Modeling Work Distribution Mechanisms Using Colored Petri Nets

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Abstract. Workflow management systems support business processes and are driven by their models. These models cover different perspectives including the control-flow, resource, and data perspectives. This paper focuses on the *resource perspective*, i.e., the way the system distributes work based on the structure of the organization and capabilities/qualifications of people. Contemporary workflow management systems offer a wide variety of mechanisms to support the resource perspective. Because the resource perspective is essential for the applicability of such systems, it is important to better understand the mechanisms and their interactions. Our goal is not to evaluate and compare *what* different systems do, but to understand *how* they do it. We use *Colored Petri Nets* (CPNs) to model work distribution mechanisms. First, we provide a basic model that can be seen as the "greatest common denominator" of existing workflow management systems. This model is then extended for three specific systems (Staffware, FileNet, and FLOWer). Moreover, we show how more advanced work distribution mechanisms, referred to as *resource patterns*, can be modelled and analyzed.

Key words: Work distribution, workflow management, business process management, resource patterns, colored Petri nets.

1 Introduction

Workflow management systems are process-aware information systems [5, 20], which are used in companies as a means for the computerized structuring and driving of complex business processes. Workflow management systems implement business process models, and use them for driving the flow of work by allocating the right employees to the right tasks at the right times. The system *manages the work of employees*. It will determine which tasks an employee has to execute and when, which documents will be used, which information will be available during work, etc. Typically, a workflow management system offers several mechanisms to distribute work. Nevertheless, we believe that existing systems are too limited in this respect. The goal of this paper is not to propose advanced work distribution mechanisms. Instead, we focus on the analysis of functionality in existing systems. The goal is not to evaluate these systems, but to understand *how* they offer specific functionality. Since work distribution defines the quality of work, it is important to consider research from the field of social sciences, e.g., social-technical design [13, 17, 21, 55]. We believe that only by combining both *technical* and *social* approaches, one can truly grasp certain phenomena. A *deeper understanding* of particular aspects of work distribution is essential for developing a new breed of more user-centric systems.

The work reported in this paper can be seen as an extension of the *workflow patterns initiative* [6] (cf. www.workflowpatterns.com). Within the context of this initiative 43 resource patterns [51, 49] have been defined. Using a patterns approach, work distribution is evaluated from the perspective of the end-user as a dynamic property of workflow management systems. The work reported in this paper adds to a better understanding of these mechanisms by providing explicit process models for these patterns, i.e., the descriptive models are augmented with executable models. Most work reported in literature (cf. Section 4) uses static models to describe work distribution. Consider for example the meta modeling approaches presented in [8, 40–42, 48]. These approaches use static models (e.g., UML class diagrams) to discuss work distribution concepts. This paper takes a truly dynamic model – a *Colored Petri Net* model – as a starting point, thus clearly differentiating our contribution from existing work reported in literature.

Colored Petri Nets (CPNs) [31, 34] are a natural extension of the classical Petri net [46].There are several reasons for selecting CPNs as the language for modeling work distribution in the context of workflow management. First of all, CPNs have formal semantics and allow for different types of analysis, e.g., state-space analysis and invariants [32]. Second, CPNs are executable and allow for rapid prototyping, gaming, and simulation. Third, CPNs are graphical and their notation is similar to existing workflow languages. Finally, the CPN language is supported by CPN Tools[1] – a graphical environment to model, enact and analyze CPNs. In the remainder, we assume that the reader is familiar with the CPN language and refer to [31, 34] for more details.

In this paper, we provide a basic CPN model that can be seen as the "greatest common denominator" of existing workflow management systems. The model will incorporate concepts of a task, case, user, work item, role and group. This model should be seen as a *starting point* towards a more *comprehensive reference model for work distribution*. The basic CPN model is extended and specialized for three specific systems: Staffware [54], FileNet [24], and FLOWer [43]. These three models are used to investigate differences between and similarities among different work distribution mechanisms in order to gain a deeper understanding of these mechanisms. In addition, advanced resource patterns that are not supported by these three systems are modeled by extending the basic CPN model.

The remainder of this paper is organized as follows. Section 2 presents the basic CPN model which should be considered a the "greatest common denominator" of existing workflow management systems. Section 3 extends this model in two directions: (1) Section 3.1 specializes the model for three different systems (i.e., Staffware, FileNet, and FLOWer), and (2) Section 3.2 extends the basic model for selected resource patterns. An overview of related work is given in Section 4. Section 5 discusses our findings and, finally, Section 6 concludes the paper.

2 Basic Model

Different workflow management systems tend to use different work distribution concepts and completely different terminologies. This makes it difficult to compare these systems. Therefore, we will not start by developing CPN models for different systems and see how these can be unified, but, instead, start with modelling the "greatest common denominator" of existing systems. This model can assist in comparing systems and unifying concepts and terminology. We will use the term *Basic Model* to refer to this "greatest common denominator" and represent it in terms of a CPN model.

The Basic Model represents a workflow management system where the business *process* is defined as a set of *tasks*. Before the process can be initiated and executed, it has to be instantiated. One (executable) instance of a process is referred to as a *case*. Each case traverses the process. If a task is enabled for a specific case, a *work item*, i.e., a concrete piece of work, is created. There is a set of *users* that can execute work items. The users are embedded in the organizational structure on the basis of their *roles*, and the *groups* they belong to. Group is an organizational unit (e.g., sales, purchasing, production, etc.), while role represents a capability of the user (e.g., manager, software developer, accountant, etc.). These concepts are mapped onto CPN types as shown in Table 1.

During the work distribution work items change state. The change of state depends on previous and determines the next actions of users and the distribution mechanism. A model of a life cycle of a work item shows how a work item changes states during the work distribution. For more detailed models about life cycle models we refer the reader to literature, e.g., [5, 18, 20, 30, 37, 41]. We develop and use the life cycle models as an aid to describe work distribution mechanisms. The Basic Model uses a simple model of the life cycle of work items and it covers only the general, rather simplified, behavior of workflow management systems (e.g., errors and aborts are not considered).

[1] CPN Tools can be downloaded from wiki.daimi.au.dk/cpntools/.

Figure 1 shows the life cycle of a work item of the Basic Model. After the *new* work item has arrived, it is automatically also *enabled* and then taken into distribution (i.e., state *initiated*). Next, the work item is *offered* to the user(s). Once a user *selects* the work item, it is *assigned* to him/her, and (s)he can *start* executing it. After the *execution*, the work item is considered to be *completed*, and the user can begin working on the next work item.

