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DEVELOPMENT OF HEURISTIC INDICATORS OF STABILITY OF COMPLEX PROJECTS IN REAL ESTATE MANAGEMENT

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Abstract. In this paper we propose and introduce a fundamental description of Project Management based on the Theory of Organisation and the Theory of Systems. Modelling aspects of projects as a set of interacting institutions leads to the application of a different view to understanding and administering Risk Management in terms of perceptibility and controllability. Based on this, methods of cybernetics and control engineering become useful to evaluate and describe factors of success for a construction project and to maintain them in order to lead even complex and inherently unperceivable projects along a well defined path to foreseeable results.

Keywords: modelling projects, project management, risk controlling, risk evaluation, systems theory.

Jel classification: C51

1. Introduction

Risk management has gained more and more significance in recent years due to the demand for higher standards of security in business. Particularly concerning singular nonrecurring projects in real estate economy, where the management of risks is of very specific importance, several attempts have been made to tackle the problem of a principally unknown outcome due to unspecifiable parameters.

Mathematical methods e.g. like the theory of decisions (e.g. Bronstein *et al.* 1979, Domschke, Drexl 2006, Gaede, Heinhold 1976, Müller-Merbach 1971, Scheer 1997) lead to the knowledge of optimal paths through a decision tree. However these approaches make use of probabilities (e.g. Hillier, Liebermann 1997, Runzheimer 1978, Johnson 1973) and therefore results are only optimal for averaging situations which is not valid in general for unique projects. Further attempts based on cybernetics (Wiener 1992) apprehend the inherent complexity of projects and their inner structure of self organisation due to interaction of participating elements (Shannon 1948, Booch 2007). Some authors (e.g. Vester 1995, Malik 2003 and 2008) pointed out how to direct a complex system via the flow of information making use of the internal structure, in particular of people being a major element of insecureness on the one hand and self organisation and self determination on the other hand.

Nevertheless none of these approaches turns out to provide actual means to reliably lead a project to success and the more furnishes parameters of reliability for such proceeding. The lack of elementary information about a specific project is very likely to complicate any fundamental proposition to management of projects at all (Jurecka, Zimmermann 1972).

Based on issues of the theory of systems and cybernetics we propose in this paper to actively establish firm control mechanisms overriding the inherent self organisation loops and therefore ruling out the development of unintended deviation to the project schedule based on more or less probable occurrence of hazards. Thus, terms of probability and damage are replaced by estimations of controllability and, in advance to this, perceptibility of situations. Furthermore a parameter of complexity of projects along with its impact on the predictable development of a project is described and defined. Making use of unified models such parameters turn out to be quantifiable and provide some useful key values for the evaluation of even singular projects in real estate economy.

2. Modelling a plan

A goal $G(p_i, t)$ is given as a point in the space of states, located at time t_e and defined by a vector comprising a number of parameters p_i. Such are e.g. cost, elements of quality, consumption of technical resources as well as temporal resources and respectively a certain amount of time. The starting point $S(p_i, t)$ is also given by a vector in this space at an earlier point of time t_s. The desired path from the starting point to the goal is described by a vector $P(t) = [p_1(t), p_2(t), p_3(t), \ldots]$ and is called a plan (Fig. 1). Thus the usage of every assigned resource as well as the expected level of production of quality in terms of well defined variables is known at every point of time. Due to the complexity of such a system interactions between parameters at any time need to be taken into account as well.

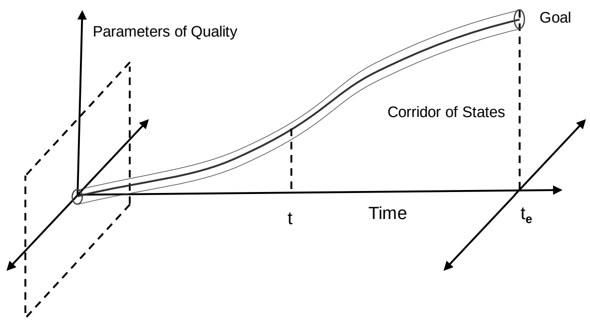

Fig.1. Plan in Space of States

As a plan is conducted over the time inevitably deviations occur regarding all parameters. As far as these are tolerable the plan needs to be allowed for some corridor of states. This additionally includes some tolerated fuzziness of the goal as well. In Construction Management surcharges on estimated offers are comparably small and rarely exceed 1 % of the project volume due to the tight market situation. In contrast to this, other safety margins e.g. in statics range up from 30 % to 70 %. This is well understood as reasons of safety lead to large and obligatorily paid add-ons. On the other hand economic safety is not as much as securing profit but ensuring financial stableness and jobs. Yet as the markets don't allow for more tolerance specific measures need to be taken to deal with this situation (e.g. Lewis 2002, Schelle *et al.* 2005, Henn, Künzi 1968).

