MODELLING, SIMULATION AND PROSPECTIVE ANALYSIS OF COOPERATIVE PROVISION OF INDUSTRIAL SERVICES USING COLOURED PETRI NETS

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Abstract: International customer demands in the capital goods industry force providers of industrial services to be present on a global market. Often this can only be realised efficiently by cooperating with partners. But the process to configure a cooperation and choose an adequate cooperation alternative still lacks adequate support. Existing approaches to evaluate services or cooperation are not suitable for an assessment of different alternatives prior to their implementation. Simulation approaches for production networks on the other hand, cannot be used for industrial services. This paper deals with an approach to overcome this problem and presents a simulation model based on Petri net theory for the prospective analysis of cooperative provision of industrial services. To achieve this goal, a domain-specific conceptual model of cooperative provision of industrial services has been developed that considers the constitutive characteristics of industrial services and their cooperative provision and maps them onto the formal notation of coloured Petri nets to form an executable simulation model. As a result, machine and equipment producers will be able to assess their cooperation alternatives related to integrated service provision in advance and thus avoid cost-intensive false decisions.

Keywords: Coloured Petri nets, prospective analysis, industrial services, cooperation, performance analysis

1 MOTIVATION

1.1 Trend towards Cooperation and Need for Assessment Support

Germany's capital goods industry has an export rate of about 70 percent and its capital goods are sold around the globe. Thus product-related services also have to be offered internationally [Bienzeisler and Meiren, 2005; Wise and Baumgartner, 1999]. These product-related industrial services (e.g. repair or maintenance) are offered to (re)establish, ensure or enhance the long-term usability of industrial products and are becoming increasingly important in the global economy and also in Germany's capital goods industry: German machine and equipment producers are realising an increasing percentage of their revenues with product-related services [Hoeck and Kutlina, 2004]. However, international provision of high-quality services requiring expert knowledge has proven to be cost-intensive and thus threatens the profit margin. Therefore, machine and equipment producers are looking for partners to form coalitions to improve their service business through cooperative advantages such as more efficient deployment of experts, shorter order processing times or cost reduction. In other words, the process of providing services for customers is no longer owned by one single company, but by several partners. This shared process is referred to as cooperative service provision.

While many companies have gained preliminary experience with cooperative service provision, the existence of problems in finding appropriate partners and reported organisational difficulties indicate that companies lack support for the planning and configuration of service networks (see Figure 1).

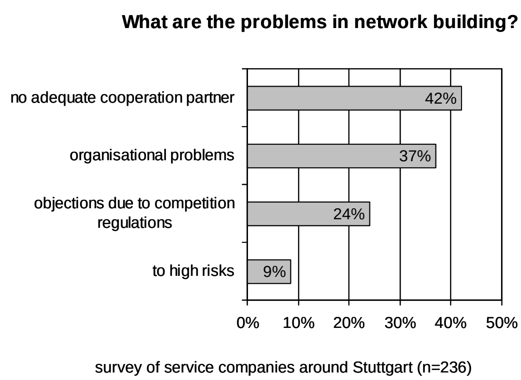

Figure 1: Problems in network building [Zahn and Stanik, 2003]

A variety of alternatives related to cooperation and configurations complicates a substantiated decision [DIHT, 2001; Gulati et al, 2000]. In this context, the possibility of assessing different cooperation alternatives before implementation is needed [Braun, 1999]. Some approaches for network and service controlling exist, but these methods are not suitable for an assessment of different alternatives prior to their implementation, i.e. a prospective analysis.

Companies are not able to evaluate, for example, whether or not a certain combination of partners in the service process leads to a shorter order processing time for service orders.

To solve problems of this kind, a model for the prospective analysis of service network alternatives in the capital goods industry is needed [Luczak et al, 2005]. This model has to consider the special requirements and characteristics of industrial services and their cooperative provision. In addition, it has to be represented in a formal notation that allows simulations and performance analysis.

1.2 Prospective Analysis of Service Network Alternatives using Simulation based on Coloured Petri Nets

The target is therefore to enable the prospective analysis of cooperative provision of industrial services. The chosen method of resolution is simulation with coloured Petri nets (CPN). Coloured Petri nets are widely used to model business processes and workflows [van der Aalst, 2002; Jensen, 1997; Jensen and Rozenberg, 1991]. The availability of many analytical techniques based on Petri nets is another advantage [Girault and Valk, 2003; Wang, 1998; Peterson, 1981]. Modern systems are often so complex that system interactions can usually only be analysed using simulation techniques [Banks et al, 2002; Banks, 1998]. Simulation is particularly suitable for assessing different alternatives before their actual implementation and has proven to be a successful method for the prospective analysis of production network design [Law and Kelton, 2000; Zhou and Venkatesh, 1999; Banks, 1998; Pritsker, 1998]. Early applications of simulation in consumer-oriented service systems (e.g. queuing models at bank counters) have produced promising results [e.g. Seel, 2002; Laughery et al, 1998].

2 RELATION TO OTHER WORK AND NEED FOR ACTION

Several existing approaches have been examined and evaluated (see Figure 2): First, approaches based on simulation in different kinds of application have been evaluated. Petri net approaches in the workflow management and service domain have also been considered. These approaches provide a valuable contribution since they show how to model specific problems and transfer them into a simulation model. Although their objectives differ significantly from the problem at hand, these approaches provide some useful pointers for the development of a simulation model for the case described in this paper. Second, to consider the special conditions related to the cooperative provision of industrial services, approaches for assessing cooperation and industrial services were analysed. These approaches are not designed for a prospective analysis but deliver valuable information about the assessment of cooperative service processes.

First simulation applications for services were developed by [Fitzsimmons and Fitzsimmons, 2004; Zülch and Greinke, 20004; Zülch and Fischer, 2004; Bruzzone and Simeoni, 2002; Seel, 2002; Banks et al, 2001; Laughery et al, 1998; Mjema, 1997]. Although these authors examined a prospective assessment for services, their approaches do not consider cooperation aspects and characteristics of service provision in an industrial context. Advanced simulation models exist for different ranges of application in the field of production [Giua et al, 2005; Wu, 2005; Kádár et al, 2004; Licht et al, 2004; Kang, 2002; Reuth, 2002; von Steinaecker, 2000; Wurmus, 2002; Feldmann and Schlögl, 1999].

Petri net approaches in the workflow domain consider consumer-oriented services in particular (e.g. [Jansen-Vullers and Reijers, 2005; Vanderfeesten et al, 2005; van der Aalst, 2002]), but they do not provide information about modelling the cooperative provision of industrial services.

