A Petri Net based Method for Distributed Process Modelling in Structural Engineering

Uwe Rueppel, Udo F. Meissner, Steffen Greb
Institute for Numerical Methods and Informatics in Structural Engineering,
Technische Universität Darmstadt, D-64287 Darmstadt, Germany
sekretariat@iib.tu-darmstadt.de

Summary
The contribution introduces a method for the distributed process modelling in order to support the process orientation in Structural Engineering, i.e., the modelling, analysis and management of planning processes. The approach is based on the Petri Net theory for the modelling of planning processes and workflows in Structural Engineering. Firstly, a central and coarse process model serves as a pre-structuring system for the detailed modelling of the technical planning activities. Secondly, the involved planning participants generate distributed process models with detailed technical workflow information. Finally, these distributed process models will be combined in the central workflow net. The final net is of great importance for the process orientation in Structural Engineering, i.e., the identification, publication, analysis, optimization and finally the management of planning processes.

1 Introduction
In structural engineering projects architects, engineers, authorities and craftsmen create complex buildings with a unique design. Thereby, the planning participants always have to incorporate current scientific know-how and technical innovations in their planning and design activities in order to create a building with technical perfection with respect to economical and ecological aspects. Therefore, the planning processes in Structural Engineering are characterised by a high degree of specialization and a great division of work. Consequently, a lot of engineers, who operate in legally independent as well as temporarily and physically distributed organisations, have to co-operate and communicate in a heterogeneous planning environment.

The presented approach is to support the distributed process modelling. Firstly, the approach provides a central and coarse process model with only an abstract description of the whole planning process with its planning activities and their interfaces. Basically, it serves as a pre-structuring system for the detailed modelling of all technical planning activities. Secondly, the involved planning participants generate distributed process models. Each model provides the detailed description of the planning activities, planning states and planning resources for the corresponding technical domain, e.g., Architecture, Statics or Geotechnics. In a first step these technical process models are generated independently from each other. Afterwards, these models will be combined in the coarse process model with respect to the pre-defined interfaces. Based on the analysis and simulation possibilities of the underlying modelling method the comprehensive process model will be evaluated and verified.

2 Petri Net based Process Modelling
During the last decades different process modelling methods have been developed each addressing its specific objectives. Anyhow, [Aalst 1998a] gives some significant reasons for the application of Petri Nets to workflow management:

- Petri Nets have consistent formal semantics, i.e., a workflow modelled as a Petri Net has a clearly defined meaning without leaving any interpretation possibilities to the modeller.
- Petri Nets have a graphical representation. Thus, workflow models using Petri Nets are quite intuitive and easy to learn.
- Petri Nets provide all basic concepts for modelling typical workflow constructs like sequence, parallelism, iteration or synchronisation. Furthermore, Petri Nets explicitly enable the modelling of states within a workflow.
- Petri Nets enable the modelling of dynamic aspects, i.e., by use of so-called tokens the flow of arbitrary objects processed within a workflow can be modelled.
- Petri Nets provide various analysis possibilities. Petri Nets are bipartite directed graphs extended by the token concept. Thus there exist various structural and behavioural possibilities possibilities of repersentation.

For a short introduction to Petri Nets see, e.g., [Aalst 1998a], for a comprehensive introduction, e.g., [Reisig 1985] or [Baumgarten 1990] are recommend. As illustrated in Figure 1 a Petri Net consists of places, transitions and arcs, with each arc connecting either a transition and a place or a place and a transition. The tokens reside on the places. Based on well defined rules the transitions can "fire" and thus let the tokens "flow" through the net.