3. Corridor of deviation

The classical understanding of Risk Management refers to terms of the probability of the occurrence of some specific risk times the possible hazard induced. As we pointed out (Zimmermann *et al.* 2008) this approach does not hold, as the statistical universe of similar situations is much too small to provide sufficient data to evaluate such probabilities. The more on nonrecurring unique projects risks are simply occurring or not. Therefore statistical compensation of situations is basically not given and any occurrence as small as ever the probability may have been leads to the full hazard and not only to any sort of weighted hazard. Thus, like on stock exchange even unfailingly rising equities are only reliable if they can be held for theoretically infinitely long time. Due to limited liquidity and time any strong aberration which is still in accordance to the statistically rising value is capable to end the engagement (Fig.2).

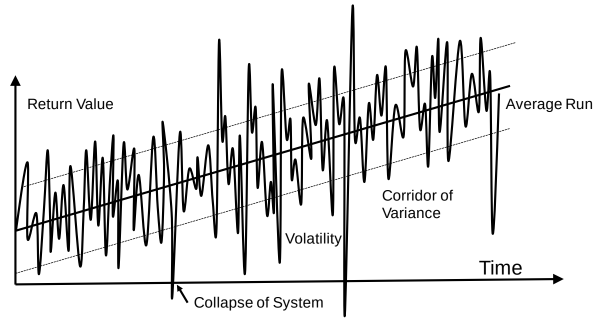

Fig.2. Effect of Volatility to Singular Projects

Beyond this human beings tend to mingle the estimation probabilities with hope and introduce asymmetric ranges of occurrence. E.g. the duration of processes are underestimated in most cases leaving the risk of change at the worse side. Such behaviour tightens the situation but is not to be tackled in this context.

On this background an approach needs to be developed to judge specifically singular and non-recurring projects as is typical for construction projects regarding their expected behaviour on small changes of parameters.

4. Deviation development in complex systems

In (Zimmermann *et al.* 2008) we proposed to focus on terms of perceptibility and controllability in order to keep the development of complex systems under control and let not arise unmanageable situations. Thus the development of changes within a complex system needs to be understood first.

A traditional network plan (e.g. Wiest 1977, Sackmann 2003, Kerzner 2003) is certainly not the all encompassing description of a system. Nevertheless extending the idea of a temporal network plan to a process network allows modelling the complete project including all relationships and making use of systems theory and the theory of graphs. In (Zimmermann, Eber 2011) we introduced some central average parameters describing complex systems given as topological graphs (Fig.3). Typically they are characterized by the existence of only one starting node and one finishing node, but the absolute requirement of being loop-less is softened with respect to realness:

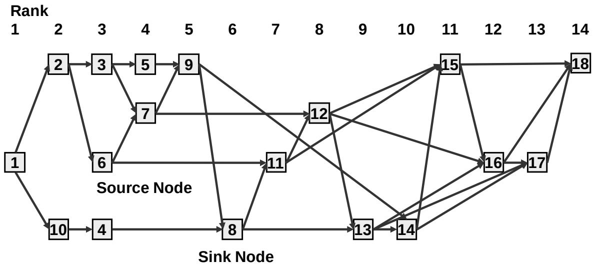

Fig.3. Model Network Plan

Values like the *maximum rank* Γ as well as the *impact* ζ, which is the average number of relationships leading to a closing node and the *interoperability* ξ which denotes the average number sourcing from a source node are taken from conventional network planning. With an average parallelity ρ we obtain the overall volume $\Omega = \rho\Gamma$.

In order to include circular effects as well without deranging methods of the theory of graphs we introduce the parameter of recursion $\beta = [0..1]$ denoting the grade to which a change at one node is returned to the same node via some circular path. Furthermore a value $\alpha = [0..1]$ denotes the overall complexity of the complete system. α is defined as the dimension of a hypercube where each element (i.e. node) out of n is connected to every adjacent element via a relationship out of k and results in $\alpha = \ln(k+1)/n$.

Based on these parameters the development T of a small change $\Delta(\zeta)$ of only one parameter over a complex system of volume Ω can easily be described by a power progression:

$$T \simeq \eta\Omega\left(\Omega^{\alpha}-1\right)\Delta(\zeta)/(1-\beta)+c\cdot\Omega\left(\Omega^{\alpha}-1\right)/(1-\beta) \quad (1)$$

The constant term mirrors just the fact that a system is not taken holistic but comprises a number of elements while the linear term indicates a strong dependence to the complexity α. The ratio η as well as the parameter of recursion β turn out to be just scaling factors since they are constant over the system. Distributed over the ranks r we finally obtain the development of a small change $\Delta(\zeta)$ according to the progression of the project using $\alpha \cdot r/\Gamma$ as the share of complexity for one step in the sequence of ranks:

$$T \simeq \Omega\left(\Omega^{\alpha r/\Gamma}-1\right)\Delta(\zeta)/(1-\beta) \simeq \Omega^{1+\alpha r/\Gamma}\Delta(\zeta)/(1-\beta) \quad (2)$$