Several authors have addressed the evaluation of service cooperations [Watt, 2005; Fischer et al, 2004; ODPM, 2004; Bauer and Kinkel, 2003; Hartel, 2003; Hermann and Langhoff, 2003; Luczak et al, 2001; Teich, 2001; Schneider and Gerhards, 1999].

Approaches in the field of cooperation controlling have proven to be of little value to the problem at hand, because of their focus on retrospective analysis and management. Concepts based on the Balanced Scorecard (e.g. [Bacher, 2004; Bamford and Ernst, 2002; Bornheim and Stüllenberg, 2002; Merkle, 1999]) benefit from the need to define assessment criteria, but remain superficial about the operationalisation of these criteria. Other approaches to evaluate cooperations are also not detailed enough [Killich and Schlick, 2006; Das and Teng, 2003; Almeida et al, 2002; Hess, 2001; Ries, 2001; Voß, 2001; Höbig and Klein, 2000; Schuh and Güthenke, 1999; Kabel et al, 1999].

With regard to controlling and quality management of industrial services, the following approaches have proven useful: [Luczak and Drews, 2005; Hlubek et al, 2004; Wireman, 2004; Smith, 2004; Arlit et al, 2003; Borrmann, 2003; Brumby et al, 2003; Kinkel, 2003; VDI, 2003a; VDI, 2003b; DIN, 2002; Eichmann, 2002; Ulber, Elsweiler, 2002; Schuh et al, 1999;]. These authors have developed assessment criteria for industrial services at different levels of detail, and their results have been taken into account in the development of the simulation model.

The analysis of the relevant literature shows that some approaches exist for parts of the problem, but shortcomings prevail, especially those related to the prospective analysis of alternatives of cooperative service provision. The following deficits can be identified:

- Most of the approaches concerning prospective analysis based on simulation refer to manufacturing or other areas of application and do not consider the special characteristics of industrial services that demand significantly different approaches than the manufacturing of material goods and the provision of consumer-oriented services [Laughery et al, 1998]. This means that approaches that do not consider these characteristics of services cannot be used to solve the problem at hand. Initial simulation approaches for services differ importantly in terms of the underlying problem, so that they cannot be adopted to solve the problem.
- Approaches in the field of cooperation controlling do not consider the special characteristics of the services, either. In addition, controlling techniques are not designed for a prospective assessment but rather for ongoing management and retrospective analysis. They are therefore not applicable for prospective analysis of service provision.
- Approaches which assess the quality of services or control services are also designed for continuous management and retrospective analysis and thus cannot be adopted for prospective analysis. In addition, these approaches focus on individual companies and neglect cooperation aspects. These aspects, however, are very important for the current case.

However, existing approaches do provide valuable information for solving different parts of the problem at hand:

- Simulation based on Petri nets as a method of prospective analysis has proven to be of great value, especially for complex cooperative processes. First promising applications for services suggest that using Petri nets and simulation for the problem at hand would be useful.
- Coloured Petri nets in particular have proven to be a valuable modelling technique for complex cooperative processes and are applicable to cooperative service provision. Their analysis potential meets the demands of the current case.
- Assessment criteria used to control services and to measure their quality represent an important input for the development of a model for the assessment of possible alternatives of cooperative service provision. Especially assessment criteria developed for industrial services are relevant for the problem at hand.

● covered
❍ partly covered
not covered

			Sector			Process design				Assessment / analysis				method
	Author	Year	Services	Industrial services	Capital goods industry	Service provision	Configuration of service provision	cooperation / network	Configuration of cooperation	Functional	Strategic	Operations research	Prospective	Simulation
Analysis based on simulation	Banks et al.	2001	●				❍	❍	❍			●	●	●
	Bruzzone, Simeoni	2002	●	●	❍	●	❍			●	❍	●	●	●
	Feldmann, Schlögl	1999			●		❍		❍			●	●	●
	Fitzsimmons, Fitzsimmo	2004	●				❍	❍		●	❍	●	●	●
	Giua et al.	2005			❍		●			●		●	●	●
	Jansen-Vullers, Reijers	2005	●			●	●			●	❍	●	●	●
	Kádár et al.	2004			●		●			❍		❍	❍	●
	Kang	2002			❍	●				●	●	●	●	●
	Laughery et al.	1998	●	❍	❍	●	❍			●	❍	●	●	●
	Licht et al.	2004			❍					❍	❍	❍	●	●
	Mjema	1997	●	●	●	●	❍			●	❍	❍	●	●
	Reuth	2002			❍		❍			●		❍	●	●
	Seel	2002	●	❍		●	●			●	❍	●	●	●
	van der Aalst	2002	❍			❍	❍			●	❍	❍	●	●
	Vanderfeesten et al.	2005			❍					●	❍	●	●	●
	von Steinaecker	2000			❍		●	●	●	●	❍	●	❍	●
	Wu	2005			●		●			●		❍		●
	Wurmus	2002								●				●
	Zülch, Greinke/Fischer	2004	●	●	❍	●	●			●	❍	●	●	●
Service cooperation analysis	Bauer, Kinkel	2003	●	●	●	●		●	●		●			
	Fischer et al.	2004	❍				❍	●	●	❍	●	●	●	
	Hartel	2003	●	●	●	●	●	●	●	●	❍			
	Hermann, Langhoff	2003	●	●	❍	●		●	●		●			
	Luczak et al.	2001	❍			❍	●	●	●	●	●	❍	❍	
	ODPM	2004	●			❍	❍	●	●	❍	●	●	●	
	Schneider, Gerhards	1999	❍			❍	●	●	●	●	●	❍	❍	
	Teich	2001	❍			❍	❍	●	●	●	●	❍	❍	
	Watt	2005	❍			❍	❍	●	●		❍			
Asessment of services	Arlit et al.	2003	●	●						●	●			
	Borrmann	2003	●	●	●					●	●			
	Brumby et al.	2003	●	❍		●	●			●	❍			
	DIN	2002	●	●	❍	●	❍			●	❍			
	Eichmann	2002	●	●	❍	●	❍			●	❍			
	Hlubek et al.	2004	●	●	❍	❍	❍			●	❍			
	Kinkel	2003	●	●	❍	❍				❍	●			
	Luczak, Drews	2005	●	●	●	❍	❍			❍	●			
	Schuh et al.	1999	●	●	●	❍				❍	●			
	Smith	2004	●	●	●	●				●	●			
	Ulber, Elsweiler	2002	●	●	❍	❍				❍	●			
	VDI 2886	2003	●	●	●	❍	❍			●	❍			
	VDI 2893	2003	●	●	❍	●	❍			●	❍			
	Wireman	2004	●	●	❍	●	❍			●	●			
Cooperation analysis	Almeida et al.	2002						●	❍	❍	●			
	Bacher	2004						●	❍	❍	●			
	Bamford, Ernst	2002						●	❍	●	●			
	Bornheim, Stüllenberg	2002						●		❍	●			
	Das, Teng	2003						●	●	❍	●	❍	●	
	Hess	2001						●	●	❍	●			
	Höbig, Klein	2000						●	●		●			
	Kabel et al.	1999					●	●	●	●	●			
	Killich, Schlick	2006					❍	●	❍	●	●	❍	●	
	Merkle	1999						●	❍	❍	●			
	Ries	2001					❍	●	●	❍	●	❍		
	Schuh, Güthenke	1999						●	❍		●			
	Voß	2001						●	❍		●			
	presented research project		●	●	●	●	●	●	●	●	❍	●	●	●

