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Formalizing a Procedure for Generating Uncertain Resource Availability Assumptions Based On Real Time Logistic Data Capturing with Auto-ID Systems for Reactive Scheduling

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***Abstract*—**As one result of the project "Reactive Construction Project Scheduling using Real Time Construction Logistic Data and Simulation", a procedure for using data about uncertain resource availability assumptions in reactive scheduling processes has been developed. Prediction data about resource availability is generated in a formalized way using real-time monitoring data e.g. from auto-ID systems on the construction site and in the supply chains. The paper focusses on the formalization of the procedure for monitoring construction logistic processes, for the detection of disturbance and for generating of new and uncertain scheduling assumptions for the reactive resource constrained simulation procedure that is and will be further described in other papers.

***Keywords*—**Auto-ID, Construction Logistic, Fuzzy, Monitoring, RFID, Scheduling.

I. Introduction

TODAY construction schedules often have to be modified due to disturbance in construction production or construction logistic processes. For creating and e.g. reactive modifying construction schedules the method of simulation (introduced for construction by [1]) and especially resource constrained discrete event simulation has been improved in research (see e.g. [2] or [3]). In practice schedulers often have to consider uncertain information e.g. about logistic processes and so about resource availability. Reference [4] shows a way, how uncertain information about resource availability could be integrated into reactive resource constrained discrete event simulation scheduling procedures.

The unsolved question is: Can this uncertain information about resource availability be generated in a formalized way using real-time information from logistic monitoring systems?

Some approaches of logistic monitoring systems using auto-ID-techniques, especially RFID-techniques (Radio Frequency Identification), which was firstly introduced by [5] in the construction context, are shown in [6], [7] or [8]. It was shown that logistic relevant real time information can be generated for e.g. personnel, machines and materials and how this information can be made available in real time to all participants.

Some aspects and interdependencies of resource constrained construction production scheduling and monitoring systems for monitoring logistic aspects of making resources available are shown in [9] and [10]. Reference [9] concluded that due to complexity reasons there is a need for a clear cut between the software systems for simulation based scheduling on the one side and for monitoring logistic processes on the other side. Between these systems iterative and interdependent data exchange is necessary for generating resource requirements profiles and resource availability profiles. Reference [10] concluded that as a part of the system for generating resource availability assumptions there is a need of integrating human skills like expertise, considering context, creativity, weighting in the case of tradeoffs etc.

One target of the ongoing project is to formalize the way of getting resource requirements profiles from the actual construction production schedule, using this information for logistic monitoring systems, getting alerts from these monitoring systems in the case of disturbance and then sending formalized information to the reactive scheduling system, even if this information is uncertain. In Fig. 1 the part of the project described in this paper is highlighted by a red broken-lined frame.

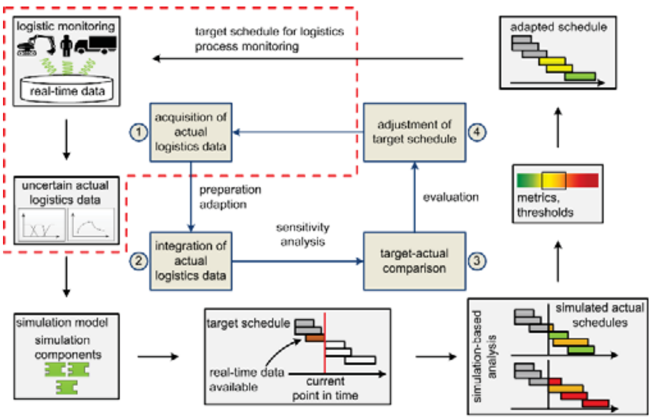

Fig. 1 Focus of the paper in the context of the cyclic reactive construction scheduling approach (based on a figure from [4])

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The unsolved questions handled in this paper is: Is there a way of formalizing a procedure for confirming resource requirement profiles defined by an initial construction schedule or for modifying resource availability assumptions for a reactive scheduling cycle using real-time data about logistic processes? How can the data sets about these resource availability assumptions be designed? The way found by the authors is described in the following section.

