Support of Project Planning in Chemical Engineering via Modeling and Simulation

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Abstract. The following approach shows a method that supports an experience based generation of a project plan as well as the simulation supported examination and improvement of projects with flexible structure. Methods are briefly introduced via an example from the chemical engineering industry. It can be shown how various stochastically generated project constellations can be compared using Petri net simulation. The example project is simulated with different numbers of employees and different resource configurations. An analysis of results shows the best combination of employees and resources that leads to a decrease in project duration.

1 Introduction

Development projects are associated with great calculative risk since it is difficult to predict the resources and personnel necessary for the course of a project. It would therefore be beneficial for project planners to be able to estimate cost sources as early as possible. This planning task is based primarily on existing know-how, i.e., experience during project management. Gröger's [1] most recent data shows this is insufficient, and indicates that approximately only 13% of work in projects is actually valuable. Since even very small projects can quickly reach a high level of complexity, it is impossible for even well versed project managers to prospectively view all identified key factors and connect them to a collision-free workflow. Currently available tools provide project managers with limited possibilities to regard all parameters in the same way. Thus, to determine work capacity or productivity necessary for a project, detailed experience about the project work must be acquired first through inclusion of employees. To counter these problems the IAW, in collaboration with partners from the Institute of Process Systems Engineering and the chemical engineering and software industries, developed an analysis tool able to evaluate different workflow management alternatives that produce factor characteristics. The analysis includes modeling of development processes, transfer into a simulation model, and evaluation of data gained through simulation campaigns.

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2 Process-oriented Modeling and Simulation

Well-structured projects are easily presentable in an information technical manner [2], which forms the system-based aspect of project planning tools. However, Wallmeier [3] posits that only a portion of activities should be regarded as well-structured routine tasks if these activities are seen as components of development projects [4]. A further portion – the important stochastic factor necessary for the later simulation – results only from intermediate results. Thus, planning tasks quickly become extremely complex and no longer manageable. As a result, and depending on application background, different procedure models have been developed that allow for a general structuring of the work processes. Possibilities for depicting temporal or temporally abstract connections (SADT/IDEF [6]), attributes (DIN 66001 [7]) or their quantifications (IUM [8]) are still missing. Killich [9] presents several additional deficits of popular modeling methods. The C3 modeling method was developed for the depiction of these important characteristics, and allows the mapping of complex development processes by using 14 base elements, ten of which are shown below:

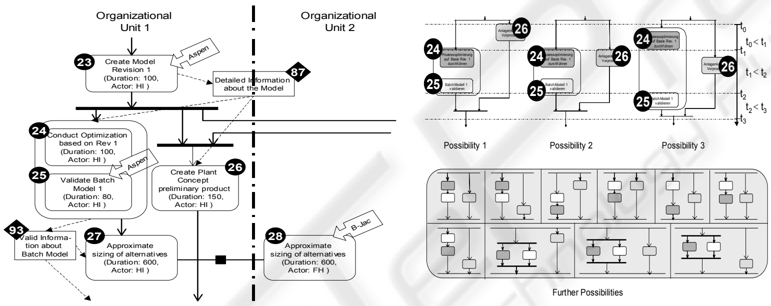

Fig. 1. Core elements of C3 and different stochastic decompositions of the blob.

The left side of Figure 1 shows an excerpt of a development process with two different departments involved. First, activities 26, 24 and/or 25, as well as a further activity not shown here, on the right side follow activity 23. As example attributes of the activities, the duration and required training of the participants were extended. In activity 23, using the tool "Aspen", the detailed model information (87) was compiled, which is necessary for beginning activity 26 as well as the blob. The blob contains activities 24 and 25, meaning these two activities can take place in arbitrary order (see right side of Figure 1). By retaining this level of stochastic abstraction, the simulation shows the effect of the different operational sequences on the total project. The sequence of the activities in the blob that should be chosen depends on the number and qualification of the actors available, along with the availability of necessary resources, such as Aspen. If activity 24 and 25 are completed, and if the information about the batch model (element 93) necessary for the succeeding communication as well as for further activities is compiled, synchronous communication of both organizational units occurs (activities 27 and 28). Thus, at least two participants with respective affiliation to the two organizational units involved for the same time are needed for the communication task. If one of the two communication partners is not available at the specific time, the work routine is suspended until suitable participants can implement both activities. The tool “B-Jac” must also be available for activity 28. Another input condition is represented by the synchronization node: activity 26 can be started after the two predecessor activities, 23 and an additional activity not depicted on the right side, are completed along with input 87. The following section deals with the simulation software architecture.

