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A Simulation-Based Decision Making Framework for the Anticipatory Change Planning of Intralogistics Systems

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A Simulation-Based Decision Making Framework for the Anticipatory Change Planning of Intralogistics Systems

Mustafa Güller, Tobias Hegmanns, Michael Henke and Natalia Straub

Abstract

In many industries flexibility and changeability are becoming a more important characteristic for providing responses to fluctuating conditions without significant loss in time, costs and efforts. In order to cope with turbulences and the increasing level of unpredictability, future intralogistics systems have to feature short reaction times, high flexibility in processes and the ability to adapt to frequent changes. However, the flexibility planning of the design and operations of intralogistics systems as a mean for improved supply chain agility has been ignored. There are many forecasting methods in the literature that can be used to predict future conditions, such as market development, product portfolio or future customer expectations. Nevertheless, analyzing the impact of these forecasts on the performance and costs measures of intralogistics systems is still experiencing insufficient methodical and tool support. Anticipatory change planning can be a usable approach for managers to make contingency plans for intralogistics systems to deal with the rapidly changing marketplace. In this context, this paper proposes a simulation-based decision framework for the anticipatory change planning of intralogistics systems in order to cope with unpredictable events in the future. This approach includes the quantitative assessments based on the simulation in defined scenarios as well as the analysis of performance availability in terms of the degree of fulfillment of customer requirements. The implementation of the approach is illustrated on a new intralogistics technology called the Cellular Transport System.

Keywords: anticipatory change planning, performance availability, flexibility, simulation

1. Introduction

Most companies source globally, produce in various plants and serve customers all over the world with a complex distribution network that has several facilities linked by various activities. This globalization of supply chains brings some challenges as well as benefits. As supply chains become more global, they are becoming more vulnerable to business disruptions, and hence, they are usually slow to respond to changes (Tang & Tomlin, 2008). Outsourcing, e-commerce and volatility in the business environment are creating greater the risk of disruption. In addition, there have been large natural disasters that have the potential to severely affect the continuity of a supply chain (Christopher & Peck, 2004). In this sense, flexibility to respond appropriately to these disruptions is essential to reduce the negative impacts of the occurrence of certain events associated with risks (Tang & Tomlin, 2008). Thus future logistics systems have to feature short reaction times, high flexibility in structures and processes, and the ability to react on unexpected events (Wilke, 2008).

Intralogistics systems are essential elements of the modern supply chain. The term intralogistics in general refers to the organization, control, execution and optimization of in-plant material flow, information streams and goods handling with the help of technical systems and services (ten Hompel & Heidenblut, 2008). Intralogistics systems are difficult to incorporate into an agile supply chain because of limited flexibility and their long-term physical build-up. In order to cope with new requirements, modern storage and material handling systems should combine the high quality of service of automated systems with the high flexibility of manual systems (Schmidt & Schulze, 2009). Conventional models often ignore the constraints imposed by intralogistics systems on the efficiency of the warehouse and production operations, thereby implicitly assuming that the

intralogistics system does not constitute a bottleneck or a limited resource (Crama, 1997). For most systems it was common to run for many years in the same configuration. However, increasing market dynamic causes frequently varying intralogistics' requirements. For this reason, it is often needed to change the layout in response to new market conditions after a couple of years. Companies that use automated material handling systems have reduced their investment in automated systems significantly, since the systems are insufficient to cope with changes in the requirements and processes (Furmans et al., 2011). Therefore, appropriate strategies for unpredictable environments require an inherent ability to make changes in the system. As a result, in today's fluctuating business environment, flexibility, responsiveness, and reconfigurability in the field of intralogistics are key characteristics, as well the level of automation, cost effectiveness and maximum throughput (Furmans et al., 2011).

