Modeling Human Actors in an Intelligent Automated Warehouse

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Abstract. Warehouse automation has progressed at a rapid pace over the last decade. While the tendency has been to implement fully automated solutions, most warehouses today exist as a mixture of manually operated and fully automated material handling sections. In such a hybrid warehouse, men and machines move around goods in between sections in order to retrieve, transport and stack goods according to their nature and quantity. The biggest challenge in hybrid warehouses is to optimize the alignment of manual and automatic processes in order to improve the flow of materials between storage areas and distribution centers. Integrating individuals as human actors in an automation solution is not straightforward due to unpredictable human behavior. In this paper, we will investigate how we can model the characteristics of human actors within an automation solution and how software systems can unify human actors with automated business processes to coordinate both as first class entities for logistics activities within a hybrid warehouse.

1 Introduction

Warehouses come in different sizes and shapes, but they are all used for the receipt, storage, retrieval and timely dispatch of a variety of goods. To ensure that productivity targets are met and to maximize the manufacturing floor space, warehouse managers often rely for repetitive material handling processes on automatic guided vehicles (AGVs) [1], automated storage and retrieval systems, and on conveyor and sorting systems. For other tasks that require certain creativity, human actors are indispensable. In hybrid warehouses, manual and automated material handling processes are intertwined.

Within a hybrid warehouse, it is possible that for a single purchase order, goods from different storage areas need to be collected and consolidated. Fig. 1 shows a manual task that is assigned to a human actor, in this case an individual driving a fork lift to transport goods to their designated area. Fig. 2 shows an example of an automated storage and retrieval system. To ensure a smooth product flow within the warehouse, manual and automated material handling processes need to be properly aligned. However, for warehouse managers it is not evident to integrate human actors into an automation process, because human behavior is far from being predictable and people make mistakes more easily. To circumvent problems that may arise during the harmonization or integration of human actors within automated warehouse systems,

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MANUAL AND AUTOMATED MATERIAL HANDLING PROCESSES

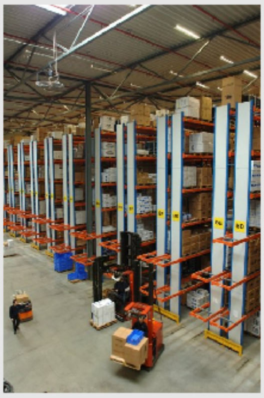

Fig. 1. Human-driven material handling

Fig. 2. Automated storage and retrieval

warehouse managers often decouple the warehouse into a manually operated and a fully automated storage area. Because automated and manual material handling processes are fundamentally different, their supporting software systems - the Warehouse Management System (WMS) - are often developed with a different background. In many cases both types of warehouse management systems independently do location allocation and transport planning [2] for the goods within their area. Integration is often limited to a high-level coupling between both systems at the Enterprise Resource Planning (ERP) level. Because synchronizing manual and automated systems is hard, hybrid warehouses suffer from significant inefficiencies and suboptimal throughput of the hybrid warehouse due to the extra buffers that are often introduced as a workaround to deal with this performance loss.

A global approach to an intelligent hybrid warehouse where manual and automated processes are considered and optimized as a whole could lead to an improvement of the Total Cost of Ownership (TCO) of a hybrid warehouse. The fundamental problem that needs to be addressed to achieve this goal is the lack of modeling and software support to incorporate human actors as first class entities within a warehouse automation process. In this paper we will first investigate how we can model human behavior by identifying the characteristics of a human actor within logistics systems, which tasks human actors fulfill and which properties are of importance. Secondly, we will investigate how we can explicitly model expectation patterns for more complex jobs in order to address the possibility of and the response to unexpected human behavior. A last aspect we address in this paper is a mapping of this human behavior model on a software architecture to fully support human actors within a hybrid warehouse management system.

In section 2, we discuss the role and characteristics of a human actor in a hybrid warehouse. We present our modeling support for human actors in a material handling process in section 3. We discuss our initial mapping of this model onto a software system in section 4. An overview of our contributions, the conclusion and opportunities for future work are presented in section 5.