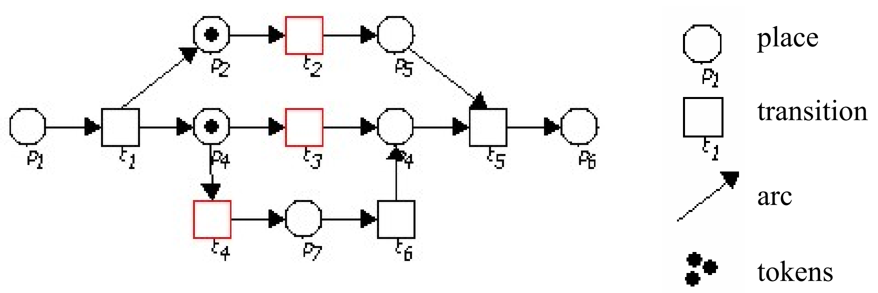

Figure 1:

Petri Net with AND/OR-Split and -Join

Places, transitions and arcs form finite sets. Additionally, a mapping function and fireing rules asign tokens to places. Based on the mathematical formalism, various structural, behavioural and linear analysis posibilities can be derived from the Petri Net.

The basic idea in modelling Structural Engineering processes with Petri Nets is to describe

- planning states with places
- planning activities with transitions
- planning dependencies with arcs
- planning information with tokens

The Petri Net in Figure 2 could represent an engineering workfow modelling concurrent planning activities of a structural engineer and a geotechnical engineer:

- The concurrent planning activities are initiated by an AND-split (transition t_1).
- The marked place p_2 indicates, that the structural engineer can start with the design of the raising building structure.
- The marked place p_4 indicates, that the geotechnical engineer can start with the design of the foundation. Additionally, place p_4 serves as OR-split: upon the "geotechnical category", specified in [DIN4020 2003], either a simple dimensioning procedure e.g. a shallow foundation (transition t_3) is sufficient X-or a more complex dimensioning procedure e.g. for a combined pile-raft foundation (transitions t_4 and t_6) is necessary.
- Finally, the AND-join (transition t_5) denotes a synchronisation planning activity where e.g. the architect assembles the information generated by the structural and the geotechnical engineer.