Figure 2: Examination and evaluation of existing approaches

As a result of the deficits and advantages of existing approaches outlined above, the following tasks need to be addressed [Winkelmann, 2005]:

- A conceptual model for the cooperative provision of industrial services has to be developed.
- It has to be implemented into a simulation model based on coloured Petri nets.
- The model has to be capable of prospective performance analysis of cooperative provision of industrial services.

3 MODELLING THE COOPERATIVE PROVISION OF INDUSTRIAL SERVICES USING COLOURED PETRI NETS

To create a model of the cooperative provision of industrial services, the special characteristics of this domain have to be taken into account. These characteristics have to be integrated into a conceptual model of cooperative provision of industrial services before this model is translated into a CPN model.

3.1 Conceptual Model of Cooperative Provision of Industrial Services

Services can be defined using constitutive attributes [Corsten, 2001; Sontow, 2000]. This definition comprises three dimensions: process, structure, and outcome [Corsten, 2001; Donabedian, 1980].

The process dimension stresses the fact that the customer as the external factor has to be integrated into the process [Corsten, 2001]. Another important characteristic in the process dimension is the simultaneity of production and consumption of services in respect to time and space. Together with the integration of the external factor, this implies two more features for industrial services that are not consumer-oriented but are rather business-to-business services in an industrial environment: Since services have to take place at the location of the product, the required resources have to travel there. In addition, technicians of the client company often have to be integrated into the service process and work together with personnel of the service company. Services and especially industrial services are also very heterogeneous and the standardisation of processes is not easy.

The structure dimension defines services as the ability to perform a service [Corsten, 2001]. This shows that services are intangible and thus conventional approaches that are oriented towards tangible attributes of products are not applicable to services [Sontow, 2000].

The simultaneity of process and production also affects the outcome dimension: It implies that there is no product whose quality can be measured in the end but the process itself is the service. Since services are not storable, this means that any delay in the process directly affects the quality of the services.

The conceptual model of cooperative provision of industrial services is based on these three dimensions and integrates the outlined characteristics of industrial services.

3.1.1 Process Dimension

To represent the process of industrial service provision, reference models have been developed [Kallenberg, 2002; Borrmann, 2003]. These reference models have been adapted to fit cooperative service provision and to fulfil the modelling requirements of the Petri net notation. Furthermore, the resulting model has been structured in a three-level hierarchy: The top level provides a process overview; all process steps of this overview are then modelled in more detail on the second level. On a third level, different kinds of service orders (repair, maintenance and spare parts service) are distinguished in the process of order fulfilment (see Figure 3 to Figure 5).

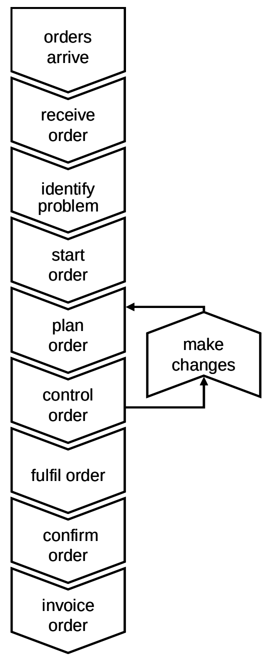

Figure 3: Service process on first level of detail

The sub-processes in the hierarchy can be interpreted as separate modules that interact via interfaces. This concept provides, on the one hand, flexibility, since modules can be changed easily and locally without having to deal with the whole model. On the other hand, it allows to model process parts in sufficient detail while keeping complexity at the top level low.

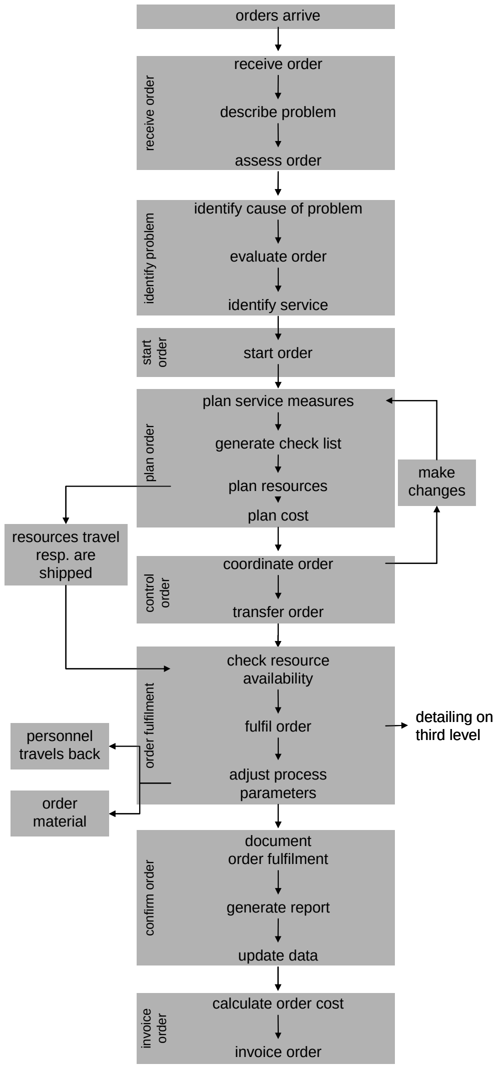

Figure 4: Service process on second level of detail

To account for the heterogeneity of the process, locally different process alternatives (e.g. necessity for problem description or revisions) have been defined [Winkelmann and Luczak, 2006a]. Probability functions control the flow of orders through these alternatives (see Figure 6). All process control elements are depicted in Figure 7.

