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SIMULATION OF IN-TRANSIT SERVICES IN TRACKED DELIVERY OF PROJECT SUPPLY CHAINS: A CASE OF TELECOM INDUSTRY

Giacomo Liotta

Center for Industrial Production

Aalborg University
A.C. Meyers Vænge 15
Copenhagen, DK-2450, DENMARK

Jan Holmström

Department of Industrial Engineering and Management
Aalto University School of Science
POB 15500
Aalto, Espoo, FI-00076, FINLAND

ABSTRACT

Network construction projects in telecommunication industry require large amounts of materials and components available at multiple sites. Items are often customized, valuable and delivered following design specifications subject to frequent changes. When design changes occur, lack of real-time item visibility and traceability can lead to excess inventories at sites, errors, and inefficient transportation. Supply chain digitalization based on Internet-of-Things can mitigate these waste and inefficiency risks. This work aims to estimate the potential benefits of in-transit services based on in-transit control for project network construction operations. Two services are analyzed: Re-direct service based on item re-routing to and reusability for other sites; and Call-back and delivery-on-request services based on centralized collection of items temporarily unneeded at any sites any longer. These services are simulated and evaluated for a telecom network project case study. Experiments show that the in-transit services lead to remarkable improvements mainly of component waste and dwell times.

1 INTRODUCTION

Complex network construction and installation projects in telecommunication industry require the delivery and availability of large amounts of specific materials and components at multiple project sites. These project supply chains have to be highly responsive and manage flows of items that are often highly customized, valuable and delivered following design specifications of construction and installations subject to frequent changes. However these project environments are quite unpredictable (Ala-Risku et al. 2010). When design changes occur, the lack of real-time visibility and traceability of these goods can lead to excessive inventories of items at project sites unneeded any longer, duplications, errors, and inefficient transportation. The supply chain digitalization achievable through Internet-of-Things (IoT) technologies (Xu, He, and Li 2014) can mitigate these materials waste and inefficiency risks while enabling advanced logistics and transportation services. The objective of this paper is to estimate the potential benefits of in-transit services based on in-transit control for network construction operations, carriers and third party shippers of goods. Two potential services are analyzed: (*i*) Re-direct service based on item re-routing to and reusability for other sites; and (*ii*) Call-back and delivery-on-request services based on centralized collection of items temporarily unneeded at any sites any longer. These in-transit services are simulated and evaluated within the context of frequent design changes of a telecom network construction and installation case study. Discrete Event Simulation (DES) experiments compare scenarios with and without in-transit services mainly on the basis of materials waste indicators, delivery lead times and inventory management indicators.

The paper is structured as follows: Section 2 includes a review of relevant literature and the work's contribution. The problem statement and case study, as well as the methodology are presented in Section 3 and 4, respectively. Section 5 describes the simulation models while Section 6 includes the computational results and their discussion. Conclusions and future research tasks follow.

2 THEORETICAL BACKGROUND AND CONTRIBUTION

The body of literature related to this work addresses two relevant themes: (*i*) means to confer visibility and intelligence to product-centric supply chains; and (*ii*) logistics, transportation and supply chain management for capital investment projects supported by this means, with cases mainly from telecommunication and construction industry.

Concerning the first theme, items and process digitalization is particularly important in operations management for project and service supply chains. Individual product tracking is an intervention leading to efficiency and differentiation improvements in project delivery, industrial asset management, and industrial service delivery (Holmström, Främling, and Ala-Risku 2010). It makes it possible to reduce information loss in decision making when variable customer processes and requirements are present and there is a need for coordination of the involved supply-chain actors throughout the asset lifecycle (Holmström, Främling, and Ala-Risku 2010). This finding is aligned with the aim of overcoming products idleness, mismanagement of storage location decisions as well as delayed delivery times to actually needed usage points through smart tags and ubiquitous connectivity (IoT elements) for objects distributed self-control in the concept of physical internet (Montreuil 2011). The application of IoT technologies to industrial cases looks already promising within the context of logistics and transportation to track both objects and transportation processes (Xu, He, and Li 2014).

The second theme is motivated by the unpredictability of capital investment projects due to engineering design often taking place in parallel with project delivery (Ala-Risku et al. 2010). Therefore, supply chain agility as well as accuracy and robustness of planning of installations' tasks and inventory enabled by item tracking constitute key elements as the complexity of projects increases (Ala-Risku et al. 2010). The strong limitations of project management methods for efficient and responsive material flow management have been tackled by devising a delivery model based on materials tracking methods for transparency and near-term project task scheduling (Ala-Risku and Kärkkäinen 2006). Uncertainty and variation of procurement processes may cause long lead times and time waste in engineer–procure–construct projects, thus requiring flexible and dynamic scheduling, synchronization and control of project supply chains (Yeo and Ning 2006). A critical supply chain management model based on integrated dynamic planning process, partnering relationship and inter-enterprise information system has been proposed (Yeo and Ning 2006). In project supply chains, dwell time has been introduced as novel inventory management metric in order to cope with the uniqueness of specific items and overcome the limitations of aggregate metrics such as inventory turns (Holmström, Tenhiälä, and Kärkkäinen 2011). However, additional metrics related to materials waste have not been investigated in parallel so far.