Table 1. Basic Workflow Concepts

color Task = string;
color Case = int;
color WI = product Case * Task;
color User = string;
color Role = string;
color Group = string;

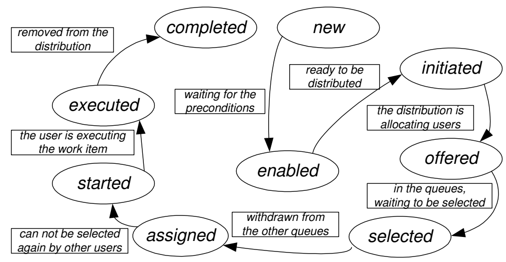


Fig. 1. Basic Model - Work Item Life Cycle

For the simulation (execution) of the work distribution in the model it is necessary to initiate the model by assigning values for four *input elements*[2], as shown in Table 2. Initial values of input elements describe a real-world situation that the model should execute.

Table 2. Input For The Basic Model

name	color	description
new work items	color WI = product Case * Task;	work items that have arrived and are ready to be distributed to users;
system users	color Users = list User;	a set of available users;
task maps	color TMap = product Task * Role * Group;	decision about which work items can be executed by which users is made based on the authorizations given in the process definition, for every task;
user maps	color UMap = product User * Roles * Groups;	the organizational structure is used to map users to the authorization of tasks;

As a model of an abstract workflow management system, we have developed the Basic Model on the basis of predefined assumptions: (1) we abstract from the process perspective (i.e., splits, joins, creation of work items), (2) we only consider the "normal" behavior (i.e., work items are completed successfully; errors and aborts are not included), and (3) we abstract from the user interface.

The Basic Model is organized into two sub-systems: the Work Distribution and the Work Lists module. The CPN language allows for the decomposition of complex nets into sub-pages, which are also referred to as sub-systems, sub-processes or modules. By using such modules we obtain a layered hierarchical description. Figure 2 shows the modular structure of the Basic Model. The two sub-modules communicate by exchanging messages via six places. These messages contain information about a user and a work item. Every message place is of the type (i.e., the CPN color set) "user work item" (*color UWI = product User * WI*), which is a combination of a user and a work item. Table 3 shows the description of the semantics of different messages that can be exchanged in the model.

[2] Initial marking for the CPN model.

Table 3. Messages Between Modules

Place	Message
to be offered	A work item is offered to the user.
withdrawn offer	Withdraw the offered work item from the user.
selected	The user requests to select the work item.
approved	Allow the user to select the work item.
rejected	Do not allow the user to select the work item.
completed	The user has completed executing the work item

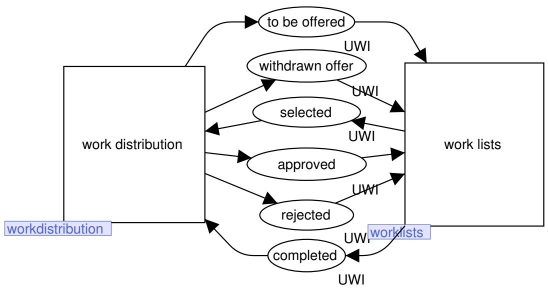


Fig. 2. Basic Model - Main

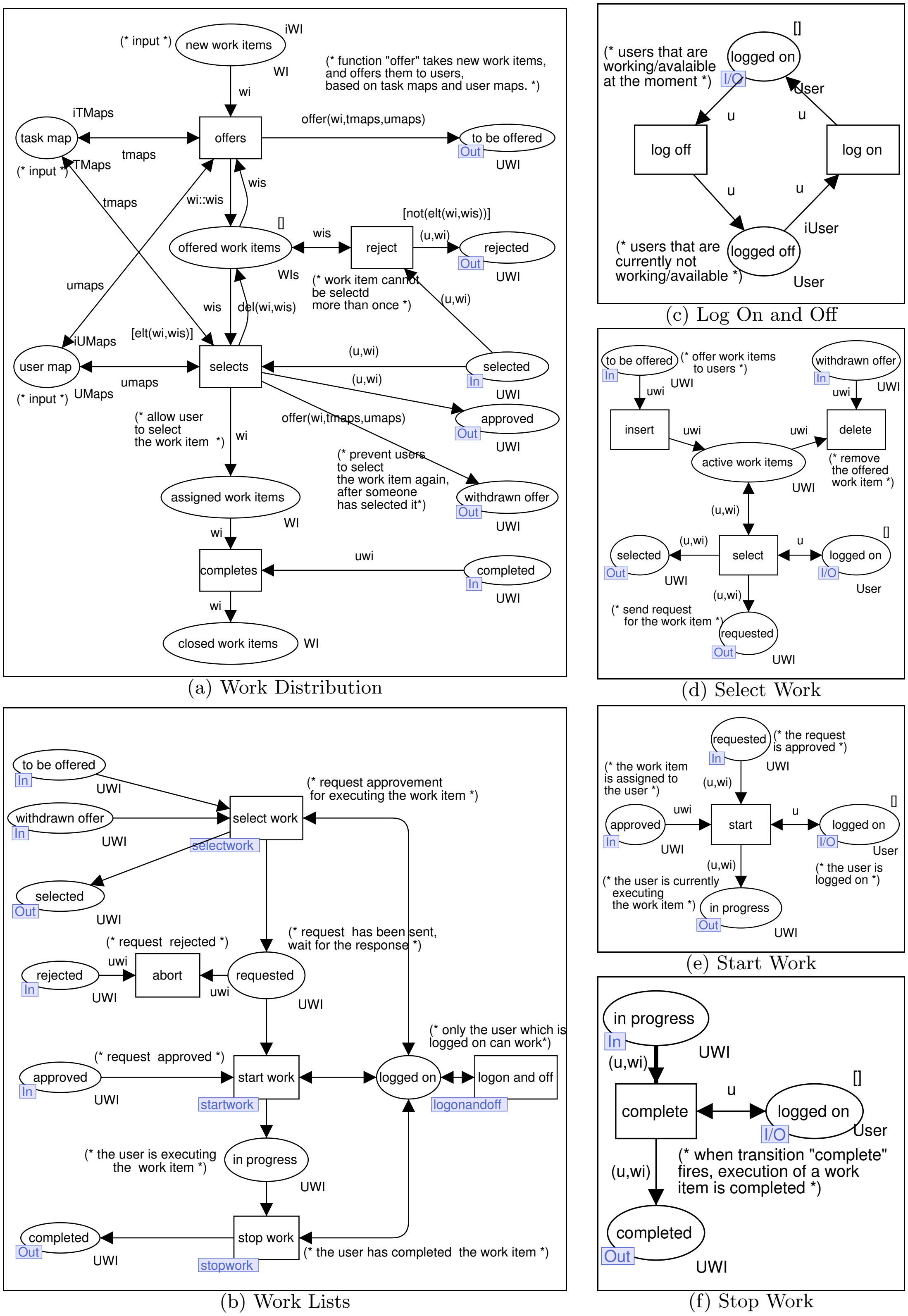
Work Distribution. The Work Distribution module manages the distribution of work items by managing the process of work execution and making sure that work items are executed correctly. It allocates (identifies) users to whom the *new work items* should be offered, based on authorization (*TMap*) and organization (*UMap*) data. Three (out of four) input elements are placed in this module: *new work items*, *user maps* and *task maps*. The variables used in this module are shown in Table 4.

