Modeling Uncertainty in a Decision Support System for Business Process Planning

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ABSTRACT: During the last years, the process-oriented view led to extensive restructuring in practice as well as to an intensive discussion in economical research. To improve business processes, a generally applicable, object-oriented, simulation-based decision support system GEPSIS has been developed. It is used to model business processes and to evaluate different process alternatives quantitatively to determine the optimal process. Especially in business processes tasks, work flows, and decisions are influenced by persons whose behavior is not deterministic and cannot be described crisply. Therefore, the adequate consideration of uncertainty and vagueness is of special importance for such a decision support system. An object-oriented approach has been selected here for the simulation of business processes. For the modeling of flows, particular object classes are deduced, which contain defined attributes and behaviors. These objects are used to model the flow structure in accordance with a representation technique which is based on event-driven process chains. Not only stochastic but also linguistic uncertainty of the data which describe the objects are considered. The vagueness of verbal formulations is modeled using linguistic variables. Several specific procedures are developed for the process control, which result from specific priority rules for the object classes as well as a knowledge-based procedure on the basis of approximate inference. In this way, rules for the sequencing of handling objects can be modeled very closely to reality. The suitability of the system GEPSIS and the effects of the application of different procedures for process control are demonstrated by analyzing the business process of the order processing of a post-exchange book and sound carrier store. The example covers some typical flow structures which can be found in most order processing situations.

KEYWORD: Business process, decision support system, simulation, linguistic variable, approximate inference, order processing

SIMULATION TO SUPPORT BUSINESS PROCESS PLANNING

Numerous methods to support the planning of business processes have been suggested. Usually, they base on a special technique for modeling and graphical documentation (Hess and Brecht, 1996). The modeling is used to structure the process so that the existing and alternative sequences of tasks can be analyzed systematically and comprehensively. They are the basis for the analysis and evaluation of business processes. This approach only gives a static view of the process. So far, the application of quantitative models and methods for the planning of business processes is not very frequent, although there are several aspects in production process planning which are rather similar (Buzacott, Shanthikumar 1993, Cypress 1994).

For the modeling and analysis of production processes, simulation is a well-suited method to evaluate the dynamic behavior of processes globally (Davies 1997, p. 267). Due to the large flexibility, its application is even possible in complex situations. Before high interest arose in the context of business reengineering, simulation was applied only in particular cases to support the planning of office or administrative processes. For instance, at the beginning of the 80's, the software package CAPSIM was developed on basis of the simulation language GPSS to simulate information handling processes with peripheral data processing systems (Brandenburg 1983, p. 71, Krcmar 1984, p. 162). In the meantime, numerous commercial software tools are offered for the simulation of business processes. In a survey, Bach (1997) refers to 97 tools that assist in business reengineering, 30 of which contain the possibility of simulation. The special advantages applying simulation are the opportunity of a quantitative analysis of several organizational measures with consideration of dynamic characteristics, the possibility of a systematic generation of alternatives by modifications in identified weak points, the high flexibility in modeling as well as in adequate consideration of stochastic influences (Davies 1997, p. 268, Witte 1997, p. 6, Wood 1993, p. 18). A point of criticism is that the application of a simulation often requires high expenditure for the creation of a simulation model. It has to be stressed, however, that the expenditure strongly depends on the simulation software used and its suitability for the considered range of application. It can be shown that the simulation offers a very broad spectrum of use and general possibilities for the quantitative analysis and an evaluation of business processes.