In-transit services based on customer options to delay, redirect or combine shipments of smart goods operated by transport operators have been introduced and successfully tested through simulation demonstrating the possibility to achieve operational efficiencies in hub & spoke and direct shipment transport on the basis of transport-related performance indicators (Arnäs, Holmström, and Kalantari 2013). Simulation is deemed very important to support decision-making processes, evaluate models and strategies in intelligent freight transportation systems (Crainic, Gendreau, and Potvin 2009). However, there is still little research on simulation role and usage in supply chain digitalization in general, and project supply chains in particular, with simultaneous consideration of wide sets of indicators.

This work contributes to bridging this gap by exploring new services and a set of newly grouped performance indicators for supply chains serving capital-intensive projects. More specifically, it considers two types of in-transit services, out of which one entails a logistics network re-configuration. Key service performance indicators addressing waste, time and inventory are used to compare the new services. The aim is to produce significant savings in planning and execution of complex projects that make use of expensive materials, components and project resources. Implications for environmental sustainability in terms of obsolescence risk mitigation and material waste are also relevant.

3 PROBLEM STATEMENT AND CASE STUDY

The problem is to identify effective means to reduce the components waste, project duration as well as potential component obsolescence when frequent design changes occur in project supply chains traversed by high value-added items and subject to high responsiveness requirements. The goal of this research is to estimate the potential benefits of two new logistics and transportation services in this complex supply chain scenario and related operations within the context of telecommunication industry projects.

The risk of material waste of customized systems that have to be supplied and installed in such project supply chains can have a huge, detrimental impact on project assets and finance. The reusability of unneeded materials at other project sites is difficult to exploit, especially when there is limited visibility and availability of IT devices and tools able to timely and precisely communicate inventory details of installation sites. Therefore, component waste is an indicator of primary importance to be minimized. The design changes may also prolong the project duration because of the new specifications required in geographically dispersed locations that have to be met eventually through new instances of production and distribution processes. Again, the lack of visibility of items that are already available and unneeded significantly contributes to this potential risk. Hence, the time indicator of project duration including also the event of design changes is highly relevant as well. Moreover, the inventory levels of the components not utilized, whilst of great importance to measure the asset value, do not fully reflect the impact of keeping high-tech components stored for long times at project sites. These time intervals unnecessarily prolonged may most likely cause obsolescence risks. Therefore, an additional time-related key performance indicator is the dwell time, i.e., the time between the receipt of an item at a project site and its issue (Holmström, Tenhiälä, and Kärkkäinen 2011), e.g., for utilization at or transfer to other locations.

Potential solutions address better equipment utilization and project time performance, as well as new logistics and transportation services based on intelligent control logics enabled by track & trace devices embedded in items and project resources (Arnäs, Holmström, and Kalantari 2013; Ala-Risku et al. 2010). These supply chains can be very complex and typically consist of multiple installation sites. It is however very difficult to estimate the impact of in-transit services based on in-transit control on network operations, carriers and third-party shippers. These in-transit services aim to (*i*) move components that are already present in the project supply-chain sites to supply other project sites requiring the same component specifications (redirect services), or (*ii*) centrally handle and deliver components that are collected at project sites when they are unneeded anymore. Therefore, the in-transit services that are investigated here are:

1. Redirect services based on component re-routing to and reusability for other project sites.
2. Call-back services, for the extreme case of impossibility to provide redirect services, and subsequent delivery-on-request services from centralized warehousing locations.

This work is based on a case study of telecommunication industry. The problem instance used in this work is envisioned following a realistic replication of such scenario of network operations.

In this work, more than 100 projects have to be carried out within the context of a network of 12 project sites. The projects are launched with a frequency entailing a portfolio of approximately 12 activated projects each month. Each project has an average duration of about 40 days. Transportation resources (carriers) are utilized to deliver the components from the sourcing locations of third-party shippers and between the project sites. The time horizon of the investigation is one year.

