Intelligent Products for Monitoring and Control of Road-Based Logistics

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***Abstract*—This paper presents a new architecture of an intelligent information system for monitoring and control of road-based logistics. The typical business of road-based logistic companies is to transport goods from a certain source to a certain destination by the use of trucks. During the actual transportation of goods, small disturbances such as delays or wrongly loaded goods can prevent the original plan from being executed as intended. Some of the main problems caused by these disturbances, and how they are currently dealt with, are investigated in a medium-sized logistics company. Typically, traditional planning and control systems have difficulties handling these kinds of problems effectively. However, recent technological developments, such as intelligent products, enable new solutions in the field of information systems. Therefore, a new system architecture is proposed here to tackle the outlined problems. The system is designed to detect local disturbances in real-time, and solutions to problems caused by these disturbances can be presented to the users directly. This approach is validated through an evaluation method based on real-life descriptive scenarios.**

***Index Terms*—Intelligent Products, Monitoring and Control, Logistics, Information System, Decision Support.**

I. Introduction

The typical business of road-based logistic companies is to transport goods from a certain source to a certain destination by the use of trucks. This can be done in several ways, as is shown in Figure 1. The way this is typically done in practice is that trucks pick up nearby goods from several sources, and deliver them to a central warehouse. Other trucks deliver these goods from the warehouse to their final destination. The process of unloading goods from one truck and loading them into another at the company warehouse is referred to as cross-docking. In some cases, a truck directly delivers goods from a source to the destination, without an intermediate stop at a warehouse. This typically happens when the amount of goods which have to be transported from a single source to a single destination fills the entire capacity of the truck. However, when transportation requests only require a small part of the capacity of the truck, goods of several transportation requests have to be combined in order to improve transport efficiency.

In order to proper schedule truck capacity for the transportation demands, planning and control of the logistics processes is required. To achieve this, four overlapping activities are typically performed within planning and control: loading, sequencing, scheduling, and monitoring and control [1]. The first three constitute collectively the planning function, the last function represents control. The advances in planning and control over the past decades have mainly focused on the sophistication of the planning function. This steadily resulted in centralization of the planning and control activities such as vehicle routing and fleet management [2], [3], [4]. This seems to be justifiable especially for the planning activities, due to their mathematical nature. However, the monitoring and control activity as performed by planners has received much less attention, although planners in real life spend most of their effort to monitor and control, instead of performing planning activities [5], [6], [7], [8].

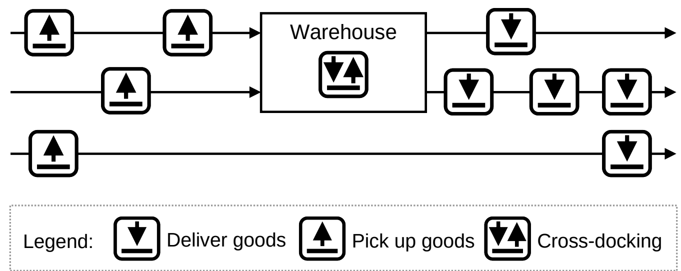

Figure 1: Overview of logistic processes in a road-based logistics company

The drawbacks of centralized monitoring and control appear in practice, and are caused by the many small disturbances that occur during transportation, and the way they are dealt with. A typical example of such a small disturbance is when a truck is delayed by a traffic jam, at the pickup, and/or delivery of goods at customer locations. Because of these events, the execution of the plan can be troublesome, especially if several other trucks are waiting for goods which are currently carried by the delayed truck. In this case, proper and timely rescheduling is needed in order to minimize the effect of the delay. Often, these kinds of disturbances are not made known to the central planners in time, although they might be registered by a vehicle routing system, as the truck drivers try to solve first these problems themselves on a local level. Other kinds of disturbances can include: goods loaded in the wrong truck, last-minute order cancelations, etc. These disturbances are part of the many causes why central plans in logistics are rarely realized as intended.

This paper argues that proper monitoring and control in the context of logistics requires detailed feedback on disturbances, in terms the transported goods, the resources, and the conditions. In order to allow timely response to logistic problems, agents representing the goods and resources should act immediately, investigate the options for re-planning, and inform the human planners. Therefore, a new system architecture for logistics monitoring and control is presented in this paper.

