

# Integrated Workflow Planning and Coordination

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**Abstract.** Two major tasks in process management are the planning of a process and the coordination of its execution. Workflow management systems support and automate the coordination of a process, but planning the process remains a manual task. This paper argues that planning and coordination are closely interrelated and therefore restricting the attention to the automation of coordination can lead to problems concerning consistency and performance. A concept is presented to avoid these problems by adding automated planning. It is shown how planning algorithms from Artificial Intelligence can be combined with workflow management concepts to build an integrated workflow planning and coordination system. Advantages, limitations and areas of application of this approach are discussed.

## 1 Introduction

Competition in dynamic markets forces organizations to take advantage of information technology to improve their business. A crucial point for the competitiveness of organizations is the performance of their processes [7, 18]. Two major tasks in process management are the planning of a process and the coordination of its execution. Workflow management systems [6, 9, 11] support and automate the coordination of a process, but planning the process remains a manual task. This paper argues that planning and coordination are closely interrelated and therefore concentrating on the automation of coordination and disregarding planning aspects can lead to problems concerning consistency [14, 16, 19] and performance. In this paper, a concept is presented to avoid these problems by adding automated planning and building an integrated workflow planning and coordination system.

A *process* is a defined set of partially ordered steps intended to reach a goal [4]. It is the means to change a given situation in order to fulfill a company's goal. The information about this situation including all relevant documents is called a *case*. Examples of cases are an incoming purchase order that has to be handled or a sick patient who has to be cured. From an organizational point of view, the life cycle of a process includes the phases planning and coordination. *Planning* is the development of a description called a *process definition* of what has to be done in which order to reach a particular goal. The subsequent phase is *coordination*, which is the organizational task to schedule the work in accordance to the process definition. Workflow management systems take a process

definition as input and use it to support and automate coordination. In contrast, there is rarely any automated planning of business processes. Planning and supplying the process definition to the workflow management system has to be done manually. Manual planning is a time intensive work of specialists and thus a costly task. For this reason, it is not economically advantageous to plan an individual process definition for every case. Instead, similar cases are grouped together and planned conjointly. For example, there is only one generic process definition used for all incoming purchase orders. Finding a process definition that copes with all possible variants of purchase orders becomes more difficult the more the structure of the cases varies. Normally one process definition is used to coordinate a process, but if something unanticipated occurs threatening the achievement of the goal, it becomes necessary to react by changing the process definition. This *replanning* has to be done manually and, thus, delays execution. Afterwards the workflow management system has to adapt its coordination to the changed process definition. This change of process definition at run time has already been investigated [3, 16, 8, 19]. It proves to be a difficult task for the workflow management system to assure consistency, because it does not have all the required information on the dependencies between process steps.

This paper describes how these problems can be avoided by an integrated planning and coordination system. Since automated planning is done without human effort, it changes the possibilities to organize planning and coordination. Instead of planning just one process definition for a group of similar cases, automated planning allows to individually plan every case. This can result in an optimized process definition taking into account all the specific properties of the case. This capability can realize a competitive advantage, since individual treatment of cases and thereby of costumers becomes increasingly important [7]. Furthermore, an integrated planning and coordination system can automatically trigger and perform replanning if necessary. Thus, a delay of the process execution can be avoided. If a process definition has to be changed at runtime, consistency can be assured, because all necessary information on the dependencies between the process steps is available for the planning system. To automate planning, algorithms are needed that take case and goal as input and deliver an appropriate process definition. Such planning algorithms exist in Artificial Intelligence (AI) [5]. This paper describes how these planning algorithms can be combined with workflow management concepts, to build an integrated workflow planning and coordination system. In Section 2 the relevant foundations on AI planning algorithms and workflow management concepts are introduced. Section 3 describes the functional integration and behavior of the overall system and deduces the advantages and limitations of this approach. Finally, in Section 4, related work, areas of application, and unsolved problems are discussed.

