities etc, as the registration scheme in the company has been changed several times in recent years. Only 44 reliable sets of data were reconstructed.

Input

Inputs related to macro-economic trends in society:

Rate of employment, volume of construction work, turn-over in industry, level of export, rate of interest, stock marked index, balance of trade, rate of investments etc.

Inputs related to trends in the company:

Volume of work, level of acquisition activities etc.

Results

The best net had one hidden layer with 10 neurons and tested as indicated:

100%	+/-60%
100%	+/-50%
100%	+/-40%
50%	+/-30%
40%	+/-20%
25%	+/-10%

Conclusion

This study indicates that:

* Good statistics are scares in many companies associated with construction.
* Building a reliable model predicting total work load in the specific consulting company was difficult. This might be due to the nature of the problem or the limited amount of data available.
* Traditional methods based say on regression analysis might be a better choice.

Further information

Reference no 7 in the list of references gives a detailed description of the study.

3.5 Forecasting Earnings in Consulting Company on specific Jobs

Objective

Forecasting earnings on specific jobs in a consulting company is a difficult task. The objective of this study is using neural network technology to try to find a pattern between characteristics of the job and earnings.

Client

This study was made in collaboration with one of the largest engineering consulting companies in Denmark.

Data

Again we realized that good, solid data are very scares in practice. Only 56 suitable cases were located. Of these 45 were used for training and 11 for testing purposes.

Input

For each job the following parameters are specified:

Type and identity of client, type of job, person responsible for total job performance, person responsible for daily activities on job, geographical location of job, type of contract, estimated total number of man-hours in the different departments in the company.

Output

Expected gross earnings on job.

Results

The net had 50 input neurons, 25 hidden neurons in one layer, and one output neuron.
As mentioned previously, training was done on 45 cases, and test on 11 new cases. The tests gave the following results:

91%	+/-20%
55%	+/-10%

The company found these estimates better than intuitive methods used today.

Conclusion

This case has indicated that:

* It seems possible to build a reasonable net, forecasting earnings on specific jobs in an engineering consulting company.
* But lack of reliable data is again a major limiting factor.

Further information

Reference no 1 in the list of references gives a detailed description of this study.

4. CONCLUSIONS

Testing simple neural network technology in practice leads to the following main conclusions:

* The neural network technology is able to handle problems in the construction industry not solvable by traditional software.
* Neural nets should be used as supplement not as an alternative to traditional software.
* Developing simple workable neural networks are not as complicated as the name indicates. Inexpensive and easy-to-learn software is available on the marked which means, that the technology is affordable to industry, and easy to use by the manager himself.
* Lack of tradition for reliable data collection in the construction industry is a main obstacle for wide usage of the technology.
* Neural network models do not explain their reasoning, it's so to speak a black box process, which often creates a feeling of insecurity.
* Tests have shown, that the technology has potential of producing valuable results in some cases in managing real life construction problems.

Most practitioners will associate neural networks with something very theoretical, and not directly applicable to their own daily problems. The main idea with this paper is to demonstrate, that this is not true, and to demonstrate, how simple standard software for producing neural nets can be used by people in industry to increase effectiveness of construction activities.

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