The remainder of this paper is structured as follows. In Section II, several problems in logistics monitoring and control are further elaborated. Afterwards, the system architecture is presented in Section III, and evaluated in Section IV. The paper ends with discussion and conclusions in sections V.

II. Problems in Logistics Monitoring and Control

The problems as described in this section are inspired by a case study in a Dutch medium-sized road-based transportation company, but these problems are more generic and apply to many similar companies [9], [10]. The main business of the company studied is to transport frozen and cold goods from The Netherlands and Belgium to destinations in Central Europe. During the execution of a logistics plan in such a company, several problems occur which cannot be managed effectively by the planners in their current approach towards monitoring and control. Several of these problems are described next. The system requirements and architecture as presented in Section III explicitly addresses the problems described. The problems as described in this section are additionally clearified with several scenarios from the case company. These scenarios will also be used to evaluate the utility of the system architecture in Section IV.

Problem 1: A truck is delayed, but the planners are not aware of this.

This problem is quite common in the logistics company, due to how the progress is monitored. According to the planners in the company studied, it is too much effort for them to monitor the progress of all the trucks manually, even though an information system is monitoring this progress. This is also caused by the fact that they are already very busy with many other activities. A planner only becomes aware of a delayed truck, when this information is pushed to him by the driver of the truck, through a phone call or text message. In order to reduce the amount of telephone calls and text messages, the company has a policy that truck drivers should only call the planners if they have at least one hour of delay. This however implies that the planners become aware of the problem relatively late, which can make it more difficult to find a solution for the consequences of the delay.

- *Scenario 1:* A truck is 15 minutes behind schedule, due to a traffic jam. However, the truck is heading for the company warehouse, where 3 other trucks are waiting for cross-docking. This small delay can have bigger consequences for the global plan. Waiting another 45 minutes with reporting this delay to the planners will decrease the possibilities for rescheduling.

Typically, planners using a centralized planning and control system work in a hierarchical way. This has the advantage that the complexity on the different levels in the organization's structure is reduced, when each level can function at least partly independent from the other levels. However, performance feedback is important in hierarchical systems, in order to have a properly functioning system [11]. Two assumptions are required to make such a system work properly. Firstly, proper feedback needs to be given in time by the lower levels to higher levels. Secondly, the higher levels need to be able to adequately respond in time to this feedback. If any of these requirements are violated, it is nearly impossible for planners to monitor the progress of the plan execution in an effective way. This seems to be the cause of problem 1. Feedback often reaches the planners too late, which is one of the reasons that prevent the planners to give an adequate response in time.

Problem 2: An individual pallet is loaded into the wrong truck, but the planners are not aware of this.

This is another typical problem in the logistics company, due to how the progress is monitored and controlled. The progress in the plan execution is monitored on the structural level of trucks, albeit in a delayed way. However, if by accident one box or pallet is loaded into the wrong truck by the crew of the company warehouse, this is only noticed at the moment when the driver wants to unload at a certain destination. Only at this moment the driver will inform the planners, which is too late for the planners to resolve the matter properly.

- *Scenario 2:* An order of 30 pallets is split up where by accident 29 pallets are loaded into one truck and one single pallet is wrongly loaded into another truck. In this case, information about the location of individual pallets would be needed to detect that one pallet is wrongly loaded. An early notification would again enable a quicker response which would allaw the problem to be resolved effectively.

Currently, centralized planning and control systems often have difficulties dealing with problems related to individual boxes or pallets. The main reason for this is that these systems typically work with aggregated data. Firstly, central planning systems aggregate over location. Goods which have to be transported are for example booked as being inside a warehouse or truck, but no precise account is available where inside exactly these goods can be found. In many cases this is no problem, but if goods are lost, it suddenly becomes a huge issue. Secondly, central planning systems aggregate over the goods which are to be transported. For example, all the different boxes and pallets of one order and the small differences between them are not explicitly present in planning systems. Furthermore, the progress during plan execution is often only monitored on a truck level, which also results in an aggregating over the progress of individual pallets. However, problems in monitoring and control often occur in a detailed, disaggregated form.

Problem 3: A truck will arrive too late at the company warehouse, but several other trucks are waiting for the goods inside the delayed truck.