2 Human Actors in a Hybrid Warehouse

In a hybrid warehouse, some of the material handling processes can be automated while others have to be carried out manually. For both types of activities a Warehouse Management System will assign a specific logic [3] to the various combinations of order, items, quantities and locations. Such a logic either optimizes space utilization (*e.g. pick-to-clear logic*), number of movements (*e.g. fewest locations logic*), travel times (*e.g. nearest location logic*), etc. For any of these transportation logics, the consolidation of a customer order would result in a sequence of transport operations of an amount of products at a given location. For larger orders, multiple human actors and automated systems can work on the same task list, which may require some synchronization between the different transport activities. But while automated storage and retrieval systems are capable of storing and consolidating goods at a given and fixed rate, the rate at which human actors can transfer goods is less predictable. In brief, integrating human actors in a hybrid warehouse raises a few concerns:

- **Choice** versus **Time Constraints:** Human actors have some autonomy to handle more complex jobs, because some decisions are better made by people due to their flexibility, intuition and wisdom. To reduce the duration variability of such jobs, we need to balance the number of options given to human actors and the processing time to complete the job.
- **Indeterminism:** Human actors can behave in unforeseen ways, such as performing tasks out of order according to the sequence of tasks they were assigned. The challenge here is to monitor the overall effect of human tasks and to take decisions whenever human actors do not behave as expected.
- **Roles** and **Responsibilities:** The role and responsibilities of human actors participating in a process help to define interchangeable human resources. We must also describe how the different human actors can collaborate and synchronize with each other while the material handling process progresses.

2.1 Choice versus Time Constraints

Human actors can introduce unexpected delays in the material handling process. The main reason is that human actors usually perform their tasks slower than automated facilities, but also because they make mistakes more easily. For example, a fork lift driver may waste time if he needs to go and find goods mistakenly placed elsewhere if a given pellet turns out to have fewer items than expected. However, one cannot automate every single task, either because they are too complex to automate, or they require human expertise or intuition to handle a particular product. The main concern here is to find a way to minimize the human impact on the overall processing time. A first alienating approach transforms human actors into robots: (1) reduce the number of possible actions to a minimum; (2) make sure that human actors do not have to take any decision and that they always know what to do next. Unfortunately, this would result in an inflexible sequence of tasks to be executed within a fixed time frame without the ability for an operator to solve problems (e.g. broken vehicles, missing items or other unexpected delays) without jeopardizing the order of the task list.

Instead, to maintain a certain level of job satisfaction, we want to give human actors some autonomy to make choices and take decisions, and investigate how dynamic decision models [4] to help estimate delays in order to take appropriate actions when deadlines expire, such as exception handling, sending reminders. Helping human actors to prioritize their task is another approach to reduce these delays. In brief, we have to find a balance between the autonomy of human actors making choices and the delays this autonomy brings.

2.2 Indeterminism

Autonomy does not only bring delay, it also brings indeterminism. Indeterminism means that given the same initial conditions a human actor does not always behave in the same way. He may perform unexpected actions or carry out actions in an unexpected order. For example, some operators may cancel a picking job if a pellet contains fewer items than advertised, while others may suspend the job, replenish the good from a reserve storage location, and then resume the original job with picking the number of items needed. Since we want to give autonomy to the human actors, we cannot prevent this indeterminism at all times. However, we can try to prevent it as much as possible, and try to compensate its effects when we cannot avoid it.

Preventing indeterminism means that we must describe the allowed degrees of freedom a human operator has to handle a batch of tasks. As a result, we must monitor such tasks assigned to human actors and detect approaching deadlines and expired deadlines. Reminders can be sent when a deadline is approaching. Escalation [5] can be triggered when a deadline expires or when an error or exception occurs. Escalation means that a person with a higher level of responsibility is notified that a deadline expired. Escalation may also transfer the responsibility for a task to another operator.

2.3 Roles and Responsibilities

If we want to integrate human actors in automated business processes we must be able to define the roles and the responsibilities of each actor that participates in a process. A high-level overview of material handling activities in a warehouse business process is shown in Fig. 3. Some of these activities can be carried out by both automated systems and by individuals. Roles and responsibilities are assigned to groups for each of these material handling activities. A business process usually involves several participants, some of which may be human actors, others can be automated systems. For example, in a warehouse, there may be groups for truck drivers, automatic guided vehicles, fork lift drivers, packers, conveyors, order managers, automated storage and retrieval systems, etc. Additionally to the roles of their respective groups, human actors can be granted other roles to help define interchangeability of human and systems resources within a warehouse business process.