To improve business processes, a generally applicable, object-oriented, simulation-based decision support system GEPSIS has been developed. For the modeling of flows, particular object classes are deduced, which contain defined attributes and behaviors. These objects are used to model the flow structure in accordance with a representation technique, which is based on event-driven process chains. Even complex functional dependencies can be modeled. In contrast to event-driven process chains the explicit representation of event nodes is omitted. Not only stochastic but also linguistic uncertainty of the data which describe the objects is considered. The vagueness of verbal formulations is modeled using fuzzy sets theory. Several specific procedures are developed for the process control and are now available as standard components by which a multiplicity of alternatives can easily be analyzed. The procedures result from specific priority rules for the object classes as well as from a knowledge-based procedure on the basis of approximate inference. In this way, rules for the sequencing of handling objects can be modeled very closely to reality. Approaches which apply fuzzy sets and approximate inference methods in the context of simulation are rather new. Especially for the modeling of the flows of business processes, where uncertain, imprecise, and vague information often occur and the flows are not technically determined, this approach is well-suited. The concept presented here is the basis for a simulation-based decision support system for the planning of business processes.

A standard simulation system was used for implementation. Compared with the use of a general programming language, a simulation package, or a simulation language the expenditure for implementation could be reduced substantially. Components for the support of the modeling, the simulation, and the analysis of results are already available here. We selected the object-oriented simulation system SiMPLE++ (AESOP 1997). The high flexibility of the simulation system selected results from the fact that user-defined model objects with specific characteristics and behavior can be created by using available object classes and an integrated programming language. The model objects were implemented as object classes and enlarge the standard basic object library available in SiMPLE++. Using the user defined application object library consisting of these two subsets, the modeling of flows and the simulation of appropriate business processes can be done rather easily. With the special modeling objects for the business process simulation, the standard basic object library is substantially extended. Since the consideration of fuzzy sets and approximate inference are not supported by SiMPLE++, additional objects had to be developed and added.

UNCERTAIN ATTRIBUTES

To create a simulation model, the selection and ordering of objects using the respective object classes (for details see Völkner, 1998) has to be done by the user. Additionally, he or she has to specify values of one part of the attributes. The other values are assigned by the simulation control. The attributes with automatic value specification can be classified into structure attributes, control attributes, and statistics attributes. During the model creation, values are assigned to some object attributes which contain structure information about relations to other objects. For example, the attributes *assigned_buffer* and *outgoing_connection* of an activity indicate those objects which are necessary for the entering and forwarding of handling objects. All such structure attributes are invariant concerning time since the model structure remains unchanged during a simulation run. Control attributes contain information about control-relevant aspects of the status of the system during the simulation. For example, the attributes *waiting_handling_objects* of a buffer and the *status* of resources are analyzed by an object of the class *rule* before an allocation can be done. Thus, control attributes are time-variant. The statistics attributes of handling objects and resources serve for the collection of data which are needed for the analysis following the simulation. They are time-variant, too.

The values of the structure attributes are determined with certainty and the attribute values of the control and statistics attributes uniquely result from calculations during the simulation. Differently, the attributes which are determined by the user describe circumstances, which might be deterministic or stochastic, crisp or fuzzy. The consideration of stochastic influences in the model is appropriate if the probability distributions are known on basis of available data. However, imprecise, vague, or verbally described information need to be modeled adequately, too. This concerns predicates as e.g. "high probability", "rare occurrence", or a "long handling time". Here, an alternative concept is used which determines a probability distribution on an indirect way. A special advantage results when regarding applications in the context of the process control on basis of approximate inference.

For the modeling of verbal information, linguistic variables are used. For example, handling time for the execution of an activity can be described using the terms "short", "medium", "long" and "very long". If the linguistic variables are defined in the simulation model, by the specification of the model suitable terms can be assigned to the attributes which are determined by the user. He or she must indicate the name of the linguistic variable X and a term from the term set T. For example, the value (DurationEC, medium) can be assigned to the attribute handling time of an activity "Ensure_Completeness" for which a linguistic variable DurationEC is defined. In the context of time-discrete simulation certain points in time, events, are to be considered at which the change of a model status occurs. Fuzzy sets cannot be used directly for the calculation of such events. This applies similarly to the description of sources to generate a certain number of new handling objects entering the system.