The connections described above were transformed into a Petri network simulation. The resulting task net distinguishes between a) connections that represent the execution conditions, and thus the interaction of individual elements, and b) elements, e.g., persons, organizational units, activities, tools, or information. While the connections (a) can be directly transferred into a Petri net, the behavior of individual elements (b) was transferred into simulation by means of partial models. The simulation model therefore consists of the task net itself, which–with regard to its structure–corresponds to the C3 model, and of the partial models of the activities, persons, tools and information. For the implementation, the Petri net simulator Renew [10] was used.

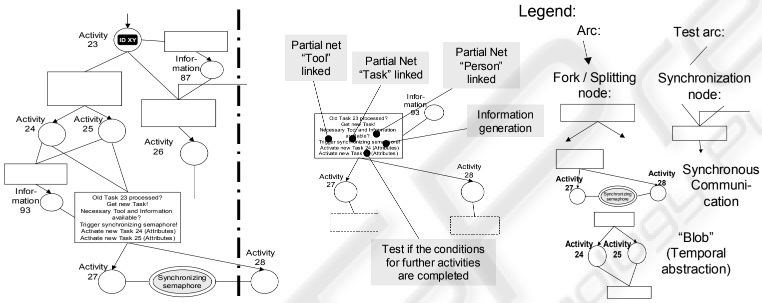

Fig. 2. Petri net model resulting from the C3 model in Fig. 1 and its substantial elements.

Figure 2 shows an excerpt of the whole task net with some substantial elements, such as the use of resources and information, synchronous communication, the branching out and the combination of the control flow. The basic Petri net functions were adopted and subdivided according to the possibility of using subnets as tokens, thereby keeping the partial nets of the activities, tools and information in the respective places. Thus, the dominant conditions can be reconstructed and analyzed at the time of the execution of individual activities. Using the same structure, project specific partial nets differ only in the attributes used for parameterization of the individual elements; different partial nets can be reused in different project structures. The partial net of the activity determines the boundary conditions necessary for the flexible execution of the individual activity. Another stochastic element, besides the degree of freedom of the task sequences, is the actual duration used in the simulation run, either subject to a normal distribution or to a beta distribution. This distribution is integrated considering the fact that the actual duration of an activity must be initially estimated. Moreover, the qualification contains many further attributes. This attribute determines to which organizational unit the implementing person should or must belong to, which tools are suited for task execution and to which extent qualification deviations are considered. The partial net of the tool provides the list of tools generally available and reserves certain tools during their usage. Finally, the partial net of the information contains only the different elements of information that are generated in an activity and stored in a database, which are then made available for subsequent activities.

The Petri net simulation now accomplishes the calculation of the total project duration, the level of parallelization (LP) and the grade of integration of the persons available (G_{IP}). This is done by combining the stochastic elements, such as weakly structured task interdependencies and the dispersion of the duration of each task, with the team constellation boundary condition and available tools.