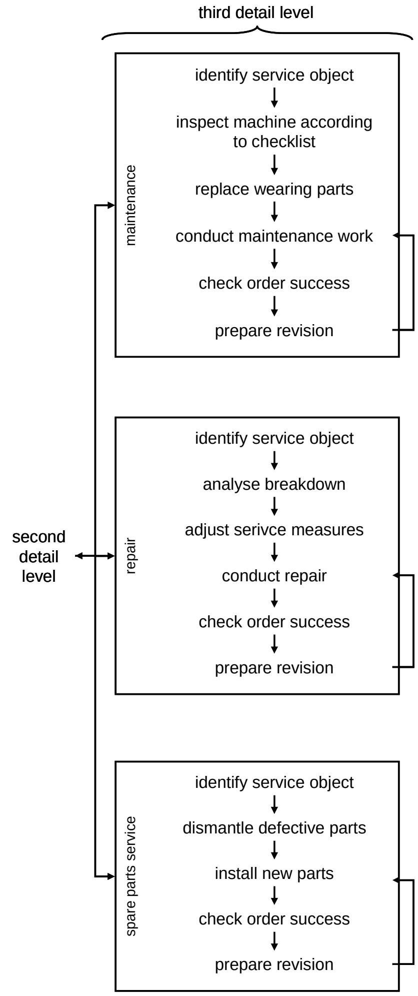

Figure 5: Service process on third level of detail

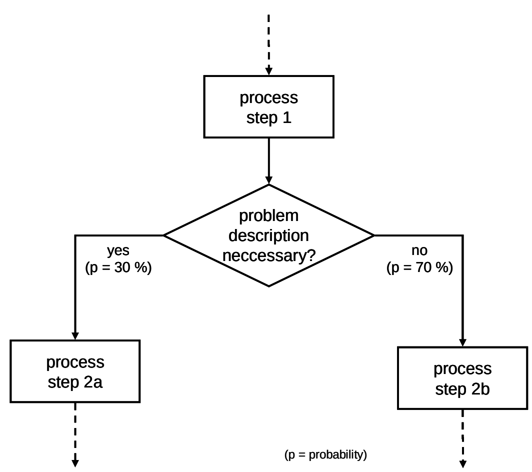

Figure 6: Local process alternative

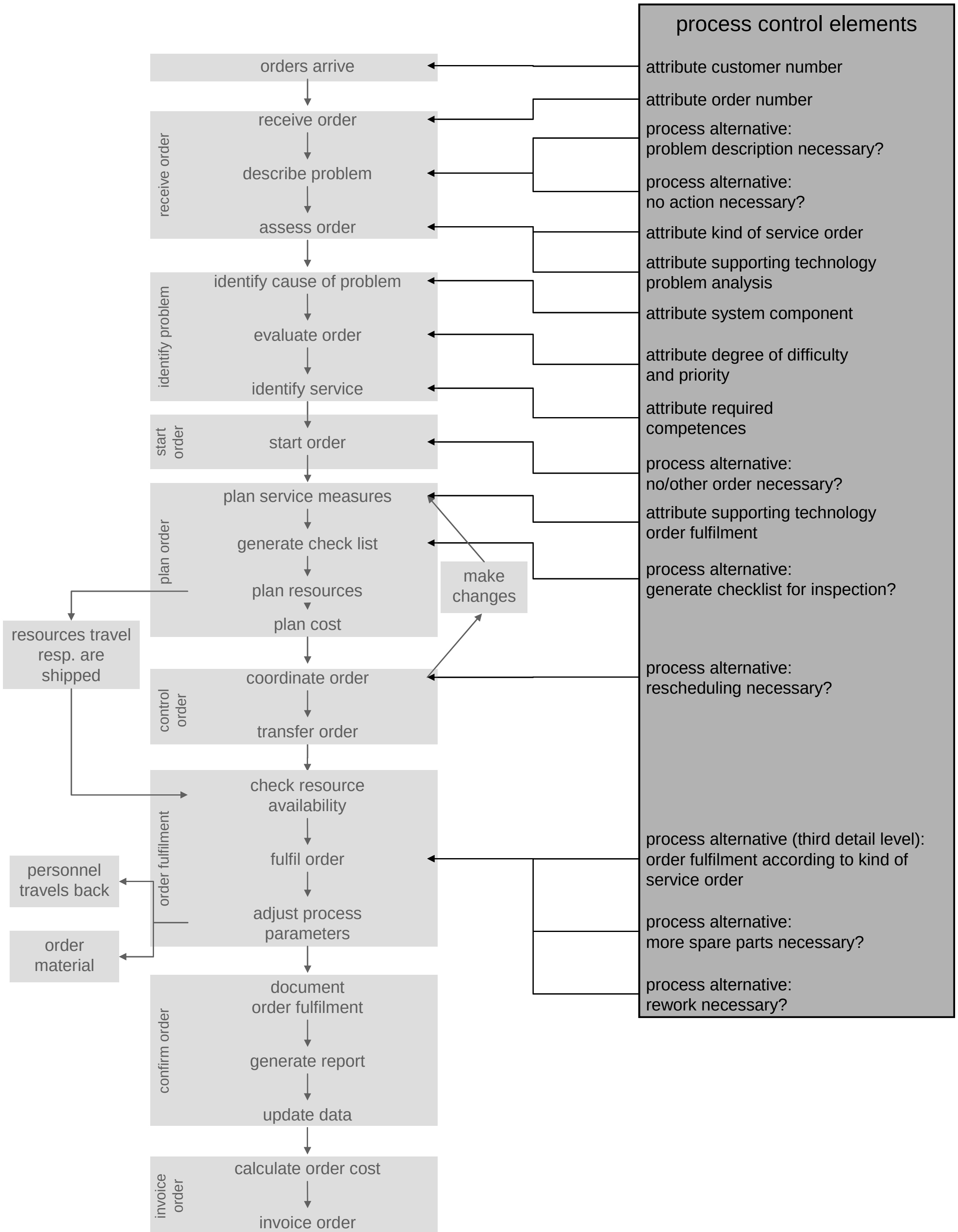

Figure 7: Process control elements

3.1.2 Structure Dimension

The structure dimension represents the resources needed to execute the processes. Mapped resources are different categories of personnel and material (e.g. service engineers, service technicians, client technicians for personnel and tools, spare parts, operating resources like gaskets or lubricants). Depending on the degree of difficulty of the order and required competencies, different categories and quantities of resources are consumed.

The structure dimension also accounts for the mapping of different cooperation alternatives. The cooperation partners provide different resources and thus certain parameters change. Such parameters are the amount and structure of the provided resources and their consumption based on the degrees of difficulty of the orders. Depending on the location of the partners and spare parts suppliers, times for personnel travel and spare parts shipment vary. The times required for fulfilling a service order and the probability of the need to correct this work depend on the qualification of personnel.

3.1.3 Outcome Dimension

The outcome of a service is the finished service order which results from the process carried out by the resources. The outcome dimension of the model therefore comprises the set of all service orders and their status as they are fulfilled. This status contains different pieces of information: the degree of difficulty of the order, executed changes and revisions, and the order processing time. This information is used to calculate performance measures for the alternatives. In order to evaluate the alternatives, six performance measures in the three dimensions time, cost and quality have been implemented into the model: Average time in system and average waiting time per order, average cost of personnel per order and personnel utilisation, first hit rate and variation of average time in system.