## 2 Preliminaries

The integrated planning and coordination system presented in this paper is based on the planner and the coordinator as the two main sub-systems. On planning

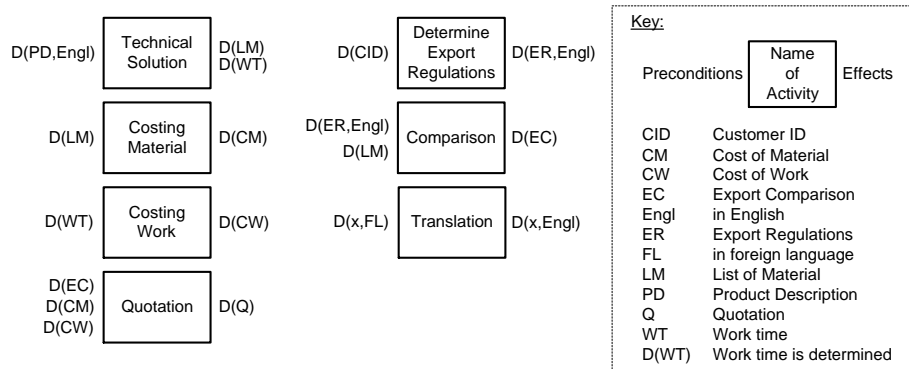


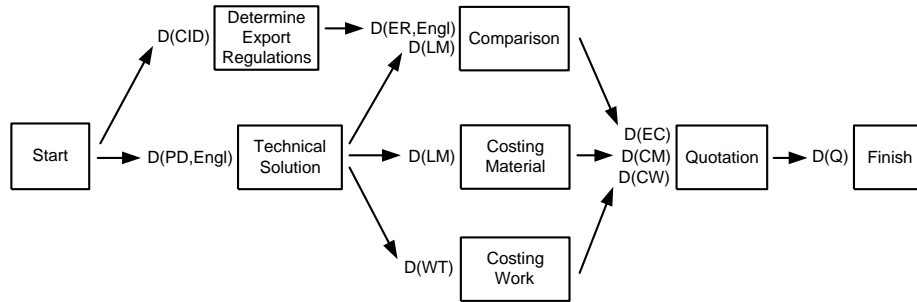
Fig. 1. Activities with Preconditions and Effects

and coordination there has already been done a lot of research in the areas of AI planning algorithms and workflow management systems respectively. This section presents the concepts from both research areas that are important for an integration. Common concepts of both areas are described using one continuous terminology, instead of applying the area specific terminology at each case. The example introduced in this section will be used throughout the paper to illustrate the integration to an overall system.

## 2.1 Planning Algorithms

Planning algorithms [5, 12] take a description of the current state of a case, a goal and a set of activities as input. The *goal* constitutes the wanted state of the case. The means to transform the case from its actual state to the goal are the activities. An *activity* is a piece of work that forms one logical step within a process. The conditions under which an activity can be executed are called *preconditions* and its impacts on the state of the case are called *effects*. *Planning* is defined as a search problem, which is to find an partially ordered set of activities that when executed transforms the case from its current state to the goal. The description of this set of activities and their ordering – the process definition – is the output of the planning algorithm.

To illustrate the basic procedure of a planning algorithm and the relationship between its input and output, the planning of a simplified process in a company that manufactures individual products for international customers is presented. The process is the handling of a request for quotation. Thereby, a customer describes a desired product and asks the company to propose a price. To model the input of the planning algorithm a formal description of the current state of the case, the goal and the activities is needed. The initial state of the case and the goal are described using a set of ground clauses in first order logic [5]. The initial state of the case is that the customers identity (CID) and a product description