Table 4. Basic Model - Variables in Work Distribution Module

var tmaps: TMaps;
var umaps: UMaps;
var wi: WI;
var wis:WIs; (color WIs = list WI;)
var uwi: UWI;

Figure 3(a) shows the Work Distribution module. The allocation function *offer* appears on the arc between the transition *offers* and the place *to be offered*. This function contains allocation rules (allocation algorithm) of the specific distribution mechanism. Work items that are offered to users are stored in the place *offered work items*. After receiving a request from the user to select the work item, the decision is made whether to allow the user to select the item (and thus to execute it), or to reject this request. This decision is made based on the assumption that at one moment, only one user can work on the work item. If the work item has already been selected (i.e., it is not in the place *offered work items*), then the model rejects this request. If nobody has selected the work item yet, the approval is sent to the user and the work item is moved to the place *assigned work items*. A work item that is moved to the place *assigned work items* cannot be selected again.

Work Lists. Figure 3(b) shows the Work Lists module. This module receives messages from the Work Distribution module about which work items are to be offered to which users. The Work Lists module further manages events associated with the activities of users. It is decomposed into three units, which correspond to three basic actions users can make: *log on and off* (cf. Figure 3(c)) in the system, *select work* (cf. Figure 3(d)), *start work* (cf. Figure 3(e)), and *stop work* (cf. Figure 3(f)). Once the work item has been *offered* to users, they can *select* it. When a user selects the work item, the *request* is sent to the Work Distribution module. If the request is *rejected*, the action is *aborted*. If the Work Distribution Module *approves* the request, the user can start working on the work item. Once the user has started working, the work item is considered to be *in progress*. Next, the user can stop working, and the work item is *completed*. In order to perform any of these actions, it is necessary that the user is *logged on* in the system.



(a) Work Distribution

(b) Work Lists

(c) Log On and Off

(d) Select Work

(e) Start Work

(f) Stop Work

Fig. 3. Basic Model

3 Work Distribution Models

The Basic Model presented in previous section (Section 2) is used as a reference for different extensions and specializations of work distribution. In this section, we first extend and specialize the Basic Model to accommodate the capabilities of Staffware, FileNet and FLOWer (Section 3.1). In Section 3.2 we select four of the more advanced resource patterns reported in [49, 51]. These four patterns are not supported by Staffware, FileNet and FLOWer, but we will show that it is easy to extend the Basic Model to adequately address the patterns.

3.1 Workflow Management Systems

We have modelled the work distribution mechanisms of three commercial workflow management systems: Staffware, FileNet and FLOWer. FileNet and Staffware are examples of two widely used traditional workflow management systems. FLOWer is based on the case-handling paradigm, which can be characterized as "the more flexible approach" [3, 9]. Each of the models we have developed will be described shortly in the remainder of this section. For a more detailed description of the models we refer the reader to a technical report [44].

Staffware The Basic Model is upgraded to represent the work distribution of Staffware. The way of modelling the *organizational structure* and *resource allocation algorithm* are changed, while the concept of *work queues* and the possibility of the user to *forward and suspend* a work item are added to the model.

Organizational Structure. Simple organizational structure can be created in Staffware using the notions of *groups* and *roles*. The notion of group is defined as in the Basic Model, i.e., one group can contain several users, and one user can be a member of several groups. However, specific for Staffware is that a role can be defined for only one user. This feature does not require any changes in the model itself. It changes the way the initial value for the *user maps* should be defined – one role should be assigned to only one user.

Work Queues. Groups are used in Staffware to model a set of users that share common rights. The work item can be allocated to the whole group, instead of listing the names of users that can execute it. Staffware introduces a *work queue* for every group. The work queue is accessible to all members of the group. Single users are also considered to be groups that contain only one member. Thus, one work queue is also created for every user and this personal queue is only accessible by a single user. From the perspective of the user, (s)he has access to the personal work queue and to work queues of all the groups (s)he is a member of. Table 5 shows which color sets are added to the model to represent work queues in Staffware. While the Basic Model (Section 2) offers the work item directly to *users*, Staffware offers items in two levels. First, the work item is offered to *work queues* (color set WQ). We refer to this kind of work items as to *queue work item* (color set QWI). Second, after a queue work item is offered to a group (work queue) it is offered to each of its members and only one member will execute the queue work item once. We refer to a queue work item that is offered to a member as to *user work item* (color set UWI).

Table 5. Staffware - "Work Queue" Color Sets

color WQ = string;
color QWI = product WI * WQ;
color UWI = product User *QWI;

Figures 4 and 5 show that we create two levels in the Work Distribution module to support the two-level distribution of Staffware:

1. In the module itself a new work item is offered to work queues (as a queue work item). The new work item is completed when each of its queue work items is executed. Thus, if a new work item is offered to multiple work queues, it is executed multiple times.
2. In the sub-module *Offering to Users* every queue work item is offered to the queue members (user work item). A queue work item is completed when one of the members executes the user work item.