3.1.4 Interpretation Framework According to Service Strategy

After the calculation of the performance measures the results have to be interpreted in order to gain design recommendations for the cooperation configuration. In a first step the performance measures have to be evaluated. Initially directions of optimisation can be identified for individual performance measures (see Table 1). These directions of optimisation indicate, which alternative should be ranked higher or lower within the individual performance measure. This evaluation within the individual performance measures is relatively easy, since no overall evaluation of the alternatives against one-another is necessary.

Interpretation of performance measures		
Performance dimension	Performance measure	Direction of optimisation
Time	Time in system per order	Minimisation
	Waiting time per order	Minimisation
Cost	Cost per order	Minimisation
	Personnel utilisation	Maximisation
Quality	First Hit Rate	Maximisation
	Variance of time in system	Minimisation

Table 1: Interpretation of performance measures

Subsequently this evaluation has to be appreciated according to the characteristics of the service portfolio and the service strategy of the company. Depending on these characteristics the different performance dimensions are of varying importance. For this reason design recommendations differ for each company and depend on the corresponding background.

Figure 8 shows possible market segments in the business of industrial services. On the one hand customer orientation can vary between product and solution orientation. On the other hand, market conditions can vary between price and performance competition. Thus the four different segments in Figure 8 can be identified [Schuh et al, 2004; Lay and Jung Erceg, 2002]:

- Segment I: The first segment is characterised by price competition and product oriented customers. A service oriented strategy is not the first choice in this this segment. Performance measures in the cost dimension dominate.
- Segment II: Customers are still product oriented in this segment, but competition is more performance oriented. Thus services that focus on product optimisation make sense in this segement. Therefore performance measures in the time and quality dimensions become more important.
- Segment III: The third segment encourages a service oriented competitive strategy, since customers are solution oriented and competition is performance oriented. In this segment, service bundles combining products and services are important. Performance measures in time and quality dimensions are of high interest.

- Segment IV: In the fourth segment the customer still is solution oriented, so service bundles like in segment III are of high interest. However, they have to focus on cost reduction rather than on the optimisation of the solution. Thus performance measures in the cost dimension again come into the focus.

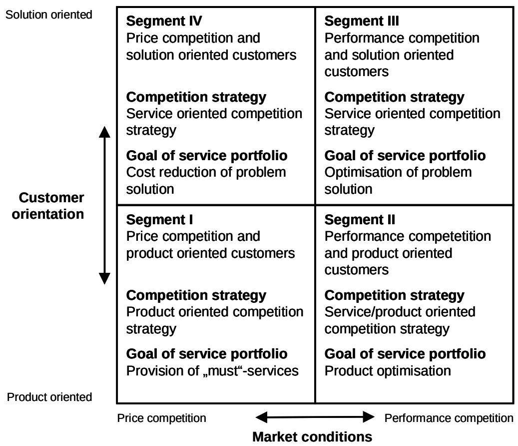

Figure 8: Service market segements [Schuh et al, 2004; Lay and Jung Erceg, 2002]

These remarks show that conclusions based on the outcome of a comparison of cooperation alternatives may differ depending on the market conditions a company is operating in and the individual service strategies.

3.2 Implementation of the Model Using CPN Tools

The dimensions of the conceptual model have to be translated into a CPN model. Based on the work of [van der Aalst, 2003] the following analogy is presented: Figure 9 maps the three dimensions process, structure, and outcome, and connects resources, process steps, and orders to work items and activities. Using Petri net notation (italics in brackets), orders and resources are represented by tokens and process steps by transitions. A work item corresponds to an enabled transition and an activity to the actual firing of a transition.

To transfer the conceptual model into a simulation model, the software CPN Tools of the University of Aarhus was used [CPN Tools, 2006]. All aspects of the overall model were mapped into a directed graph consisting of places, transitions, arcs, and markings. Place and transition names have been chosen according to the usual terminology in the area of application. Since the detailed presentation of all model elements is beyond the scope of this paper, the implementation of some of the main concepts is presented below.

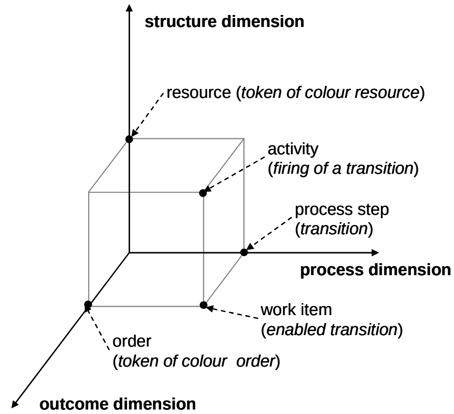

Figure 9: Conceptual dimensions and corresponding Petri net notation [Winkelmann and Luczak, 2006b]

3.2.1 Process Modelling

First of all, the entire process was represented in coloured Petri net notation using places, transitions, and arcs. The main flow of the process is as follows: Requests for service orders arrive and get received. Then, the problem and the corresponding service measures have to be clarified and the request develops into an order. This order then is planned and controlled. In case changes are needed, the order moves into a loop and back to the planning process step. After successful order fulfilment the order is confirmed and invoiced.

The hierarchical concept described in section 3.1 was realised using the technique of substitution transitions. A substitution transition represents another page (subpage) in the net which starts and ends at the same places as the substitution transition, but contains a more detailed process comprising several other transitions and places. Figure 10 gives an example of a process description in CPN Tools on the second level of detail.

All time delays for process steps use random distribution functions, because the duration of the process steps can vary.

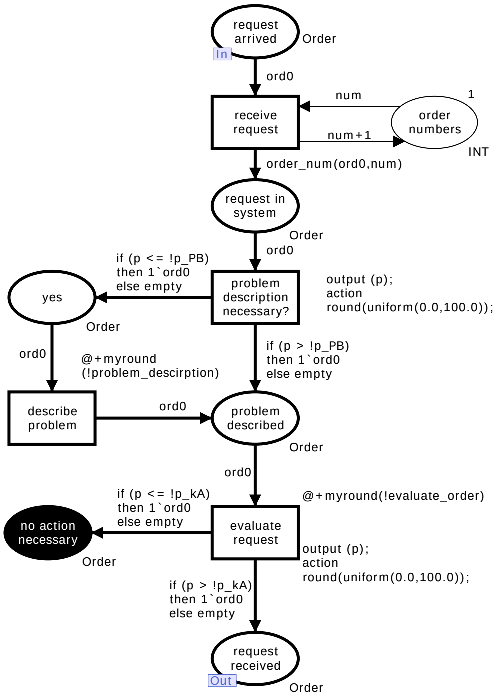

Figure 10: Subpage receive_request

3.2.2 *Order Modelling*

The primary markings in the net are orders that pass through the process. The colour set of orders consists of:

- an indexed order (the index indicating the degree of difficulty of the order),
- a customer number,
- an order number,
- a status attribute (indicating changes and reschedulings),
- several integer numbers (to store time information),
- an attribute indicating the kind of service order (repair, maintenance or spare parts service),
- information about the relevant system component,
- information about the supporting technologies and
- required competencies.