Furthermore taking into account the multiplicity of paths leading to the final closing node leads to

$$T \simeq \xi^{\Gamma+\alpha r}\Delta(\zeta)/(1-\beta) \quad (3)$$

and a progression per rank $\omega \simeq \xi^{\alpha}$ (Fig.4)

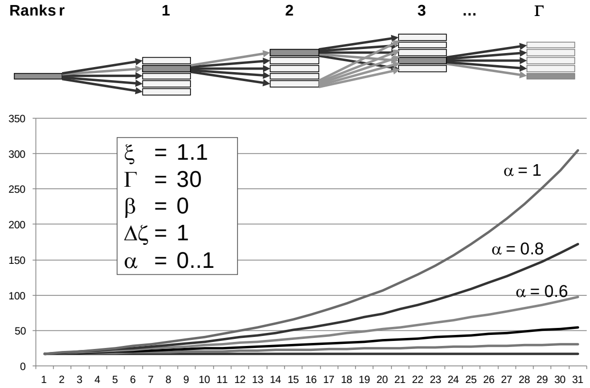

Fig.4. Propagation of Risk in a Complex System

On very simple models $\alpha = 0$ we obtain constant propagation as expected. Yet with rising complexity e.g. $\alpha = 0.1$ and structures expanding to e.g. only 5 subsequent sink nodes per source we obtain clearly more than a factor of unity for every step of development which leads to potential rise of effect.

On this background it is well understood, that no matter how small a probability may be any deviation will inevitably lead to enormous consequences. Finally some effort had been spent to estimate the force of a restoring measure. Due to the potential characteristic of the development it turns out, that the one and only efficient measure is to completely undo the mislead structure. Then the power of correction

$$\lambda = \xi^{\alpha\gamma r_d}/\xi^{(\gamma-1)\alpha r_d} = 1/\xi^{-\alpha r_d} = \xi^{\alpha r_d} \quad (4)$$

allows controlling the deviation independently of steps/ranks by leading the system back to the initial state immediately by undoing the fault and all its consequences (Fig.5).

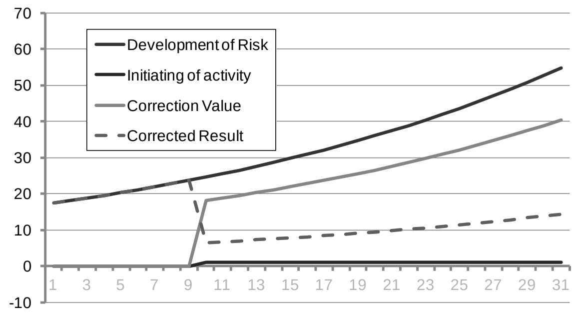

Fig.5. Attempt to Control Risk Propagation

This gives evidence to the recommendation to initiate controlling mechanisms as fast as possible in order to keep the needed force of correction low as well as the deviation within the originally determined corridor of tolerated states.

5. Equilibrium and control mechanisms

Stable systems need stabilising mechanisms. As shown above deviations are rather destabilising a complex system. As a matter of fact no automatisms exist in project management which were capable to interfere, save motivating procedures working on the staff. As the regulating speed needs to be about one order beyond every development time constants correcting the course within the corridor of tolerance implies the need of active control mechanisms (Picot 2008, Haken 1983, Schulte-Zurhausen 2002).

An active system is expected to sense the deviation and initiate some force to lead back. Such is described by potentials with a sharp minimum at the reference value (Fig.6). Shape and parameters of this potential defines the type of reaction in accordance to classical control theory (Schulz 1995).

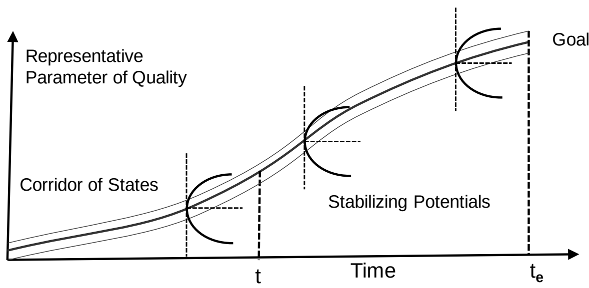

Fig.6. Control Loops on Plan Corridor

At this point we need to consider the boundaries of the system. We assume that a deviation of any kind can not be detected by itself but only by its effect on the observed item. Therefore the control loop compares only the result to the reference value, calculates some control reaction from it and applies this to the system (Fig.7). Since the unintended impact is also operating on the system, the result indicates the effect of the control mechanism in interaction with the disturbance.