4 METHODOLOGY

For this kind of problem the use of an analytical approach can make it difficult or even impossible to simultaneously capture the dynamic system behavior (including the in-transit services provision), visibility and states of items and projects (especially in the event of design changes), and evaluate the selected service, time and waste indicators. Simulation is one of the alternatives to study the mechanisms supporting the explanation of how interventions generate outcomes (Holmström, Främling, and Ala-Risku 2010). Here the outcome is the system performance according to the goals of this study. Simulation is therefore suitable for this case (dynamic simulation models particularly). The method used to tackle the problem is DES. Compared to continuous simulation approaches such as system dynamics, DES can capture all the necessary details of items, projects, services and system (events, conditions, objects properties, etc.), as well as randomness. DES is indeed used more frequently than system dynamics in problems concerning supply chain structure, supply chain optimization, distribution and transportation planning, and it is highly used for inventory planning/management (Tako and Robinson 2012). Hence, DES has been chosen because:

- The supply chain scenario is particularly complex and subject to randomness of lead times and high probabilities of design changes, making the use of analytical models extremely problematic.
- The supply chain scenario ideally consists of various actors (i.e., component suppliers – third-party shippers, carriers, project contractor) handling specific, differentiated and valuable objects.
- The simulation models can dynamically reproduce the real-time availability of objects data.
- Routings, inventories and flow times of the discrete objects across the network can be evaluated.

The study has been conducted by, first, identifying the study goals and key performance indicators to be analyzed. Secondly, the definition of the scenarios of interest to be compared and a conceptual representation of the supply chain have been carried out. The key model logics have been represented by using Business Process Model and Notation (BPMN) 2.0. Third, the simulation modeling tasks have been performed following an incremental approach based on the upgrading of the models, from a basic scenario to the most complicated ones which reproduce the in-transit services. For each finalized model, verification and validation have been done by iteratively observing the output in relation to predefined inputs, in both deterministic and random situations, and improving the models, as well as by visual observations. The results were coherent with the overall conceptual system representation and satisfactory for the goals of the study at the present stage of this research. Being not existing in-transit services, this study step was particularly challenging but also inspiring for service modeling. Finally, the experimental campaign has been conducted together with the analysis and discussion of the results, and documentation.

The simulation design principle is based on modeling the projects and each item (component) because of the need to simulate over the time its data, status, location, history, (re-)planned and actual use. This is highly important to simulate the real-time visibility of items and related information enabled by IoT technologies, as well as the precise identification, handling and transport of items in the provision of the in-transit services. On the one hand, this approach can lead to high computer memory loads for problem instances with very high quantities of items to be handled. On the other hand, for the tackled problem instance this approach allows for very detailed analyses in reasonable computational times (see Section 6 for details). Nevertheless, the model design choices for the efficient simulation of such supply-chain and IoT systems are particularly stimulating in studies regarding smart products and highly digitized supply chains of the future. As an alternative, the pure implementation of agent based simulation can also be relevant to the investigation of distributed decision-making processes in these systems. In the studied scenario, basic decision logics are used for automated flows of entities and services provision at this research stage. Their proper activation and synchronization are however quite complicated.

This work is based on a single case study. The scenario is envisioned following the key characteristic of the case study faced in (Ala-Risku et al. 2010).

5 SIMULATION OF IN-TRANSIT SERVICES

The simulation reproduces a project network consisting of 12 project sites. A demand of maximum 108 projects to be executed is distributed throughout one year with an exponential interarrival time of projects. Each project requires one component that can be customized according to four different specifications. A quantity (number of items) of the specific component is also demanded by each project. Three simulation models have been built at this stage of the research. The first one is the Baseline model in which no in-transit service are provided. The second one (Redirect Services) includes the redirect services between project sites, i.e., the transfer of components available and not utilized at a certain project site to another project site where are needed. The third model (Call-back & Delivery-on-Request) simulates the call back and delivery-on-request services in addition to the re-direct services, i.e., the periodic collection of components not utilized at project sites and the delivery of centrally stored components upon request of a new project. In the models there is an extensive use of data dynamically generated throughout the simulation runs, stored in dedicated tables and used. This feature aims to mimic the availability of data of items and service delivery processes enabled by IoT technologies. The models have been designed following a modular structure of, e.g., central logic of projects generation, component generation, routing, data writing and reading processes throughout a simulation run. The simulation models have been developed using Simio Version 8.132 (Aalborg University uses Simio under a grant from Simio LLC).

5.1 Description of the Baseline Simulation Model

The basic logics of the Baseline model are presented in Figure 1 using BPMN. First, the projects are created and execute the main project activation process. This process triggers the creation of the required components that carriers deliver from third-party shippers to the project sites according to the initial demand of component specification and quantity (as planned) in order to allow the project execution. The projects can however undergo a design change with a probability of 50%. Each design change occurrence randomly assigns the new specification using approximately equal probabilities. In this event, the creation and delivery to the project sites of the required components following the new design change specification are carried out. The projects are then executed at the project sites with a processing time following a Triangular probability density function (Table 1). The components initially delivered as planned and not utilized are kept in inventory at the project sites where they were originally assigned and delivered to. The delivery of the components of the initial demand requires a transportation lead time while the components requested in the event of a design change require an additional lead time to be delivered. These lead times follow the Triangular probability density functions presented in Table 1. All the design changes occurred, their location and components details are dynamically registered in a dedicated table in the simulation model.