These attributes are changed according to the gradual processing of the order and are used to control the flow of the order through process alternatives and to calculate performance measures at the termination of the process.

3.2.3 *Resource Modelling*

The resource allocation is modelled with a separation between personnel and service material. The places containing personnel and service material are made available on different subpages by using fusion places. Fusion places are duplicates of places which make the places accessible at different pages or different locations on one single page. Resource places (both personnel and service material) contain different colours of resources. Depending on the degree of difficulty of an order and required competencies, different multi-sets of resources need to be allocated. A multi-set is a combination of several appearances of different colours, e.g. 1 service engineer + 2 service technicians + 3 client technicians. In order to allocate personnel and service material multi-sets to an order, resource lists have been defined and these have been added into a product colour set with the order.

3.2.4 *Parameterisation*

In order to initialise the model with company-specific starting and boundary conditions, these factors have been parameterised in the model by using global reference variables. That means that a company can specify the basic conditions of its service process by defining different values for the global reference variables. These parameters comprise time values for the different process steps and their stochastic functions (e.g. a Poisson arrival of requests) as well as probability values for certain process characteristics (e.g. the probability that an order has degree of difficulty of 2 or the probability that revisions occur). The list of initialisation parameters is provided in Table 2.

To account for the concept of cooperative service provision, the model has to change with regard to different cooperation alternatives. This means that different parts of the process may be provided by different partners and thus may differ with respect to time, cost, and quality (see section 3.1). Therefore additional parameters that are influenced by a change in responsibility of certain process steps have been added. These cooperation-relevant parameters are used to configure cooperation alternatives for performance analysis. The list of cooperation alternative parameters is provided in Table 2.

4 EVALUATION

The coloured Petri net model implemented using CPN Tools has been evaluated for correctness by verification (i.e. testing if the conceptual model has been implemented correctly), validation (i.e. testing if the model behaves as expected), and performance analysis of two cooperation alternatives (i.e. evaluating alternatives by comparing performance measures).

Parameters	Initia-lisation	Configu-ration of alter-natives
Probabilities		
Distribution of kinds of service orders, required competences, degrees of difficulty and priorities	x	
Problem description necessary	x	
No action necessary	x	
No order necessary	x	
Other order	x	
Rescheduling necessary	x	
Rework necessary		x
Time parameters		
Unit of model time	x	
Frequency of incoming requests	x	
Order fulfiment times		x
Travel time personnel		x
Shipping time material	x	
Time values for different process steps	x	
Time reduction for order priorities	x	
Personnel resources		
Structure and quantity of personnel		x
Required personnel for order fulfilment		x
Cost of service engineers and technicians		x
Material resources		
Structure and quantity of material	x	
Required material for order fulfilment	x	

Table 2: Parameterisation of the model with initialisation and cooperation alternative parameters

4.1 Verification

The full state space and strongly connected components graph were calculated to verify the model. Stochastic functions which model probabilities have been replaced by variables from a small colour set that are assigned in bindings. The subpage modelling the arrival of orders and the two transitions initialising the resources have also been neglected for the state space analysis, since they are only needed for simulation. In order to keep the number of state spaces within a reasonable range, the possible technologies and system components have been aggregated under one header each. The state space analysis was carried out for one case in isolation, because competition between cases for resources is only relevant for performance analysis [van der Aalst, 2003] and is considered in the validation process. The full state space and strongly connected components graph consist of 20640 nodes and 37308 arcs.

Boundedness properties: In state space analysis upper and lower bounds of all places are calculated, i.e. the maximum and minimum number of tokens of a certain colour that a place can contain. A coloured Petri net is bounded, if all places have an upper and lower bound [Jensen, 1997].

The analysis shows that all places of the net are bounded. All places containing orders have an upper bound of 1 and a lower bound of 0, which corresponds to the fact that one single case is considered and thus these places cannot contain more than one token. The places containing resources are split into two groups: personnel and service material, with three fusion places each. These places have an upper bound of 147 (personnel), 300 (service material), respectively, as specified in the starting conditions for the state space analysis. The lower bounds are 142 for personnel and 291 for service material, which correspond to the maximum number of resources consumed by an order of the highest degree of difficulty. Thus, the net is bounded.

Home properties: A home marking is a marking to which it is always possible to return [Jensen, 1997].
In the net presented here, the initial marking is not a home marking. This is correct because once the order is received and has entered the fulfilment process, it is not possible to return to the state of the incoming order.

Liveness properties: A net is live if a set of binding elements remains active, this means that every transition will be enabled at some point [Jensen, 1997]. In a dead state on the contrary, no transition is enabled.

The state space shows 649 dead markings for the model, because the order is supposed to reach the desired end states, i.e. the process of fulfilling an order comes to an end.

- In one dead marking, the place no_action_necessary contains a token of the colour order, that has not yet been evaluated. This marking refers to the case that during the process of dealing with an incoming request, it is seen that no action has to be taken and the request does not have to be followed.
- In 216 other dead markings, no order or another kind of order is necessary. These markings represent the case that after requests have been evaluated and the corresponding problems and measures are clarified, it is possible that a request (of any degree of difficulty) does not have to be followed by an order, or it does not have to be treated as a service order but as some other kind of order. In both cases, no further action within the process of the industrial service provision is necessary. At this point in time the order can have different degrees of difficulty, different priorities, different kinds of services and different competence requirements. Therefore 216 dead markings in this stage are possible.
- The remaining 432 dead markings correspond to tokens in the place order_invoiced, when the order is successfully fulfilled and finished. In addition to the different attributes mentioned

above, there are four possible modes in which an order can finish (N = normal, CH = changed, Nr = normal_revised, Chr = changed_revised). So altogether there are 432 different dead markings at this point of the process.

Thus, all 649 dead markings are desired end states.

Fairness properties: Fairness shows how often different binding elements occur [Jensen, 1997]. The model is structured so that no infinite occurrence sequences exist. Although there are two loops in the net (making changes and revisions), they only occur if the order has not gone through these loops before. Thus, it is correct that the net does not contain infinite occurrence sequences.