**Fig. 2.** Process Definition: Request for Quotation

(PD) in English are determined (D). The terms  $D(CID)$  and  $D(PD, Engl)$  formally describe this state. The goal  $D(Q)$  is the determination of the quotation (Q) for the customer. The available activities with their preconditions and effects can be found in Fig. 1. The activities are depicted by rectangles. The clauses on the left hand side of the activities are their preconditions and the clauses on the right hand side are their effects. *Technical Solution* can only be executed if a product description in English is available. As the effect of this activity a list of material and the expected time to build the product are determined. Based on this information *Costing Material* and *Costing Work* can determine the original costs for the manufacturing. *Determine Export Regulations* determines the export regulations for the country of the customer. *Comparison* checks if material needed for the manufacturing of the product breaches the export regulations. *Quotation* determines the price and the delivery terms of the product. *Translation* takes any document – indicated by the variable  $x$  – in a foreign language as input and delivers a translation of that document into English. To complete the input of a planning algorithm, two extra activities are introduced: an activity *Start* that has no preconditions and whose effect is the initial state of the case and an activity *Finish* that has the goal as a precondition and no effects. The task of a planning algorithm is to find a process definition that allows to reach the goal. A solution is depicted in Fig. 2. The activities are partially ordered in a way that the effects of preceding activities satisfy the preconditions of subsequent activities. For example the list of material needed by *Costing Material* is determined in *Technical Solution*. This directed relationship between two activities is called a causal link and is displayed as an arrow. A causal link always implies a temporal ordering. Therefore, *Technical Solution* has to be executed before *Costing Material*. If the coordination of the process follows this ordering, all preconditions are satisfied when their corresponding activities are executed and the goal will be reached. The effects of the activities are not displayed in the process definition, because the causal links combined with the preconditions of the subsequent activities make them a redundant information.

## 2.2 Workflow Management

The purpose of workflow management systems [6, 9, 11, 17] is to support and automate the coordination of business processes. Coordination means that pieces of work have to be passed to the right participant at the right time with the support of the right tool. A central property of a workflow management system is that this functionality is not hard coded for a specific process, but implemented in a way that the system can take any process definition as input. For a workflow management system the relationship between effects and preconditions as the causal origin of the ordering of the activities is not relevant. Therefore, a process definition that a workflow management system takes as an input only contains ordering constraints instead of causal links. As a causal link always implies an ordering constraint, a corresponding process definition can be derived from the process definition in Fig. 2 by omitting the effects of the activities and changing the semantics of the arrows from causal links to ordering constraints. Next to the process definition the workflow management system needs information on the potential participants of the process and the available tools.

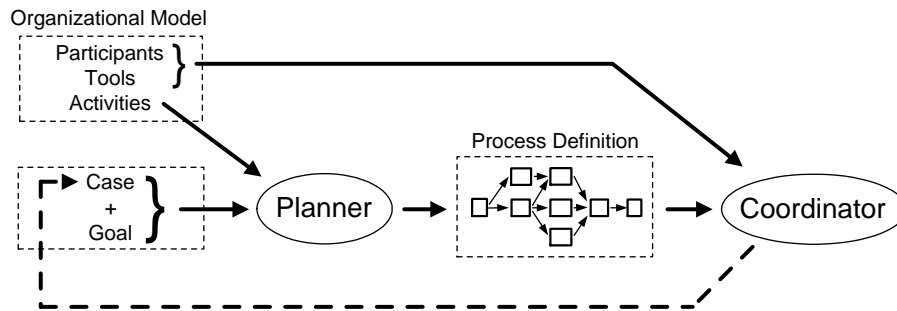
The execution of a process starts with the activities in the process definition that have no predecessors. In the process definition in Fig. 2 the activities *Technical Solution* and *Determine Export Regulations* are scheduled first. When an activity is executed the workflow management systems automatically starts the appropriate tool with the data that has to be processed in this activity. After the execution of an activity its subsequent activities are started. This iterates until all activities are executed and the process is completed. An execution is *consistent*, if all preconditions of each activity are satisfied when it is executed and the execution leads to the achievement of the goal. To guarantee consistency, an appropriate process definition has to be planned and the activities have to be scheduled accordingly. Planning takes the dependencies between the activities and their contribution to the achievement of the goal into account. The workflow management system maintains consistency by following the ordering in the process definition when scheduling the activities.

## 3 Integration of Planning and Coordination

In this section a conceptual framework for an integrated planning and coordination system is outlined. Then the resulting ability to plan case-individual process definitions is presented. Finally the framework will be enhanced by the factor of uncertainty to make it more realistic and to show the potential of the integrated approach in this concern.