The third problem is a more complicated problem for the logistics company. The plans as created by the planners often

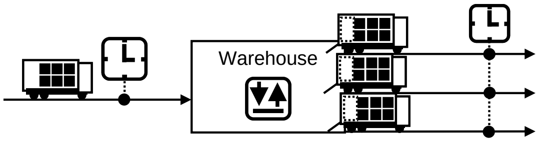

Figure 2: Truck delayed, 3 trucks waiting

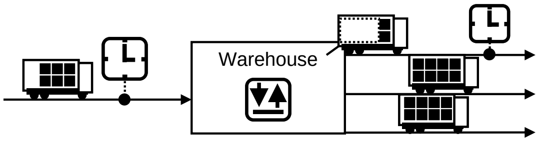

Figure 3: Truck delayed, 2 trucks rescheduled, 1 waiting

require that many transported goods have to be cross-docked at the warehouse. As long as everything goes according to schedule, this will not cause any problems. However, when one truck with goods for the warehouse is delayed, this can cause delays for all the other trucks which are waiting for goods inside that truck. To minimize this 'avalanche'-effect, proper and timely rescheduling is needed. However, this can be a difficult task for human planners, as it is difficult to analyze all possibilities for rescheduling in a very limited amount of time.

- *Scenario 3:* The truck that was 15 minutes behind schedule is now 20 minutes behind schedule. However, the driver of the truck reports that it will be delayed for at least an hour. This situation is depicted in Figure 2. For human planners, it is very hard to find and analyze all possible alternatives. However, a proper monitor and control system could come up with alternatives and propose them to the human planners. Such an alternative could for example be that the 3 trucks, which were waiting for cross-docking, redistribute their goods in order to let 2 trucks leave the warehouse and have only one truck waiting for the delayed truck. This alternative is depicted in Figure 3. In this way, the majority of the goods will be delivered in time. The total driving distance per truck will be increased, but the total costs can be lower compared to the situation where all 3 trucks keep waiting for the delayed truck.

Without proper and fast feedback on problems, and without detailed, disaggregated data, it is currently a difficult task for human planners to find the best solution to a disturbance in plan execution. However, even if those two properties are present, it can still be hard for planners to find a good solution to this problem. Currently, such a problem is solved manually based on the aggregated data available. However, such a solution is not likely to be optimal. Using aggregated data however leads to a reduced solution space, which makes it possible for a human to at least find a solution. When detailed, disaggregated data is used, new and better possibilities for solutions can become available, but the solution space may become too big and complex for humans to find them. In that case, a proper monitor and control system should assist the human planners, by searching through a bigger solution space to find a more elaborated and (near-) optimal solution.

III. Information System Design

This section will describe the generic architecture of the proposed information system. First, the requirements are presented. Next, certain new technologies are discussed which can be applied to incorporate these requirements. Afterwards, the main design principles of the proposed planning and control system architecture are described in detail.

A. System requirements

As discussed in Section II, centralized planning and control systems have problems dealing with disturbances. One important reason is that feedback often reaches the planners too late, which prevents the planners to respond adequately and in a timely fashion to disturbances. This leads to the formulation of the first requirement:

- *Requirement 1:* The system should be able to give feedback about disturbances to planners directly when they occur.

Another reason why centralized planning and control systems have difficulties dealing with disturbances is because centralized planning and control systems work with aggregated data. However, as disturbances seldom present themselves in aggregated terms, an effective monitoring and control system should work with data on the same level of detail as disturbances occur. This leads to the second requirement:

- *Requirement 2:* The system should work with data on the same level of detail as disturbances occur.

With the use of detailed, real-time, and disaggregated data, the search space for a suitable solution to a disturbance increases significantly, compared to the current situation. The big amount of information in this space can make it difficult to find a suitable solution manually. Therefore, the support of a system which can search this space effectively is required. Hence, the third requirement is as follows:

- *Requirement 3:* The system should be able to propose solutions to problems directly when they occur.

B. New technologies

Nowadays, there is an increasing interest in the field of intelligent products, and how intelligent products can be applied in different fields, such as in manufacturing, logistics and supply chain management [12]. McFarlane et al. [13] define an intelligent product as a physical and information-based representation of a product. A pallet or box can for example be the physical product, the information-based representation of the product can be stored in the database, and a decision making agent can providing the intelligence. The fundamental idea behind such an intelligent product according to Kärkkäinen et al. [14] is the inside-out control of the supply chain deliverables during their life-cycle. In other words, the product individuals in the supply chain themselves are in control of where they are going, and how they should be handled.