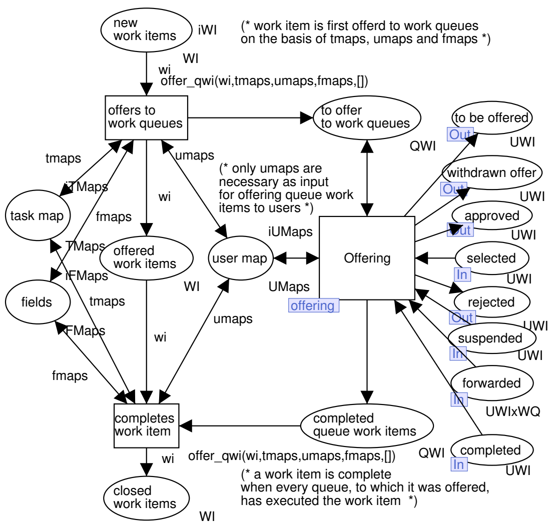


Fig. 4. Staffware - Work Distribution

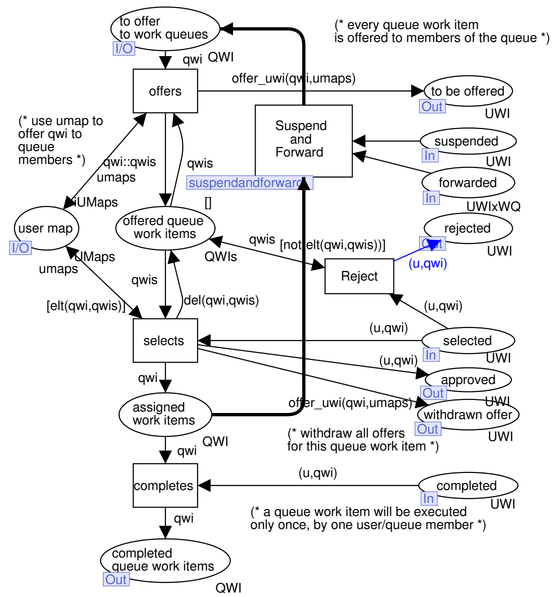


Fig. 5. Staffware - Offering

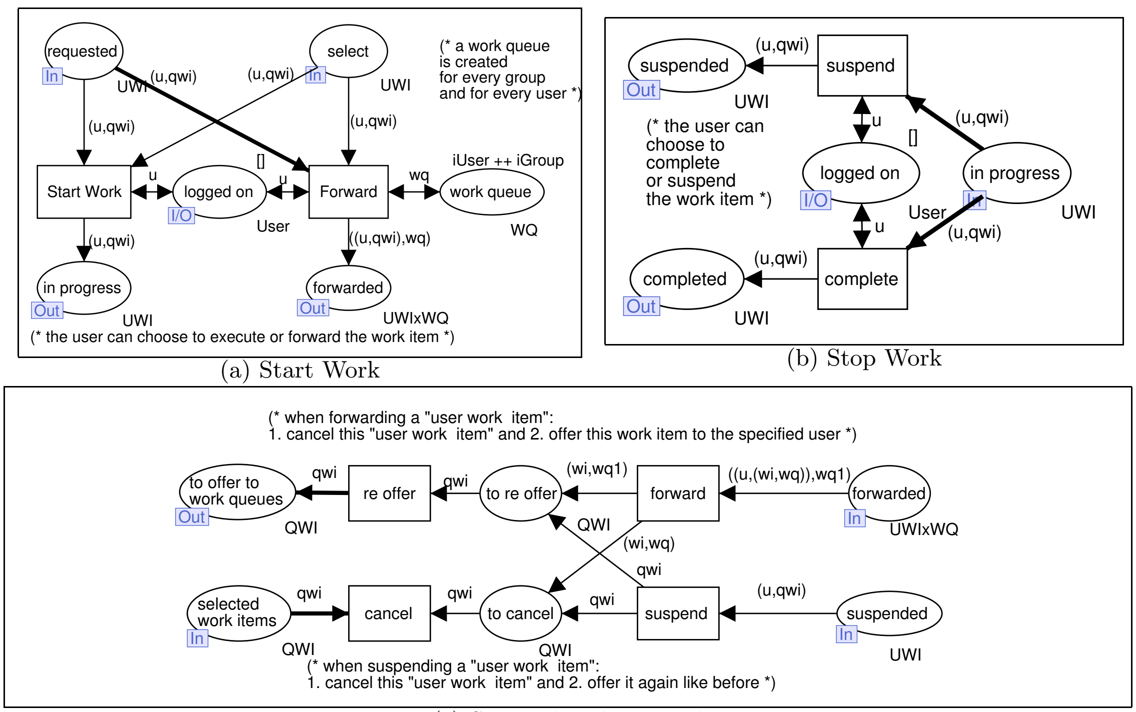
Resource Allocation. We have changed the allocation function *offer* to represent the allocation algorithm in Staffware. Just like the Basic Model, Staffware searches for possible users based on *roles* and *groups*. In addition to this, in Staffware users can be allocated by their *user-names* and *data fields* in the process. In *user maps* we use the fields reserved for groups when we want to specify the allocation for user-names. We do this by assuming that every user-name refers to a group with only one member – the specified user. The second addition in Staffware refers to the fact that resource allocation can be also done at "run-time" on the basis of *data fields* in *task maps* (cf. Table 6). This kind of allocation is referred to as a dynamic work allocation: the allocation is executed based on the current value of the field during the process execution. Staffware assumes that the value of the assigned data field is a group name, a role name or a user name.

If the allocation refers to group names the work item is allocated to *group work queues*. In an allocation that refers to user names or roles the work item is allocated to *personal work queues*.

Table 6. Staffware - Dynamic Work Allocation

color Field = string;
color Fields = list Field;
color FValue = string;
color FMap = product Field*FValue;
color FMaps = list FMap;
color TMap = product Task * Users * Roles * Groups * Fields;

Forward and Suspend. Staffware allows for *forward* and *suspend*, i.e., a user can put a work item on hold (suspend) or forward it to another user. Forwarding and suspending of work items adds two messages that are exchanged between Work Distribution and Work Lists modules in Staffware model. Figures 4 and 5 show two new places – *forward* and *suspend*. These two new actions are triggered in the *Work List* module by the user. Figure 6(a) shows that in the module Start Work the user can choose to *select* or *forward* (to another work queue) the work item. Figure 6(b) shows that in the module Stop Work the user can choose to *complete* or *suspend* the work item. The Work Distribution module handles forwarding and suspending in the Offering to Users submodule. Figure 6(c) shows how: (1) in case of forwarding the work item is automatically *cancelled* for the current work queue and *offered* to the new work queue, and (2) in case of suspending the work item is *cancelled* for the current work queue and *re-offered* as a new work item.



(a) Start Work

(b) Stop Work

(c) Suspend and Forward

Fig. 6. Staffware - Forward and Suspend

FileNet Like Staffware, FileNet is a widely used traditional process-oriented workflow management system. In this section we will describe the FileNet CPN model that we develop using the Basic Model as a starting reference model.

Organization. The organizational model in FileNet does not allow for modelling *roles*. Table 7 shows which color sets are added to the CPN model to represent the two types of organizational groups:

1. Administrators define *work queues* (color set *WQ*) and assign their members in the FileNet system. A work queue is valid for every process (workflow) definition.
2. Process modelers can define *workflow groups* (color set *WG*) in every process model. Thus, a workflow group is valid only in the process (workflow) model in which it is defined. While executing a task of a process definition, users have the possibility to change the structure of workflow groups that are defined in that process. Workflow groups represent teams in FileNet.

Queues. *Work queues* and *personal queues* are two types of pools from which users can select and execute work items. A work queue can have a number of members while a personal queue has only one member. When a work item is offered to a queue one of the queue members can select and execute the work item. Table 7 shows which color sets are added to the FileNet model to represent queues. FileNet distributes work in two levels using queues. First, the work item is offered to queues as a *queue work item* (color set *QWI*). Second, the queue work item is offered to the members of the queue as a *user work item* (color set *UWI*).

Table 7. FileNet - "Queue" Color Sets

color Q = string;
color WQ = Q; (color WQs = list WQ;)
color WG = Q; (color WGs = list WG;)
color UMap = product User * WGs* WQs;
color QWI = product WI * Q;
color UWI = product User * QWI;

Figures 7 and 8 show that the model of the two-level work distribution in FileNet is similar to the Staffware model. For more detailed description of this kind of distribution we refer the reader to the Staffware description in Section 3.1.