4.2 Validation

Although validation measures are presented after the description of the model, it is stressed that model validation is not a task to be performed at the end of model development, but rather accompanies the whole process of model development [Bastian, 2004; Law and Kelton, 2000; Banks, 1998; Naylor and Finger, 1976].

To validate the model, a panel of 13 subject matter experts was involved in the development of the model from the beginning. Three workshops and several interviews with these experts have been organised. Joint development of the model, as well as a structured walkthrough of the conceptual model [Law and Kelton, 2000], was used to validate the logics and assumptions of the model. The use of common expressions in names of places and transitions, as well as the graphical representation and hierarchical structure of the model in CPN Tools have proven of high value to facilitate the communication with potential users and their understanding of the model.

Simulation was then used to assess the behaviour of the model [Law and Kelton, 2000]. Interactive and terminating simulation runs showed that the simulation results were consistent with the perceived system behaviour.

These measures, together with the evaluation of the example of performance analysis and the experimental design described in the next sections, show that the model has been validated.

4.2.1 Experimental Design

In order to gain more information about the model and the effects of the cooperation parameters on the performance measures, an experimental design was carried out. In this case, a 2^k factorial design was used [Robinson, 2004; Law and Kelton, 2000]. In this design all six cooperation parameters were varied systematically using two levels (- and +) for all factors, leading to $2^6 = 64$ design points. Main effects and two-factor interaction effects on two performance measures (average time in system and average personnel cost) and their 95% confidence intervals were calculated using 64 replications in the design points with five simulations runs each (320 runs in total). The results were used to reproduce expected system behaviour, as depicted in Figure 11 and Figure 12.

Factors 5 and 6 (travel time and time to accomplish order) have the highest influence on the average time in system (see Figure 11): Changing one of the factors from its – to its + level (i.e. a higher travel time or a higher time to accomplish order) increases the time in system according to the expectations. Changing the probability of revisions has a minor effect on the time in system.

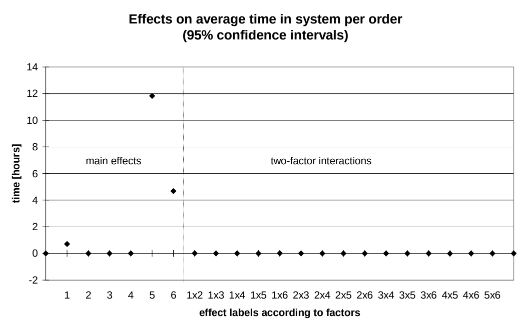

Figure 11: Effects on average time in system

Three main factors dominate the effects on the average personnel cost (see Figure 12).

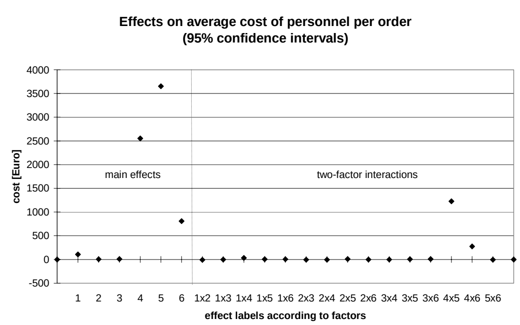

Figure 12: Effects on average personnel cost

Travel times (factor 5) have the highest direct influence, followed by cost rates and times to accomplish order (factors 4 and 6). These effects make sense, since personnel cost highly depends on the time in system, while the time in system itself depends on the travel time as main factor of influence. In addition, two-factor interaction effects exist for the factor combinations 4 and 5 as well as 4 and 6, because higher cost rates and higher travel times / times to accomplish orders amplify one-another.

The results show that the model represents a consistent behaviour since no unreasonable effects were produced and the main influencing factors are feasible.

4.2.2 Performance Analysis

The purpose of the model presented here is to execute a prospective analysis of cooperative provision of industrial services. Thus, an example of this prospective performance analysis is presented.

The example compares three alternatives for a reference company to provide industrial services in the Eastern European market. The alternatives correspond to different scenarios: In alternative 1 it is assumed that the company is not cooperating and thus is sending out its own engineers and technicians. This leads to high travel times, but also accounts for short order fulfilment times and a low probability of revisions, since the company's personnel is highly qualified. Alternative 2 represents the case in which the company cooperates with a partner closer to the service sites but with less qualified personnel. Finally, alternative 3 represents the cooperation with a partner right in the market with lowest travelling times but longer accomplishment times and a higher probability of revisions because of less qualified personnel. Initialisation and cooperation alternative parameters have been chosen according to the input from subject matter experts. The example has been chosen for ease of understanding and output assessment.

Ten samples (n = 10) were collected for each alternative. For the calculation of the performance measures, a start-up phase for each simulation run was neglected to eliminate errors due to transient behaviour of the system (e.g. faster processing times because of lower resource utilisation for the first orders entering the system). The length of the start-up phase was calculated according to [Banks et al, 2001] and [Welch, 1983]. For the performance measures relating to time 95%-confidence intervals were constructed. The simulation results are presented in Figure 13 to Figure 18.

The simulation results in the time dimension (Figure 13 and Figure 14) show, that the average time in the system is the longest for alternatives 1 and 3. The shorter time to complete orders of alternative 1 is over compensated for by longer travel time. In contrast the longer time to complete orders of alternative 3 leads, despite a short travel time, to a longer time in the system than observed in alternative 2. Waiting time consists of travel time and waiting time due to lack of personnel. Alternative 1 clearly has the worst ratio of waiting time to time in system.

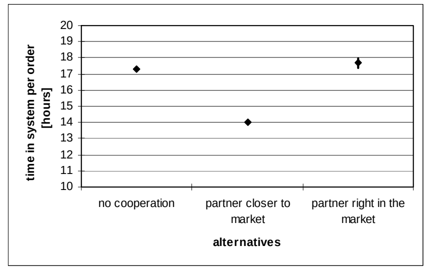

Figure 13: Simulation results for average time in system per order

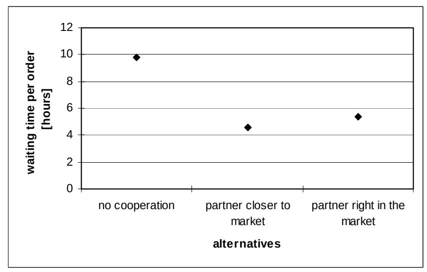

Figure 14: Simulation results for average waiting time per order

The cost of personnel per order is the highest for alternative 1 and the lowest for alternative 3 (see Figure 15). The high time in system in alternative 3 is over compensated for by low cost ratios. Personnel utilisation is the lowest in alternative 2 (see Figure 16).