II. Procedure for Linking Actual Resource Availability Assumptions to Planned Resource Requirements of the Construction Schedule after Real-Time Detection of a Disturbance in a Logistic Process

A. Step 1 - Getting Information about Resource Requirements from the Initial Construction Schedule

Logistic in this context means the procedure of making required resources available. The first step of logistic planning in the context of the project is getting information about the resource requirement profiles of a construction project. This information can be taken from construction production schedules if these are generated using a method of resource constrained scheduling. The interdependence between resource availability assumptions as an input and resource requirements as an output of the initial scheduling process is neglected at this point. In general a logistic planner must be able to generate a list of resource requirements for a construction site that corresponds with the initial construction production schedule. Thereby the single resource requirement data sets can be automatically linked to single construction production processes or even process steps.

For this paper we use a simple example for resource requirements. Fig. 2 shows a section of a construction schedule, that reflects the work brake down structure (WBS) of the construction project or a part of the project. For the construction production task B of the WBS the required resources are given in a resource requirement table linked to the task B. For task B the requirement profile consists of one precast element that should be delivered just in sequence on April 1st 2015, three workers with the ability to mount this element on the same day between 10 and 12 a.m. and a mobile crane. From the construction production schedule we know, that the workers and the mobile crane are bound for other works before 10 and after 12 a.m.

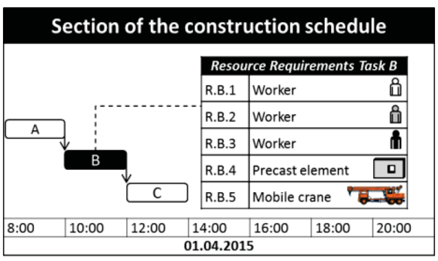

Fig. 2 Data from the initial construction production schedule: resource requirements

The procedure of generating lists of resource requirement profiles after resource constrained scheduling has be done is implementable in scheduling software systems, so that from the point of research there is no need for manual interaction for generating the lists of resource requirement profiles corresponding to a developed construction production schedule.

B. Step 2 - Modelling Construction Logistic Process Chains

The logistic planner now has to model the process chains of making these resources available. If he later wants to monitor the fulfillment of the process steps of the single logistic process chains, he has to schedule the logistic process chains as part of his construction logistic process schedule. For modeling the logistic process chains for the single resources he can either use experience and expertise, which means data in his mind, communication processes, which means data generated e.g. by talking with suppliers of this resource, or formalized data which e.g. could be taken from knowledge data bases, e.g. expert systems, or books.

If resources are classified, the process of linking logistic process chains to construction production processes with defined resource requirements, e.g. in the case of resource constrained scheduling, is possible after the work of formalizing typical logistic process chains has been done once. In the case of formalized logistic process chains, the linking of default logistic process chains to single construction production processes can be done automatically.

So in general logistic process chains can be formalized for every resource used for construction work, whereby there will be a high dependence from local parameters and context. So in real life logistic planners will have to define their individual default logistic process chains.

For task B of the example the generated logistic process chains as a section of a corresponding construction logistic schedule are shown in Fig. 3. There you can see process steps and their linkage to the corresponding construction production process in a simplified way. In real life these process chains of course often will be more complex considering different junctions and/or intersections. Each process step or task of the logistic schedule includes linked information. As an example the start and end times linked to process step R.B.4.-10 are shown in the small table.

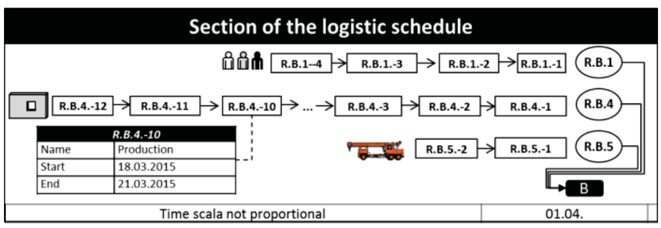

Fig. 3 Construction logistic process chains R.B.1 to R.B.5 linked to the construction production process B with example-data for process step R.B.4.-10

C. Step 3 - Monitoring of Construction Logistic Process Chains and Rules for Alerts

For monitoring the processes of making the resources available the logistic planner has to define points of monitoring. That means he must find ways to detect that something belonging to the corresponding resource has or has not happened as planned until a defined point of time. Therefore he has to think about relevant process steps which can be controlled. Therefore controlling could be done, as focused in this paper, e.g. by auto-ID-systems without manual input, but in general also by automated procedures which require manual input.

For handling real life resources and real life detection points it is useful to make these objects identifiable by outfitting these objects with ID.

