Managing Contingencies in Timed Transportation Networks by Agent Technology

Natalja Pulter and **Jens Nimis** and **Peter C. Lockemann**[1]

Abstract. Lean production is characterized by low levels of inventories at the production sites. Because classical strategies such as just-in-time or just-in-sequence are susceptible to deviations from the original plan ("contingencies") supply chains based on regular and guaranteed delivery times ("timed" transportation networks) have been proposed which potentially seem more robust if one can compensate for the contingencies within a single clock cycle. Since contingencies may be of different severity, compensation strategies may vary from the local to the global and, consequently, may sometimes pose serious challenges if one wishes to stay with one cycle. Consequently, intelligent contingency management becomes an essential factor for the success of a timed supply chain. The paper introduces a multi-level model that escalates contingencies to the appropriate compensation level. It examines which kinds of contingencies and, hence, which compensation level is particularly well suited for agent technology, and discusses an agent solution within the escalation model.

1 Introduction

Lean production is characterized by low levels of inventories at the production sites. Typically, these are achieved by strategies such as just-in-time or just-in-sequence, but have as a drawback a high susceptibility to disturbances in the supply chain with a concomitant high cost in downtime and/or high effort of replanning. To overcome these drawbacks, a timed approach has lately been proposed where parts are delivered in a timed fashion of regular intervals. While such a strategy requires a modest amount of inventory, production planning is eased by working from fixed and guaranteed delivery times, and the hope is that delays or other disturbances can be compensated for more robustly within a single clock cycle. This paper addresses the issue of such compensations. More specifically, it concentrates on the part of the supply chain where parts are transported from a supplier to the manufacturer. Since deviations from the original plan ("contingencies") may be of different severity, compensation strategies may vary from the local to the global and, consequently, may sometimes pose serious challenges if one wishes to stay within a single clock cycle. Knowing the kind of exceptions and the compensation techniques and their cost in terms of resource demands may also allow the stakeholders to trade off compensation for longer cycles and concomitant higher inventories.

There is also an economical and an ecological side to timed transportation networks. Due to its central geographical location German highways carry an extremely heavy load of truck traffic: 77% of goods are transported by trucks. Within the present highway system the load limits have practically been reached. There is little chance of much further extension of the road network, both because of the high cost and because of popular resistance. On the other hand carriers like trains or ships still offer considerable spare capacities. The problem so far has been that rail and ship transports run on regular schedules and thus were considered too inflexible. Once manufacturing is based on timed processes, rail and ship become natural partners in a timed transportation network. Consequently, intelligent contingency management becomes an essential factor for the success of a timed supply chain.

Today the intelligence is provided by human dispatchers. With the continuous growth of the logistic networks, the increasing number of criteria to be observed and the ever shorter times for decision making the dispatchers become overextended. Hence, contingency management should be computer-based to the extent that simple measures can be triggered automatically so that the dispatchers can attend to the more complex contingencies, and for these the system should provide valuable assistance.

The paper is organized as follows. The second section introduces the logistical and organizational difficulties, which make dealing with incidents so complicated in the logistical area. Section 3 proposes a multi-level model that escalates contingencies to the appropriate compensation level. As part of this model, the fourth section discusses how contingencies can be detected and then classified in order to determine how to attempt compensation. Section 5 describes the escalation procedure with the specific purpose of identifying the kind of what contingencies for which agent technology seems particularly well suited. We argue that this is the case whenever negotiations become an essential part of the solution. Section 6 discusses the agent approach in more detail and illustrates it by an example. Section 7 concludes the paper.

2 Problem Reach

Contingencies are fairly local events, such as a traffic congestion, engine breakdown, incomplete load, driver sickness, etc. Their effects, however, may become more widespread if not treated properly. Treatment may involve securing new resources, and these may have to be withdrawn from other supply processes. Clearly then, the more local the compensation is the more limited the effects will be on the same or other logistical processes. We give a few examples below.