The transformation of a fuzzy set into one crisp value using an usual defuzzification method (Klir, Yuan 1995, p. 336 ff.) is inappropriate, because this is equal to directly assigning a crisp value to each term of the linguistic variable. Therefore, the method suggested by Chanas, Nowakowski (1988) is used here, which is based on the concept of a possibility distribution introduced by Zadeh (1978, p. 5 ff.). For the construction of a probability distribution with the assumption "Y = A" and A is a fuzzy set, first a realization α of a random variable uniformly distributed in the interval [0, 1] is determined. Subsequently, the realization of an uniformly distributed random variable in the α-cut of A is generated. This value is considered as a realization of the variable Y. A closed formula for the determination of these values using random number generators is known (Negi, Lee 1992) if the membership function of A is trapezoidal. This approach is applicable, if one term is assigned to an attribute. If one of several terms happens randomly for an attribute, probabilities for the realization of the different terms can be considered additionally. This procedure permits to model and analyze verbal descriptions and vaguely given statements from questionings in the simulation model appropriately.

USING APPROXIMATIVE INFERENCE FOR PROCESS CONTROL

Essential to the simulation of business processes is that the allocation of free resources to handling objects and to activities to be executed is prescribed uniquely, so that status transitions can be determined. The suggested simulation concept uses a special kind of objects, the rules, to fulfill this task. For the object class "rule", suitable procedures are to be designated. Using them, a simulation model with a certain specification of the process control can be configured. The procedures suggested in GEPSIS are all applicable in dynamic planning situations. Thereby, it is not necessary to assume that all handling objects taken into account in one period are already known at the beginning of this period. The activities which are to be executed during a business operation are not completely known in advance, since a flow can contain branching and unification. Furthermore, some of the handling times are assumed to be stochastic. Compared with procedures for static planning GEPSIS can be used without a substantial restriction on a few situations only. In addition to procedures on basis of conventional priority rules for the process control, procedures are used here which are based on approximate inference. The use of priority rules is done related respectively to one of the types of objects resource, handling object, and activity, so that an allocation results gradually. With this gradual methodology different selection sequences are optional. Since the selection of a handling object automatically determines the activity where the handling object is waiting, a total of five relevant combinations result.

The procedure for the process control presented here in more detail is based on approximate inference. It likewise determines priorities for all allocation combinations which are feasible at one decision point in time. These priorities influence the schedule. The determination of the priority values results from a rule set which is given by the user. The production rules can contain different factors influenced by the system status and they can be described verbally. The application of approximate inference for process control requires the definition of a rule set and the definition of linguistic variables, to which the production rules refer. The production rules are laid out in such a way that for each idle resource a waiting handling object is assigned if possible. This is the model of the behavior of an employee who decides on the next activity after he or she has terminated an activity or after an interruption of work. Since the executing resource is therefore known as a user of a rule, the condition part of the production rule contains statements about object attributes of activities and of handling objects. In a decision situation, the input data for the production rules are determined considering the values of the object attributes. For example, the waiting time in the buffer results from the difference of the current simulation time and point in time when the respective handling object enters in accordance with the attribute buffer.*waiting_ handling_ objects*.

The condition part of a production rule can contain several parts which are combined by conjunction or disjunction and which refer to linguistic variables. Additionally, negations of parts of the conditions can be considered. For a fuzzy set A with membership function μ_A the negation $\neg A$ is defined with $\mu_{\neg A} = 1 - \mu_A$ (Dubois, Prade 1980, p. 12 f.). Accordingly, the negation of the condition $X = A$ in a rule is $X = \neg A$. The conclusion here always refers to the allocation priority for a handling object. For the respective linguistic variable the terms can be "very low", "low", "medium", "high", and "very high", with the interval [0, 100] as the base variable. A rule set contains e.g. production rules, which are formulated dependent on the handling time (H) and the waiting period (W) of the objects in the buffer. The conclusion assigns an allocation priority (P).

