Criteria on the Value of Expert’s Opinions for Analyzing Complex Structures in Construction and Real Estate Management

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Abstract

Traditionally an expert is considered somebody who knows more and can appraise something better than anyone else can on the ground of specific knowledge. In this paper, such an assumption is put on solid grounds as to reveal what makes the expert superior to the common observer. Commonly an expert’s view on a system is taken to be valid justified by reputation, which is described by the term of experience. Proper experience means to have already investigated a sufficient number of similar systems and therefore to be able to predict values and behavior of system variables within acceptably small margins. This approach refers to the similarity of complex systems, calling for a large number of well-understood systems to form the knowledge base and for an appropriate similarity of the systems to evaluate. Thus, we conclude the resulting accuracy to be naturally poor or the approach mistaken. An expert’s expertise can therefore only be judged by the presentation of a comprehensive structure of the given situation leading to a set of evaluations for single branches or, in more sophisticated approaches, a set of possibly nonlinear functions allowing to merge the subsystems into one encompassing system. Then, the singular subsystems may become comparable to known situations and thus are understandable and predictable with sufficient accuracy. This will only help understanding the total system if the concatenation of the subsystems would not introduce additional complexity by taking their interaction into account, i.e. if the subsystems can be considered as superimposable. This will be the case if the interactions are exclusively linear and the proposed structure loop-less. Based on systems theory, this article provides criteria of how the validity of an expert’s opinion on a complex system can be strictly evaluated and made use of in further considerations on solid grounds.

Keywords: construction, real estate, expert, system, complexity, project, management.
1. Introduction

Since tasks and challenges in particular in Construction and Real Estate Management are becoming more and more complex, means to evaluate and predict a respective situation’s or project’s future development need to be improved. Furthermore, increasingly high risks require equivalently high accuracy of the predicted results which are particularly difficult to achieve due to the unique character of the considered situation [16, 18, 25, 35, 40, 42]. On this background more and more calls for experts turn up, to offer an expert’s opinion on the problem [15, 20, 27, 31] claiming that these have understood such situations and therefore are capable to present valuable and precise advice based on their specific knowledge.

From a statistical point of view, such an approach does not hold. Scientific arguments are not based on opinions but on reasoning. Statistically surveying a large universe transforms the number of irrelevant single opinions into the very relevant parameterization of a situation, i.e. a market of demand or supply, a picture of political or social ambience or an ecologic system [44]. Different from this but based on the same reasoning, technical systems are investigated similarly as a number of irrelevant single issues forming relevant parameters for the complete system [23, 24, 33, 34]. In any case, the precondition is the absolute independency of the single issues as well as the large number of available subjects.

An expert’s opinion does not meet even one of the given preconditions. Experts are commonly required if the subject is too complex to evaluate otherwise, in particular neither argumentative methods nor an appropriate universe for a significant survey are available, so only very few expert’s opinions are available. A single statement would in terms of statistics lead to a well-defined mean value, with infinite standard deviation \((n-1)^{-1/2}\) while for very few opinions \(n\) the add-on to the standard deviation due to the size of the universe according to the Student t-distribution – proportional to \(n^{-1/2}\) - will be very large for sufficient accuracy [4, 22]. Furthermore, if more than a single statement is available, the independency of the adepts is to be doubted since their knowledge is likely to be based on the same few situations and they will know each other as well as their backgrounds [1, 28, 29].

Consequently, a statistical approach to the utilization of expert’s opinions allows clearly for no substantiation of the given proposition. In the following a more general approach is established to investigate the contribution which can be made by an expert beyond the statistical understanding.

2. The Subject of Interest

First of all the system to be considered needs to be modelled in general, e.g. making use of Systems Theory. Therewith the subject of appraisal is a system of unknown complexity comprising elements and their interactions [13, 36, 41]. Without introducing any restriction, the elements can be considered most simple i.e. containing exactly one variable each. Then all the complexity of the system is located with the interactions, where also nonlinear functions may be given.