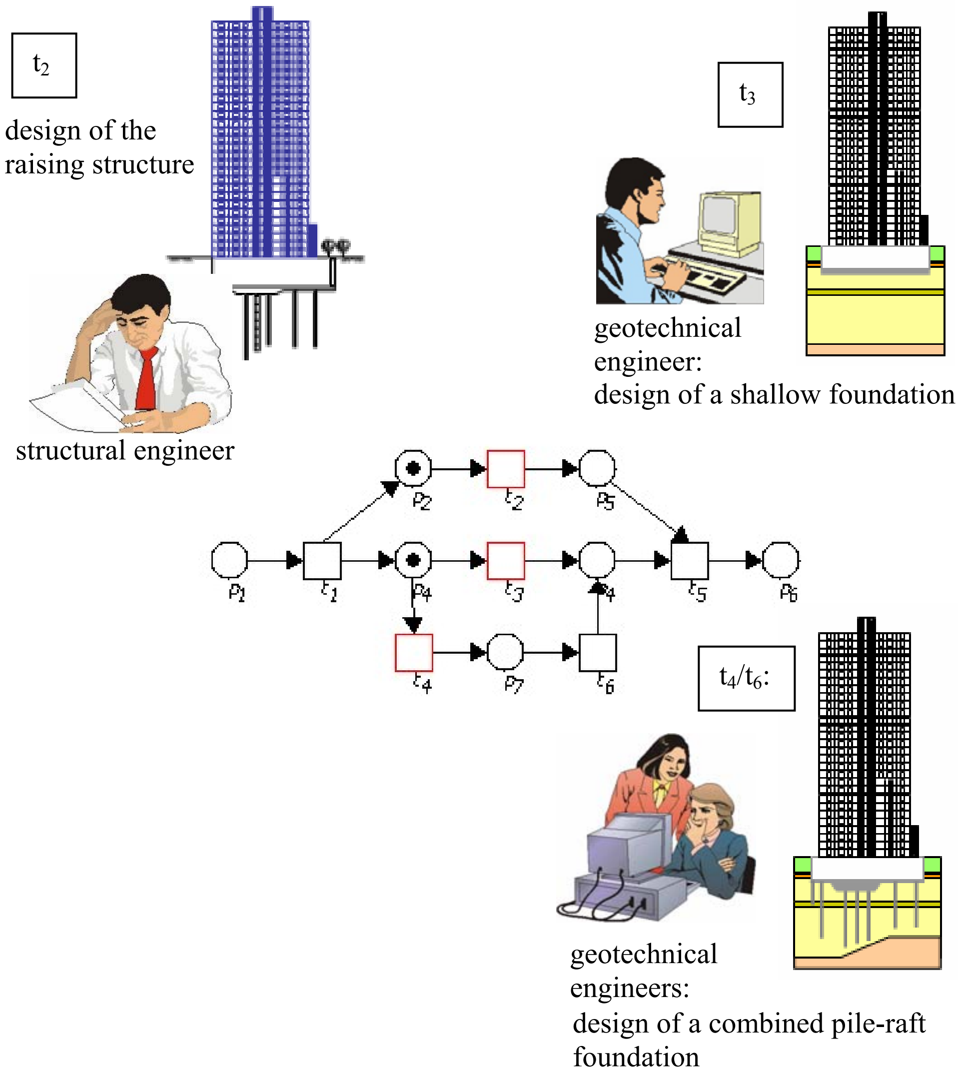

Figure 2:

Engineering Workflow Modelled with a Petri Net

Based on such a Petri Net based workflow model several analysis possibilities are available to verify the processes, to draw conclusions or to optimize the processes. Essentially, these possibilities are

- structural analysis,
- behavioural analysis,
- simulation,
- operations research methods, and
- a graphical validation.

It is very important for the approach to have a great variety of analysis possibilities in order to examine the process model. This is introduced in the following.

3 Discributed Process Modelling

The distributed process modelling is based on hierarchical Petri Nets and concepts introduced in [Jensen 1996] with the substitution of transitions based on distinct places so-called "socket places" and "port places". In [Aalst 1999] another approach to manage interorganizational workflows based on Petri Nets is presented. The approach focuses on loosley coupled inter-operability between business or planning partners, respectively. Anyhow, the defined Petri Net sets for modelling aysnchronouse and syncronous communication between planning participants defined in [Aalst 1999] can extend the approach introduced in the following.

The central and coarse process model provides only an abstract description of the whole planning process. This model is generated by the architect or a project manager, respectively. A transition, i.e., a planning activity, that will be described in more detail by a distributed process model, is identified by socket places as input- and output places. Figure 3 shows an architect modelling a coarse process net – from his point of view – just as a simple sequential process. The place p_2 denotes an input-socket place, the place p_3 denotes an output-socket place and the enclosed transition t_3 indicates a coarse description of a planning activity, e.g. "design foundation".

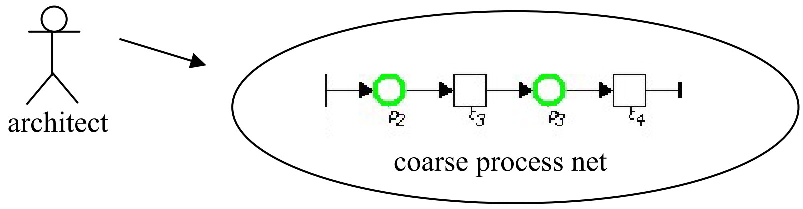

Figure 3:

Architect Modelling a Coarse Process ;odel with Socket Places (places p_2 and p_3)

On the other hand different distributed engineers generate their workflow nets describing technical aspects of their planning actvities in detail. Essentially, these nets have to fullfil the requirements of a Workflow Net defined in [Aalst 1998a] with a single input place (p_1) and a single output place (p_2). Input place and output place are denoted as "port places".