### 3.1 Framework

The two central sub-systems of the framework are the planner and the coordinator. For each case the planner generates a process definition, that is used by the coordinator to schedule the work steps. In the following the basic functional and



**Fig. 3.** Integrated Planner and Coordinator

behavioral aspects of the interaction of these components are described. Fig. 3 gives an overview of the interrelation of input and output between planner and coordinator. The basis for the overall system is the formal description of the activities, the participants and the tools. They describe the means of the company to process individual cases. To handle a case it has to be associated with a goal. The planner takes a case, the associated goal and the activities as input and generates a process definition as output. The process definition combined with information about participants and tools builds the input of the coordinator. This allows the coordinator to schedule the execution of the activities in accordance to the process definition using the company's resources until the goal is reached. The dashed arrow from the coordinator to the case depicts the effects of the activities on the case, which are scheduled by the coordinator.

To illustrate the behavior of the overall system the example of a request for quotation is carried on. Before cases can be handled, the organization has to be modeled by defining activities, tools, and participants. The activities shown in Fig. 1 are a subset of a company's set of activities. They have in common that they are usually needed to handle a request for quotation, but they represent self-contained business rules that can be used to handle all kinds of cases. For example the activities *Determine Export Regulations* or *Comparison* can be part of every process dealing with export. After the organizational model is defined, the system is ready to process individual cases. In our example the trigger for processing is a request for quotation arriving in the company. The participant who handles the incoming request has to build a corresponding case by defining its initial state and assigning a goal. This means he has to enter the customers identity and the product description into the system. Then he assigns the goal of determining the quotation to the case. When this initial work is done the planner is triggered to find a process definition to handle this case. The planner delivers the process definition shown in Fig. 2 and passes it on to the coordinator. The coordinator starts the execution of the process by enabling the activities *Technical Solution* and *Determine Export Regulations*.

### 3.2 Individual Planning

An important feature of the integrated planning and coordination system is that each case is planned individually. Using a classical workflow management system, the participant who handles an incoming request has to assign a predefined process definition matching more or less the requirements of the case. With integrated planning, for each case an individual process definition is generated, taking into account all particularities of the case. For example, a customer wants to buy only the necessary material and to assemble the product on his own. In this case no work costs have to be calculated. This can be easily taken into account when defining the initial state of the case by setting the work costs as already determined. As a result the planner delivers a process definition without the activity *Costing Work*, because its effect  $D(CW)$  is already set and thus this precondition of *Quotation* is already satisfied. Another example for an individual customization of the process definition is the handling of a product description written in a foreign language (FL). Thereby, the initial state is formally described by  $D(CID)$  and  $D(PD,FL)$ . To reach the goal starting from this initial state the activity *Translation*, shown in Fig. 1, is needed. When generating the process definition the planner inserts this activity between *Start* and *Technical Solution*. In this way the precondition of *Technical Solution* that the product description is in English, will be satisfied.

Using a classical workflow management system only predefined process definitions are available. Thereby, particularities of cases have to be taken into account by anticipating possible variants of cases and modelling alternative execution paths. Often this can not be done completely because not all possible variants are known when the process definition is planned. A conceptual problem lies in the fact that the process definition has to be planned before the cases are known. An integrated planning and coordination system avoids this problem, by planning after the state of the case is known. No predefined process definitions exist. They are planned when they are needed to handle a given case. Therefore, all particularities of a case can be considered and no unnecessary alternatives have to be defined. Thus, the resulting process definitions are only as complex as a given case requires and potentially more concise.

### 3.3 Automated Replanning

The interaction between planner and coordinator becomes more interlaced if the aspect of uncertainty is taken into account. Until now it was assumed that the planner always had full knowledge about the effects the activities will have. To be more realistic it is necessary to deal with partial knowledge in this concern. Modeling an activity, effects are assigned that are anticipated from the execution of this activity. For example, the anticipated effects of *Technical Solution* are the determination of the list of material and the work time. But it is possible that the activity has other, unanticipated effects. For example, the participant executing *Technical Solution* remembers that recently a technical solution for a similar product was determined. Therefore, the old solution can be reused, i.e.

the list of material and the work time. Furthermore, even the cost for material and work of the old case can be adopted. Thus, *Technical Solution* has the two additional effects D(CM) and D(CW), which makes executing the activities *Costing Material* and *Costing Work* redundant.