Business level Take a dispatcher who has to compensate for late provision of a parts load. She can choose among a variety of solutions, e.g., change the order of load points in the tour, send an idle vehicle at a later time, cooperate with other company in the network passing the load point. Ideally she will evaluate the different solutions in light of various attributes deemed important for the

[1] All authors are with FZI Forschungszentrum Informatik an der Universität Karlsruhe, Germany, email: {pulter, nimis, lockemann}@fzi.de

carrier: additional cost, tour distance, tour period, current time or load buffers, etc. More often than not the evaluation must consider several such attributes in combination. Further, making use of time or load buffers or of idle vehicles uses up precious resources that are not available for subsequent contingencies. Several such contingencies may occur concurrently, making the decision even more complicated.

Network level Mostly dispatchers try to solve contingencies by mobilization their own resources. Sometimes they will resort to help by other network partners. In this case a dispatcher has to make phone contact to the dispatchers of other partners and try to negotiate an offer, which can be very difficult because of competing interests. The fact that a dispatcher can only negotiate with one participant at any one time complicates the situation, at least if she is under high time pressure. There are indications that in a timed network cooperation among otherwise competing partners must increase in order to keep the cost of collection runs ("milk runs") under control so that negotiations become more of a norm.

Supply chain level A supply chain involves a good number of partners, e.g., the local distributors at the supplier's and manufacturer's ends, and one or more large carriers (rail, ocean-going vessel) in the middle. Contingencies at any one of them that remain unresolved impact all the ones that follow, and even a solution may impact the preceding ones if it imposes new constraints on them. In general then, contingencies often have a habit of spreading across a large part of the network. Hence, any solution should be checked on its effects on the remainder of the supply chain in order to ensure that no follow-up contingencies will occur. In summary, a dispatcher should find a solution as fast as possible, while making as few changes as possible, and always keep an eye on follow-up effects.

The simultaneous management of all this requirements under the high time pressure is difficult enough, but it becomes even more difficult when multiple incidents happens at the same time or during a short time span. Clearly, coping with contingencies would benefit from automated help.

3 Contingency Management Model

The basic concept behind our contingency management is the notion of ***buffer***. A buffer is a spare resource kept in reserve, like an extra vehicle or a tolerance in delivery time, and is provided as part of a planning process. Buffers are the means for resolving contingencies. Contingency management, then, offers mechanisms for determining which among the available buffers offers the most effective and efficient solution, i.e., for selecting among the buffers those that add to the robustness at least cost and least spread of effects. The search starts with the most local buffers, and only if no solution can be found successively escalates to buffers with more global reach. Of course, before any remedial action can be taken a contingency must be detected as such, and must be classified in order to determine the buffers that have the potential to overcome the contingency. Consequently, contingency management consists of two main parts: contingency detection and classification, and the actual contingency management (Figure 1).

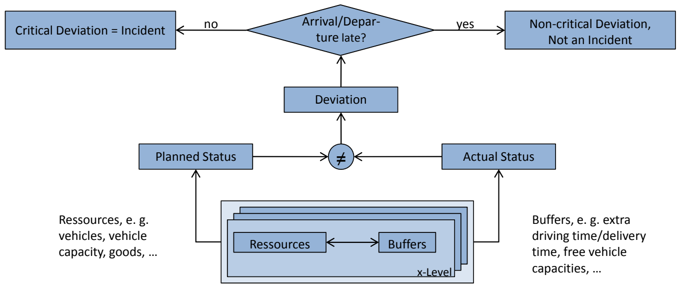

Figure 1. Contingency model

4 Contingency Detection and Classification

4.1 Related Work

Contingencies are events that fall outside the (planned) norm. Tools for detecting such events are known under the name "supply chain event management (SCEM)" and monitor the logistics processes and compare the observed events with predefined events. If an event does not occur when expected or occurs when not expected it is reported. Events that characterize critical plan deviations are filtered out and reported to the user in realtime [3].

One of the better known supply chain management systems is SAP SCM. With SAP EM as a part of SAP SCM supply chain processes can be monitored for exceptions [7]. Each relevant process is represented by an object that includes all relevant milestones. The observed events are categorized, and a rule engine determines whether follow-up activities are necessary. If a logistics partner knows early enough whether to take action the management of the logistics processes has a decidedly pro-active flavor.