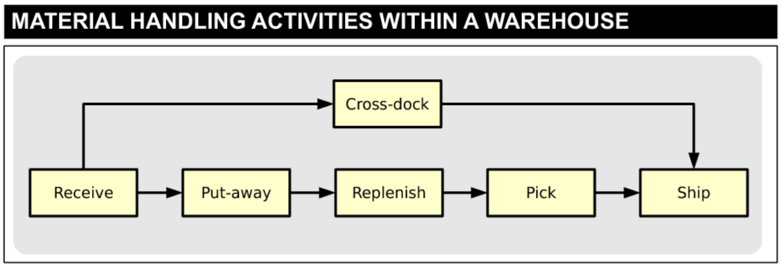

Fig. 3. Simplified schematic overview of material handling activities

3 Modeling Human Behavior and Expectation Patterns

In recent years many researchers have proposed various task models [6-8] to describe human activities and related aspects for various domains. Our focus is more oriented to business process modeling. Although there are many business modeling methods, no well established modeling standard is available in the area of hybrid warehouses. Our aim is to design a model that can be easily mapped onto business process standardization efforts in the area of integrating people in service oriented architectures. The basic concepts of our model are depicted in a schematic way in Fig. 4.

3.1 Human Transportation Tasks and Activities

Human transportation tasks (picking, replenishing, putting away, etc.) within a hybrid warehouse have a life cycle with states that are independent of the logic that the WMS uses to decide exactly which location to pick from, replenish from/to, and putaway to, and in what sequence these tasks should occur. The life-cycle can be described with the following states:

- **Unclaimed:** The transportation task is available for designation
- **Claimed:** The transportation task is assigned to an individual
- **Started:** The transportation task is in progress
- **Finished:** The transportation task has finished
- **Error:** The individual provided fault data and failed the task

In fact, these states are typical for transportation tasks for both humans and automated systems. However, humans are often also involved in other activities that cannot be classified as transportation tasks which have been fully planned in advance:

- **Wait** or **Delay tasks:** This task represents a lack of activity. One has to wait until a certain condition with respect to the product flow is met. This task can be unplanned or planned. For example, a truck driver may have to wait for a confirmation of an order manager. Finding a realistic distribution of the time of delay of this task is fundamental.
- **Off-tasks:** Off-tasks are typically human and are not related to the product flow or the material handling processes. Such tasks may include having a coffee, responding to a telephone call, going to the bath room, etc. It is hard to estimate if and

when these tasks take place, because their occurrence is often unknown in advance, but they can be modeled as delay tasks with possible zero delay.

- **Escalation tasks:** This task does relate to the product flow. If a start or a completion deadline of an ordinary transportation is missed or an error occurs, this may trigger one or more escalation actions that, for example, reassign the transportation task to another participant or handle the exception.
- **Compensation tasks:** This task undoes the effects of partially completed activities to ensure that an order is either fully completed or not carried out at all.

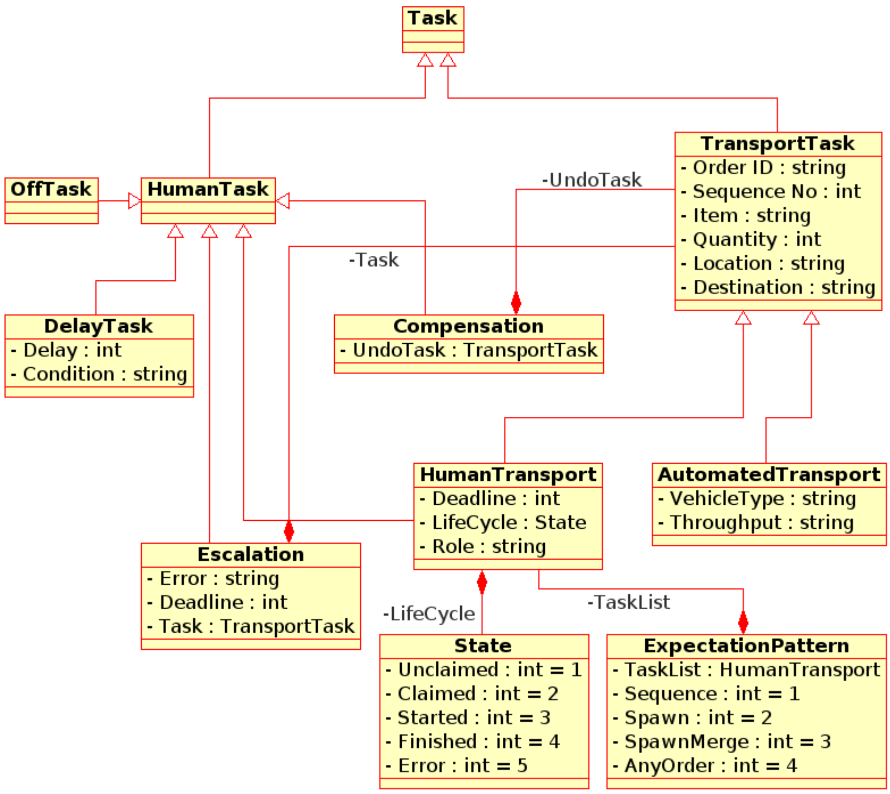

Fig. 4. UML class diagram of the basic concepts of the model

Being able to accurately represent them in a human behavior model is fundamental when manual and automated processes are considered and optimized as a whole. For transportation tasks, we will focus on order picking because a warehouse generally has more outbound transactions than inbound transactions, so being able to quickly and accurately process customer orders is essential to increase customer satisfaction. However, conceptually there is not much difference with the other transport tasks (putting, away, replenishing, cross-docking, etc.).