For generating monitoring rules the logistic planner e.g. has to define which resource object, which e.g. is detectable by a resource object ID, has to pass which detection station, which also could be identifiable by a detector object ID, until which point of time.

Therefore it is necessary to link the virtual resource requirements to identifiable real world resource elements, as shown e.g. in [11]. Reference [12] shows, that therefore modelling of data about the construction work and the construction object itself, e.g. by using the method of BIM (Building Information Modelling) has to be done in a way fulfilling the data-needs in all corresponding processes. For real time logistic monitoring a high level of detail (LoD) is necessary in the logistic planning. And a high LoD in logistic planning requires a high LoD of construction production planning, e.g. a high LoD of construction production schedules with all information about the resource requirements linked to the single construction production tasks.

If a logistic planner works with formalized process chains, he would be able to integrate typical points of monitoring as default values in his process chains, e.g. as mile markers that are linked to the corresponding control information.

For the example of the precast element requirement R.B.4 some points of control are given in Fig. 4. As an example the data needs for defining a monitoring rule for the monitoring point R.B.4.-10_end is shown.

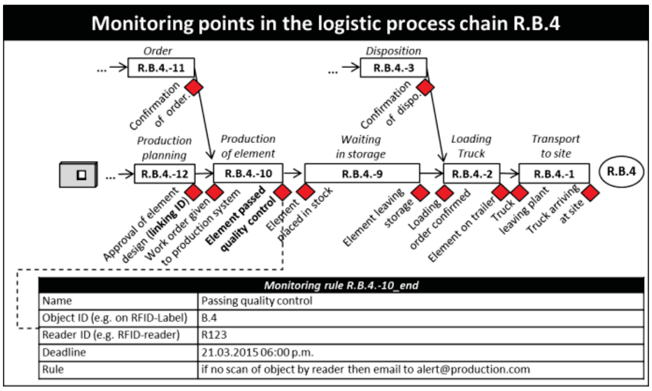

Fig. 4 Points of monitoring visualized as milestones at the beginning and end of process steps

The monitoring rule is: If real life object with ID B.4 (precast element for task B) won’t pass real life reader ID R123 (e.g. reader at exit of the precast fabrication plant or reader at the entrance of the precast production plant’s storage) until 6 p.m. on March 21th 2015, an alert has to be generated and sent to the production manager by e-mail.

To demonstrate the concept of monitoring rules using real life ID for resource detection at real life detection points some other examples are given below:

1) Detection of persons using ID-cards at the entrance of construction sites.
2) Detection of machines using RFID- or barcode-tags by an auto-ID reader of the construction site’s machine and tool management system.
3) Detection of materials using RFID- or barcode-tags by auto-ID readers alongside the supply chain, e.g. at the gate of the supplier, by a mobile reader which is part of the contractors material management system etc.
4) Detection of paper based documents using barcodes by auto-ID readers e.g. within incoming goods inspections, within the delivery of planning documents, permits or work orders etc.

Other monitoring rules for automatic monitoring can be defined for process steps of the logistic process chains not dealing with real life objects equipped with auto-ID-tags. E.g. workflows can be monitored automatically. Examples are:

1) Detection of the absence of expected electronic data interchange (EDI) processes or missing content in enterprise resource planning (ERP) systems.
2) Detection of the absence of expected electronic data interchange (EDI) processes or missing content in project content management (PCM) systems.
3) Detection of the absence of expected electronic data interchange processes or missing content in operating and machine data logging systems or in computer-aided production data acquisition systems.
4) Getting information about weather conditions from web services.
5) Getting information about traffic situation from web services.

Because in real life monitoring of all logistic process chains for a construction project won’t be fully automatable, the concept of real time monitoring using formalized rules has to be compatible with manual monitoring. So alerts used in the following steps also can be generated by or after human interaction. Some examples for situations in which human monitoring is necessary are:

1) Visual quality control processes.
2) Weighting of resource quality, e.g. personal soft skills and experience and concluding.
3) Weighting the influence of a disturbance from other projects on resource availability of the actual project (multi-project interdependencies).
4) Weighting the influence of the quality of another resource on the resource requirement and availability of the actual resource.
5) Weighting the actual weather conditions and

prognosticating the influence on resources and logistic processes.