Pro-active process management is also the objective of arvarto services [4], an approach of a pro-active process management by proactive messages to important process participants. The appearance or absence of events triggers messages like SMS or Email to the best-suited participants. The services include a clear trend towards automatic actions like generation of an electronic order if the original delivery time is by far exceeded. For the generation one may draw on suggestion from a knowledge base.

4.2 Contingency Detection

Supply chains are a sequence of transportation processes executed by successive carriers. Today for all practical purposes, events can only be observed when the load is handed over from one carrier (or service provider like a warehouse facility) to the next, i.e., at the so-called transshipment points. In the future, events will become more numerous, e.g., by reading RFID tags also during shipment [5], or by tracking the position of trucks by GPS. At any rate, most events (hopefully all) are of no further relevance. What is needed, then, is a filter that compares the characteristics of each event to a set of prescribed criteria drawn from the plan, and only pass along those events that are determined to be critical deviations, such as time delays, missing, damaged or incorrect loads. An interesting issue is what to do with those events that can easily be satisfied by one of the most local buffers, like an arrival time within the tolerance level. Should it be filtered out or passed on to contingency management? In the former case the number of events can further be reduced and processing of the contingency can be sped up, but at the price of functional redundancy because one must register that the buffer used has been reduced in size, a functionality that is also an essential part of contingency management. Notice that because not all contingencies are known in advance events must follow an abstract (generic) model.

Our present solution utilizes a commercial platform by ptv AG and opts for the first approach of strong filtering. The input consists of the actual and planned states of the transportation resources, e.g., vehicles, orders etc. In the first step corresponding states are compared regarding properties like quantities, arrival and departure times. When a deviation is detected, it is tested against the existing local buffers in the affected transportation chain like driving time, handling time and capacity range. If the deviation can be compensated by any of these buffers it is classified as a non-critical deviation. A buffer must then be chosen for this deviation type, and adjusted.

If the deviation cannot be compensated for by such a buffer, it is classified as critical, the details of the event are stored in a database and the contingency management is notified.

5 Contingency Management

5.1 Escalation and Optimization

Take a contingency where a load is not provided on time. Contingency management may try to reorganize buffers of the affected tour. For example the tour points of the affected tour could be rearranged according to the earliest possible and latest acceptable pickup or delivery time. But this may have an effect on other tours visiting some of the same tour points. Instead one may try to use buffers of other tours or orders. Clearly the effect becomes much more global and must be dealt with on another level. Clearly too, the higher up the level is where one seeks a solution, the wider is the range of potential buffers, but also the effect on buffers. Hence, escalation quickly becomes an issue of optimization. It is not sufficient to optimize only with respect to one criterion, e.g., costs, because every resolution of a contingency consumes buffers which may also be needed in case of another contingency.

5.2 Escalation Levels

Since buffers are resources, and one can associate a certain reach with each, it seems only natural to define the escalation levels by classifying buffers into solution levels. To follow the typical planning strategy, the demand for transportation arises either from the need for production material or from the provision of a certain amount of goods. So a transportation chain starts with a transportation ***order*** between participants in the ***logistic network***, which describes the amount of which goods that have to be transported from a certain source to a certain destination. Then the transportation order is mapped to a ***transport***, which has to pass several transshipment points on its way to the recipient. This is especially true for multimodal transportation networks where the goods may change between (several) trucks, rail or ship, and often also when transports start and end in milk-runs rather than hub-and-spoke transports to avoid half-empty trucks. Next the planning process assigns the transports to ***vehicles*** and these to ***tours***. Accordingly the basic solution levels are order, transport, and tour level. Thus leaves out two other kinds of buffers: Substitute trucks and substitute carriers. Both are costly remedies and may have a wide reach. Consequently, these two – fleet and network – are placed on top of the order level as the levels "of last resort". Besides every process step consists of several substeps. Each of these levels can further be divided into sub-levels. The sub-levels of the network level reflects the participants of the logistic network: customers/suppliers, carriers and transshipment point owners. The fleet level concentrates only on the available vehicles, while the order level is divided into one for latest delivery time sub-level and another for a volume split. Alternative transshipment points and the tolerance within pickup/delivery times are the sub-levels of the transport level. Buffers on the tour level are grouped according to alternative tours, tour points and routes. Figure 2 shows the complete set of levels.