3 Simulation

Prior to using the models to identify causes and effects [11], they must be checked to see if they are valid representations of the systems to be studied. The C3 modeling method has been used for the assessment and modeling of different development processes in chemical engineering, performed in cooperation with experts and researchers from this field. Additionally, VDI 3363 [12] suggests the comparison of real data to simulation results. To show the results of one selected simulation model later on, the Polyamide 6 process [13] was used as an example case of the research project CRC476. The underlying process here, consisting of 79 activities executed through coordination between eight organizational units, describes the different phases of new development for the manufacturing of PA6. It contains five blobs and 13 synchronous communications with up to four participating organizational units. The following section deals with the parameterization, the variables and hypotheses:

To determine the best constellation for the realization of this project, the numbers of persons and tools were systematically varied. A minimum of nine different tools and two different actors are necessary to conduct the project. This "basis" constellation is then extended, first by additional actors [number of working persons (N_{WP})] able to conduct each activity, and second, by a multiplication of tools [total number of tools (TN_{OT})]. Additionally, the variance of task duration (V_{TD}) was varied between 10% and 30% with the Gaussian normal distribution (G) and with the right skewed beta (β) distribution (α=6, β=3) (variation of the distribution: V_{DT}). As a consequence of this distribution, combined with the abstract elements in the process flow, several thousand possible sequences arise. In total, 5222 runs with 155 selected different constellations of independent variables were performed.

The most important dependent variables are total time of project duration (TT_{PD}= beginning of first task to end of last task) and total time of work (TTW), also seen as total effort needed to execute project. Further dependencies are the level of parallelization (LP) and the grade of integration of the persons available (G_{IP}). The average of the personnel workload AG_{IP} is the sum of G_{IP} divided by the N_{WP} and considered as the average integration of working persons. The null hypotheses state that the total time of project duration (TT_{PD}) is independent of the number of working persons (N_{WP}) (H_{01}) as well as of the total number of tools (TN_{OT}) (H_{02}) as of the variance of task duration (V_{TD}) (H_{03}).

By analyzing these coherences, prognoses can be made about the cost of the developing process, realistic milestones, workload of actors and tools, time of the assignment of actors and the application of tools and other resources.

4 Results

A detailed high dimensional five-way analysis of variance (ANOVA) enables analysis of main and side effects. The first hint for an optimal project organization can be gained by analyzing the effect of the variation of the most cost-intensive variable N_{WP}. At a 5% level of significance (α= .05), using a 95% confidence interval, highly significant ($p \leq .0001$) differences between the groups of 2, 3, 4, 5 and 6 persons can be discovered (see Fig. 5). Additionally, the percentage reduction of TT_{PD} is given by a sensitivity analysis. An increase above at least 6 persons does not significantly affect the TT_{PD}, though this is the one-dimensional view of the simulation result. The other independent variables must also be taken into account.

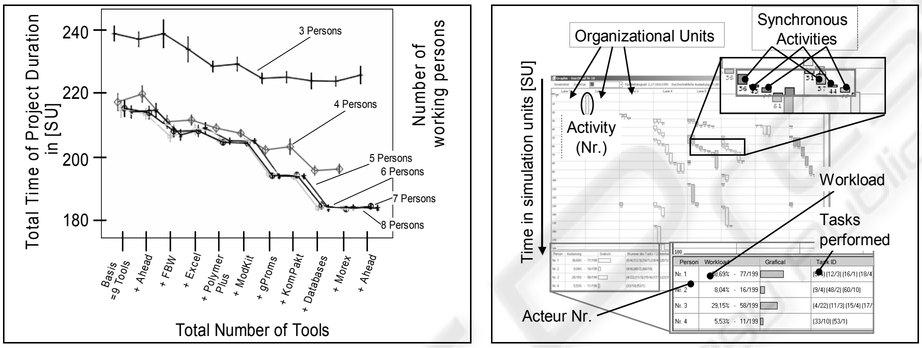

Fig. 5. Interdependencies between N_{WP}, TN_{OT} and TT_{PD} and prototype of a user interface.