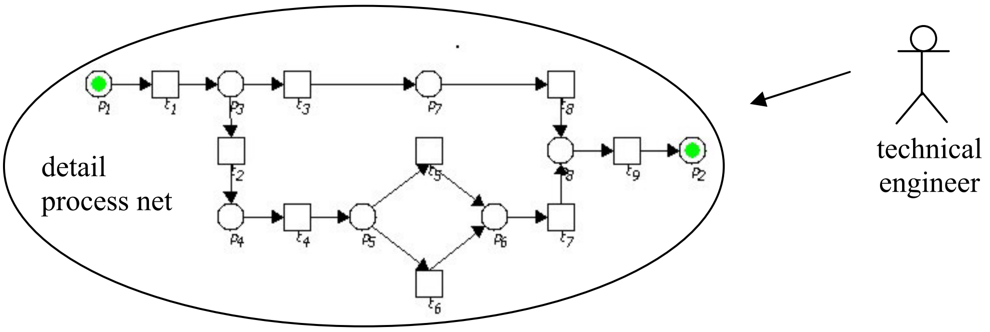

Figure 4:

Technical Engineer Modelling a Detail Process Model with Port Places (place p_1 and p_2)

The "technical engineer" in Figure 4 e.g. represents a geotechnical engineer who models the planning activities and planning states in order to design a foundation more detailled.

The combination of the coarse process net and the distributed detail process nets is based on the unique assignment of port places to socket places. For this assignement different techniques are possible: The goal is to support an autmatic assignment of port places to socket places, e.g., based on a unique terminology or onthology, respectively. However, until now the introduced software ProMiSE (see section 4) supports a manual assignement. Once the places are assigned, the detailed process net is incorporated in the coarse process net as subnet of the denoted transition t_3 (see Figure 5).

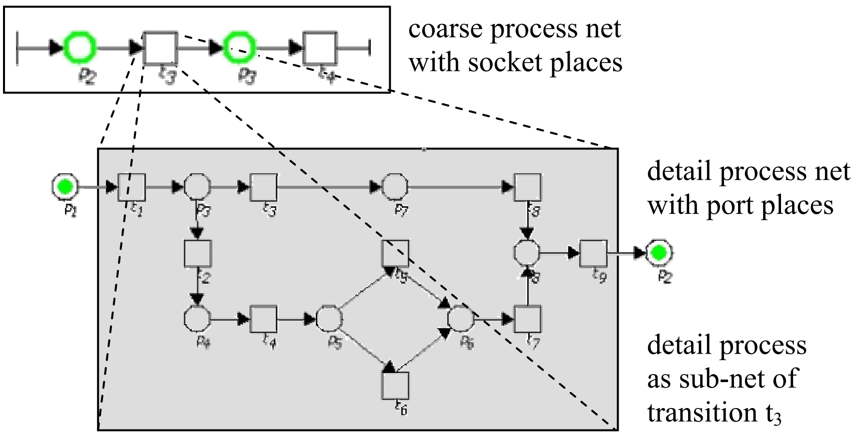

Figure 5:

Detailed Process Net as Subnet of Transition t_3 in the Coarse Process Net

Of course, the assignement of port places to socket places and the submission of the detail process nets to the central server with the coarse process net requires some network communication. This communication is realised with WebServices and the SOAP/XML standard. The modelling, the assignement and the network communication will be introduced in the following.

4 Reference Implementation *ProMiSE*

ProMiSE is a Java-based Petri Net tool for the modelling, analysis and control of planning processes in Structural Engineering. The persistent representation of Petri Net information is based on the Petri Net Markup Language (PNML), an XML exchange format introduced in [Kindler 2002]. Especially, ProMiSE provides means for the network communication with client applications based on the WebService technology and appropriate SOAP client- and server-processors: For the network exchange the Petri Net data structure is serialized as a XML stream in the PNML format, wrapped as a SOAP Message, and then sent from the SOAP Client processor to the WebService endpoint. ProMiSE itself serves as a client application for the modelling of the detail process model and as a server application containing the coarse process model. The distributed modelling and the network communication is illustrated in Figure 6 as an UML sequence diagramm, with the following actors:

- The technical engineer, as modeller of the detailed process net in the ProMiSE client.
- The ProMiSE client, as a modelling tool for the detailed process net with communication mechanisms with the WebService agent.
- The WebService agent, as a communication interface between ProMiSE client- und server-application.
- The ProMiSE server, as a modelling tool of the coarse process net with communication mechanisms with the WebService agent and analysis possibilities.
- The architect or project manager, as modeller of the coarse process net and the analyser of the combined process net containing the former distributed process nets as subnets.