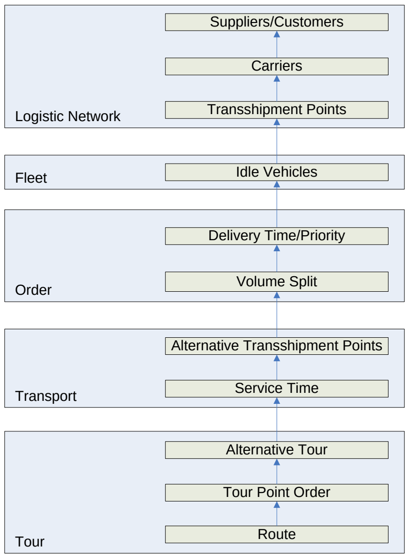

Figure 2. Escalation levels with sub-levels

5.3 Escalation Procedure

The idea underlying search by escalation is to find a solution on the lowest possible level. This way the number of affected buffers and, hence, of additional resources can be kept to a minimum (and in particular, the use of additional vehicles or carriers may be avoided). Therefore the search for a solution always starts at the lowest suitable level, and only if no solution can be found the search is extended to the next higher level, and so on. Take a vehicle breakdown. There is no use in looking for an alternative route or an alternative tour point order. In a first attempt one would examine the service time level in order to determine whether there is enough latitude in, e.g., the delivery time. If an escalation is necessary, one could review the transshipment points and decide, e.g., on replacing rail by a light truck to make up for the delay. Notice that solutions on higher levels may necessitate an adjustment of buffers on lower levels.

In general, the search must be based on accompanying information gathered over time. Some of the information can be obtained by automatic means, e.g., whether and how fast a vehicle had recently been moving. We expect that most of the information will be entered manually via PDAs by persons such as drivers, transshipment point owners, suppliers, using predefined masks (e.g., contingency cause – traffic jam, estimated delay – 60 min). Often more than one solution may be found on a given level, for example two different alternative transshipment points on the transport level. We supply ranking functions in order to make an intelligent choice.

To give a bit more detail, the various levels may offer the following solution possibilities:

Tour – Route A new route for a planned tour is generated based on additional information such as road closures.

Tour – Tour Point Order A tour is rescheduled based on revised earliest arrival times or load capacities resulting in a new tour point order.

Tour – Alternative Tour Other tours in the vicinity of a transport point are searched and an attempt is made to place the load in such a tour.

Transport – Service Time A transport is picked up or delivered the next regularly scheduled visit.

Transport – Alternative Transshipment Points A load is picked up at or delivered to an alternative transport point without changing the carrier. Conditions to be observed are whether there is still enough storage space in the chosen transshipment point, or if there is some other transshipment point that has goods that could be used as a replacement because they have sufficient latitude in their delivery time. The tour is then rescheduled according to the new pickup/delivery location.

Order – Volume Split Sometimes the supplier or the customer can tolerate that a volume of parts is picked up or delivered in several batches. Alternatively, if there is enough slack at later transshipment points, an order may still be split during the transportation as long as the batches can be consolidated in time before the delivery.

Order – Delivery time/Priority The planned tours are checked for transportation orders with later delivery times than the critical transports. If such transports are found, they are removed from a tour and replaced by the critical transports.

Fleet – Idle Vehicles The critical transports are rescheduled with a vehicle that is idle at the time of the pickups/deliveries of the transports.

Network – Transshipment Points Other participants of the logistic network are contacted, e.g., to negotiate the use of their transshipment point, to replace the missing load by goods stored with them.

Network – Carriers Other carriers of the logistic network are contacted whether they could take over the transportation of one or several orders.

Network – Suppliers/Customers Other suppliers/customers are contacted to negotiate with them whether they could provide certain critical goods or take excess goods.

The goal is to maintain robust schedules (reliable regular schedules) for suppliers and manufacturers: No matter what the contingencies are they remain invisible to the two groups. That is true unless the escalation reaches the top with no solution. In this case the participants will have to renegotiate the entire order.