2.1. Modelling a System as a Set

Hence the system is defined as a set [2, 38]:

\[
S = \left\{ n_i, k_i | i = 1..N, j = 1..K, K = N^{1+\varepsilon} \right\}
\]  

(1)

Each element \(n_i\) contains the single local variable \(Q\) including the instruction of how to modify it according to the input while each interaction connects exactly one element to another and therewith sends the respective modification value to the requesting element:

\[
\frac{\partial Q}{\partial t} = f(Q, r) | r = 1..N \quad k_j : \{ n_i \rightarrow n_j \} | i, r = 1..N
\]

(2)

The object of this consideration may be restricted to stationary systems where all variables are at rest. Other systems being far away from equilibrium are more difficult to consider and to predict with some accuracy. In case of
equilibrium or at least close such a state, as only very small changes during the time interval $\dot{t}$ are taken into account, the functions $f_i$ can be developed into Taylor series.

$$ n_i : \frac{\partial Q}{\partial t} = \sum_{j=1}^{N} c_{i,j} g_j$$

(3)

Here, constant terms are already eliminated by transformation of the system where each $Q$ is replaced by a respectively shifted value. Therewith, constant values are eliminated as well as constant modifications of variables. This equals the restriction to the consideration of systems at states of equilibrium (stationary) and their close proximity.

Furthermore considering nearly stationary states, only the first terms need to be used leaving the system modeled with linear interactions.

$$ n_j : \frac{\partial Q}{\partial t} = \sum_{j=1}^{N} c_{i,j} Q_j$$

(4)

2.2. Equations of Motion

Such sets of differential equations are generally solved by complex exponential systems of the form

$$ Q_i = \sum_j g_{i,j} e^{\lambda_j t} \left( \sum_j g_{i,j} e^{2\lambda_j t} + ... \right)$$

where the term in brackets refers to higher terms of the Taylor development, $g_{i,j}$ are constants and $\lambda_j$ are the roots of the characteristic equation. Since the roots may be real or imaginary, the solutions will dampen or grow exponentially or may expose oscillating components. Thus, the systems behavior in close proximity to stationary states can be investigated [2]. If only linear terms are considered, this corresponds to the Laplace matrix $c_{i,j} - \delta_{i,j} \lambda$ of the graph defined by the weighted adjacency matrix $c_{i,j}$ of the system. Therefore the roots $\lambda_j$ represent the Eigenvalues of the graph [3, 6, 19].

Remark 1: If only linear terms are taken into account, the solution remains with terms of the type $e^{\lambda_j t}$ which corresponds to the fundamental frequency of the system behavior regarding this specific root. Higher partial components arise with higher nonlinear terms and their interaction. Hence, the linear system is described by the most simple spectrum. The negligence of higher order terms of the Taylor development leads to this basic description.

Remark 2: Completely linear systems are subject to the principle of superposition. Then each modification of a variable leads to responding modifications of other variables and thus a single reaction of the system. Any other simultaneous modification can be treated separately as the consequences are additive [36].

2.3. Boundary Conditions

The limitation of the system may be granted by some boundary conditions, which are not precisely given by a clear definition of the non-system share of the universe. Yet, the limit of a system is only sensible if the crossing information is strongly predictable. System boundaries can be modelled as a set of further interactions tying possibly each system-variable $Q_i$ to an outer state $\Omega$, formulated as an external system comprising outer elements $\{ n_r | r = 1..R^{(\alpha)} \}$ and the system boundary as a set of interactions $H = \{ F_i | i = 1..N \}$ with $F_i : \partial Q_i / \partial t = f_{s,i}(n_r^{(\alpha)})$.

The most simple case would then be presented by $F_i : \partial Q_i / \partial t = f_{s,i}(n_r^{(\alpha)}) = 0 \forall i$ where the boundary is defined clearly and the system considered absolutely closed.
Otherwise, sensible boundaries need to be defined by starkly limited functions leading to strongly reduced local complexity at the location of the boundary. As long as these can also be developed into Taylor series and approximated by the first terms and, more importantly, are predictable and changing at least one order slower than any time development within the system, the system can also be treated as being closed.

\[ F_i : \frac{\partial Q_i}{\partial t} = f_{r,i}(\Omega) = \sum_i c_{r,i} Q_i^{(a)} \]  
\[ (6) \]

In order to maintain predictability, \( \Omega \) needs to be stable enough and the \( c_{r,i} \) need to be small enough to be negligible or at least constant in comparison to the system coefficients \( c_{i,j} \).