There are unlimited numbers of potential events, trends, or occurrences that can happen in the future, such as uncertainty of the order arrival process, transportation disruption, machines' breakdown, increased customer expectations in terms of quality and delivery time, financial crisis, etc. In order to cope with unknown events that are assumed to be completely unpredictable, firms need to identify all possible high-impact events that might occur and make contingency plans to deal with them (Goodwin & Wright, 2010). The ability of a system to respond effectively an unpredictable event depends more on the decisions taken before the event than those taken during or after. In order to counter this problematic and its repercussions, forecasting and anticipation methodologies have been widely used techniques. The main limitation of forecasting is the low-ability to accurately estimate the occurrence of rare, high impact events because the future rarely moves in predictable or incremental ways (Goodwin & Wright, 2010) (Caplice & Phadnis, 2013). In other words, these events and their impacts are very difficult to predict using traditional forecasting methods since unpredictable events do not follow any historical patterns. Anticipatory management is a general concept used in several fields. The concept of anticipation was introduced by Rosen (1985). A system that make

decisions in the present on the basis of what may be happening in the future is called an anticipatory system. In other words, an anticipatory system is defined as a natural system that contains an internal predictive model of itself and of its environment, which allows it to change state at an instant in accord with the model's predictions. In traditional forecasting methods the past is the cause of the present. The major difference in the anticipatory system is their dependence on future states, and not only on past states (Rhodes & Ross, 2009). Hence, the anticipatory method may be quite useful for intralogistics systems to challenge the unpredictable high-impact events and to be better prepared for possible future developments.

In order to assess and compare the performance of intralogistics systems, there are different key figures in the literature, such as, the utilization which denotes the fraction of time in which the server is occupied, and the system throughput which is defined as the number of customers served in a single time unit (Huber, 2011). Other key figure used to calculate the performance of intralogistics systems is the performance availability. The performance availability is defined in VDI-Guideline 4486 as "the degree of fulfillment of processes agreed between contract parties in accordance with the requirements and deadlines and in compliance with the agreed basic conditions" (VDI10). This study presents an anticipatory change planning framework based on the performance availability to support the decision making process of intralogistics systems. The proposed approach integrates the quantitative assessments based on the simulation in defined scenarios. The efficiency of the framework is evaluated by considering a new intralogistics technology called the Cellular Transport System (CTS). This paper is organized as follows. After we present the definition and overview of the performance availability in section 2, the process chain modelling technique is briefly discussed in Section 3. Section 4 is devoted to introduce the simulation-based anticipatory change planning concept for intralogistics system. Experimental results of different scenarios are presented in section 5. Finally, conclusions follow in section 6.

2. Definition and overview of the performance availability

The term "performance availability" was first introduced by Wittenstein (2007). It is defined as the state of a system in which a process is carried out according to requirement and the required result can be completed on time. Four essential steps are defined to reach the performance availability (Maier, 2011):

1) Formulation of the business objective:

The new system has the task of the operator to facilitate the achievement of its business objectives or facilitate. Therefore it is necessary that these goals are concretely defined.

2) Formulation of logistics processes:

The business objectives are achieved by various logistics processes that are carried out successfully on the system. These processes must also be defined and quantified.

3) Formulation of boundary conditions:

In order to measure and evaluate the performance in a meaningful way, reliable boundary conditions must be defined, based on which the necessary resources can be scheduled.

4) The difference between consequences when process disturbances occur:

Two factors are defined in order to quantify the degree of fulfillment of the performance availability. If undesirable waiting times occur at the considered workplace due to a disturbance, the performance availability η_W of this workplace is calculated as follow (T_B is the observed time and T_W is the waiting time in observed period):

$$\eta_W = \frac{T_B - T_W}{T_B}$$

If the process is not completed at a certain time due to the lack of availability, the power availability η_L is calculated as follow (N is the total load and n is the delayed loads in observed time):

$$\eta_L = \frac{N - n}{N}$$

As mentioned in the previous section, an alternative definition of the performance availability is introduced in VDI-Guideline 4486. Based on this definition, the performance availability is the degree of fulfillment of processes agreed between contract parties (manufacturer and user) in compliance with the agreed basic conditions (VDI10, 2010). Nevertheless, the above definition is not used directly for the assessment of the performance of entire logistic systems. Every company tries to deliver some sort of service or product in order to satisfy their customer wants and needs. The creation of these products or the delivery of these services is achieved through processes. According to Klaus and Krieger (2009), a logistic process consists of a number of activities that is comprised of a measurable input, which is converted by a transformation into a measurable output. To meet business objectives, output of processes must be controlled by performance indicators, which usually involve efficiency and effectiveness metrics (Schmelzer & Sesselmann, 2008). Efficiency of logistic processes is often measured from dimensions such as, time, quality, quantity, product, and cost. Other performance dimension suggested in the literature is flexibility that provides the ability to adapt to both internal and external business changes.