Table 1: Time input parameters.

Time Parameter (days)	Probability Density Function
Projects interarrival time	Exponential (2.5)
Project duration	Triangular (32, 40, 48)
Components delivery lead time	Triangular (1.5, 3, 4.5)
Transport lead time (Design change)	Triangular (3, 6, 9)
Transport lead time (Redirect services)	Triangular (0.3, 0.6, 1)
Transport lead time (Call back/Delivery-on-request)	Triangular (0.5, 1, 1.5)

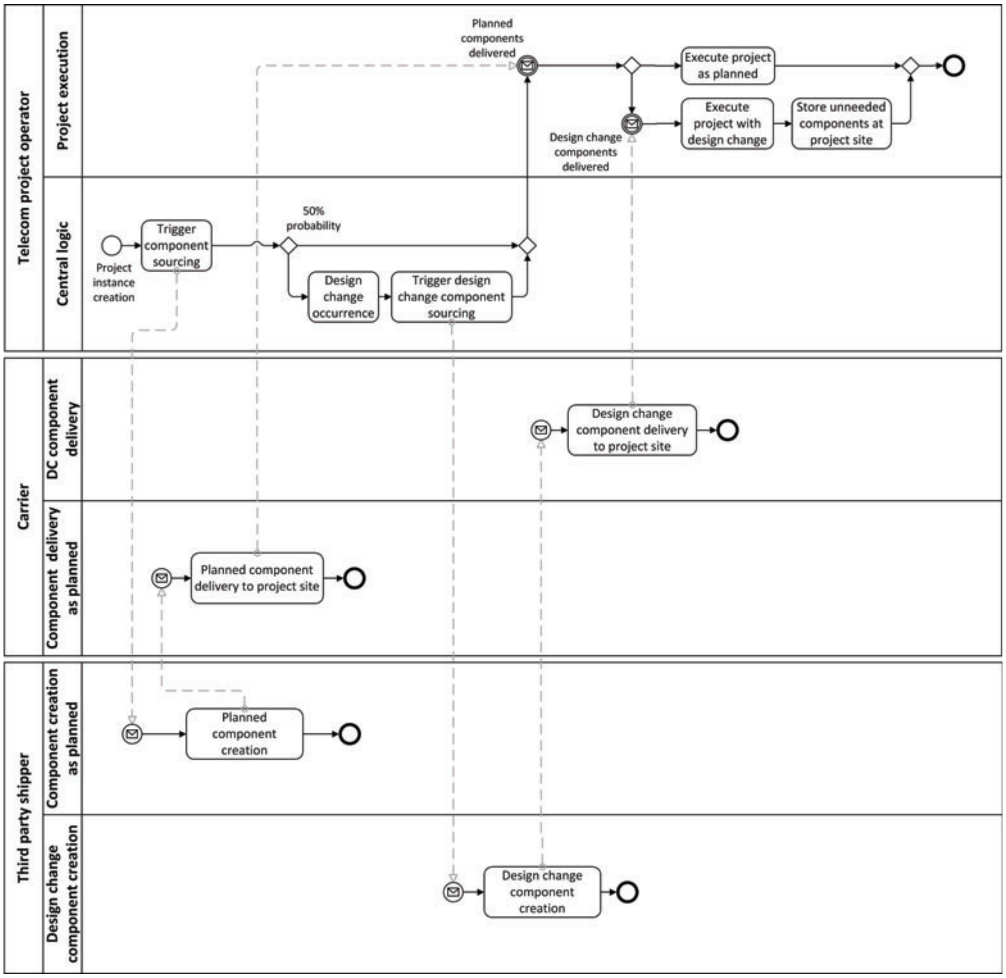

Figure 1: Main logics of the Baseline model.