The compositional rule of inference is used for evaluation, frequently in combination with the minimum or the product operator (Klir, Yuan 1995, p.335). Both operators are no generalization of the classical implication. But a substantial advantage of these operators is that the results can be calculated very efficiently. In an empirical study, in which eleven different operators in a prototypical expert system were examined in the context of a financial analysis, the minimum operator, the Goedel implication, and two further operators, suggested by Mamdani, resulted in particularly good results compared with the judgement of experts (s. Werners 1994). Since rule evaluations are very frequently necessary for the process control in the context of the simulation, the required computing time is of special importance. Because of its very good characteristics the minimum operator is chosen for GEPSIS. If the center of area method is used for the defuzzification, calculated with discrete values for simplicity, a crisp value for the allocation priority results. In order to be able to execute allocations for one point in time, appropriate calculations are necessary for all other resources and handling objects. The application of the procedure up to the termination of all business operations leads to a schedule for all handling objects, which is taken as a basis of the analysis. The procedure developed here is simply comprehensible and can be explained to an expert using common verbal terms of the respective context. If some specifications of attributes are given only verbally, the terms can be used directly as input values of fuzzy production rules. Compared with classical priority-based methods the costs for computation in order to determine an allocation are higher.

SIMULATION OF THE ORDER PROCESSING

The business process of the order processing of a post-exchange book and sound carrier store exemplarily clarifies the effects of the application of different procedures for the process control. If the rules for the process control in the simulation model lead to good results, they can be transferred to guide the way of acting in the business process considered. The example consists of some typical flow structures which are portable accordingly to other order processing flows and other business processes in general.

Orders are received with the store by letter post, fax, or by an Internet purchase order form. Letter orders arrive two times a day. For the two other types of order random interarrival times are supposed. After the customer and the order data are listed they are passed on by data line to a computer in the stock room where the order data are printed out. On the basis of this information, the articles of each order are grouped. When the packing and the input of the data of the actually supplied media are finished, the bill is printed out, and the dispatch takes place. The following figure 1 shows the operational sequence.

The activities following the entry of an order must be specified in more detail, since for the different kinds of order further differences are to be considered, despite of a generally identical part of the operational sequence. These concern the handling duration as well as the determined frequency of orders by new customers and with missing specification of the customer number. For example, the handling time of the listing of data is substantially shorter if the ordering is done by Internet and not by letter, since the order data can be taken over directly from the appropriate electronic form. The order acceptance of letter, fax, and Internet jobs is executed by three coworkers. Two of them process the letter and Internet orders while the third is responsible for the fax orders. Two warehouse workers print out the order data, group the articles, and enter the data of the actually supplied media. A further coworker packs the packages, prints out the bills and dispatches the goods.