2.4. Complexity

The structural complexity \( \alpha \) is given by several definitions. Here, the approach of Shannon [30] is made use of whereas the complexity is determined by the information held within the system or in average in every node. In this case the structural complexity is \( \alpha_{struct} = \ln(K/N + 1)/\ln(N) \). According to this approach, the information residing at a single node is the complete information of the (averaged number \( K/N \)) adjacent nodes \( c_{i,j} \) and of itself (“+1”) expressed as the natural logarithm and related to the total information of all nodes \( N \).

A more detailed determination takes into account the degree of strength represented by an interaction. This value might be given by the linearized first term coefficients \( c_{i,j} \). If \( c_{i,j} = 1 \) equals total dependency, the maximum complexity value will still be \( \alpha = 1 \) while no dependency at all results in \( \alpha = 0 \). The meaning of \( c_{i,j} = 1 \) would be that within one time-unit \( \partial t \) the variable \( Q \) will completely take over the value of \( Q_j \). Then we obtain for a linear complexity \( \alpha_{in} = \ln(N^{-1} \sum c_{i,j} + 1)/\ln(N) \). Using this, the structural complexity can be reduced or escalating if feedback-loops are taken into account [32, 41]. A strong controlling, i.e. damping, loop may hold a certain value stable independent of other changing variables and therefore an existing interdependency loses significance. On the other hand fairly weak interdependencies may lead to vast consequences if they are part of an escalating loop.

3. Understanding a System

Understanding a system to some degree involves particular knowledge of the elements and the interactions. According to the description above, the cardinality is given by the number of elements \( N \), the number of relationships \( K \) as they correspond to the linearized interaction parameters \( c_{i,j} \) and the number of boundary conditions \( R \). Relationships are determined by factors ruling the behavior of a single variable with respect to all other system variables, in particular the respective \( c_{i,j} \) if linear. According to the definition of complexity \( \alpha \) their number is approximated by \( K = N^{1/\alpha} \).

The knowledge of boundary conditions can be neglected within this estimation since they are modelled by constant or slowly varying parameters mainly not impacting the behavior of \( S \). This explicitly does not cover an estimation of the required knowledge to judge the sensibility of the definition of the system itself. In this context the system \( S \) is regarded as existing and being well defined, well separated from the universe and in particular close to a stationary state. Hence, a comprehensive knowledge of the system implies understanding a cardinality of \( K = N^{1/\alpha} \).

If the complexity is unknown, the number and character of relationships are undefined and need to be determined. This task means to judged possible interactions and define them accordingly even if the consideration leads to the decision of no interaction between two elements. Hence, full complexity must be assumed \( \alpha = 1 \) leading to \( K = N^2 \).

Remark: The required experience as a basis for understanding a system can therefore be estimated easily: The number of variants \( V \) for a system holding \( n \) independent variables each open for a number of \( m \) options would be \( V = m^n \) resulting in the required information \( I_{\alpha=0} = \ln V = n \ln m \). Introducing full complexity, this develops into \( I_{\alpha} = \ln V = n^{1/\alpha} \ln m \to n \ln m \)
Let e.g. a very small system comprise a number of only 10 independent elements \( n = 10 \) with just five options each \( m = 5 \), the number of principally distinguishable versions of the system would be \( 5^{10} \), while the possible interactions raise this number to \( 5^{50} = 10^7 \), wherefore no experience can possibly exist.

### 3.1. Separability of a System

From boundary conditions we obtain the understanding, that a system’s behavior is in particular defined by the elements and their interactions within, where the boundary is given by constants or at least slowly varying variables which are of no concern for the super-system’s characteristics. Therefore, a system may be separable i.e. divided into a set of subsystems where the dependencies are mostly localized and the interdependencies weak (See remark before). This will be true if the interaction parameters are small as the resulting time-constants will be slow. Separating a system into a number \( s \) of weakly interacting subsystems of assumed equal order of size allows the required knowledge to be reduced according to

\[
V \simeq m^n \rightarrow V \simeq \sum s \cdot m^{n/s} \rightarrow \ln V \simeq n \cdot s \cdot \ln s \cdot m
\]  

\( (7) \)

![Graph](image-url)  

**Fig. 1. Decrease of Variations with Separation**

Thus, an expert’s knowledge may be defined as the ability to divide a system into a set of weakly interacting subsystems which are subject to experience due to their more general character, their common characteristics and more frequent occurrence.