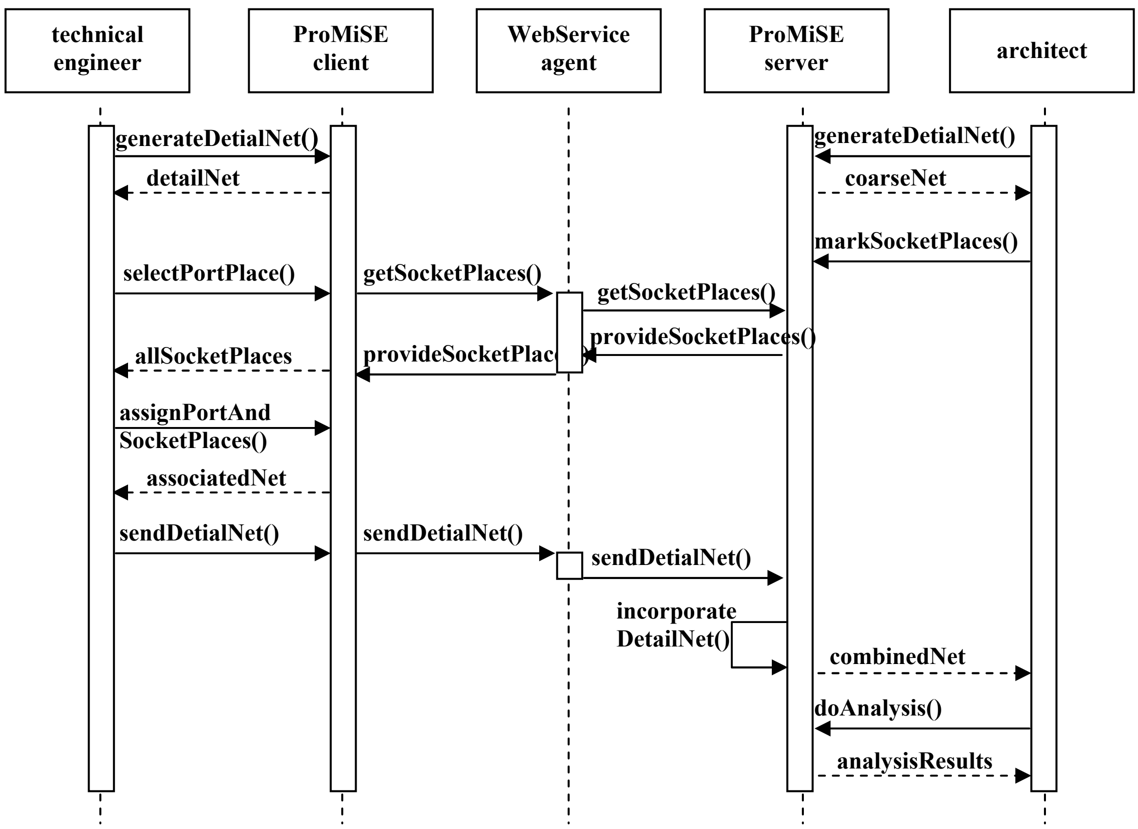

Figure 6:

Distributed Process Modelling and Network Communication Illustrated as UML Sequence Diagramm

Once the distributed detail process models are incorporated, the architect holds a comprehensive hierarchical structured net providing a process-oriented view on the whole planning process. Modelling mistakes, like deadlocks or a lack of synchronisation, indicate an inadequate coordination of the real planning processes, which often leads to serious problems concerning the quality of the building, the building time or the costs. In order to detect these deficiencies mistakes, ProMiSE provides various analysis possibilities, some of which are fundamental properties of the Petri Net theory, others are extended Petri Net properties with focus on the workflow management. An important analysis possibility in the context of process modelling is the soundness property defined in [Aalst 1998a]. The soundness property provides information about the structural and behavioural properties of the process model, it states