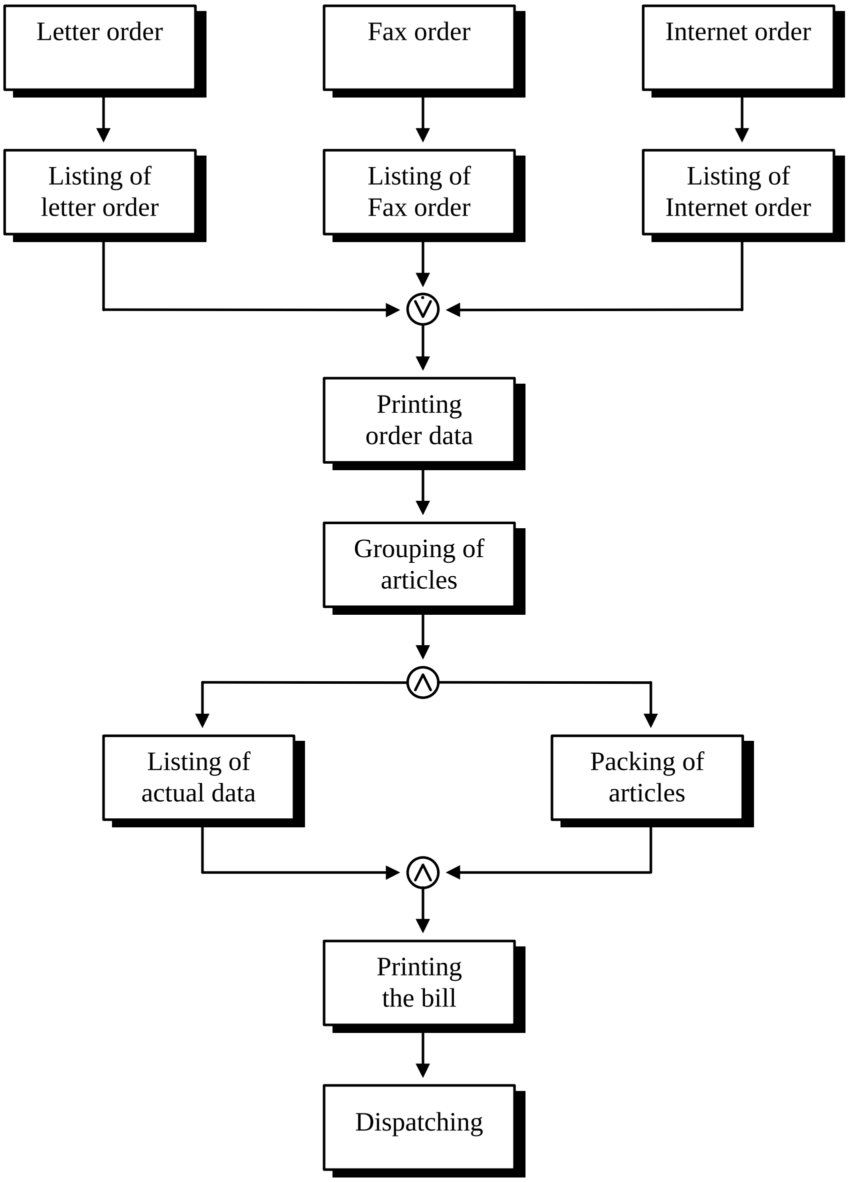

Figure1: Order processing of a post-exchange book and sound carrier store

The simulation component of GEPSIS is used to model the flow of the order processing. The activities "Listing of order data" with letter and fax orders as well as "grouping of articles" are those, which usually indicate the longest handling time. These times are modeled using linguistic variables. To model the duration of the listing of order data, linguistic variables are used with the terms ”varying” and ”strongly varying”. To model the duration of the grouping of articles the term set "short", "medium", and "long" is used and the probability distribution with the probabilities 0.15, 0.70, and 0,15 for the terms, respectively. The terms are modeled by trapezoidal membership functions.

First, the simulation study is done using different priority-rule-based procedures for the process control. The alternative procedures for the process control lead to considerably different results. The imbalance of the rates of utilization among the coworkers is remarkable for all alternatives and indicates the requirement of modification of the allocation of tasks to the coworkers. Modifying the model, appropriate alternatives and their consequences can be evaluated again. Thereby, the activity-oriented analyses can assist in modifying and improving business processes. Due to the results a removal of the separation of the competencies in the order acceptance is meaningful in order to adjust differently high extents of utilization of the coworkers. Additionally, the warehouse workers can be relieved if the print out of the order data were taken over by the packman. This would entail a reduction of the waiting time before this activity, on the one hand, and a more balanced extent of utilization among the two warehouse workers and the packman, on the other hand. The consequences can be evaluated more precisely on the basis of an accordingly modified simulation model.

Additionally, the business process of the order acceptance is examined on basis of approximate inference using three process control alternatives. For all resources, the same rule set is the basis for the determination of the next activity to be processed. After its determination, the handling object with the longest waiting period before this activity is chosen and treated. The rules are formulated concerning the buffer stock and the handling time which a resource needs for execution due to his or her qualification. The linguistic variables "buffer stock" and "handling time" can take the terms "empty", "half-full", "full" and "short", "medium" and "long", respectively, for which trapezoidal membership functions are defined. The following table contains the nine rules of the rule set. They assign particularly high priority to activities with short handling duration if the buffer is full.