In summary, H_{01}, H_{02} and H_{03} must be revoked. However, the ANOVA cannot explain which factor affects the dependent variable and to what extent a (estimated) measure of effect strength $\hat{\omega}^2$ expresses the portion of total variance explained by a single (statistically significant) effect [14]. The main effect strengths occur as follows: 69% of the variance of $\mathbf{TT_{PD}}$ can be explained by variation of N_{WP}, 15% by variation of $TN_{OT.}$ The **LP** is explained by 57% with the N_{WP}, 23% with TN_{OT}. $\mathbf{AG_{IP}}$ is highly affected by N_{WP}: 99% of the effect detected on this variable can be explained by the variation of $N_{WP.}$ The sensitivity analysis is more detailed in terms of optimizing the project progression, taking into consideration necessary personnel and financial effort. As shown in Fig.2, six is the optimal number of persons involved in the project. With increasing personnel assignment the total time of project duration could be decreased by more than 36% or 89 [SU]. With 1[SU] $\hat{=}$ 0.5d the total project duration could be reduced more than two months.

5 Conclusion and Outlook

A new simulation model based on the C3 modeling language was developed and offers project planners a suitable technique for quantitative comparisons of several alternative project structures. The influences of persons as well as tools were investigated in the first simulation runs. These experiments produced satisfactory results, as stated by experts of different leading chemical engineering companies. However, for further validation additional an empirical survey and further extensions are planned in close cooperation with enterprises. Furthermore, the correlations of individual factors are empirically calculated through the modeling of several example processes to ensure a transfer of the realizations to planned work processes.

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References

1. Gröger, M.: Wertschöpfungspotenzial Projektmanagement In:. REFA-Nachrichten 1/2006, Pp. 4-7, 2006.
2. Horn, S.: Die schemabasierte Modellierung und Steuerung von Projektvorgängen, Institut für Informatik, Universität Erlangen, Nürnberg, 2003.
3. Wallmeier, S.: Potenziale in der Produktentwicklung. Möglichkeiten und Grenzen von Tätigkeitsanalyse und Reflexion, VDI-Verl., Düsseldorf, 2001.
4. Badke-Schaub, P. & Frankenberger, E.: Management kritischer Situationen. Produktentwicklung erfolgreich gestalten. Berlin: Springer. 2004.
5. Vogel, G. H.: Process development: from the initial idea to the chemical production plant Weinheim : Wiley-VCH, 2005.
6. Khneisseh, A; Schach, R.: Application of Coloured Petri-Nets for the Business Process Modelling in Construction Companies, In: 22nd Conference on Information Technology in Construction, Dresden July 19 - 21, conference transcript, p. 63 – 68, 2005.
7. Awiszus, B. Current approaches for an integrated product and process modeling. Proceedings of PDT Europe 1999 Stavanger, QMS Sandhurst, UK, S. 353-360, 1999.
8. Keller, S.: Entwicklung einer Methode zur integrierten Modellierung von Strukturen und Prozessen in Produktionsunternehmen. Fortschritt-Berichte VDI, Reihe 16, Technik und Wirtschaft, Nr.117, VDI Verlag, Düsseldorf, 2000.
9. Killich, S.; Luczak, H.; Schlick, C.; Weissenbach, M.; Wiedenmaier, S.; Ziegler, J.: Task modelling for cooperative work. In: Behaviour & Information Technology, Hampshire, 18 5, S. 325-338, 1999.
10. Kummer, O.; Wienberg, F.; Duvigneau, M.: Renew – The Reference Net Workshop. Available at: http://www.renew.de/, 2005. Release 2.02.
12. Daalen, C.E.V.; Thissen, W.A.H.; Verbraeck, A.: Methods for the modeling and analysis of alternatives, in: W.B. Rouse (Ed.), Handbook of Systems Engineering and Management, Wiley, New York, 1999, p. 1236.
13. VDI 3633:Simulation von Logistik-, Materialfluss- und Produktionssystemen. Hrsg.: VDI-Gesellschaft Fördertechnik Materialfluss Logistik.Berlin: Beuth-Verlag, 2001.
14. Eggersmann, M.: Analysis and Support of Work Processes Within Chemical Engineering Design Processes, Published in: Fortschritt-Berichte VDI, Nr. 840, Düsseldorf, 2004.
15. Hays, W.L.: Statistics for the social sciences. New York: Holt Rinehart, and Winston, 1973.