It is critical that the agreement between the provider and customer must be aligned with the performance requirements of the system. Furthermore, performance metrics should be specified in a range in order to adjust to fluctuating conditions of customer needs. In flexible logistics systems, these fluctuating conditions in internal and external environment are already considered in the planning phase (Schuh et al., 2012). The system has to be ensured that these expected changes can be realized within a pre-defined and limited scope of action.

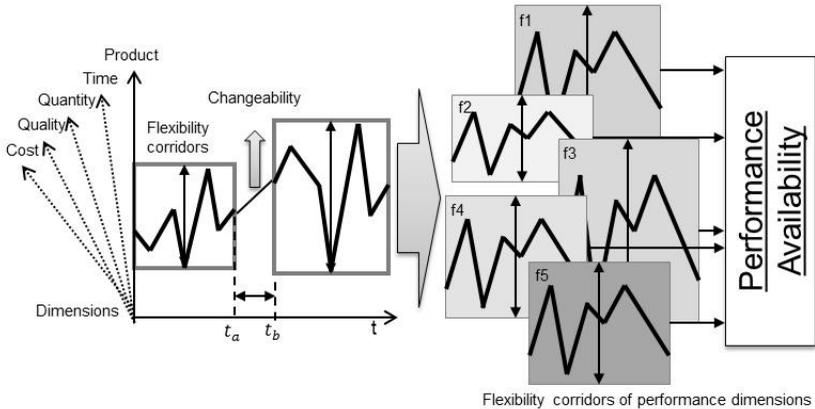


Fig. 1: Performance availability with flexibility corridors of performance dimensions

There is a flexibility corridor for each of the performance dimensions (quantity, quality, time, product, and cost). From the logistic process point of view, the performance availability reflects performance dimensions listed above as shown in Figure 1. There exist a large number of logistic processes modelling technique such as, Flowcharting, Petri Nets, OMEGA, Process Chain Modelling and Event-driven Process Chains. The following section describes the process chain modeling.

3. Process chain model of logistics systems

The process chain paradigm introduced by Kuhn (1995) is a model-based method for the visualization, evaluation and analysis of the processes within a system. The process chain model presents a process by the logical and chronological alignment of individual process chain elements alongside a timeline. It allows a time-oriented view of a business process. The starting point of this model is the general process chain element that defines the closed and bounded subprocess (Nyhuis & Wiendahl, 2009).

The components of each process chain element are sources, sinks, processes, resources, structures and control layers. The model with its 17 individual parameters describes logistic networks and explains their control mechanisms (Hellingrath, 2010). Figure 2 depicts a process chain element and its individual parameters. The source describes inputs of a process or process chain that represents material and information flows of logistic objects (Adaev, 2012). In other words, the transformation objects enter the element through the source. They are delivered to the system's environment through the sink as a transformed object.

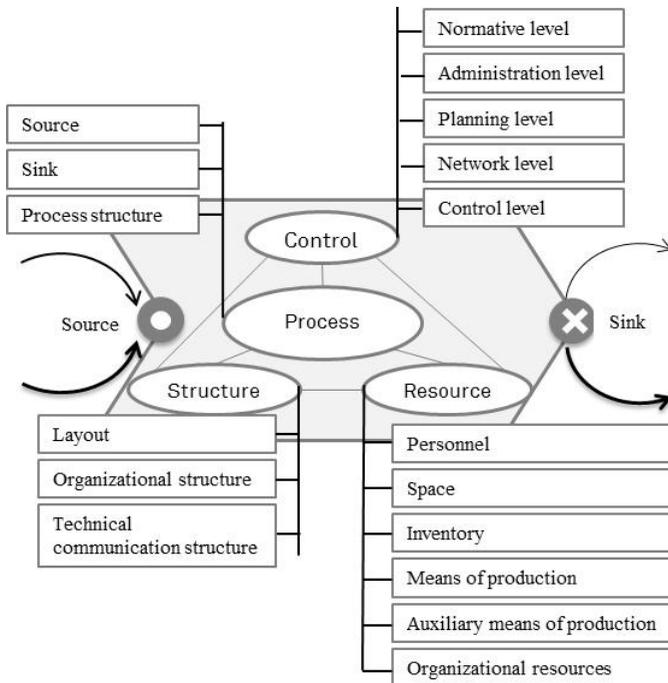


Fig. 2: Process chain element (Kuhn, 1995)