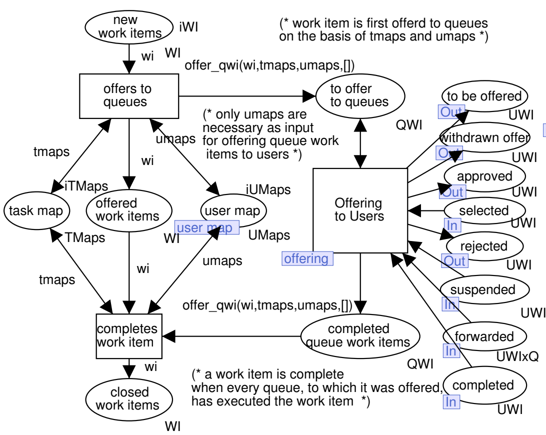


Fig. 7. FileNet - Work Distribution

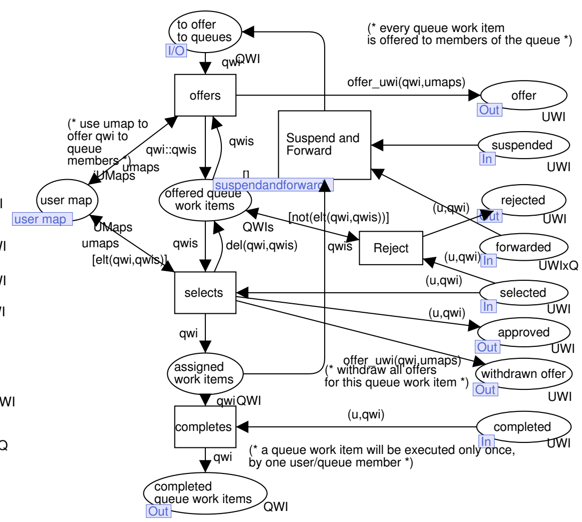


Fig. 8. FileNet - Offering

Resource Allocation. FileNet allocates work using a work queue or a list of participants. Users and workflow groups can be entries of a list of participants. In the FileNet model task maps are defined as a combination of a task, a list of work groups, and a work queue (*color TMap = product Task * WGs * WQ;*). It is necessary to highlight that, when defining the input value for a task map, only work queue or a list of workflow groups should be initiated.

If the task is allocated to a work queue FileNet offers the work item to the work queue. If the task is allocated to a list of participants then it is offered to personal queues of all users that are listed as participants or are members in workflow groups that are listed. Allocation via participants is introduced to support team work in FileNet, via so-called "process voting" [44].

Forward and Suspend. Users can forward and suspend work items while working with FileNet. In the model of FileNet we use the same adjustments as in the Staffware model to implement forwarding and suspension: modules *Start Work* and *Stop Work* are changed and sub-module *Suspend and Forward* is added in the Work Distribution module. For detailed description we refer the reader to Staffware description and Figure 6 in this section.

FLOWer FLOWer is a case handling system. Case handling systems differ in their perspective from traditional process-oriented workflow management systems because they focus on the case, instead of the process [3, 9]. The user is offered the whole case by offering all available work items from the case and s(he) does not have to follow the predefined order of tasks in the process definition. When modelling FLOWer, we upgraded the Basic Model in such a way that (1) it supports *case-handling distribution* (instead of the process-oriented one), (2) it enables the complex *authorization* and *distribution* specifications that FLOWer has, and (3) it enables users to *execute*, *open*, *skip* and *redo* work items.

Authorization and Distribution Rights. When designing the process it is necessary to define process-specific roles and to assign each role authorization rights for tasks in the process. The authorization rights determine what users *can do*. Information about the authorization is stored in task maps (i.e., *color TMap = product Task * Role * CaseType*). Distribution rights define what users *should do*. These rights are used to model the organizational structure and to assign authorization rights from the process definitions to users. *Function profiles* and *work profiles* define distribution rights. *Function profile* is a set of authorization roles from different process definitions. *Work profiles* assign function profile(s) to users and they can be used to structure organization into groups, departments or units.

Case Handling. Table 8 shows which color sets are used to model FLOWer as a case-handling system. Every process definition in FLOWer is referred to as a *case type*. One *case* represents an instance of a case type and is identified by the case identification (color set *CaseID*). Figures 9 and 10 show that FLOWer distributes work in two levels:

1. The case is distributed to users (color set *UCase*). Only one user can select and open the case at one moment. Figure 9 shows that in the FLOWer Work Distribution module a *case* becomes the object of distribution instead of a *work item*.
2. The selected case is opened for the user in the *Case Distribution* sub-module. Work items from the case are offered to the user, based on the authorization and distribution rules. The user can execute, open, skip and redo work items from the selected case. The *Case Distribution* sub-module (cf. Figure 12) is described in the remainder of this section.

Table 8. FLOWer - Basic Color Sets

color CaseType = string;
color Tasks = list Task;
color Process = product CaseType * Tasks;
color CaseID = INT;
color Case = product CaseID* CaseType;
color WI = product Case * Task;
color UCase = product User * Case;

Open, Execute, Skip and Redo. Although in a case type tasks in the process definition have the execution order that is suggested to the user, (s)he is not obliged to follow it. When working with an open case in FLOWer, users can: (1) *Execute* the work item which is next in the process definition; (2) *Open* for execution a work item that is still not ready for execution according to