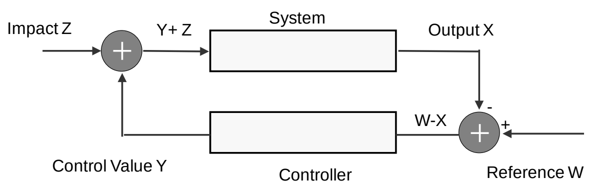

Fig.7. Classical Control Loop

Thus, a control loop needs to be fast enough to compensate for external impacts and keep the output within the corridor. We investigated some standard models of control in particular regarding their ability to adjust and characteristic time response.

5.1. Harmonic control

The first approach is taken from mechanical systems: We assume a back leading force proportional to the deviation $F = -Dx$ and some idleness corresponding to physical inertia $F = m\partial^2 x / \partial t^2$ which keeps things going as they are. This leads to the well known differential equation $\partial^2 x / \partial t^2 = -(D/m) \cdot x$ which solves easily to $x = A \sin \omega_0 t$ and identifies the circular frequency $\omega_0 = \sqrt{D/m} = 2\pi f$, respectively the cycle duration $T = 1/f = 2\pi/\omega = 2\pi\sqrt{m/D}$. Obviously this control system – known as the harmonic oscillator - inevitably results in oscillation of a frequency which increases on a rising constant of force and decreases on rising inertia. The original deviation finally remains as a repeatedly occurring value.

Only an additional term $F_R = -R\partial x / \partial t$ proportional to the speed of variation leads to a decay of the deviation. The resulting differential equation

$$\frac{\partial^2}{\partial t^2} x = -\frac{D}{m} x - \frac{R}{m} \frac{\partial}{\partial t} x \tag{4}$$

is solved by $x = A \cdot \sin\omega t \cdot \exp(-\gamma t)$ and identifies $\omega^2 = \omega_0^2 - \gamma^2$ using $\gamma = R/2m$ and $\omega_0 = \sqrt{D/m} = 2\pi f$. Thus with increasing damping the circular frequency is slowing down and the decay of amplitudes is modulated (Fig.8).

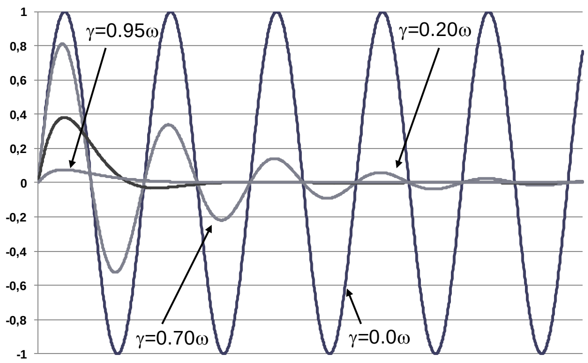

Fig.8. Harmonic Control

Calculating extreme values yields a critical damping configuration $\omega^2 = \omega_0^2 - \gamma^2 = 0$ where the time constant $\tau = 1/\gamma$ is at minimum. In this case no oscillation occurs at all and the deviation is corrected within the shortest possible time. Thus the optimal control would be determined by $\gamma = \omega_0 = \sqrt{D/m}$.

5.1. Proportional control

If the idea of modelling idleness as inertia does not match, the approach of a proportional control is the consequence. Yet a virtually zero value of m leads to an infinite reaction frequency ω_0 and thus a zero time constant. Since real reaction times never come to be zero we need to consider control systems based on discrete timing and a control force just linear with the observed deviation:

$$x(t+dt) = x(t) + [w(t) - x(t)]k \tag{5}$$

In this context k represents the factor of reaction, proportional to the deviation of the system variable $x(t)$ to the reference $w(t)$. Unfortunately this does not give a differential equation, so a discrete time interval Δt where the reaction is applied needs to be considered. Exemplarily in Fig. 9 the development of a control reaction is plotted for $w(t) = 0$ over the time axis for a linear control force $k = 0.5$ (Fig.9):

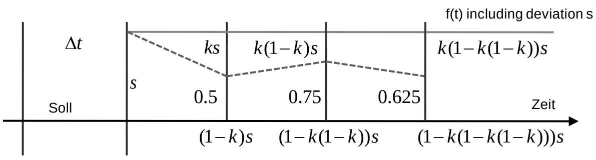

Fig. 9. Proportional Control

Basic consequences of such a control are easily to be derived:

A given deviation will never be completely eliminated. The remaining value for step i of control is given by

$$R_i = (w - x)\sum(-k)^i \tag{6}$$

which leads, normalized to a deviation of unity, as the limit of a geometrical series to

$$\lim_{n\to\infty} \frac{(-k)^{n+1} - 1}{-k-1} = \frac{-1}{-k-1} = \frac{1}{k+1} \neq 0 \tag{7}$$

Secondly we still obtain oscillating behaviour, defined by the time interval and the linear constant k as the factor of improvement for every step Δt. A standardized level of improvement is given by $k^n = e^{-1}$, leading to an average time constant of $\tau \approx n\Delta t = -\Delta t / \ln k$ for a reduction of the oscillation amplitude to a neglectable value.