Processes describe the behavior of a logistic system and its internal operations (Uygun, 2012). The main task of a process element is to transform objects

according to customer requirements. Processes are described by the parameter control, structures and resources. The main task of a process element is to transform objects. The parameter process is linked to the parameter resources that determine all necessary resources for performing the processes. The control layer, which is divided into five levels (normative, administration, disposition, network, and control layer), encompasses the rules-based coordination, regulation and monitoring of defined processes that ensure the overall functionality of the system (Adaev, 2012). The process chain model has been also used to develop a holistic, process-oriented planning model of complex logistics and production systems (Kuhn et al., 2007). The model consists of three planning levels, covers five planning phase and describes six iterative planning steps. The Figure 3 illustrates the planning steps graphically. The iterative process starts with the definition of the system load (Beller, 2009). In this step, the objects running through the system and the desired transformation performance are defined.

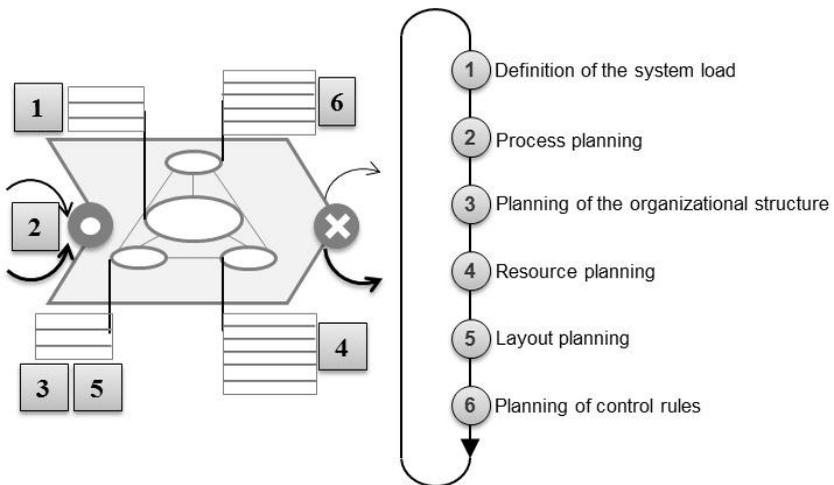


Fig. 3: Iterative planning steps for the planning of logistics systems

The systems load specifies the transformation objects in terms of type and quantity. The process planning describes the second step in the model. This step includes all sub-processes that are required in order to manage the previously determined system load and to transform the objects. The next step of iterative process is the planning of the organizational structure. The task of this step is to define an efficient organization and areas of responsibility based on the previously defined processes. The next step is dealing with the resource planning. In this step, the goal is the determination of the type and amount of the required resources with their specific characteristics. Resources contained within the process chain are: inventories, space, means of production, auxiliary of production, means of organization and personnel. The fifth step of the model is the layout planning that is built upon the previous planning results. The planning process of this level deals with the static planning of factory rather than dynamic planning. The last step of the iteration process is the planning of control rules. In this step, rules at five different levels are defined in order to control and manage the logistics systems.

4. Anticipatory change planning framework

4.1 Anticipatory system

Over the last decades, there has been a significant growth in interest in industry which seeks to foresee the possible future technology, development and market in order to be better prepared. A huge variety of techniques are applied to predict changes in future, ranging from forecasting to simulation, from planning to trend extrapolation, from future studies and scenarios to anticipatory systems (Poli, 2010). Anticipatory management is a general concept that have been proposed in fields as different as physics, biology, sociology, economy, political science and business management. In this approach, all decisions are made based on the possible changes of both internal and external operational environment. In other words, anticipatory management refers an ability of a system to make decision based on future events and redirection of the system by influencing the

environment (Allgood, 2000). Furthermore, the anticipatory system considers the possible future consequences of actions taken today under the dynamic conditions. In the following section, the proposed anticipatory change planning framework is introduced.