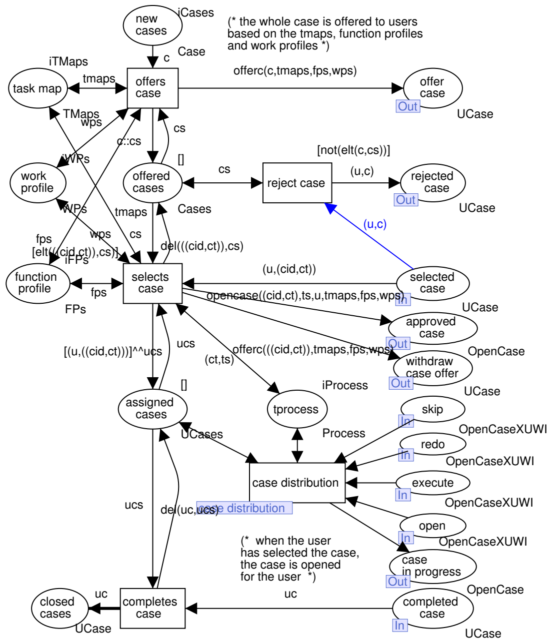


Fig. 9. FLOWer - Work Distribution

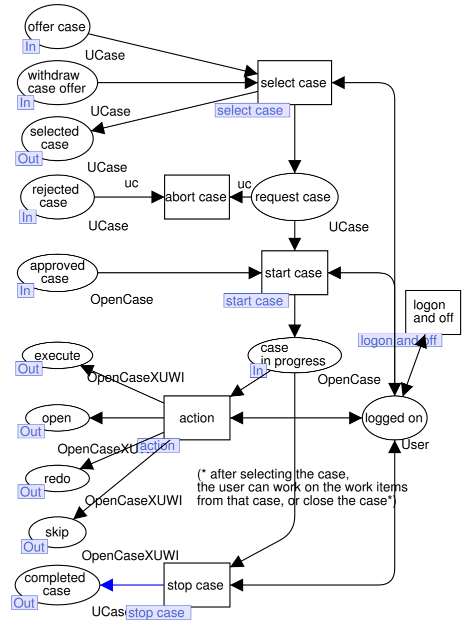


Fig. 10. FLOWer - Work Lists

the process definition; (3) *Skip* a work item by choosing not to execute the work item which is next according to the process definition, or (4) *Redo* a work item by executing again a work item which has already been executed. Figures 9 and 10 show that four new places are added to the model to represent these four actions. In order to implement these possibilities in the FLOWer model it is necessary store the information about the *case state*, i.e., about the work items that are (1) *waiting* to be enabled, (2) *active* (i.e. they are enabled and can be executed), (3) *finished* (executed), and (4) *skipped*. Thus, an open case (*color OpenCase = product UCase*CaseState;*) stores information about the case state (*color CaseState = product WIs*WIs*WIs*WIs*) in four lists of work items (waiting, active, finished and skipped).

Figure 11 shows the sub-module *Action* (in the FLOWer Work List module) where we model how user performs the actions to execute, open, skip and redo work items. In FLOWer users can choose work items on their own discretion but (due to the complexity of the model) we model this selection as a random function. When the user wants to:

1. **open** an item s(he) selects a work item from the list of *waiting items*;
2. **execute** an item s(he) selects a work item from the list of *active items*;
3. **skip** an item s(he) selects a work item from the lists of *waiting and active items*;
4. **redo** an item s(he) selects a work item from the lists of *finished and skipped items*.

Each of the four actions the user performs changes the state of the open case. For example, opening a work item transfers it to the state active (and, therefore, it is transferred to the list of active items). Figure 12 shows that the Case Distribution module responses in different ways (functions *execute_item*, *open_item*, *skip_item*, and *redo_item*) when each of the four actions is performed. When an action is performed over a work item, the state of the work item changes, as shown in Table 9. The four actions are listed in the column "action". The column "work item becomes" shows how the action changes state of the work item. It often happens that an action performed on a selected work item also affects other items and this is described in the column "side effects".

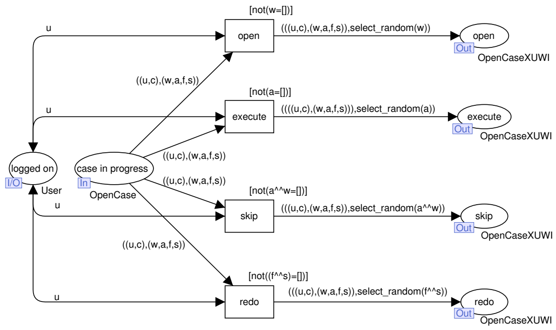


Fig. 11. FLOWer - Action

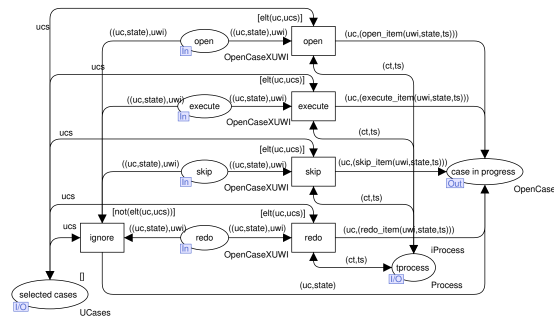


Fig. 12. FLOWer - Case Distribution

Table 9. FLOWer - The Four Actions

action	work item becomes	side effects
open	*active*	Items from *waiting* that preceded become *skipped*.
execute	*finished*	The direct successors in *waiting* become *active*.
skip	*skipped*	Items from *waiting* that preceded become *skipped*. The direct successors in *waiting* become *active*.
redo	*active*	Subsequent items from (*skipped* & *finished*) become *waiting*.

3.2 Resource Patterns

Instead of extending the Basic Model for more systems, we also looked at a more systematic way of work distribution. As indicated, similar concepts are often named and presented differently in different workflow management systems. Therefore, it is interesting to define these concepts in a system-independent manner. We have used 43 documented *resource patterns* [49, 51]. These patterns can be used as representative examples for analyzing, evaluating and comparing different workflow management systems with respect to work distribution. Resource patterns are grouped into a number of categories: *creation patterns*, *push patterns*, *pull patterns*, *detour patterns*, *auto-start patterns*, *visibility patterns*, and *multiple resource patterns*. Each of these patterns can be modeled in terms of a CPN model. We cannot elaborate on each of the patterns, but we will discuss four to illustrate our work. None of the systems supports *Pattern 16: Round Robin*, *Pattern 17: Shortest Queue*, *Pattern 38: Piled Execution*, and *Pattern 39: Chained Execution*. Patterns 16 and 17 are push patterns, i.e., they push work to a specific user. As auto-start patterns, patterns 38 and 39 enable the automatic start of the execution of the next work item once the previous has been completed.

Round Robin and Shortest Queue. Round Robin and Shortest Queue push the work item to one user of all users that qualify. Round Robin allocates work on a cyclic basis and Shortest Queue to the user with the shortest queue. This implies that each user has a counter to: (1) count the sequence of allocations in Round Robin and (2) count the number of pending work items in Shortest Queue. As Figures 13 and 14 show, these two patterns are implemented in a similar way in the Work Distribution Module. The required changes to the Basic Model are minimal. A counter is introduced for each user (token in place *available*) and functions *round_robin* and *shortest_queue* are used to select one user from the set of possible users based on these counters. Similarly, most of the other patterns can be realized quite easily. The model for Shortest Queue has an additional connection (two *arcs*) that updates the counter when a work item is completed to remove it from the queue.