5.2. Integral control

As the classical approach of a proportional control is not capable to eliminate deviations, it is of no further use if not modified. Yet, additionally considering an integrating term leads to much more useful results. The according differential equation comes to be:

$$x(t+dt) = x(t) + [w(t) - x(t)]\,k\,dt \tag{8}$$

respectively

$$\frac{\partial x}{\partial t} = \frac{x(t+dt) - x(t)}{\partial t} = [w(t) - x(t)]k \tag{9}$$

and solves simply to a standard damping function $x(t) = Ae^{-kt}$ where the relaxation time constant is given by $\tau = k^{-1}$ (Fig.10).

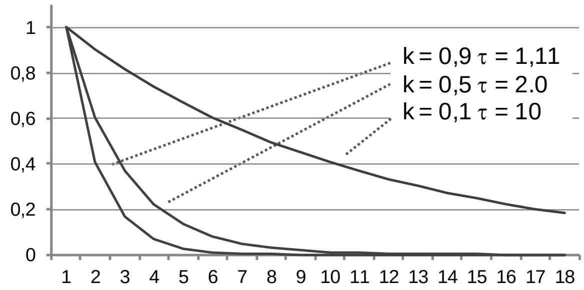

Fig.10. Integral Control

The structure of an integrating approach is identical to the introduction of a friction term to the harmonic differential equation as a returning force linear with the derivative of x with respect to time is applied.

6. Time constant of control

In any case the time constant of a control loop which is capable of returning a value to the reference comes to be $\tau = 1/k$ respectively $\tau = 1/\gamma$ and is taken exemplarily from the differential equation of the integral control mechanism:

$$\frac{\partial x}{\partial t} = [w(t) - x(t)]k \tag{10}$$

This allows for as well a plausible understanding as a quantitative evaluation of $\tau = 1/k$: The parameter k equals the percentage of a production rate deviation $w(t) - x(t)$, which the responsible is ready to invest in additional production speed $\partial x / \partial t$, which again corresponds to efficiently utilised resources. k is given as percentage in units of [1/time] and therefore we obtain $\tau = 1/k$ as a measure for the expected mean time of appropriate reaction. Beyond this, the previously introduced term of controllability of a risk is so far substantiated by the determination of k.

7. Criticality of processes

As explained before, processes are likely to deviate from their expected goal according to accidentally aberrating production factors. The potential rise of discrepancy is owed to the complex arrangement of a multiplicity of processes. Yet as control mechanisms interfere about one order faster, i.e. on the level of processes, variations don't reach the nonlinear complexity of the system and thus can be kept under linear control (Fig.11).

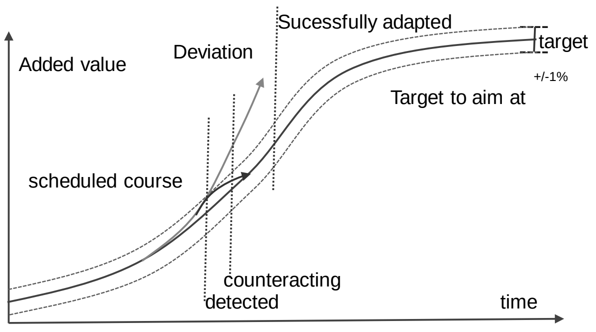

Fig.11. Criticality of a Situation

In order to evaluate the efficiency of the mentioned mechanisms they need to be compared to the given time reserves specified for the singular process. In contrast to slack times (float times) which emerge accidentally from their situation within the network structure of a system, the reserve durations are well defined intentionally kept time frames, allowed for the expected or at least suffered prolongation of the particular process.

Reserve times (Fig.12) can be easily calculated from the accepted fuzziness δw of the production rate $w = dQ/dt$, which is the gradient of the production curve assumed linearly:

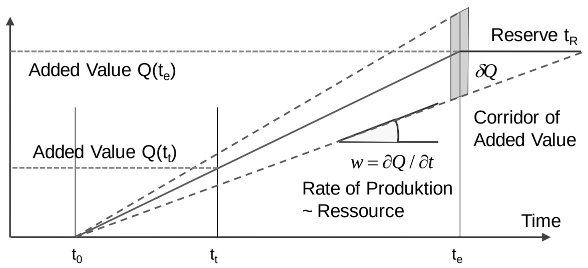

Fig.12. Reserve Time on Fuzzy Production Rate

$$w \cdot t_e - (w + \delta w) \cdot t_e = \delta Q = \delta w \cdot t_e \quad \Rightarrow \quad t_R = \frac{\delta w}{w} \cdot t_e \qquad (11)$$

Thus, the relative reserve time t_R corresponds to the relative tolerated deviation of the production rate per time unit.