6 Agent-based Contingency Management

6.1 Choice of Network Level

Logistics is a highly developed technology with a wealth of optimizing algorithms for almost all the escalation levels [2]. Unfortunately most of them aim at the optimization of a collection of tours rather than a single tour. Consequently, they are very inefficient if one tries to perform replanning. Mes et al. have shown that agent-based transportation planning may be more efficient and almost equally effective [11]. Neagu et al. use agents to optimize a collection of tours when a single order is being added ([12]).

None of these planning algorithms optimized more than one criterion, whereas in dealing with contingencies we believe that several criteria (several buffers) should be considered. Outside logistics several promising approaches for agent-based multi-criteria negotiation exist in the e-commerce area ([6, 10]).

In summary then we feel that the use of agents is a promising technique in contingency management. This is supported by Weiss, who claims in [13] that software agents can be both efficient and effective in combinatorially complex settings. The network level provides such a setting. Below we develop an agent-based approach on the network level as a first example before we try to extend agent-based solution to the lower levels.

6.2 Related Work

Agents have already been used in several fields of logistics. One is supply chain event management. [15] introduces an approach of an agent-based SCEM. It defines monitoring criteria, gathers information on the criteria and interprets it and in case of an unexpected event generates alerts and directs them to the actors. These tasks are realized by different agents. E.g., the communication with supply chain partners is managed by a discourse agent, while the gathering of information is realized by a surveillance agent.

A second field is transportation management. [8] introduces an agent-based approach for optimization of tour plans. Thereby a shipping company allocates orders to its trucks. The trucks represented by truck agents bid on whole or on parts of transportation orders while the shipping company agent combines the best bids to a tour plan. Instead the shipping company agent may elect not to execute an order on its own, but to cooperate with another company. In this case a negotiation between the two company agents takes place.

Another approach to optimize tour planning is presented in [12]. Here the transportation area is divided into regions and the tours are optimized by the AgentClusterManager of the single region. If a transportation order concerns different clusters, the agents of the clusters agree which of them can handle the transportation in a cheaper way. In order to optimize tours within a region, trucks negotiate with one another about transfers of the transportation orders to other tours until cost-saving changes are no longer possible.

6.3 Agent Types and Tasks

The network scenario is typical for situations that tend to be approached by software agents. All participants pursue their own egoistic goals and, therefore, try to keep the information about their orders, customers, resources, and problem details secret from the other participants. On the other hand the participants need to collaborate from time to time in pursuance of a common goal. Negotiations have the purpose of maximizing one's own benefits and still satisfy the common goal [13]. In our scenario we distinguish between the following participants and, consequently, agents, which become active only in case of a contingency, and they only deal with contingencies (Figure 3):

Supplier agents The supplier agents have two main tasks and two goals. On the one hand the supplier agents are activated when the goods committed to a customer cannot be provided in time for the pickup. In this case a supplier agent can either contact the carrier agent and try to schedule a new or additional pickup date or it can contact other supplier agents for help and negotiate with them the conditions for their support. To meet such a contingency each supplier agent maintains a list of suppliers producing the same kind of products together with their location information. The negotiation goal of a supplier agent is to find a partner who can provide the

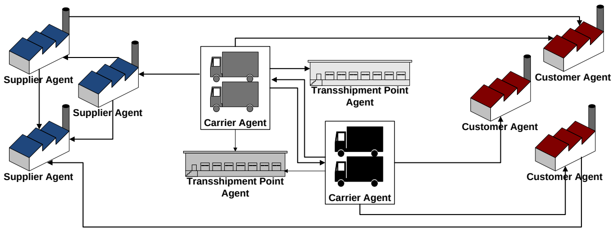

Figure 3. Network agents and their possible negotiation partners

necessary goods at the earliest possible time for the lowest possible price. On the other hand a supplier agent may be on the receiving end when contacted for help. In this case the agent checks whether the requested goods can be provided at which time and in which quantity. Its negotiation goal is to get the help order at an acceptable price but to achieve the highest possible price.
An additional function may be to contact customer agents in the case of an overproduction or of an order cancellation by a customer. While not a logistics problem by itself, the supplier agent would be the source of one by trying to find a customer (it may maintain a customer list for this purpose) who would be willing to buy the goods, and to negotiate the price. If all these negotiations come to a successful end one or more agents must contact their carrier agents.