The vision of intelligent products is to seamlessly connect the products in the physical world with their representation in information systems, e.g. through a product agent as proposed

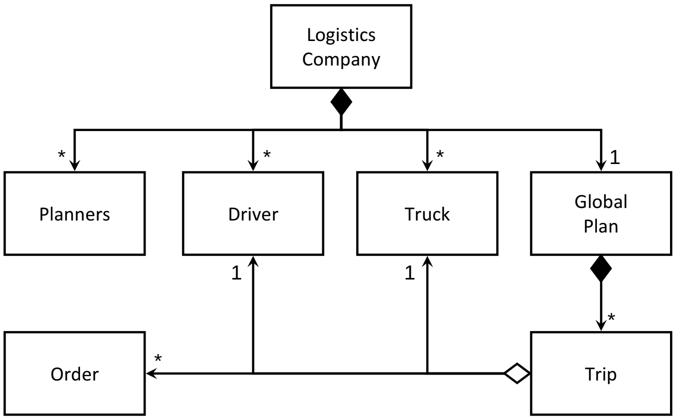

Figure 4: Existing company class diagram

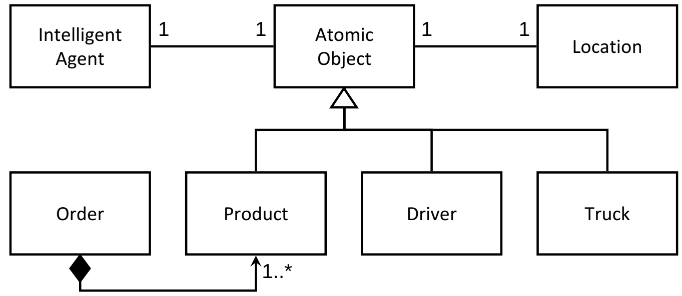

Figure 5: Addition of Product and Intelligent Agent classes in new system design

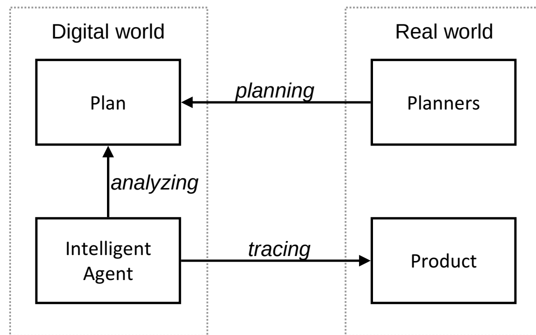

Figure 6: Information gathering of the Intelligent Agent

by Främling et al. [15]. Because of continuous synchronization, data about the current and past state of products in the physical world can be retrieved and updated in the digital world when needed.

As is the case with intelligent resources, agent technology is considered as a good match to implement the intelligence part of intelligent products, because of several reasons. First of all, when the number of products is high, the number of products in need of explicit control from the user has to be reduced. This can be achieved by making the products autonomous. In this way, intelligent products with knowledge and reasoning capabilities can do most of the repetitive tasks in an automated way. Secondly, intelligent products should be able to detect and react to changes in the environment. Agents can pro-actively assist the product and try to achieve goals given the change in the environment. Finally, agents can help in discovering information about the environment by communicating with agents of other products. Therefore, intelligent products seem to be an appealing approach for solving problems within monitoring and control in the context of logistics.

C. System architecture

As a starting point for the new system architecture, the current structure of the logistics company is used. A simplified versio of this structure is presented in Figure 4. The logistics company at the top of the figure is composed of a set of planners, a number of drivers and trucks, and has an association with a global plan. The global plan is composed of trips, which in turn consists of drivers and their trucks that carry the goods of the orders. This structure reveals the location of the problem concerning the aggregation over individual products by only focusing on the order. As shown in Figure 5, the aggregation problem is addressed by decomposing the order into products. In this way, requirement 2 can be met, as problems with goods typically happen on the level of pallets or boxes (which are now represented as products in the system) and not on the level of orders. This enables the system to monitor the location of every individual product.