6) Considering new information e.g. about future events that hadn't been considered in the last planning cycle and prognosticating.
7) Bounding of renewable resources like e.g. personal or crane-capacity through construction production tasks if there is no real time system for construction progress monitoring.
8) Weighting the influence of accidents and other unforeseeable events.

D. Step 4 – Handling Alerts after Disturbance Detection in Construction Logistic Process Chains

An alert in generally informs a person or IT-system that something hasn't happened as planned. Or, if the logistic process chains or the setting of the control points or deadlines have been done considering float or buffer, an alert means that something probably won't happen as planned.

After an alert was generated by a monitoring system a procedure of alert-handling has to start. The design of this procedure depends on the kind of resource and a lot of project specific parameters, e.g. the involved actors, the time of the alert, the fact if there is buffer or float in the logistic chain at a later step or not etc.

If these procedures are formalized, they can be linked to the single monitoring points described above and initiated by electronic systems automatically. If human interaction is required – and in the authors' opinion it will be, because problem handling requires creative skills that are not automatable today – the process of human interaction can be monitored by electronic systems automatically. So human interaction has to be modelled in the procedure of alert handling.

Fig. 5 shows a possible, simplified procedure for handling the alert for the example of the precast element. It only reflects a small part of real life procedures which often include a lot of more interaction and interdependences. For the precast plant's production manager the procedure starts with an e-mail in his inbox that includes the alert message: "Precast element B.4 didn't pass quality control point R123 as planned until 6 p.m. on March 21th 2015."

This e-mail was automatically generated by the ERP-system that was and is monitoring the precast plant's production and intra logistic processes. The production manager now has to evaluate the alert message using all available data. He has to find out, if the disturbance sent to him from the monitoring system will have any influence on delivery dates or if there are internal ways to handle the disturbance, e.g. by using buffer / float in the planned internal logistic process chain, so that there will be no influence on the delivery dates. If there is influence on delivery dates, the production planner has to send a message to the construction site's logistic planning instance.

He can send this message in a formalized way by EDI or by e-mail to the IT-system of the logistic planning instance. This IT-system e.g. can automatically analyze this message with regard to the existence of rules for handling the content of this message about a disturbance automatically by IT-systems. If there is no way of automatic handling or if the automatic handling will lead to the result that there will be an influence on the actual construction production schedule, the logistic planner will be informed by his IT-system.

His expertise is required and the logistic planner now has to analyze the message. If he finds a way for handling the problem, so that influence on the actual construction production schedule is avoidable, there is no need to inform the scheduler and for reactive scheduling. But if the logistic planner concludes that there will be an effect on the actual construction production schedule, he has to define a message for the scheduler about new resource availability assumptions.

And in the context of the ongoing research project this message is formalized as shown in following step 5. This formalized message can be received by the scheduler automatically by IT-systems which are responsible for the further workflow of reactive scheduling.

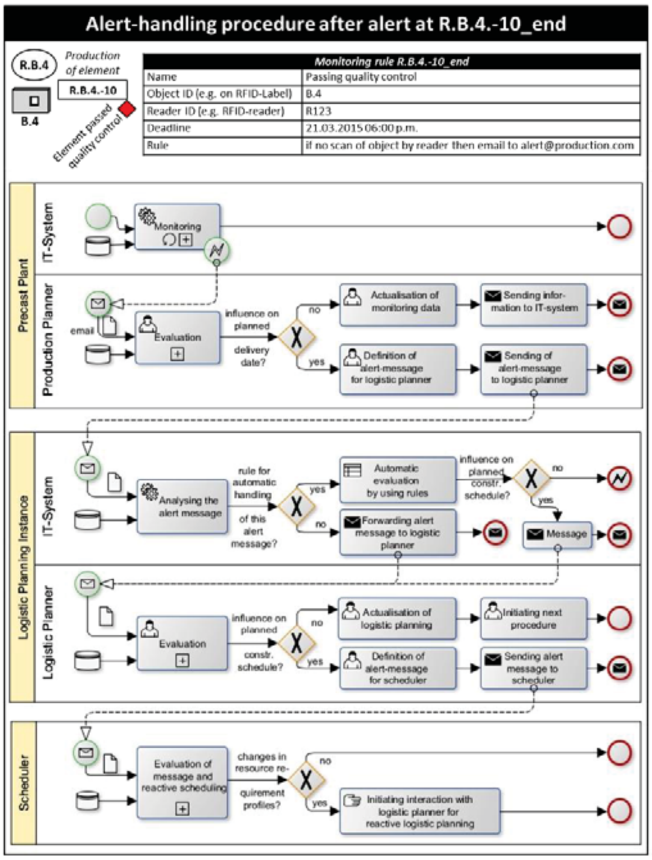

Fig. 5 Procedures of handling an alert modelled in BPMN (Business Process Modelling Notation)