4.2 A simulation-based anticipatory change planning framework for intralogistics systems

An anticipatory framework/model to support the strategic decision making process of intralogistics systems is first introduced by Uygun and Wötzel (2009). They propose several phases to harmonize the requirements of logistics and to support the changeability of production system. This paper extends their work with the performance availability and the quantitative assessment based on the simulation. The proposed simulation-based anticipatory change planning for intralogistics systems in this paper follows the steps illustrated in Figure 4. These frameworks include the consideration of which parameters of a process chain element to adapt for flexibility and changeability (e.g. layout, personal, space or resource) and how to accommodate potential change (iterative planning steps). The sources of a change planning are the change of the system load, cost pressure and change of the service (Uygun & Wötzel, 2009). In this context, various dimensions of change are defined, such as product, quantity, time, quality and cost (Nyhuis & Wiendahl, 2009).

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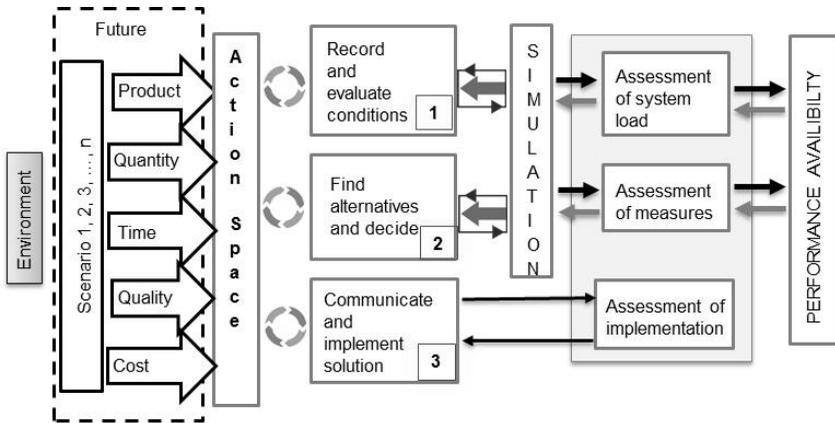


Fig. 4: Simulation-based anticipatory planning framework for intralogistics systems

In this context, various dimensions of change are defined, such as product, quantity, time, quality and cost (Nyhuis & Wiendahl, 2009).

The approach starts with the analysis of these change drivers based on the future scenarios within a company and the business environment. Afterwards, the future scenarios are transformed into the input data. By using different input-sets in the simulation model, it is possible to analyze a need for change in order to respond appropriately. Furthermore, this allows checking whether the flexibility corridor complies with the change drivers and the performance availability. If the flexibility of system is insufficient to deal with the change drivers, it has to be identified the required changeability in the second phase. In this phase, the changeability of the system and measures to adapt to the change are determined according to the process chain elements. The main steps of the second phase are illustrated in Figure 5. The final phase includes the identification of solutions based on the provided information from the simulation model.