5.2 Description of the Redirect Services Simulation Model

The main logics of the Redirect Services (RDS) model are presented in the BPMN diagram in Figure 2. The model builds upon the basic structure of the Baseline model. Nonetheless, this new model includes substantial differences and add-ons in the central logic as well as in the logical modules to mimic the provision of the redirect services. A project, after being generated, might again incur in a design change request with 50% probability. In this case, the components initially requested and already delivered in the initial stage are dynamically registered in a table during the simulation run. This table contains the necessary data regarding the project, the component specification, quantity, and location. First, for each newly generated project (a new project instance), a search for available and unneeded components and related quantity in the overall project sites' network is carried out using the mentioned table. Second, if a needed component is available, a specific process flow launches the activation of a redirect service. A redirect service, according to the origin and destination project sites, specification, and quantity of the available components, picks them up at the origin site where they are not needed anymore and transport them to the destination site where the new project instance is ready to receive them. The available quantities over the network are updated accordingly when they are promised. A redirect service is subject to a transport lead time between the origin and the destination. A dynamic table of the redirect services provided is filled-in throughout the simulation run. The search and identification of available components and the potential provision of redirect services are the first process steps a project instance incur in. Therefore, they do not trigger the production and delivery of new components unless the search process does not succeed. In this latter case, the project instance requires the production and delivery of the required component but can again incur in a design change probability equal to 50%. If a design change is not needed, the production and delivery of the required components ordinarily takes place and the project is carried out as initially planned. Otherwise, the design change process is initiated as described in the Baseline logic and the search table is updated accordingly. The identification of available components at other project sites and the subsequent provision of redirect services are not subject to probabilistic design changes.

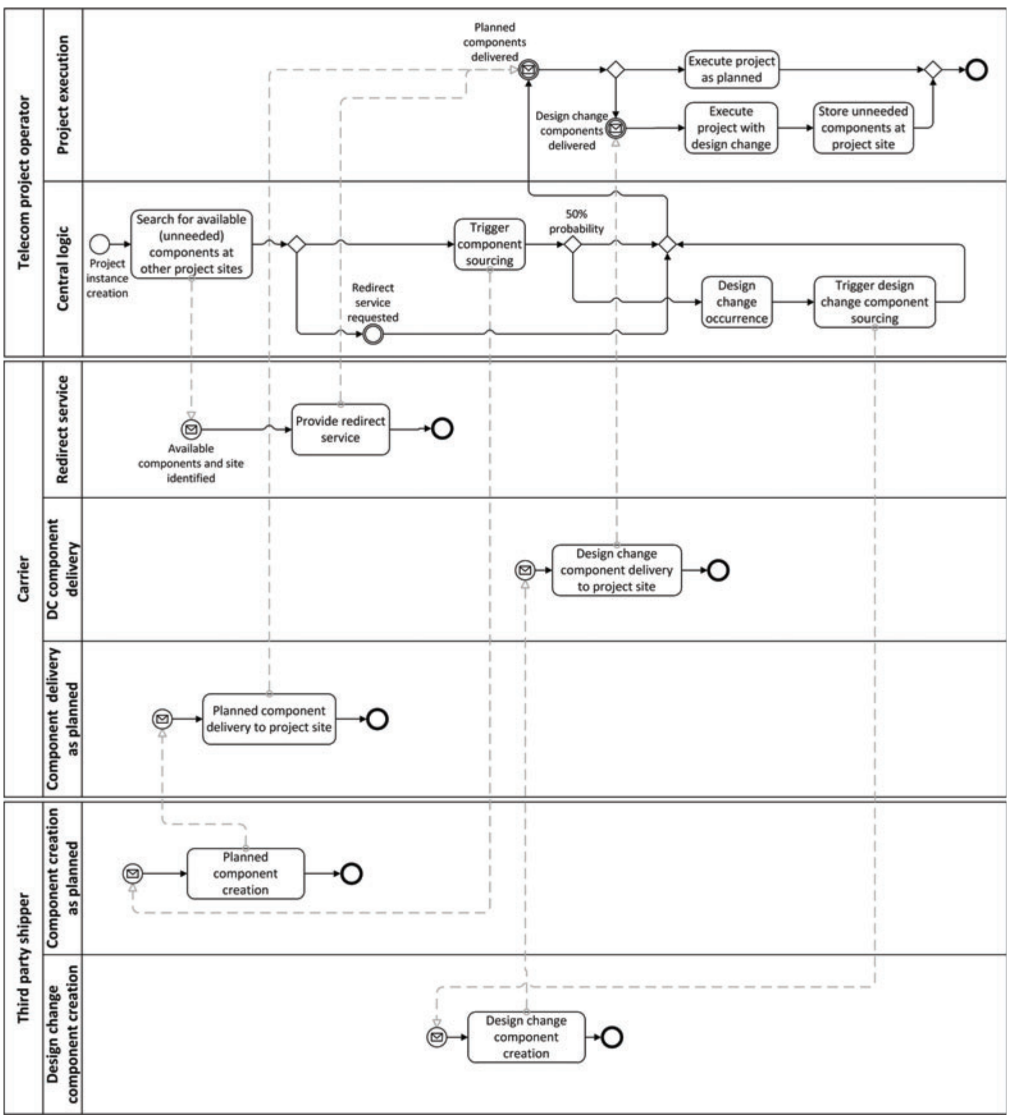

Figure 2: Main logics of the Redirect Services model.