E. Step 5 - Generating Certain or Uncertain Resource Availability Assumptions Usable for Reactive Simulation

After an alert the main result of alert handling procedure as an output from the logistic system is a new set of assumptions about resource availability linked to the resource requirements of the initial schedule's tasks. Because this set of assumptions generated by the logistic planner should be used by the construction scheduler's system automatically, these assumptions have to be formalized into machine-readable data.

In the context of the research project especially the formalization of uncertain assumptions had to be solved, using the fuzzy concept introduced by [13]. In this concept the degree of memberships reflects the possibility, not probability.

The authors found that resource availability assumptions data sets could be modelled as shown in the Fig. 6. Hereby the data set is able to handle certain, uncertain and probabilistic data in the same way.

Formalized resource availability assumptions

Resource Availability Assumption Data Sets	
Res. Avail. Ass. Data Set ID	RAADS.000001
Timestamp	31.03.2015 06:15 p.m.
Resource ID	B.4
Resource Amount Value Set Value 1	1
Resource Amount Value Set Value 2	
Resource Amount Value Set Value 3	
Resource Amount Value Set Value 4	
Resource Amount Value Set Function	
Earliest Time of Avail. Val. Set Val. 1	02.04.2015 06:00 a.m.
Earliest Time of Avail. Val. Set Val. 2	03.04.2015 10:00 a.m.
Earliest Time of Avail. Val. Set Val. 3	04.04.2015 18:00 p.m.
Earliest Time of Avail. Val. Set Val. 4	05.04.2015 18:00 p.m.
Earliest Time of Avail. Val. Function	
End Time of Avail. Val. Set Val. 1	
End Time of Avail. Val. Set Val. 2	
End Time of Avail. Val. Set Val. 3	
End Time of Avail. Val. Set Val. 4	
End Time of Avail. Val. Set Function	
Comments	

Interpretation schema and examples of visualization

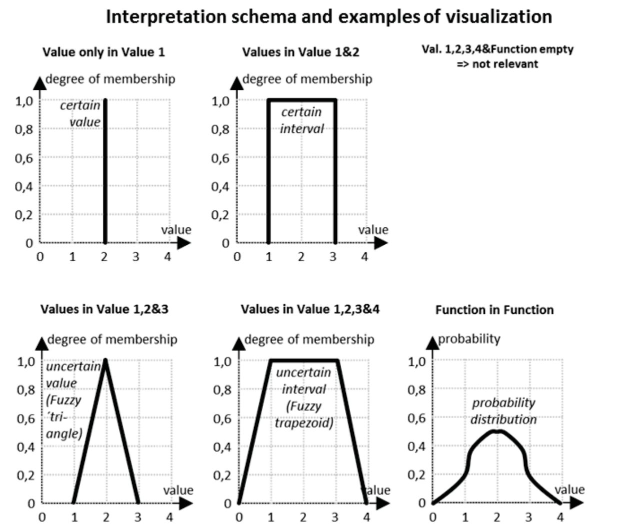

Fig. 6 Formalization of resource availability data sets: certain, uncertain (fuzzy) or probabilistic

Uncertainty could be expressed for amounts or/and time-values about resource availability. The following examples will help to explain the concept:

1) Uncertain value set reflecting the statement "Resource 123 will arrive on site around next Tuesday to next Thursday instead of next Monday as planned." (4 values for the "time of avail. value set" => fuzzy interval for expected time of delivery):

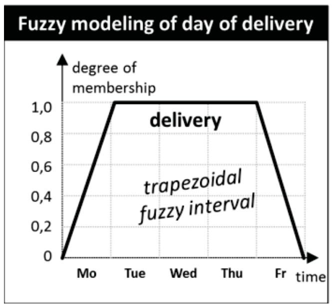

Fig. 7 Example for trapezoidal fuzzy interval

2) Uncertain value set reflecting the statement: "We will only be able to deliver around 100 cbm of concrete tomorrow instead of 400 cbm as planned." (3 values for the "resource amount value set" => fuzzy value for expected amount of delivery).