Customer agents Similarly, customer agents pursue two main tasks and two goals. One has to do with the need for additional goods if the demand increases over plans or if goods cannot be delivered on time. In this case a customer agent contacts other supplier agents to find one who is willing to sell the goods. The goal is to do so and achieve the lowest possible price. The complementary task is to provide offers for suppliers that try to sell spare goods. When a customer agent receives an offer for certain goods it checks for available inventory space and negotiates the price of the goods with the goal of obtaining the lowest possible price. Again, if all these negotiations come to a successful end one or more agents must contact their carrier agents.

Transshipment Point Agents A transshipment point agent is purely reactive. Requests for helping out with goods involve checking the stocks at hand, their recipients and delivery times and potential resupplies. If suppliers help out customers, or vice versa, the transshipment point agent checks for spare capacity for intermediate storage of goods.

Carrier Agents At its core, transport logistics is about scheduling carriers and their resources. Hence, carriers are the ones who suffer the consequences of all short-term changes, and to cope with them carrier agents must be able to contact all other agents, be they supplier, customer, transshipment point or other carrier agents. Every carrier agent maintains a list of the other partner agents together with additional information about them such as location information or types of produced goods. To give an example, if a carrier needs to offload an order to some other carrier its agent will determine the most suitable negotiation partners according to additional information like the transshipment points within a certain radius of the contingency. The negotiation goal of the agent requesting help is to keep the additional cost as low as possible, to find a solution as close to the original plan as possible, and presumably to avoid new long-term competition. On the other hand, a carrier agent receiving a request for help will check whether it can provide the requested resources without endangering its own plans. If this is the case it tries to get the additional transport order at an advantageous price.

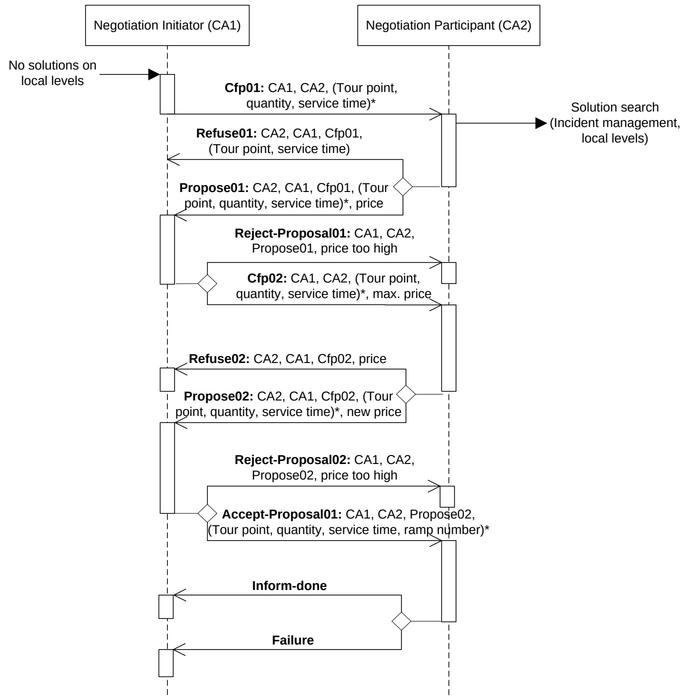

Figure 4. Example of a negotiation procedure between two carrier agents

6.4 Agent-based Negotiations

We developed first solutions for all these negotiations based on the FIPA Iterated Contract Net Interaction Protocol [9], a modification of the original Contract Net protocol [14]. In the Contract Net protocol an agent generates a task announcement and sends it to one or more other agents. The agents listen to task announcements and bid on a task they would like to execute. The requesting agent selects one bidder and informs them by an award message. Finally the requesting agent is informed when the task is done [14].

The FIPA Iterated Contract Net Interaction Protocol extends this basic protocol by adding confirmation and rejection communicative acts. It also allows the requesting agent to alter the original announcement (call-for-proposal/cfp) rather than accept offers in the first negotiation round, and start a second negotiation round in the hope of getting more suitable proposals [9]. We decided to allow only two negotiation rounds to stay reasonably reactive. Notice that for reasons of competition the protocol must meet its purpose under the constraint that no information other than absolutely necessary for the task is provided with the call-for-proposal and the proposals. In particular, no information is exchanged on orders, resources etc.. The standard solution procedure on the carrier sub-level of the network solution level including negotiations looks as shown in Figure 4.