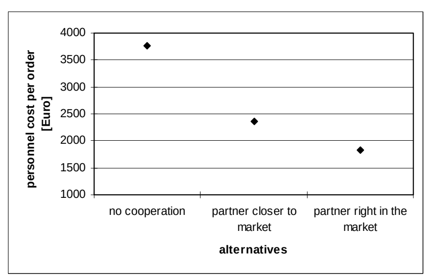

Figure 15: Simulation results for average cost of personnel per order

According to the results in the quality dimension (see Figure 17 and Figure 18) alternative 1 scores best in the first hit rate, whereas alternative 2 has the lowest variance in time in system, which is an indicator for high adherence to delivery dates. Alternative 3 scores lowest in both performance measures first hit rate and variance of time in system.

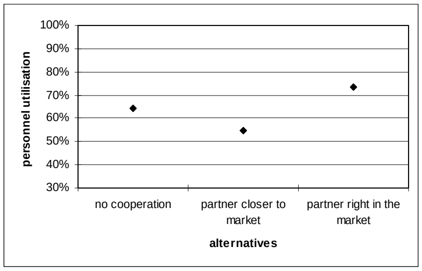

Figure 16: Simulation results for personnel utilisation

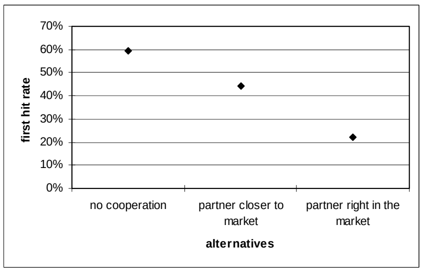

Figure 17: Simulation results for first hit rate

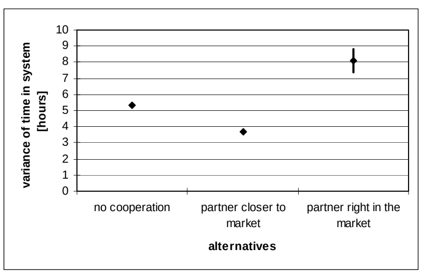

Figure 18: Simulation results for variance of average time in system

The diagrams of these performance criteria show that the conclusions drawn from the results depend on the goal a company is following and the corresponding rating of performance criteria. This shows that the entrepreneurial decision for one alternative is always linked to trade-offs between different objectives. Linking this example to a market condition with solution oriented customers and a price competition (according to segment IV in Figure 8), a possible solution is to choose alternative 3 – because cost dimension is most important in segment IV – and trying to enhance performance especially in the time dimension by supporting technologies. The following scenario describes the application and influence of these technologies.

Scenario application of technology

One possibility of process enhancement is the application of modern technology in order to compensate for less qualified personnel and to reduce order fulfillment times. An application of augmented reality for example projects working aids into the range of vision of the technician (e.g. via a special viewing device). For example, in order to locate the cause of a breakdown within a complex engine, projected working aids can lead the technician faster to the location of the breakdown. In this manner orders can be fulfilled within a shorter amount of time and by less qualified personnel. The application of teleservice enables the remote fulfillment of the service without personnel on-site (e.g. update of control software). In this case travel time is omitted.

This scenario focuses on service repair orders. These orders are fulfilled traditionally in one alternative and are supported by augmented reality and teleservice in two other alternatives. In case of augmented reality a reduction of order fulfilment time by 10 percent (orders with degree of difficultiy 2) or by 20 percent (orders with degree of difficulty 3 can be observed. For teleservice travel time and on-site personnel are omitted. Figure 19 and 20 present the results.

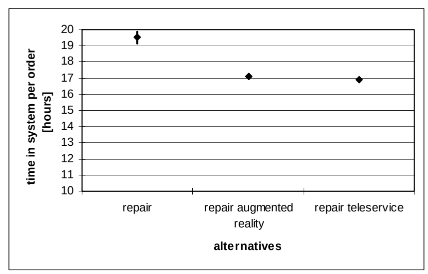

Figure 19: Simulation results for average time in system per order (scenario application of technology)

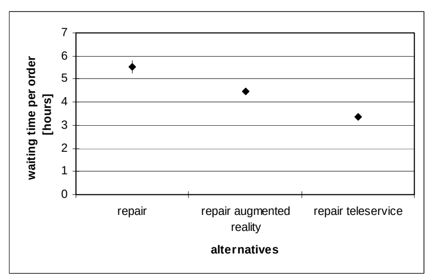

Figure 20: Simulation results for average waiting time per order (scenario application of technology)

Figure 19 and Figure 20 show that both technology supported alternatives reduce both order fulfilment and waiting time. The application of teleservice especially reduces waiting time, since travel time is omitted. The main advantage of augmented reality is the qualitative support of the technician to improve fulfillment time, whereas the main advantage of teleservice is the reduction of travel time.

With respect to to the goal of supporting technology – i.e. the enhancement of performance in the time dimension – both alternatives offer good potential. However, the application of technology is connected to high investments and therefore has to to be assessed in an investment appraisal.

Altogether the example shows the effectiveness and functionality of the model in principle. The comparison of alternatives using performance analysis based on simulation demonstrates the utility of the model in decision support. The flexibility of the model also allows for detailed analysis of different scenarios and adaptation to individual company conditions.

5 CONCLUSIONS AND OUTLOOK

The conceptual and simulation model of cooperative service provision presented in this paper reflects the major features of industrial services as well as their cooperative provision. It allows prospective analysis of cooperation alternatives by varying the factors relevant to the cooperation and comparing the results of this analysis.

The use of coloured Petri nets as a modelling and simulation formalism provides several benefits: On the one hand, the graphical representation of the model leads to transparency, consistency, and conformity with user's expectations, so that understanding and acceptance of the model are facilitated. On the other hand, the maturity of the Petri net formalism and the availability of appropriate tools allow for the direct implementation into computer models for the purposes of analysis.

It has been shown that the cooperative provision of industrial services can be modelled, analysed, and simulated using coloured Petri nets and that the prospective assessment of alternatives is possible. Verification and validation of the model has shown that it properly maps the cooperative provision processes of industrial services and shows consistent behaviour. The influencing factors identified in a 2^k factorial design support these findings. Thus the goal of this work, to develop a CPN model capable of prospective analysis on the cooperative provision of industrial services, has been achieved.

Additional research would be helpful to further facilitate communication with model users in order to foster ease of understanding of the model by the users. In this context especially the connection to animation in order to communicate simulation results in an understandable way towards the users [Westergaard and Lassen, 2005] and web based input/output facilities would be helpful.

Because the application of simulation to the area of industrial services is relatively new, there is still a backlog of demand concerning the collection of accurate and detailed service process data compared to production systems where simulation has already been established. But the more quantitative data about industrial service processes will be available the more feasible a further integration of modelling and analysis of industrial services and the production of machines and plants the services are provided on will become.

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