5.3 Description of the Call-back & Delivery-on-Request Simulation Model

The Call-back & Delivery-on-Request (CB-DoR) model is built upon the logic of the Redirect Services model. However, in this model two additional features and service logics are added. The first one concerns (*i*) the call-back service process while the second one (*ii*) the delivery-on-request service process.

In the former service process, a dedicated logic monthly generates call-back services to collect from the project sites the components that are available and unneeded. The collected components are moved to a central warehouse where they are stored. Dedicated processes dynamically register the call-back services produced and the service details (e.g., quantity called-back, specification, origin site) as well as the dynamic update of the warehouse database where the quantities and specifications of the inbound components and total quantities are updated.

The central logic controlling the generation of project instances of the CB-DoR model is therefore an upgrade of the corresponding one of the Redirect Services model. In fact, when a new project is launched, its corresponding instance, first, searches for the required component that might be available and unneeded in the project network, i.e., the project supply-chain network, in order to launch a possible request for a redirect service.

If this search does not succeed, then a new search on the database of the central warehouse is carried out. This results in the potential provision of the latter service belonging to the overall CB-DoR. In fact, in the event of identification of the needed component and quantity at the central warehouse, a delivery-on-request service process is launched in order to provide the enquiring project instance with the components at the right project site where the project can be implemented. Also in this case, the outbound component flows trigger the update of the database when the component quantity is promised. If also the search in the central warehouse does not succeed, the project instance follows the normal path. It therefore triggers the production and delivery of the new components which might either be regularly executed or subject to design changes, thus entailing all the above described consequences.

Both call-back and delivery-on-request service processes entail a transport lead time following a triangular distribution (Table 1). A 3D screenshot of the CB-DoR model is presented in Figure 3.

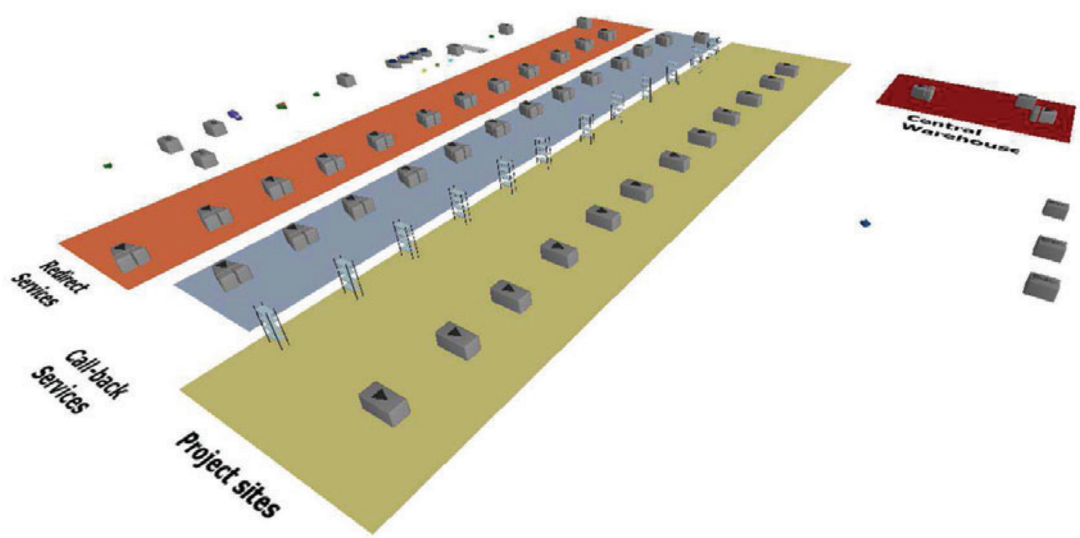

Figure 3: Screenshot of the Call-back & Delivery-on-Request model.

6 COMPUTATIONAL RESULTS AND DISCUSSION

According to the study goals, the experimental campaign compares the three models on the basis of the following key performance indicators:

- Waste rate, measuring the items produced-delivered and not utilized with respect to the total produced-delivered.
- Average and maximum total project duration (Avg. total time, Max. total time).
- Average and maximum design change flow time, from occurrence to project finalization (Avg. DC time, Max. DC time).
- Number of redirect services provided (No. RDS).
- Number of call back services provided (No. CBS).
- Number of delivery-on-request (from central warehouse) services provided (No. DoRS).
- Average and maximum dwell time at project sites (Avg. DWT, Max. DWT).