Finally we define the criticality χ of a process as the ratio of the time constant of the according control mechanism and the scheduled reserve time:

$$\chi = \frac{\tau}{t_R} \qquad \chi \begin{cases} \gg 1 & \text{critical range} \\ \approx 1 & \text{transition value} \\ \ll 1 & \text{uncritical range} \end{cases} \qquad (12)$$

If the controller time constant is much less than the time reserve, any deviation can be eliminated in time. However if the controllers time exceeds the time reserve, discrepancies are likely to be carried over to the consequent processes and therefore effectuate potential rise of risk.

8. Representative project modeling

This approach is valid for singular processes and useful to elaborate reliable estimations of stability. In order to transfer such methods to complex projects, the number of processes can be simply accumulated linearly since the stability of processes become independent from each other on the establishment of fast enough control loops. Yet a project can only be judged if the respective network diagrams are unified to some extent. Only then statements about i.e. the ratio of stable and well controlled processes become sensible.

Therefore we need to break down networks to a comparable level of detail. We propose to do so using the following criteria:

Firstly, the time slots of processes should be about the same in order to avoid much longer or shorter processes than the average. The variance of the distribution may serve as a measure for this issue. From this we derive qualitatively comparable forces of control and comparable terms of adding value within processes.

Secondly we assume linear production rates within the particular processes. Thus, if the production rate comes to be nonlinear a more complex subsystem is likely to be hidden within the nonlinear process. A straightforward model allows substituting probable subsystems (Fig.13 and 14).

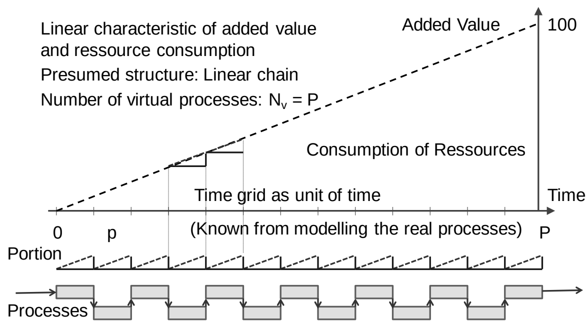

Fig.13. Linear Substitute for Processes

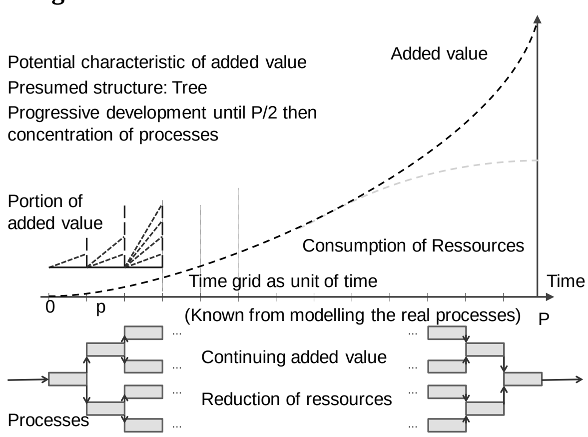

Fig.14. Potential Substitute for Processes

Presumed a tree shaped system of linear processes forms the substitute of duration P, the development of the added value runs like $W \sim \xi^p$ where p is the index of unified timeslots and ξ is the average interoperability. Then the nonlinearity is modelled by the given potential function ξ^p and ξ for this subsystem can be measured e.g. by the half-time value

$$\omega = \frac{W(P)}{W(P/2)} = \frac{\xi^P}{\xi^{P/2}} = \frac{\xi^{P/2}\xi^{P/2}}{\xi^{P/2}} = \xi^{P/2} \tag{13}$$

Therewith we find the number of hidden virtual processes to be:

$$N_V = 2\sum_{p=0}^{P/2} \xi^p = 2\frac{\xi^{P/2}-1}{\xi-1} = 2\frac{\omega-1}{\omega^{2/P}-1} \tag{14}$$

and the number of virtual interactions:

$$K_V = \sum_{p=0}^{P} \xi^p = \frac{\xi^P-1}{\xi-1} = \frac{\omega^2-1}{\omega^{2/P}-1} \tag{15}$$

With this, at least the volume of a presumably complete model can be obtained from the given data which allows for evaluation of criticality. Thus, the grade of virtually modelled processes and interactions needs to be kept in mind when judging a system. For this purpose the degree of modelling

$$M = \frac{N_{Real}}{N_{Real} + N_{Virtual}} \tag{16}$$

provides the proportion of real elements in comparison to the expected total volume of the system.

9. Evaluation and criticality of a project

As soon as the completeness of a project model can be judged e.g. by a value of $M \cong 1$ we take the model to be highly representative for the project and therefore observe the multiplicity of processes as a well established measure for the sensitivity of the total project.