In general, the coordinator has to compare the actual effects with the effects described in the activity's definition. If they differ, the current process definition becomes invalid, because it was planned based on wrong assumptions concerning the effects of activities. For this reason the coordinator has to trigger a replanning, which is the development of a new process definition based on the current state of the case. This implies considering the previously unanticipated effects. In the example the new process definition misses the activities *Costing Material* and *Costing Work*. The coordinator has to adopt the new process definition by leaving out these activities. The alternating phases of planning and coordination are iterated whenever an unanticipated effect occurs. In contrast to the example above, activities can also have unanticipated effects that endanger the achievement of the goal. For example, the participant executing *Determine Export Regulations* is unable to find an English version of the export regulations, i.e. the effect of the activity is D(ER,FL) instead of D(ER,Engl). *Compare Material* can not be executed because its preconditions are not satisfied. This problem can also be solved by triggering replanning, which delivers a new process definition with *Translate Document* as predecessor of *Compare Material*. Next to unanticipated effects, there can be other reasons for replanning. For instance unavailable activities, a change in the preconditions of an activity, or a change of the goal. All of these possibilities can be handled by triggering replanning.

A prerequisite to allow replanning when using a workflow management system is the support of dynamic change [3, 16, 8, 14, 19]. This means the ability to adopt a new process definition during process execution. Nevertheless, replanning has to be done manually. While the initial process definition usually is developed, checked and optimized by specialists, who spend a lot of time and effort on this task, replanning often has to be done in an ad-hoc manner and is time critical. This is especially problematic, if temporarily no specialist is available. Hence, an integrated planning system helps to save time and costs. A more conceptual problem when using a workflow management system, is assuring consistent execution when replanning is necessary. Without replanning one process definition is valid from the beginning of the process until the goal is reached and the workflow management system can maintain consistency by scheduling the activities in accordance to the process definition as described in Subsection 2.2. This becomes more complex if replanning is necessary, because the coordinator has to switch from one process definition to another. A classical workflow management system knows nothing about the dependencies causing the ordering of the activities. Thus, its ability to check the consistency, when adopting a new process definition is limited. The integration of a planner solves this problem. The planner always has the necessary information to guarantee consistency when replanning, because it takes the current state of the case and thereby the effects of already executed activities into account.

## 4 Discussion

Only recently there has been interest in the application of AI techniques to workflow management. PLMFlow [20] avoids the use of predefined process definitions in order to be independent from the availability of specific activities. Instead, this approach combines activities by considering sets of possible predecessor and successor activities. A goal driven backward chaining algorithm is used to determine process definitions, but the state of the case is not taken into consideration. In [13] the application of contingent planners to existing workflow management systems is discussed. Oz Collaborative Workflow Environment [1] stems from the automation of building software products. Dependencies between software components are mapped into preconditions and effects.

In this paper we outlined a framework for an integrated planning and coordination system, which shows how AI planning algorithms and workflow management concepts can be combined to improve the support of business processes. The integration facilitates individual planning of cases and improves the handling of uncertainty by supporting automated and consistent replanning. A limitation of this approach is that automated replanning only works if a new process definition can be found. In contrast there can be situations in which the available set of activities proves to be insufficient to reach the goal. In such cases user intervention is still necessary to define missing activities or to declare the case as unsolvable. Areas of application for the presented approach are indicated by strong varying case structures and a high amount of uncertainty concerning the effects of activities. Especially if replanning is time crucial or has to be done without human interaction, the integration of automated planning can be beneficial. However, if process definitions seldom change and cases are very uniformly structured, the presented approach offers few additional value. But with indications given, integration of automated planning seems to have the potential to establish new areas of application for workflow management systems.

Future work includes the choice and adaptation of appropriate AI planning algorithms. One aspect is that alternatives are a typical element of organizational processes. As shown in Section 3.2, individual planning avoids alternative branches that result from uncertainty about the initial state of a case. To also handle uncertainty about the effects of activities, a conditional planner that is able to generate and join alternative branches seems appropriate. C-BURIDAN [2] for instance is a planner based on BURIDAN [10] and CNLP [15] that satisfies this requirement and has to be checked for its suitability.

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