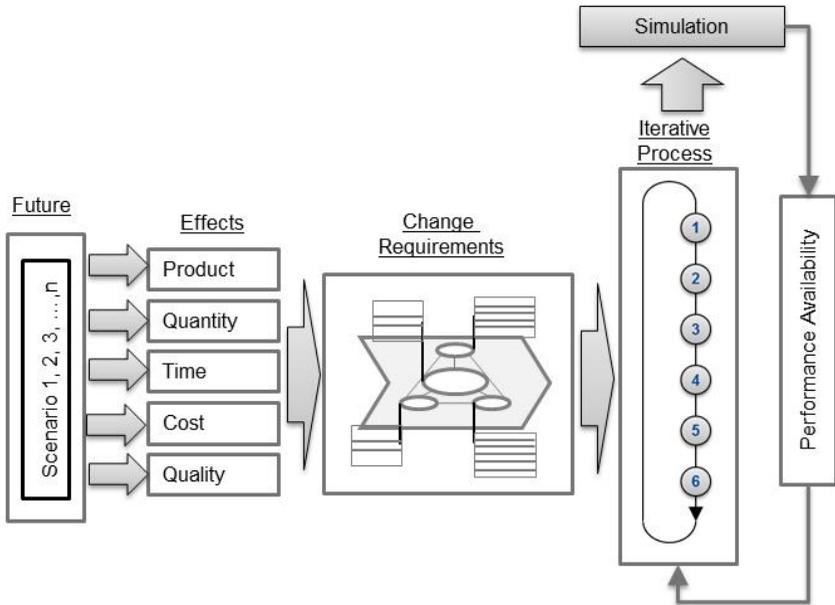


Fig. 5: Iterative planning process for the changeability of logistics systems based on process chain element

5. Case Study

The applicability of the framework was proved in a case study at an e-commerce small-sized distribution center which uses a new automated material handling technology called the Cellular Transport System (CTS). In e-commerce environment, there is always some time delay in demand fulfillment. According to Xu et al. (2009), reasons of this delay are some items not being in inventory, a picking backlog or queue of work at each warehouse and the priority rule to be picked and shipped first. Within e-commerce distribution, flexibility of intralogistics systems becomes more critical due to unpredictable demand characteristics of online orders in order to meet uncertain delivery requirements and customer expectations.

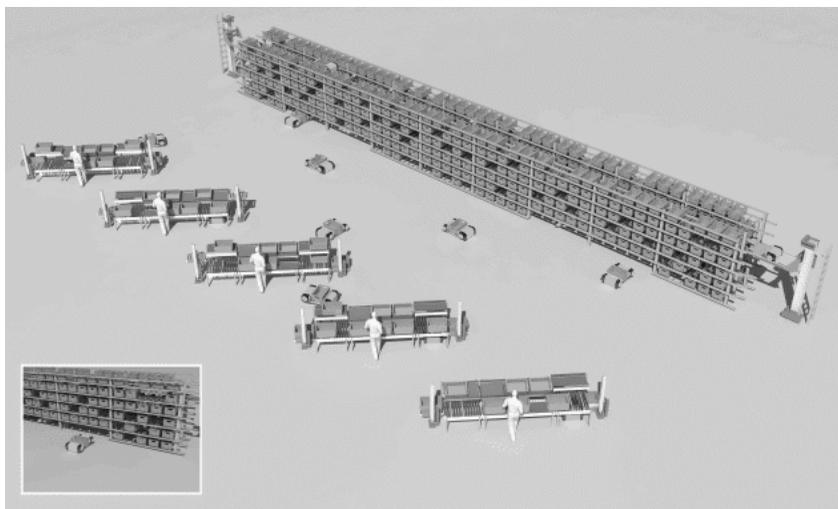


Fig. 6: The experimental area of Cellular Transport System with MSMs © Fraunhofer IML

The Cellular Transport System (CTS) is developed by Fraunhofer Institute for Material Flow and Logistics (IML). In order to cope with rigid design limitations, a group of dynamic, flexible mobile vehicles called The Multishuttle Move (MSM) are replaced with inflexible continuous conveyor systems. MSMs have open path navigation and enable adaptability during runtime of a system. The decentralized control of material flow is the essential characteristic of this new concept. The Multishuttle Move (MSM) is a novel fusion of conventional shuttle and automated guided vehicle system (Kamagaew et al., 2011). In this system, MSMs can move on rack levels as well as freely within the warehouse. In other words, all transports in the rack and the surrounding area will be covered with an autonomous vehicle swarm. This allows the Cellular Transport System to be easily expanded and to modify the system configuration depending upon the system requirements. Furthermore, the position of the picking stations can be freely adapted to the changing environmental conditions.