Piled and Chained Execution. Piled and Chained Execution are auto-start patterns, i.e., when the user completes execution of current work item the next work item starts automatically. When

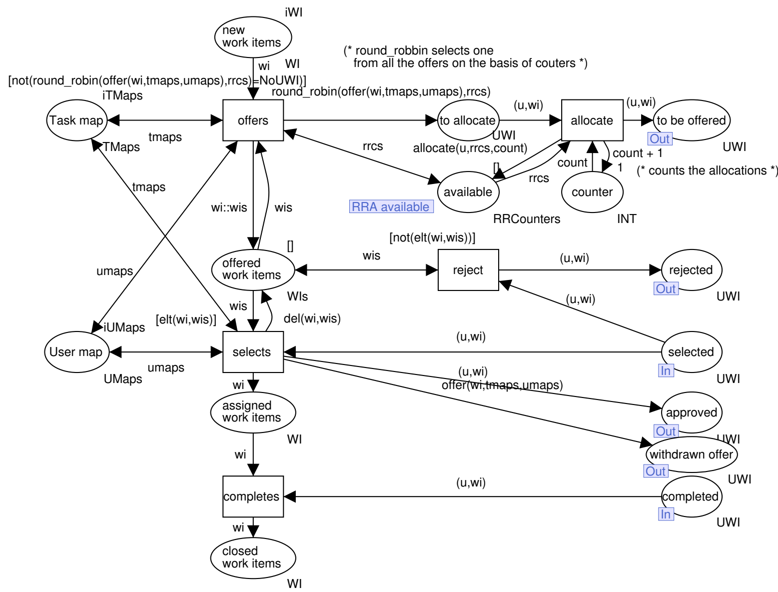


Fig. 13. Push Patterns - Round Robin

working in Chained Execution, the next work item will be for the same *case* as the completed one (the user works on different tasks for one case). Similarly, if the user works in Piled Execution the next work item will be for the same *task* as the completed one (the user works on one task for different cases). Figures 15 and 16 show how Piled and Chained Execution are implemented similarly in the Stop Work sub-module. Users can choose to work in the normal mode or in the auto-start mode (which is represented by the token in place *special mode*). The function *select* is implemented to search for the next work item for the same: (1) *task* in Piled Execution and (2) *case* in Chained Execution.

4 Related Work

Since the early nineties workflow technology has matured [26] and several textbooks have been published, e.g., [5, 20, 30, 37, 41]. During this period many languages for modelling workflows have been proposed, i.e., languages ranging from generic Petri-net-based languages to tailor-made domain-specific languages. The Workflow Management Coalition (WfMC) has tried to standardize workflow languages since 1994 but failed to do so [25]. XPDL, the language proposed by the WfMC, has semantic problems [2] and is rarely used. In a way BPEL [11] succeeded in doing what the WfMC was aiming at. However, both BPEL and XPDL focus on the control-flow rather than the resource perspective.

Despite the central role that resources play in workflow management systems, there is a surprisingly small body of research into resource and organizational modelling in the workflow context [1, 35]. In early work, Bussler and Jablonski [15] identified a number of shortcomings of workflow management systems when modelling organizational and policy issues. In subsequent work [30], they presented one of the first broad attempts to model the various perspectives of workflow management systems in an integrated manner including detailed consideration of the organizational/resource view.

One line of research into resource modelling and enactment in a workflow context has focused on the characterization of resource managers that can manage organizational resources and enforce resource policies. In [19], the design of a resource manager is presented for a workflow management system. This work includes a high level resource model together with proposals for resource definition, query and policy languages. Similarly, in [36], an abstract resource model is presented in the

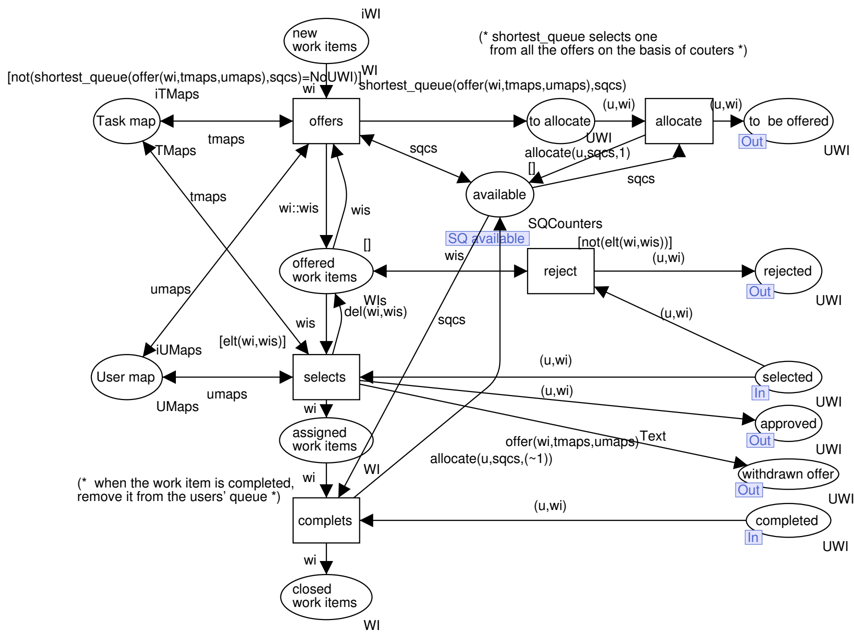


Fig. 14. Push Patterns - Shortest Queue

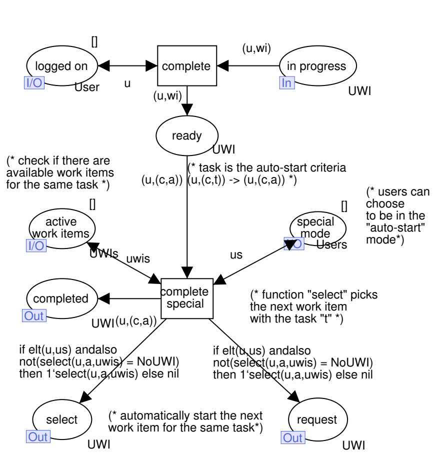


Fig. 15. Piled Execution - Stop Work

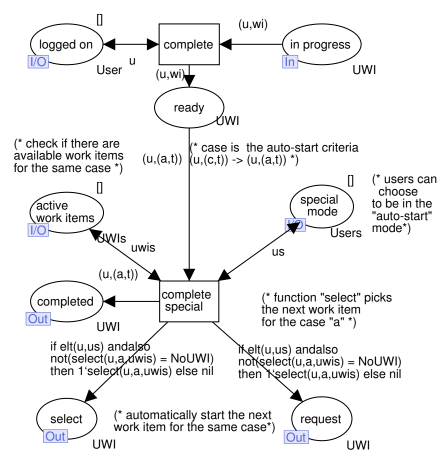


Fig. 16. Chained Execution - Stop Work

context of a workflow management system although the focus is more on the efficient management of resources in a workflow context than the specific ways in which work is allocated to them. In [29], a proposal is presented for handling resource policies in a workflow context. Three types of policy – qualification, requirement and substitution – are described together with a means for efficiently implementing them when allocating resources to activities.