**Remark 1:** The RNM-Algorithm (Recursive Neighborhood Method) \([21, 39]\) allows the segmentation of a linear system determined by its adjacency matrix \( c_{ij} \) on the basis of recursively applying system transitions on a state-vector and finally separate well distinguishable parts by a classical cluster analysis procedure.

**Remark 2:** As is known from the theory of graphs, the multiplicity of the most dominant Eigenvalue \( \lambda_0 \) indicates the number of independent sub-systems the considered system decomposes into \([\text{see e.g.} 5, 7, 9, 17, 26]\).

### 3.2. Criteria of Segmentation from Linearity

Criteria to sensibly segment a system can be derived from the equations of motion. These will be similar to the reasoning of boundary condition. Based on linearized functions, respectively first order terms of the Taylor development, in particular for some simple situations solutions can be formulated:

Let there be a loop \( Q_1 \Rightarrow Q_2 \Rightarrow Q_1 \), directly fed back. Then, the resulting linear equations of motion will then be:

\[
\frac{\partial^2}{\partial t^2} Q_1 = c_{1,2} c_{2,1} Q_1 \rightarrow Q_1 - e^{i\omega t}
\]  

\( (8) \)
More generally we conclude:

- Case 1 indicates meshes where $Q_1$ acts as its own predecessor. Here, the value develops exponentially on its own without the need of external influence.
- Case 2 represents the linear situation where a variable is linearly modified by a next neighbor element.
- Case 3 leads to differential equations of the second order resulting in imaginary exponential solutions. Therefore oscillating situations are possible.
- Case 4 finally leads to higher order terms.

From this we derive the strict necessity to separate systems where no meshes or loops are intersected since only then the low and stable impact from one subsystem to another may be granted. Thus, sensible separability implies no loops passing a separation, i.e. the subset of the system constructed by the subsystems needs to be loop-less. In this case the developed structure can be subjected to one to one causal dependencies, manifested by e.g. the assignment of ranks to the nodes. Then and only then unambiguous causal reasoning is possible.

Thus, the required structure needs to be rankable, providing unambiguous causal reasoning for each decision. Being loop-less is only granted by graph-theoretical network plans.

3.3. Criteria of Segmentation from Multiplicity of Paths (nonlinear)

An additional criterion to determine sensible segmentation the multiple impact on a node by the very same variable, manifested by multiple paths leading from one node to another, needs to be investigated. From the motion equations the impact of a number of predecessors can easily be derived:

$$\frac{\partial Q_1}{\partial t} = c_{1,0}Q_0 \quad \frac{\partial Q_2}{\partial t} = c_{2,0}Q_0 \quad \frac{\partial Q_3}{\partial t} = c_{3,0}Q_2 + c_{3,1}Q_1 \rightarrow Q_3 = \int_0^t c_{3,2}Q_2 dt^2 + \int_0^t c_{3,1}c_{1,0}Q_0 dt^2$$  \hspace{1cm} (9)

Thus, we obtain from a linear system, as expected due to the superposition property, a double path only to double the effect of a single variable. Yet, if production-systems are modelled, the restriction to linear systems may not hold. Producing-nodes are in many cases making use of predecessor variables as production factors, thus implying terms of the shape $Q_1 \cdot Q_2$ and linear terms become negligible. Then, multiple paths yield this dependency:

$$\frac{\partial Q_3}{\partial t} = c_{3,1}Q_1 \cdot c_{3,2}Q_2 \rightarrow dQ_3 = \left(c_{3,1}Q_1 \cdot c_{3,2}Q_2\right) dt \rightarrow Q_3 = c_{3,3}Q_1Q_2 dt$$

$$\Rightarrow \frac{\partial Q_3}{\partial t} = c_{1,0}Q_0 \quad \frac{\partial Q_2}{\partial t} = c_{2,0}Q_0 \rightarrow Q_3 = c_{1,0}c_{2,0}c_{3,1}Q_0 dt^2$$  \hspace{1cm} (10)

Here, the number of paths leading from one subsystem to another corresponds to the exponent of the interaction function. Therefore, proper decomposition of a system into well-defined subsystems requires furthermore to forbid the implementation of multiple paths to singular subsystems in order to avoid unpredictability due to higher order dependencies.