3.2 Defining and Modeling Expectation Patterns

People are capable of juggling many tasks at once. This flexible behavior of humans is an advantage for hybrid warehouses, but the disadvantage of multitasking is that people are not interchangeable resources the way automatic guided vehicles and automated storage and retrieval systems are. When humans are in control of certain material handling processes, a single individual can be assigned a set of tasks, or multiple individuals can work in parallel on a single task. The order in which these tasks are executed can matter if we want to reduce delays in the material handling process. In order to model how a collection of transportation tasks are expected to be executed and synchronized, we need to formalize how one task can relate to another. We will define these structured tasks with expectation patterns that describe how a Warehouse Management System would expect a collection of tasks to be executed (see Fig. 5):

- **Sequence:** A *Sequence* pattern expresses a collection of tasks that is to be performed sequentially and with a specific order.
- **Spawn:** All transportation tasks are executed concurrently. The *Spawn* pattern completes as soon as all the tasks have been scheduled for execution.
- **Spawn-Merge:** All tasks are executed concurrently with barrier synchronization to ensure that tasks are not executed out of order by different participants. I.e. the *Spawn-Merge* pattern completes if all tasks have completed.
- **Any-Order:** The *Any-Order* pattern is used when the order of the tasks is of no importance as long as they do not overlap. The *Any-Order* pattern completes when all tasks have completed.

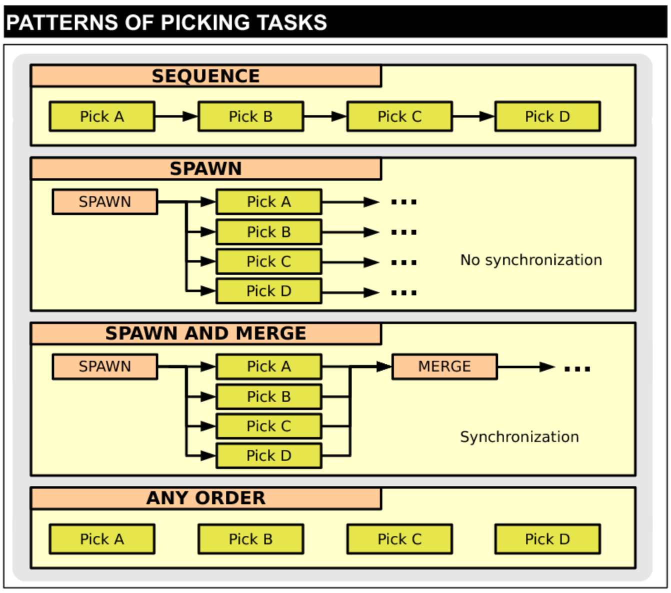

Fig. 5. Modeling expectation patterns for picking tasks

Obviously these patterns can be combined. For example, the *Spawn* and *Spawn-Merge* patterns can be combined to define tasks with partial synchronization. In a following section, we will provide an example how this could be used to align manually operated and fully automated transportation tasks. However, the same patterns can be used to model constraints between different customer orders. For example, if different orders require the same type of product, and relevant pellets can only be accessed by one human fork lift operator at a time, then it is best to describe these picking tasks with the *Any Order* pattern, so that these tasks are not executed in parallel. Explicitly modeling these constraints helps to identify delays in the workflow more easily. Other control flow constructs, such as *If-Then-Else* and *Iteration* (not shown in Fig. 5) are used to support conditional execution of tasks and repeated execution of a task in a structured loop.