- that from an initial planning state it is always possible to reach a final planning state, known as "option to complete", formally:
$$\forall M : (i \xrightarrow{*} M) \Rightarrow (M \xrightarrow{*} o)),$$
- that at the moment a token has reached the final planning state, there are no spare tokens left in the Petri Net, known as "proper termination", formally:
$$\forall M : (i \xrightarrow{*} M) \Rightarrow (M \xrightarrow{*} o)),$$
- that there are no dead transitions, formally:
$$\forall t \in T : \exists M, M' : (i \xrightarrow{*} M \xrightarrow{t} M').$$

where:	M	denotes an arbitrary marking of the Petri Net,
	i	denotes the initial marking of the Petri Net with exactly one token in the start place,
	o	denotes the final marking of the Petri Net with exactly one token in the end place,
	t	denotes an arbitrary transition of the Petri Net.

Concerning the planning processes in Structural Engineering the architect can e.g. detect planning activities that never will be executed, information that will not be synchronised or unprocessed planning information. Figure 7 illustrates the analysis menu item of ProMiSE and the soundness analysis results for the detail process model of the geotechnical engineer.

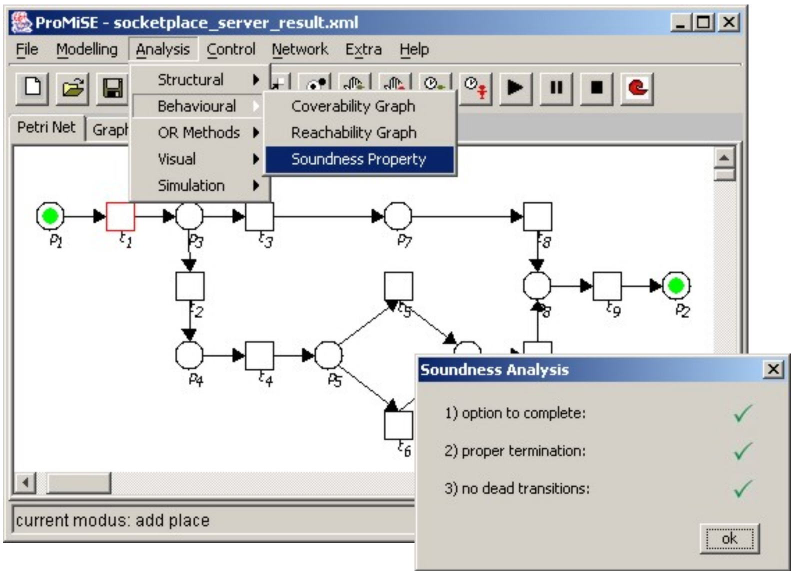

Figure 7:

Petri Net based Analysis Prossibilities of Engineering Processes (Soundness Analysis [Aalst 1998a])

5 EPC Modelling with ARIS Toolset

ARIS – the Architecture of Integrated Information Systems – provides both, a concept and a software framework for describing company structures, processes and business application systems. The "House of ARIS", shown in Figure 8, and its views are the central structuring methodology [Scheer 1998].