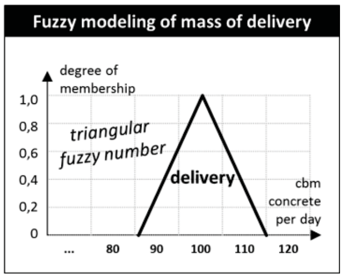

Fig. 8 Example for triangular fuzzy value

3) Certain value set reflecting the statement: "We will deliver exact 1 cbm and will be on site for unloading from exact 2 p.m. until exact 3 p.m." (1 values for the "resource amount value set" => certain value for amount of delivery, 2 values for the "time of avail. value set" => certain interval for time of delivery).

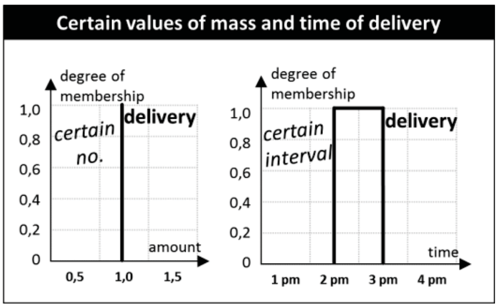

Fig. 9 Example for certain value and certain interval

F. Step 6 - Sending Formalized Certain or Uncertain Resource Availability Data to the Reactive Scheduling System

To initiate a reactive construction production scheduling process, the new resource availability assumption data sets now have to be sent to the scheduler. Because they are modelled as machine-readable data sets which, as a result of the formalized procedure are exactly linked to the resource requirement output list corresponding to the last construction schedule, the scheduling system now has all information needed for starting the simulation processes as shown in [4].

III. Open questions in the Context of Reactive Logistic Planning, Monitoring and Assumption Making

A. Procedure for Handling "Fixed" Resource Availability during Reactive Scheduling

The shown procedure only generates new assumptions about resource availability for those resources initiating an alert. But due to logistic planning at the time of reactive scheduling in the worst case all resource requirements which have been defined by the initial schedule must be seen as "fixed" resource availability assumptions for the reactive scheduling procedure, even if initial scheduling has been done considering endless resource availability for some of the now "fixed" resources. Therefore a new method to handle these "fixed" resource availabilities in the reactive scheduling procedure have to be found in addition to the shown procedure. This probably requires a lot of interaction between the logistic planner and the scheduler as well as the resource suppliers and the handling of this aspect has to be part of future work.

B. Procedure for Handling the Changes in Resource Requirements after Reactive Scheduling

After reactive scheduling there probably will be a new construction schedule with a corresponding resource requirement list that will probably differ from the list corresponding to the initial schedule. So after each cycle of reactive scheduling a procedure of reactive logistic planning has to start. The handling of this aspect also has to be described in future papers.

C. Procedure for Evaluating the Gap between "fixed" Resource Assumptions and Changed Resource Requirements during and after Reactive Scheduling

Looking at the two points above it seems to be advisable to create a procedure, which leads to a new optimization criteria for choosing one of the different alternative reactive schedules. This criteria has to reflect the gap between resource availability already "fixed" at the point of time of reactive scheduling due to logistic planning and the new list of resource requirements. The handling of this aspect has to be described in future papers about optimizing reactive schedules.

IV. Conclusion

The paper shows, that the procedure of confirming resource requirements defined by an initial schedule or modifying resource availability assumptions for a reactive scheduling cycle using real-time data about logistic processes can be formalized. Data exchange without gaps between different involved software systems generally is possible from the point of research. It is possible to link unspecified resource requirement delivered as output from resource constrained construction scheduling systems to specific ID of real life objects in logistic processes that could be tracked and traced in logistic systems automatically, when a logistic monitoring system has been established in a formalized way. And also the way of getting from alerts about disturbances in logistic process chains to resource availability assumptions for reactive scheduling could be formalized. Certain or uncertain resource availability assumptions defined by this procedure can be delivered to a reactive scheduling system as mathematical interpretable, machine readable data sets. It was shown, that in different steps of the procedure the concept is open to alternative manual interaction instead of a full automatisation of all data generating, data exchange and decision making tasks.

The interdependences between resource availability assumptions used for a scheduling process and the influence of the scheduling system itself on these assumptions as well as some other aspects of iterative relationships are neglected in this paper leaving space for further research.

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