Another area of investigation has been into ensuring that only appropriate users are selected to execute a given work item. The RBAC (Role-Based Access Control) model [23] presents an approach for doing this. RBAC models are effective but they tend to focus on security considerations and neglect other organizational aspects such as resource availability.

Several researchers have developed meta-models, i.e., object models describing the relation between workflow concepts, which include work allocation aspects, cf. [8, 40–42, 48]. However, these meta-models tend to focus on the structural description of resource properties and typically do not describe the dynamics aspects of work distribution.

Flexibility has been a research topic in workflow literature since the late nineties [4, 7, 9, 10, 16, 22, 28, 33, 45, 47, 56]. Flexibility triggers all kinds of interesting research questions, e.g., if a process changes how this should influence the running cases? [7]. Examples of qualitative analysis of flexibility of workflow management system can be found in [13] and [27]. One way of allowing for more flexibility is to use the case handling concept as defined in [3, 9]. FLOWer [12, 43] can be seen as a reference implementation of the case handling concept. Therefore, its resource perspective was modeled in this paper. Besides FLOWer there are few other case handling tools: E.C.H.O. (Electronic Case-Handling for Offices), a predecessor of FLOWer, the Staffware Case Handler [53] and the COSA Activity Manager [52], both based on the generic solution of BPi [14], Vectus [38, 39], and the open-source system con:cern (http://con-cern.org/).

The work reported in this paper can be seen as an extension of the *workflow patterns initiative* (cf. www.workflowpatterns.com). Besides a variety of control-flow [6] and data [50] patterns, 43 resource patterns [49, 51] have been defined. This paper complements the resource patterns [49, 51] by providing executable models for work distribution mechanisms.

5 Discussion

Workflow management systems should provide flexible work distribution mechanisms for users. This will increase the work satisfaction of users and improve their ability to deal with unpredictable situations at work. Therefore, work distribution is investigated as the functionality provided for the user – workflow management systems are tested in laboratories [49, 51] or observed (in empirical research) in companies [13]. This kind of research observes systems *externally* and provides insights into *what* systems do. Analysis of the systems form an *internal* perspective can explain *how* systems provide for different work distribution mechanisms. Due to the complexity of workflow management systems as software products, internal analysis starts with developing a model of the system. Unlike statical models (e.g., UML models), dynamical models (e.g., CPN models) provide for interactive investigation of work distribution as a dynamic feature. CPN models can be used for the investigation of both *what* systems do and *how* they do it.

Workflow management systems often provide for different features or use different naming for the same features. Investigation of work distribution requires analysis, evaluation and comparison of models of several systems. In order for models of different systems to be comparable, it is necessary to start with developing a common framework – a *reference model*. We have developed the Basic Model as a reference model for work distribution mechanisms in workflow management system. The models of Staffware, FileNet, FLOWer and resource patterns are comparable because all models are developed as upgrades of a reference model (the Basic Model).

The model of a workflow system is structured into two modules (sub-models). The Work Distribution module represents the core of the system which is often called the "workflow engine". The Work Lists module represents the so-called "work list handler" of a workflow system and it serves as an interface between the workflow engine and users. The interface between the two modules (i.e., the messages that are exchanged between them) should contain as little information as possible about the way work items are managed in modules. The Work Lists module should abstract form the way the work items are created, allocated and offered in the Work Distribution module. The reverse also holds: how work items are actually processed by users is implemented in the Work Lists module. Once a proper interface is defined, it is easy to implement various ways of work distribution by adding/removing simple features in either one of the modules. For example, push patterns (Round Robin and Shortest Queue) are implemented in the Work Distribution module and auto-start resource patterns (Chained and Piled Execution) in the Work Lists module.

The flexibility of a work distribution mechanism determines what users can do with work items. In the Basic Module the user follows a fixed predefined path by only executing work items. Users of Staffware and FileNet models have the freedom to forward and suspend work. In FLOWer, as the most flexible system, users have four possibilities: execute, open, skip and redo work. Our models show that a more complex model work distribution adds messages between the Work Distribution and Work Lists modules. These new messages correspond to new actions (operations) that users can do.

Both the system-based and the patterns-based CPN models showed that one of the core elements of work distribution is the “allocation algorithm”. This algorithm includes the “rules” for work distribution. It is implemented in the Work Distribution module as the function *offer*, which allocates work based on (1) new work items, (2) process definition, and the (3) organizational model. This function should be analyzed further in order to discover an advanced allocation algorithm, which should be more configurable and less system-dependent.

Every system has its own method of modelling organizational structure. Staffware models groups and roles. In FileNet the organizational model includes groups of users and teams, but does not model roles. FLOWer groups users based on a hierarchy of roles, function profiles and work profiles. Thus, each of the system offers a unique predefined type of the organizational structure. Since every allocation mechanism uses elements of the organizational model, limitations of the organizational model can have a negative impact on the work distribution in the system. For example, because in Staffware one role can be assigned to only one user, it is not be possible to offer a work item to a set of “call center operator”-s.

Each of the three models of workflow systems distributes work using two hierarchy levels. Staffware and FileNet use two levels of work distribution: queue work items are first distributed to work queues, and then work items are distributed within each of the work queues. The FLOWer model starts with the case distribution and then distributes work items of the whole case. Although all three systems distribute work at two levels, they have unique *distribution algorithms* (the set of allocation rules implemented in the function *offer*) and *objects of distribution* (work items, queue work items, cases).

Models of resource patterns [49, 51] show that push patterns (Round Robin and Shortest Queue) can be implemented “on top of” the pull mechanism, as a filter. Once the pull mechanism determines the set of allocated users, the “push” allocation function extracts only one user from this set. Auto-start patterns turned out to be remarkable straightforward to model, triggering the question why this is not supported by systems like Staffware and FileNet (FLOWer supports the Chained Execution in a limited form).

6 Conclusions

This paper focused on the *resource perspective*, i.e., the way workflow management systems distribute work based on the structure of the organization and capabilities/qualifications of people. To understand work distribution, we used the CPN language and CPN Tools to model and analyze different work distribution mechanisms. To serve as a reference model, we provided a model that can be seen as the “greatest common denominator” of existing workflow management systems. This model was upgraded for models of three workflow management systems – Staffware, FileNet, and FLOWer. Although the reference model already captures many of the *resource patterns*, we also modelled four more advanced patterns by extending the reference model. In contrast to existing research that mainly uses static models (e.g., UML class diagrams), we focused on the dynamics of work distribution. Our experiences revealed that it is relatively easy to model and analyze the workflow systems and resource patterns using CPN Tools. This suggests that CPN language and the basic CPN model are a good basis for future research. We plan to test completely new ways of work distribution using the approach presented in this paper. The goal is to design and implement distribution mechanisms that overcome the limitations of existing systems. An important ingredient will be to use insights from socio-technical design [13, 17, 21, 55] as mentioned in the introduction.

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