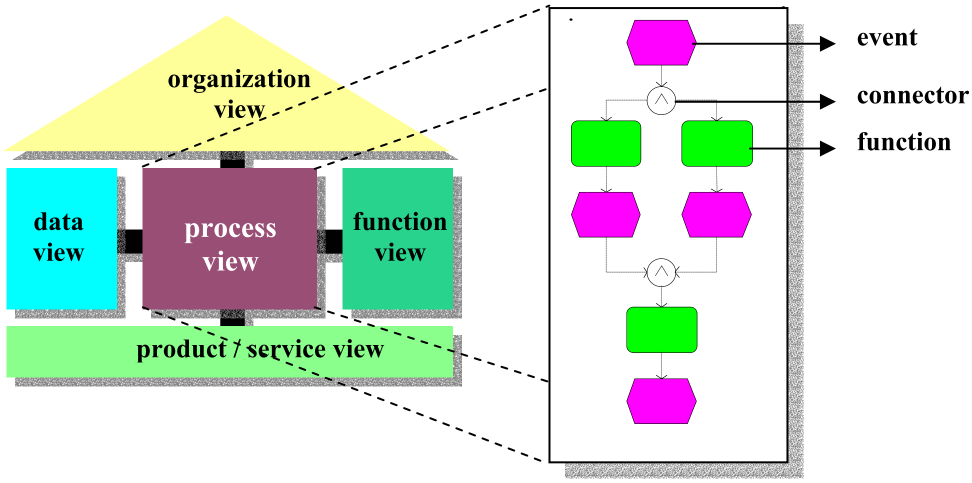

Figure 8:

House of ARIS and EPC as Central Modelling Technique within the Process View

The focus of ARIS is on the design, the analysis and the optimization of business processes. For this purpose, ARIS provides standard modelling methods for each view. Especially, for business process modelling, the Event-driven Process Chains (EPCs), also shown in Figure 8, have become a widespread process modelling method. In [Aalst 1998b] a formalism for mapping EPCs onto Petri Nets is presented. Based on this formalism, a ProMiSE module called *EPC2Petri* was implemented, allowing to import an ARIS output file with EPC information in the AML – ARIS Markup Language – format and to transform it to a Petri Net in ProMiSE.

With this import functionality, the technical engineer also can use the ARIS Toolset as a powerful and comprehensive software tool used in practice. For modelling the engnieering processes he can rely on the EPC technique and thereafter, he can import the process model in to ProMiSE, do the process analysis and mark the process net as part of the central and coarse process net.

6 Conclusions

The contribution has introduced an approach to support a distributed process modelling for the planning processes in Structural Engineering. For the process modelling the Petri Net theory is used with some extensions to workflow management and analysis possibilities. Essentially, the application of hierarchical Petri Nets with socket places and port places are the basic methodologies in order to enable a distributed process modelling. These approaches and the use of network technologies like WebServices and SOAP/XML are the basis for the development of ProMiSE, a java-based Petri Net Server for the modelling, the analysis and control of planning processes in Structural Engnieering. In order to enable a user friendly way of modelling engineering processes with a professional software tool, an import functionality for ARIS/EPCs was realised in ProMiSE. Hereby, the import of semi-formal EPC information is based on the transformation formalism in order to get formal defined Petri Net information for the modelling and the analysis of engineering processes.

7 References

van der Aalst, W. M. P. (1998), *The Application of Petri-Nets to Workflow Management*. In: Journal of Circuits, Systems and Computers 8(1), World Scientific, Singapur. 21-66

van der Aalst, W.M.P. (1998): *Formalization and Verification of Event-driven Process Chains*, Computing Science Reports 98/01, Eindhoven University of Technology, Eindhoven

van der Aalst, W.M.P. (1999) , *Interorganizational Workflows: An Approach based on Message Sequence Charts and Petri Nets*, Systems Analysis - Modelling - Simulation, 34(3):335-367

Baumgarten, B. (1990), *Petri-Netze - Grundlagen und Anwendungen*, Spektrum-Akademischer-Verlag

Jensen, K. (1996), *Coloured Petri-Nets - Basic Concepts, Analysis Methods and Practical Use*, Springer-Verlag

Kindler, E. (2002), *The Petri Net Markup Language*, In: H. Weber (Ed), Petri Net Technology for Communication Based Systems, , Springer LNCS

Chappell, D.A.; Jewell, T. (2002), *Java Web Services*, O'Reilly

DIN 4020 (2003), *Geotechnische Untersuchungen für bautechnische Zwecke*, Beuth-Verlag

Reisig, W. (1985), *Petri Nets, An Introduction***,** In: Monographs on Theoretical Computer Science, W.Brauer, G. Rozenberg, A. Salomaa (Eds.), Springer Verlag, Berlin, 1985.

Scheer, A.-W. (1998), *ARIS- Vom Geschäftsprozeßmodell zum Anwendungssystem*, 3.Auflage