For each model experiment, 50 replications (95% confidence interval) are carried out. The actual run time of each replication is less than 4.5 seconds on a Dell Latitude laptop computer running Microsoft Windows 7 operating system with Intel(R) Core(TM) i7-4810MQ 2.80 GHz processor and 8 GB RAM.

The results are summarized in Table 2 while for the dwell times in Figure 4 and 5. The results presented are average (AVG) and half width (HW) for each indicator.

First, it can observed that the baseline model, as expected, produces a quite high percentage of wasted components due to the fact that there is a straight replacement of initially planned component specifications in the event of design changes (Table 2). With the introduction of the redirect services the waste rate is reduced by approximately 56%. This is the effect of the preliminary search of new project instances for available components in the network before requesting the delivery of components from the third party shipper. Remarkably, in the CB-DoR model, the waste rate reduction is approximately 73% with respect to the baseline model, and 38% lower with respect to the redirect services model. Here the cumulative effect derives from the two-level preliminary search for unneeded components, firstly at project sites level and, secondly, at central warehouse level, respectively. The simulations also produce the following maximum waste rates: 45.7% (Baseline model), 29.5% (Redirect Services), 20.9% (Call-back & Delivery-on-Request). This confirms the benefits of these in-transit services in the worst cases.

Table 2: Simulation results.

	Baseline Model		RDS Model		CB-DoR Model	
Indicator	AVG	HW	AVG	HW	AVG	HW
Waste rate (%)	40.4	0.8	17.6	1.1	10.9	1.0
Avg. total time (days)	83.1	2.9	59.0	2.2	63.7	1.5
Max. total time (days)	131.7	5.2	160.5	5.9	183.0	5.8
Avg. DC time (days)	83.2	3.0	76.2	2.3	77.0	1.7
Max. DC time (days)	128.7	5.3	123.6	6.9	125.9	6.6
No. RDS	-	-	27.4	0.9	21.3	0.8
No. CBS	-	-	-	-	22.5	0.9
No. DoRS	-	-	-	-	15.7	0.6

Concerning the project durations, the average and maximum values of the baseline model are significantly higher than the RDS model, which produces a reduction equal to 29% for the average value but an increase of approximately 22% for the maximum value. The introduction of the redirect services speeds up the average execution time of projects in the network because of the lower lead time to acquire the components for new projects and, on average, less congested project supply chain. However, the increase in the maximum value can be caused by a stronger effect of projects that must wait for new components when these are not available at the other project sites. In the CB-DoR model, these performance deviation trends are confirmed, but with a lower positive effect on the average project duration (-23.3%) and significantly higher maximum value with respect to the baseline model (+38.9%). This amplification can be explained by the longer times to receive, potentially, the requested components from the central warehouse and use them, as well as the reduced number of redirect services provided. Again, in the worst case (maximum value), some projects might be blocked at project sites for longer times before execution. Overall, this performance of CB-DoR services is quite unexpectedly slightly worse than the model with redirect services only. The lead time to implement design changes at project sites again benefits from the new in-transit services, but with a decrease in the average value by approximately 8% and in the maximum value by about 4% with the redirect services only. The reductions for the same indicators in the CB-DoR model are roughly comparable to the redirect services. The CB-DoR services again perform slightly worse than the redirect services model. The number of CBS and DoRS services replace the number of redirect services provided, which are on average 22% less in the CB-DoR model.

A very positive impact of the in-transit services can be noticed for the average and maximum dwell times at all project sites except for one site that looks particularly congested in the RDS model but definitely improved in CB-DoR model (Figure 4 and Figure 5). This is of course an effect of the better and more timely reutilization of components thanks to the combined effect of the in-transit services. More importantly the extremely lower dwell times with respect to the baseline model (up to approximately -82% for the average and -80% for the maximum values in the RDS model, and up to approximately -90% and -87%, respectively, in the CB-DoR model) would entail a significantly lower risk of obsolescence of components. This metric is particularly interesting and has been recently introduced in the same field. Finally, for the average dwell times, half width values vary in the range 3.1-6.2 days (Baseline), 1.3-4.5 days (RDS), 0.5-2.0 days (CBS-DoRS). Half width values of maximum dwell times vary in the range 11.5-17.6 days (Baseline), 6.6-26.4 days (RDS), 4.0-13.1 days (CBS-DoRS).

Overall, the introduction of the call-back and delivery-on-request services would entail a significant investment and operating cost of a central warehouse that should be compensated by the savings in terms of waste, obsolescence costs, and less redirect services with respect to the implementation of the redirect services only.