The traditional attempt would be to plot the number of processes against the total float and obtain a graph like Fig. 15:

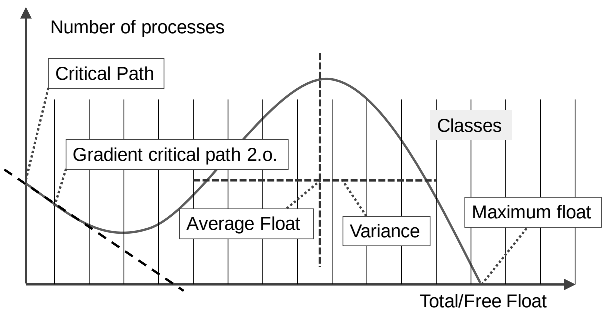

Fig.15. Evaluation of Float Times in Projects

Yet, since the total float is consumed for all subsequent processes the plot is somewhat misleading. A further and more consequent step would be the use of the free float instead. Then at least the available slack time of a process or path denotes the position in a network with respect to the critical path.

We would obtain the processes of the critical path at the zero float end of the graph, close to it the nearly critical paths along with the gradient of the curve measuring the situation around the critical path at second order. Finally all other processes are found more or less concentrated around an average float, characterized by a value of variance.

In accordance to the developed value of criticality, it is known, that floats are not available for disposition, nor do existing float times reveal actual characteristic of sensitivity. Therefore the number of processes needs to be plotted vs. the criticality χ defined before in order to obtain significant statements regarding the project (Fig.16).

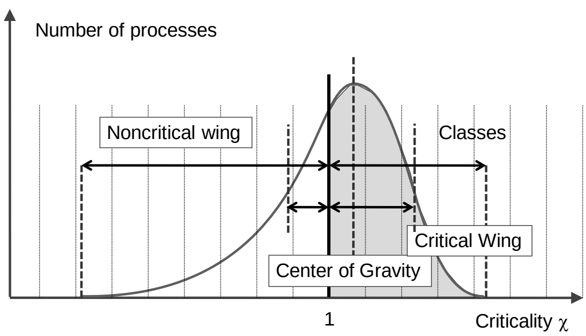

Fig.16. Evaluation of Criticality Projects

Based on this a general definition of the criticality of a project is:

$$\psi = \frac{1}{N_p}\sum_i \chi_i \tag{17}$$

which describes as mean value only the tendency of the multiplicity of processes but nevertheless indicates whether processes are in general critical or not.

The stronger message can be obtained from the share of noncritical processes within the multiplicity which comes to be unity if all comprised elements are judged noncritical.

$$\Psi = \frac{1}{N_p}\sum_{\chi_i > 1} N_p(\chi_i) \tag{18}$$

10. Conclusions

Concluding, these findings primarily provide some well founded measure of the completeness of a project structure as e.g. a network plan on the basis of the knowledge of the scheduled added value on the course of time.

On this background the explicit calculation of parameters like complexity, interoperability, impact, and parallelity allows to judge the systems behaviour on unintended deviations of crucial values. Especially we are confronted with potential development according to the complexity and the volume of the model.

Further knowledge of the added value of each process and the purposely made decisions of effort to spend on controlling activities define an applicable reaction time constant in order to obtain the controllability of risk. Comparison to the reserve time as calculatedly designated additional spare time yields a value of criticality, which stands for the certainty of a process to execute as scheduled.

Regarding criticality of an entire project comprising large numbers of highly interconnected processes of different singular criticality two criteria are given. Firstly averaged value judges the situation of the total and points out, whether in general a project is critical or not. Secondly the proportion of critical processes directly yields the number of hotspots where modifications to appropriate control mechanisms are unavoidable.

From these findings we expect some significant improvement on risk management on singular and nonrecurring projects since terms of probability can be replaced by judgement of the implemented control effort and therefore be handled in a much more comprehensive way, not least as an essential part of respective contract formulations (Zimmermann, Hamann 2008, Zimmermann 2009).

References

Booch, G. 2007. *Object-Oriented Analysis and Design with Applications*, 3rd ed., Addison-Wesley, New York

Bronstein, I.; Semendjajew, K. 1979. *Taschenbuch der Mathematik*, 23rd ed., Harri Deutsch Verlag, Thun /Frankfurt(Main)

Bronstein, I.; Semendjajew, K. 1979. *Taschenbuch der Mathematik, Ergänzende Kapitel*, 3.rd ed., Harri Deutsch Verlag, Thun/ Frankfurt (Main)

Domschke, W., Drexl, A. 2006. *Einführung in Operations Research*, 7th ed., Springer, Berlin.

Gaede, K.; Heinhold, J. 1976. *Grundzüge des Operations Research, Teil 1*, 1st ed., Carl Hanser Verlag, München.

Haken, H. 1983. *Synergetik*, 2nd ed., Springer Verlag, Berlin.