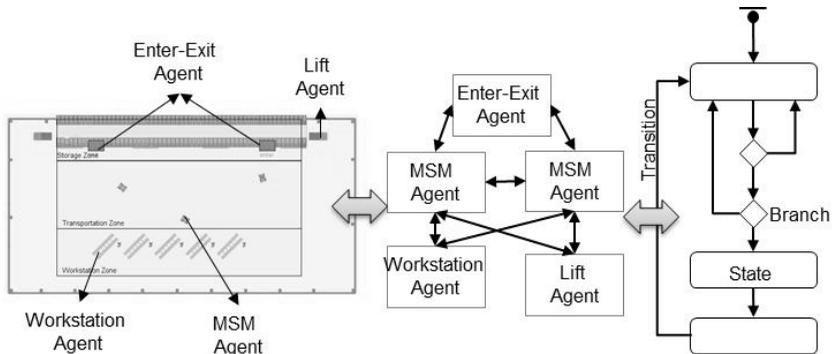


Fig. 7: Agent-based simulation of the Cellular Transport System

For a corresponding practice test, a trial hall for the application in smaller and medium-sized distribution centers was installed at Fraunhofer IML in 2011. The physical layout of the trial hall is 1000 m² with length of 65 meter. The exemplary distribution center consists of a multishuttle shelving system with 5 tiers and specially developed pick stations. Figure 6 shows the physical elements of the Cellular Transport System. In order to manage the complexity of autonomous control of the Cellular Transport System, we have developed a simulation environment using agent-based modeling. The developed simulation model is composed of a set of agents that communicate to one another by asynchronous message passing. The different developed agents that are captured to model consist of MSM agents, Lift agents, Enter-Exit agents and Workstation agents (see Figure 7). We refer the reader to (Güller et al., 2013) for details of simulation model. The system is triggered by orders that enter the system at any time. An order is composed of order lines, where each order line consists of a particular item type. In other word, an order line represents a Stock Keeping Unit (SKU) type and the required amount of items for that SKU.

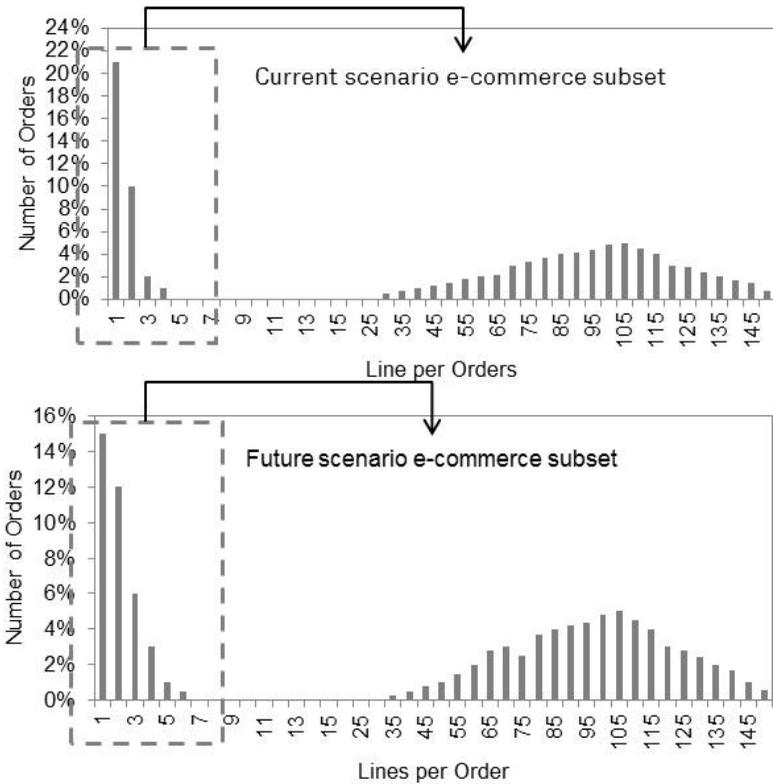


Fig. 8: Current and future scenarios for the distribution center

In e-commerce environment, there is always some time delay in demand fulfillment. According to Xu (2009) reasons of this delay are some items not being in inventory, a picking backlog or queue of work at each warehouse and the priority rule to be picked and shipped first. The other primary challenge that e-commerce distribution centers are facing is higher level of pick labor per item since each item involves a separate trip to the bin location, a separate pick transaction, and a separate trip to bring it back to the shipping area. In order to analyze to the contribution of our approach, it is essential to create appropriate scenarios. The definition of scenario covers both the description of current and a

possible future situation. In the current scenario, 34% of total orders are online order. The proportion of orders with single line, two lines, three lines and four lines are 21%, 10%, 2% and 1% respectively. In the future scenario, 40% of total orders are online order. The proportion of orders with single line, two lines, three lines, four lines and five lines are 15%, 12%, 6% 3% and 1% respectively (see Figure 8).