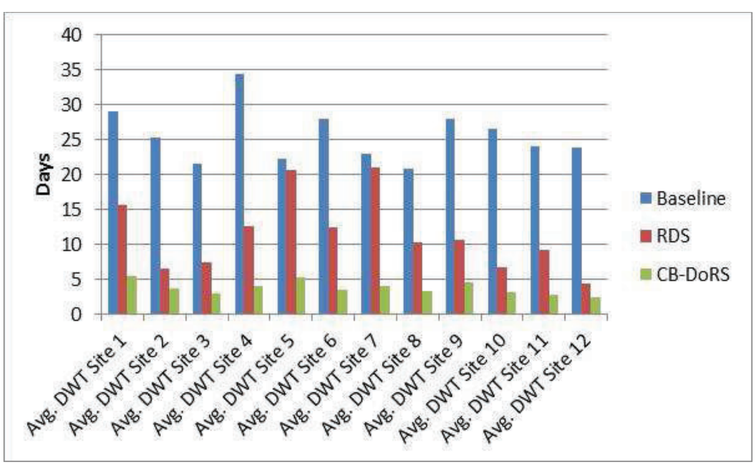

Figure 4: Average dwell times at project sites for each model experiment.

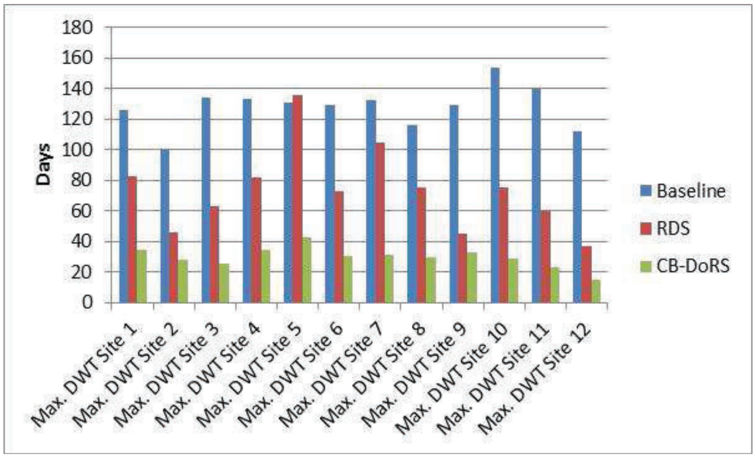

Figure 5: Maximum dwell times at project sites for each model experiment.

7 CONCLUSIONS AND FUTURE RESEARCH

A simulation-based investigation of new in-transit services for capital-intensive project supply chains has been conducted to assess their potential benefits in relation to a set of key performance indicators that have been newly grouped and simultaneously considered (e.g., waste rate, dwell times).

The introduction of redirect services reduces waste and dwell times and speeds projects up. Adding call-back and delivery-on-request services from a central warehouse further reduces the waste rate as well as dwell times but with a slightly worse performance in terms of project time performance with respect to the redirect services. The managerial question is whether the additional reduction in waste rate, dwell times together with obsolescence risk, and number of redirect services is sufficient to cover the investment and operating costs of the reconfigured supply chain with a central warehouse.

The main limitation of this work is that the in-transit services do not exist yet and therefore there is a lack of empirical data to compare with. From the simulation standpoint, some of the logics such as redirect and delivery-on-request services in the event of design changes have not been implemented at this stage of the simulations development.

Future research will aim to upgrade the models and extend all the current service options to all the project instances. Further service provision options will be explored. Collection and use of field data will also be pursued.

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AUTHOR BIOGRAPHIES

GIACOMO LIOTTA is an Associate Professor in Supply Chain Management and IT at Aalborg University, Copenhagen campus, from 2015. His current research interests concern sustainability and digitalization in supply chain and production networks including simulation and optimization of manufacturing, logistics and transportation networks. He has authored more than 35 publications in refereed international journals, books, and conference proceedings. He has been involved in national and European R&D projects in cooperation with industry and academia (currently he participates in MADE – Manufacturing Academy of Denmark, work package 5 – Digitalization of Supply Chains). He previously worked at the University of Southern Denmark and National Research Council of Italy. His educational background is in the field of Management and Industrial Engineering. He is member of ASIM SPL, IEEE and SOCOLNET. His email address is gl@business.aau.dk.

JAN HOLMSTRÖM is Professor in Operations Management. He has been, since 1999, at the department of Industrial Engineering and Management, Aalto University School of Science and Technology. He is one of three principal investigators in a cross-disciplinary research initiative on Building Information Modeling (BIM). He focuses on technology enabled innovation in operations management. He has a background as a systems analyst with Unilever and technology consultant with McKinsey & Company. He is author of more than 70 peer reviewed journal publications, numerous conference presentations and the co-author of a book in the field of supply chain management and technology driven management innovation. His email address is jan.holmstrom@aalto.fi.