Henn, R.; Künzi, H. 1968. *Einführung in die Unternehmensforschung I, II*, 1st ed., Springer Verlag, Berlin.

Hillier, F.; Liebermann, G. 1997. *Operations Research*, 5th ed., Oldenburg Verlag, München

Jureka,W.; Zimmermann, H.-J. 1972. *Operations Research im Bauwesen*, 1th ed., Springer-Verlag, Berlin. http://dx.doi.org/10.1007/978-3-642-93008-9

Johnson, K. 1973. *Operations Research*, 1th ed., VDI-Verlag Düsseldorf

Kerzner, H. 2003. *Project Management: A Systems Approach to Planning, Scheduling, and Controlling* , 8th ed., Wiley, Berlin

Lewis, J. 2002. *Fundamentals of Project Management*, 2nd ed., American Management Association, New York

Malik, F. 2008. *Unternehmenspolitik und Corporate Governan*ce, 1st ed., Campus Verlag, Frankfurt

Malik, F. 2003. *Systemisches Management, Evolution, Selbstorganisation*, 4th ed., Haupt Verlag, Bern

Müller-Merbach, H. 1971. *Operations Research*, Verlag Franz Vahlen, 2nd ed., München

Picot A.; Dietl H.; Franck E. 2008. *Organisation - Eine ökonomische Perspektive*, 5. rev. ed., Schäffer-Poeschel, Stuttgart

Runzheimer, B. 1978. *Operations Research*, 7th ed., Gabler Verlag, Wiesbaden

Sackmann, D. 2003. *Ablaufplanung mit Petrinetzen*, 1st ed., Deutscher Universitäts-Verlag, Wiesbaden. http://dx.doi.org/10.1007/978-3-322-81523-1

Shannon C. E. 1948: *A Mathematical Theory of Communication*. In: Bell System Technical Journal. Short Hills N.J. 27.1948, (July, October), S. 379–423, 623–656. ISSN 0005-8580

Scheer, A. 1997, *Wirtschaftsinformatik*, 7th ed., Springer Verlag, Berlin. http://dx.doi.org/10.1007/978-3-642-60820-9

Schelle, H.; Ottmann, R.; Pfeiffer, A. 2005. *Project Manager*, 2nd ed., GPM Deutsche Gesellschaft für Projektmanagement, Nürnberg

Schulte-Zurhausen, M. 2002. *Organisation*, 3rd ed., Verlag Franz Vahlen, München.

Schulz, G. 1995. *Regelungstechnik, Grundlagen, Analyse und Entwurf von Regelkreisen, rechnergestützte Methoden*, 1st ed., Springer Verlag, Berlin

Vester, F. 1995. *Leitmotiv vernetztes Denken*, 5th ed., Heyne Verlag, München

Wiener, N. 1992. *Kybernetik*, 2nd ed., Econ Verlag, Düsseldorf.

Wiest, J.; Levy, F. 1977. *A Management Guide to PERT/CPM*, 2nd ed., Prentice-Hall of India Private Limited, New Delhi

Zimmermann, W. 1997. *Operations Research*, 10th ed., Oldenburg Verlag, München

Zimmermann, J., Günthner, W., Eber, W., Haas, B., Lügger, M., Sanladerer, S. 2008. *Logistik in der Bauwirtschaft - Status quo, Handlungsfelder, Trends und Strategien*, 1th ed., Bayern Innovativ, München

Zimmermann, J., Hamann, M. 2008. *Vergleich bauvertraglicher Regelungsmechanismen im Hinblick auf eine optimierte Abwicklung und zur Senkung von Konfliktpotential am Beispiel von*

VOB, NEC und FIDIC, Forschungsarbeit im Auftrag des Bundesamtes für Bauwesen und Raumordnung, ISBN-Nummer: 978-3-939956-08-2, München

Zimmermann, J., Eber, W., Schieg, M., Nino, E. 2008. *Risk Evaluation in Construction Management*, Conference Business and Management 2008, Selected Papers, Volume I and II, Vilnius/Litauen: 241–244

Zimmermann, J. 2009. *Prozessorientierter Nachweis der Kausalität zwischen Ursache und Wirkung bei Bauablaufstörungen*, Forschungsarbeit im Auftrag des Bundesamtes für Bauwesen und Raumordnung, ISBN-Nummer: 978-3-939956-12-9, München.

Zimmermann, J., Eber, W. 2010. *Modelling Processes in Construction Management*, 6th International Scientific Conference, Vilnius, Lithuania, ISBN-Nummer: 2029-4441, Business and Management 2010, selected papers, Volume I and II, Vilnius, Lithuania: 1133–1139

Zimmermann, J., Eber, W. 2011. *Knowledge Based Risk Controlling*, 3rd International Symposium on Geotechnical Safety and Risk (ISGSR2011), München: 259–268