If for example the contingency detection discovered a critical delay of a vehicle because of a break down and no solution was found on lower levels, the carrier agent is activated. The carrier agent looks up other carrier agents having storage facilities in the vicinity of the affected tour points and sends a call-for-proposal to these agents. The call-for-proposal looks as follows:

```
(cfp01
:sender CA1
:receiver CA2
:content
(Tour point 1, 10 pallets, 30.09.10, 09:00;
 Tour point 2, 15 pallets, 30.09.10, 14:00))
```

The message contains the performative (cfp), the sender (CA1), the receiver (CA2) and the actual message content describing the task. In this case it would be the location information of the affected tour points, the quantity in the single tour points and the time constraints in the single tour points (earliest pickup time/delivery time, latest pickup time/delivery time).

This is a wonderful example for demonstrating the recursive nature of contingency management. The carrier agents receiving the call-for-proposal try to reschedule their plans based on the received information. From their point of view this is nothing but a contingency, albeit one of ad-hoc orders. Consequently, they will turn to contingency management with the ad-hoc orders. Recursion is easily limited because only solutions on local levels make sense now. If a carrier agent does not find a suitable solution, it sends a refuse-message to the requesting agent. This message can contain the reason for refusal (e.g., no free capacities on scheduled vehicles, no idle vehicles) or a set of conditions which have to be met in order to fill the proposal (e.g., maximum quantity: x pallets, earliest pickup time: 01.10.10, 9 am). If contingency management is successful the carrier agent estimates the additional cost of the help offer, adds the desired profit and makes a proposal. The in-reply-to (cfp01) proposal contains the same information as the cfp-message augmented by the location information of the tour points, the possible volume, the earliest and latest possible service times, and the desired price.

The requesting carrier agent evaluates all proposals. If there is a suitable proposal, the requesting carrier agent informs the winner (or several winners if only a combined proposal covers all affected transports) and all the other carrier agents about the reject of their proposals. In case of an acceptance the message contains additionally the details of the transports (e.g. the supplier name, the ramp number, ...). The reject-proposal message contains besides the usual information the reason for the reject (e.g., price too high).

If none of the proposals contains a suitable offer the requesting carrier agent starts the second negotiation round mentioned above by sending a modified call-for-proposal. This message will only go to the most promising negotiation partners based on their proposals, e.g., those that deviate from the original request only within prescribed limits. All other negotiation partners receive a reject-proposal message. The reduced group of recipients can again decide whether they bid on the new proposal or refuse to do so. At the end of this round the carrier agent has either to accept one of the bids or to escalate the solution search to the next level.

The negotiations between supplier and customer agents or between carrier and supplier/customer agents follow the same protocol. They differ only in the content of the message text, e.g., product type instead of earliest and latest service times. Where they differ drastically is, of course, how the agents reach their decisions, but this part of the solution process remains hidden from the protocol.

7 Conclusion and Further Research

This work has partly been funded by the Bundesministerium für Wirtschaft und Technologie (BMWi, German Federal Ministry of Economics and Technology, contract number 19 G 7036 E) in the LogoTakt project [1] where carries, suppliers and manufacturers collaborate with a vendor of logistics platforms and research institutions. For the SCEM we use the vendor's commercial platform. Contingency management is designed as an add-on component to the platform. At present the lower escalation levels have been implemented to the extent that they resolve contingencies locally. As mentioned before, currently we develop the agent-based network-wide contingency resolution discussed above. All these solutions will be part of large simulation studies involving two supply chains, one where parts are delivered from several geographically distributed central warehouses by truck, and a second where the main transport segment is by rail and the recipient is an automobile manufacturer.

Contingency management based on escalation is a fairly new concept. Since the concept involves measures that may spread across several levels, response times become a critical issue. This may often preclude replanning via optimization algorithms. The question of central interest to us is whether agent approaches offer faster response times while still preserving an acceptable degree of result quality. We consider the work discussed in this paper a first step towards that objective.

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