Buffer stock	**Handling time**		
	short	**medium**	**long**
empty	low	very low	medium
half-full	high	low	very low
full	very high	high	medium

Table 1: Rule set for the definition of the allocation priority

A second rule set is based on a very similar approach but now activities with a long handling time are priorised in case that the buffer is empty.

Buffer stock	**Handling time**		
	short	**medium**	**long**
empty	very low	low	high
half-full	medium	low	low
full	very high	medium	low

Table 2: Rule set for the definition of the allocation priority

The third alternative uses the second rule set, however, the membership functions of the terms of the linguistic variable ”buffer stock” are now changed. E.g., instead of the membership function (2, 5, 8, 12) for the term "half-full" now (2, 7, 10, 15) is chosen.

The results regarding the process-related quantities of the completion times and the waiting time proportions are indicated in the following two tables. With respect to these goals the second rule set achieves the best results using the membership functions selected first. The modification of the rule set here has a substantially stronger influence on the results than the modification of the membership functions which characterize the terms.

Alternative	**Rule set**	**entirely**	**Letter order**	**Fax order**	**Internet order**
1	1	1:39:26 (13:13)	2:15:36 (12:45)	2:10:50 (12:33)	40:58 (7:30)
2	2	1:11:35 (7:24)	1:47:28 (9:03)	1:36:33 (9:57)	19:43 (1:31)
3	2	1:14:12 (6:31)	1:51:27 (8:48)	1:38:26 (12:43)	21:45 (1:45)

Table 3: Mean value and standard deviation of the completion times

Alternative	Rule set	entirely	Letter order	Fax order	Internet order
1	1	70,6 % (3,1 %)	82,8 % (1,8 %)	78, 6 % (3,2 %)	54,3 % (5,9 %)
2	2	68,6 % (3,0 %)	80,1 % (2,0 %)	77,6 % (1,6 %)	51,1 % (4,4 %)
3	2	70,1 % (2,6 %)	81,2 % (1,7 %)	77,3 % (2,6 %)	54,4 % (4,1 %)

Table 4: Mean value and standard deviation of waiting time proportion

Regarding the extent of utilization of resources, the three alternatives lead to merely insignificant differences as can be seen in table 5.

Alternative	Rule set	Coworker Letter and Internet		Coworker Fax	Warehouse workers		Packman
1	1	75,1 %	42,1 %	97,4 %	93,3 %	89,7 %	36,9 %
2	2	75,3 %	40,4 %	96,9 %	96,4 %	94,9 %	36,8 %
3	2	75,5 %	40,4 %	97,4 %	96,3 %	94,5 %	36,8 %

Table 5: Rates of utilization of resources

By a direct modification of the rule set and the characterizing membership functions of the terms, which are pointed out by this example, the process control can be adapted to the respective request, accordingly. A prerequisite for this procedure is a rough know-how, so that the membership functions can be defined. If the suggested and analyzed rule set results in a good process behavior, the rules can be deduced and comprehensibly described to improve the organizational behavior.

The exemplary application described in this section shows that the user defined application object library developed here is well suited for the modeling of very different business processes. Due to the relatively high abstraction, it is nearly insignificant, whether the handling objects in a business process are material or whether the activities are of mainly information-processing nature. Likewise no considerable differences with respect to the model development result for business processes with a high or a low number of different activities.

Since no difficulties occurred with the modeling of the flows, the applicability of the concept, and its implementation the decision support system GEPSIS proved to be generally applicable for business process planning. Although the improvement of a business process mainly depends on the circumstances and context in each single case, the extensive analysis and the possibilities of evaluation offer a valuable decision support to generate and to select alternative flows and thus contribute to the optimization of business processes.

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