The only graph-theoretical structure, which fulfils this restriction would be a directed tree, where only a singular path from one node to another is permitted.
3.4. Trace as indicator for sensible segmentation

Based on the two given criteria the subject of investigation, $c_{i,j}$ is expected to be restructured into a set of (weakly) interconnected subsystems, where $A_{i,j}$ is the adjacency matrix, with particular respect to feedback loops. The vanishing trace of the adjacency matrix indicates at least the system to have no direct loops where a node is connected to itself. $Tr A_{i,j} = 0$. A criterion for indirect loops would be the trace of cumulated higher potencies of the adjacency matrix:

$$Tr \sum_{k=1}^{\infty} A_{i,j}^{k} = TrA_{i,j}^{*} = 0$$

(11)

This ensures the new structure to be free of direct loops and therefore to avoid unpredictable oscillating behavior. This is also valid for weighted adjacency matrices, but normalization requires respective reference values. Thus, we propose the relative trace with respect to the cumulated active-sums or passive-sums [see e.g. 10, 11, 12, 14, 37, 43] to be used. So far we state an elaborated structure $\hat{A}_{i,j}$ to be over all “well-structured” if $Tr A_{i,j}^{*} \ll 1^{r} \cdot A_{i,j}^{*} \cdot 1$ where $1^{r} \cdot A_{i,j}^{*} \cdot 1$ equals the cumulation of the active-sums as well as identically the cumulation of the respective passive-sums of $A_{i,j}^{*}$. On this basis, a segmentation parameter $\sigma$ of the can be defined for $\hat{A}_{i,j}$:

$$\sigma := \frac{Tr A_{i,j}^{*}}{1^{r} \cdot A_{i,j}^{*} \cdot 1} \ll 1 \quad \text{for sensible separability}$$

(12)

In more detail each element of $\hat{A}_{i,j}$ would be required to fulfil this condition separately:

- $A_{i,j}^{*} \ll A_{i,j}^{*} \cdot 1 \quad \forall j, r$ (each component of the active sum vector) and
- $A_{i,j}^{*} \ll 1^{r} \cdot A_{i,j}^{*} \quad \forall i, r$ (each component of the passive sum vector)

4. Conclusion

Commonly an expert’s view on a system like a Real Estate Development or Construction Management project is taken to be valid justified by reputation, which is described by the term of experience. Proper experience means to have already investigated a sufficient number of similar projects and therefore to be able to predict values and behavior of system variables like cost or duration in the simplest case within fairly small margins. This approach refers to the similarity of projects. This would call for a fairly large number of well understood projects to form the knowledge base and an appropriate similarity of the project to investigate to the knowledge. Thus, we conclude the resulting accuracy to be naturally poor or the approach mistaken.

An expert’s expertise might therefore be judged by the presentation of a comprehensive structure of the given situation leading to a set of superimposable evaluations for single branches or in more sophisticated approaches a set of possibly nonlinear functions allowing to merge the subsystems into one encompassing system.

Then, the expert’s knowledge may allow the project to be structured and therefore the singular subsystems being comparable to known situations become understandable and predictable. This will only help understanding the whole system if the concatenation of the subsystems would not introduce additional complexity by taking their interaction into account i.e. the subsystems can be considered as superimposable. This will be the case if the interactions are exclusively linear. If not, the sections need to be completely independent safe a single, well-defined unidirectional nonlinear relationship. A classical tree structure according to the definitions given by the theory of graphs is the only possible structure allowing for such understanding.

In no way an ad hoc judgement of an expert for the whole system or project without appropriate substructures can be held acceptable.

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