4 Example Scenario and Implementation

To incorporate human actors as first class entities in an automation solution, it is important that already during the modeling of the automation process the role of the human actor can be correctly described. See Fig. 6 for an example scenario of aligning human and automated transportation tasks. Each customer order is translated into a set of transportation tasks (A, B, C, D, E and F) that are either carried out by either human or automated operators. Each human task is carried out by someone with a certain role or responsibility. Human tasks B and C could be collecting in parallel smaller items that are combined into a *Spawn-Merge* pattern, which is synchronized at task F that could be delivering these items at a designated drop zone for shipping to the client. This pattern is combined with tasks A and F into a *Sequence* pattern. Because this sequence of tasks is aligned with a sequence of automated transportation tasks D and E (of which the completion time can be accurately estimated), the last human task F in the first sequence has a start/end deadline attached to it with an *Escalation* task that is activated when the deadline is not met. One of the results could be the activation of a compensating task. For example, if task C would be the picking of hazardous products or goods that can perish, the original transportation task may have to be undone to store the goods again at a place where they can be preserved safely. The proposed model is kept simple in order to keep it intuitive for both technical users and business users, but also to simplify the mapping onto software systems that monitor these tasks. For the implementation of the different types of tasks and the expectation patterns in model, we map our constructs to similar representations within the Business Process Modeling Notation (BPMN) [9]. BPMN already proposes a generic graphical solution to model tasks, events and workflows with diagrams, but is however more complex and less intuitive than the model we proposed and lacks a few concepts to easily model warehouse related aspects of a task. The reason for this approach is that we can leverage software tools that can map BPMN to software systems that assist with the monitoring and the coordination of these tasks. We use techniques similar to those described in [10] in order to transform BPMN process models to Business Process Execution Language (BPEL) web services. The main advantage of mapping a workflow of business processes to an equivalent workflow of software service is, whenever a warehouse manager changes its business process, he just needs

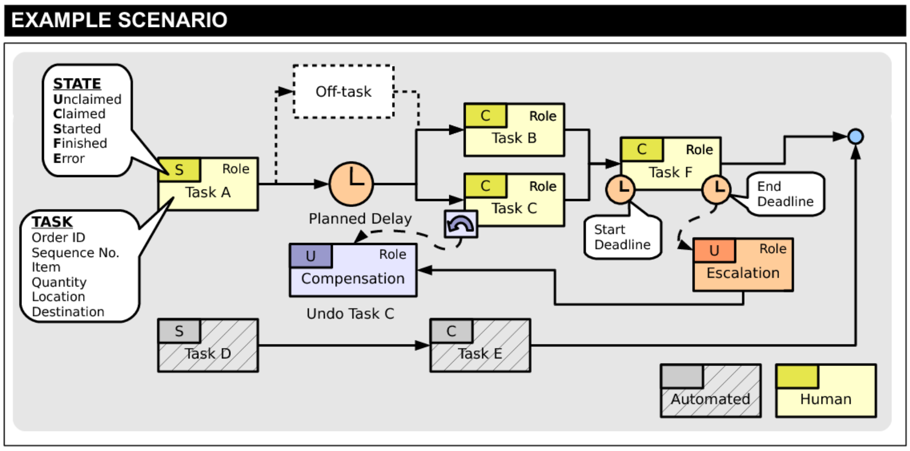

Fig. 6. A simple scenario of aligned human and automated transportation tasks

to adapt parameters within our model and the necessary translations to BPMN and BPEL will happen accordingly. BPEL has earned it merits in service oriented architectures which try to uncouple software services from one to the other. For warehouses this would mean that it would be easier to change the process and product flows, but this still needs to be investigated.

5 Conclusions and Future Work

The model presented in this paper arose from the real need to be able to integrate individuals as human actors into the product workflow of a warehouse and being able to deal with unpredictable human behavior. Therefore, the focus of our model was more oriented to mapping human actors within established business process practices, rather than focusing on theoretical aspects of task models in general. As a result, we have proposed a simple but intuitive dedicated model that captures several characteristics of transportation tasks, and that addresses the key concerns on choice vs. time constraints, indeterminism in the task flow, and role and responsibilities of each participant in the material handling process. Modeling concepts are included to describe the state and other properties of a transport task and how such a task can relate to non-transportation tasks. In order to better align human tasks with tasks carried out by automated systems, we included concepts to express how a batch of tasks is expected to be executed. This is important whenever multiple individuals and automated systems need to synchronize their activities while completing the consolidation of a single customer order. Nonetheless, some of the aspects need to be further investigated. For example, it is currently unclear how to best model and coordinate escalation tasks when both human actors and automated systems are involved (to make sure that escalation activities will not fail on their own that easily as well). We intend to continue our efforts on leveraging results achieved in the web services community, especially for integrating human tasks in web services orchestrations where two complementary standards BPEL4People [11] and WS-Human Task [12] have been proposed. The specifications are evaluated in [13-14]. Some of the observations were that both proposals provide a broad range of ways in which human resources can be represented and grouped, that there are a number of distinct ways in which manual tasks undertaken by human resources can be implemented, but that shortcomings do exist, for example, to enforce separation of duty constraints in BPEL4People processes. We will investigate how these specifications can be used or augmented specifically for the coordination of activities within hybrid warehouses.

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