Products, drivers, and trucks are considered atomic elements or objects in the architecture, since disturbances that occurs during the plan execution typically originate from these elements only. However, in order to be able to incorporate requirement 1 and 3 as well, the products, drivers, and trucks are designed to be autonomous and intelligent entities. Therefore, in the new architecture, they have an intelligent agent attached to them. The purpose as well as the behavior of the intelligent agents will be explained next.

The behavior of the intelligent agents will be introduced here according to the three levels of intelligence as described by Meyer et al. [12]. These three levels are discussed separately below, with the focus on the intelligent agents representing products.

Level 1: Information handling: Every agent, regardless of the fact whether it represents a product, driver, or truck, is aware of its part in the global plan. It is able to analyze the trips as planned by the central planners in which the object it is representing is involved. In this way, the agent is continuously aware of changes in this plan, because the agent knows where the product, truck, or driver it is representing is expected to go. However, to enable plan monitoring, the agent needs to keep track of the current status as well as the history of the object it is representing. This functionality is often referred to as tracing [16]. This requires continuous synchronization between the real world and the digital world, which can be achieved with the technology described in Section III-B. This flow of information gathering for an intelligent agent representing a product is modeled in Figure 6.

Level 2: Problem notification: As the agent has knowledge about the plan as well as the current status regarding plan execution it is able to detect disturbances. The agent employs a mechanism such as a utility function to determine whether the progress is still within schedule. In case of a product, such

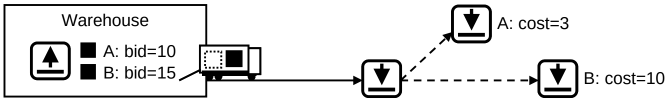

Figure 7: Product selection based on utility gain

a utility function can be based on factors like: the distance of the product to the destination, the amount of time until the delivery is due, whether there is a proper plan to get the product to the destination, and whether the plan execution is on schedule. When the utility score of an agent drops below a certain threshold, that agent enters a problem state. The agent will then decide if it is necessary to notify a human planner.

Level 3: Decision making: Besides the notification of their problem state to human planners, the agents can also search for solutions themselves. As a result of the continuous synchronization, all agents are aware of the actual situation in the real world. This enables the agents to negotiate in real-time about alternative plans to properly cope with the disturbance. The agents follow the general behavior of maximizing their utility continuously. This is achieved by negotiation among trucks and products, in which trucks try to optimize their route and capacity, and products try to find a truck which best matches their delivery demands. In this system design, this is solved with an auctioning mechanism, where products place bids for truck capacity. The bid of an agent representing a product is always equal to the expected utility gain for that product. Trucks will select products based on their own utility gain, which is the value of the offered bid reduced by additional costs for the truck, such as an increased traveling distance. Figure 7 depicts an illustrative situation which can occur after a disturbance, where the truck at the warehouse has capacity for only one additional product. Two products at the warehouse bid for this capacity and the truck analyzes the additional costs. In this particular case, taking product A will yield a total utility gain of 7 whereas taking product B only yields 5.

The total result of the negotiation between truck- and product-agents will be presented to the human planners. They will decide whether the tentative actions will be scheduled or not. If the planners do not agree with parts of the schedule, they can propose changes in a way that enables the agents to learn from it. This approach is similar to the monitoring and control mechanism of escape and intervention as proposed by Roest and Szirbik [17].

IV. Evaluation

For the evaluation, a set of usage scenarios were investigated via a well-established software architecture assessment method. In this section, the same scenarios as presented in Section II are used to show how the architecture usability assessment was performed.

To evaluate the utility of the proposed architecture, an appropriate assessment method had to be found. Due to the orientation of the case analysis towards scenario-based problem definition and requirement specification, only methods that are scenario-based have been considered from the Taxonomy of Software Architectural Evaluation [18]. Out of the so-called “early” evaluation methods, the SALUTA (Scenario-based Architecture Level usability Analysis) method [19] has been selected, due to its orientation towards usability. This method can be applied for three different goals: to predict the usability level, to detect usability issues (risk assessment), or to select a software architecture (by assessing multiple SA candidates). In this case, the goal was to predict the usability level.