The predicted changes affect the online sales volume and order line variety. In order to investigate the impact of change drivers on the performance availability and need for changeability in the system, the system load will first be analyzed by using simulation model. The target order throughput is 80 orders per one hour and the target maximum cycle time for an order is 360 seconds. The results for current and future system load are given in Table 1. As it can be seen in Table 1, the system is insufficient to deal with the future market condition. The next phase of the proposed anticipatory change planning framework is to determine the required changeability.

	Current	Future
Average cycle time (sec)	147	459
Minimum cycle time (sec)	64	71
Maximum cycle time (sec)	337	966
No. of Orders > 360 sec	0	61
Total time for 80 orders (sec)	4125	4607

Tab. 1: The analysis of current and future system load

As mentioned in the previous section, the changeability of the system is determined according to iterative planning steps for the planning of logistics systems. One of the changeability potential of the system described in the iterative process is the resource planning. At this step, the number of Multishuttle Move (MSM) in the system is increased. The effect of different number of MSMs on the system performance is illustrated at the following table.

	Future (5MSM)	Future (8MSM)	Future (10MSM)
Average (sec)	459	337	232
Minimum (sec)	71	86	65
Maximum (sec)	966	547	513
No. of Orders > 360	61	38	13
Total time (sec)	4607	4093	3898

Tab. 2: The effect of resource planning on the performance

The layout design of the warehouse has a significant impact on order-picking and traveling distances in the warehouse. In the next step of the iterative process, the layout planning will be analyzed. In particular, we are interested in the percentage of target throughput (80 orders per hour). We consider three configurations in order to assess the impact of different layout options on the system performance. We proposed a 60×10 (L) system for the single aisle configuration, a 30 × 10 (L/2) system for the two-aisle configuration, and a 60×10 system for the two-aisle configuration with the same length of the rack system (L). The results for different configuration are given in Table 3. As expected, the total number of throughputs increases from the one-aisle to the two-aisle case under the same storage capacity because of the reduction in the total travelling distance. As it can be observed, the maximum performance is reached after 10 MSMs at the two-aisle (L/2) system. When we compare the result of those scenarios, there is not a significant difference between the performance of one-aisle (L) and two-aisle (L) systems until 10 MSMs. After 10 MSMs in the system, the performance of rack configuration with two-aisle is better than a rack configuration with one-aisle.

MSMs	One Aisle (L)	Two Aisle (L/2)	Two Aisle (L)
6	71%	83%	70%
8	89%	98%	90%
10	93%	100%	95%
12	96%	100%	100%
14	100%	100%	100%

Tab. 3: Simulation results for the three configurations under study

6. Conclusion

The evolution in intralogistics systems put forward new challenging requirements. Today, flexibility, reconfigurability and high availability are important as well the level of automation, cost effectiveness, and maximum throughput. Due to dynamic changes and uncertain environment, such as order variations, product diversity, and load variations, intralogistics systems must be able to adapt to changing circumstances. However, the ability of a system to respond effectively an unpredictable event depends more on the decisions taken before the event than those taken during or after.

This paper describes a simulation-based anticipatory change planning approach for intralogistics system in order to cope with turbulences and the unpredictability in a future state. Simulation models offer an environment to test and quantify the alternative strategies as well as the analysis of performance availability in terms of the degree of fulfillment of customer requirements. Furthermore, a key element of this approach is the process chain model with iterative steps for the planning of logistics systems. The proposed approach is tested on a new intralogistic technology called the Cellular Transport System. Based on the provided information from the simulation model, the action plan including the identification of solutions is decided. Under given scenario, depending on the required performance availability, the number of the Multishuttle Move in the system is varied as well as the configuration of the rack system is changed. Further

research might investigate how a controlling tool can be developed that combines the flexibility corridors of different performance dimensions.

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II.
Supply Chain
Security Management
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