no.	Scenario	Satisfaction	Learnability	Efficiency	Reliability
1	Detect that a truck is behind schedule	2	1	3	4
2	Detect that a pallet is loaded into the wrong truck	2	1	3	4
3	Replan in case when a truck is too late for cross-docking	2	3	4	1

Table I: Attribute preference table containing usability attribute scores

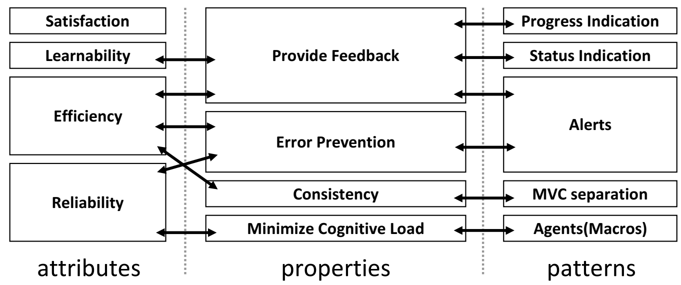

Figure 8: Usability framework

The SALUTA method identifies two types of information, captured via the analysis of the architecture (using primarily the functional design documentation) and by interviewing the users and the software architects. First, a mapping between user scenarios and usability attributes, which are predefined as *Satisfaction*, *Learnability*, *Efficiency*, and *Reliability*, is defined. This gives a measure of the required usability value. For each scenario, the goal is to determine a specific score value associated with each usability attribute. The assigning of values was done as a post requirement process where the expert users determined their values for their usability preferences. Based on the three scenarios, the results shown in Table I (called in the method the APT – “attribute preference table”) have been found.

The second source of information is the architecture, allowing the identification of usability patterns that will give a measure of the provided usability levels by using a prescribed framework. This framework provides an indirect mapping between usability *patterns* and *attributes* (the same as mentioned above) via usability *properties* [20]. In Figure 8, a list of patterns are shown that have been captured during the analysis of the architecture as described in Section III. The figure also shows which usability patterns are mapping to what usability attributes. In the particular context of Intelligent Products and Agents, the original “Macros” pattern in the usability framework is interpreted as an “Agents” pattern instead.

Comparing the results in Table I and Figure 8, it appears that in both mappings, the Reliability and Efficiency attributes are scoring the highest, which shows that the required usability level matches the provided usability level. This is a positive result of the usability assessment. From a methodological point of view, design science [21] accepts the evaluation of an artifact (in this case the proposed Software Architecture) by testing its usability. As a further step, the same usability-based evaluation will be employed for the implemented system. A pilot within the target organizations is considered to measure the system's usability.

V. Discussion and Conclusions

A centralistic planning system supports human planners to define an optimistic optimal planning schedule. However, as discussed in this paper, disturbances can occur that require proper monitoring and control in order to cope with the dynamic environment. In this perspective, a centralistic aggregated system typically has 3 weaknesses, which were outlined in the problem. First of all, centralized systems tend to detect local problems relatively slow, due to the lack of local monitoring. Secondly, by using aggregated data, problems to individual units cannot be monitored and controlled on the same level. Finally, due to the delay in monitoring and the lack of detailed information, it is virtually impossible to provide solutions to local disturbances in a timely and effective fashion.

Therefore, this paper proposed an architecture based on intelligent products in order to overcome these issues. These intelligent products are aware of their local state, objectives, and dependencies. The individual logistic units are monitored locally by these intelligent products in real-time, by applying local data, as opposed to aggregated data. Furthermore, these intelligent products can collaboratively propose solutions to disturbances at the same time as they occur. This enables planners to handle local disturbances more effectively. Instead of searching through all possible solutions themselves, the intelligent products already present solutions including the consequences to the global plan. The planner decides if one of the solutions is appropriate and thereby he also provides feedback to the system. Overall, this leads to a more robust global plan execution, by detecting and solving problems on the same level as they occur.

Finally, it is to be expected that other transportation companies can benefit from the proposed system as well. In order to confirm this, a prototype of the system is currently being realized. In future work, this prototype will be used for experimental simulations and pilot studies. Other future work intends to make the system design more generic by allowing companies to configure the system to their specific needs. This enables the evaluation to also take place in other domains, such as manufacturing and supply chain planning, which will allow for further claims about robustness and generalizability.

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