DOI: 10.2195/lj_Proc_gueller_en_201602_01
URN: urn:nbn:de:0009-14-43308

Performance Availability and Anticipatory Change Planning of Intralogistics Systems: A Simulation-Based Approach

Mustafa Güller
Tobias Hegmanns
Axel Kuhn

Lehrstuhl für Unternehmenslogistik
Fakultät für Maschinenbau
Technische Universität Dortmund

Abstract: In recent years, the ability to respond to real time changes in operations and reconfigurability in equipment are likely to become essential characteristics for next generation intralogistics systems as well as the level of automation, cost effectiveness and maximum throughput. In order to cope with turbulences and the increasing level of dynamic conditions, future intralogistics systems have to feature short reaction times, high flexibility in processes and the ability to adapt to frequent changes. The increasing autonomy and complexity in processes of today's intralogistics systems requires new and innovative management approaches, which allow a fast response to (un)anticipated events and adaptation to changing environment in order to reduce the negative consequences of these events. The ability of a system to respond effectively a disruption depends more on the decisions taken before the event than those taken during or after. In this context, anticipatory change planning can be a usable approach for managers to make contingency plans for intralogistics systems to deal with the rapidly changing marketplace. This paper proposes a simulation-based decision making framework for the anticipatory change planning of intralogistics systems. This approach includes the quantitative assessments based on the simulation in defined scenarios as well as the analysis of performance availability that combines the flexibility corridors of different performance dimensions. The implementation of the approach is illustrated on a new intralogistics technology called the Cellular Transport System.

[Keywords: Performance availability, Agent-based Simulation, Cellular Transport System, Anticipatory Change Planning]

1 INTRODUCTION

The increasing competitive pressure in modern business environments has forced companies to use global outsourcing to adapt to rapid changes, to reduce the effect of fluctuations, to develop their core competencies and to expand their flexibility (Aksoy and Öztürk , 2012). This globalization of supply chains creates opportunities for enterprises. However, these opportunities are often accompanied by new supply chain challenges and risks. 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 and Tomlin, 2008). Therefore, firms require novel approaches to design decision-making concepts that have the ability to adapt to changes in the business environment and increase resilience of each participant in a supply chain. One of the essential participants of modern supply chains is intralogistics. Recently, it has become commonly replaced the traditional concept of in-plant material flow and conveying systems. The term intralogistics refers to the management, execution and optimization of a company's internal material flow and goods handling with the help of technical equipment and resources (ten Hompel and Heidenblut, 2008). However, they are difficult to incorporate into an agile supply chain because of their limited flexibility and long-term physical build-up. Increasing market dynamics cause frequently varying intralogistics' requirements (Güller et al., 2014). The ability to respond to real time changes in operations, agility in the turbulent market environment, and reconfigurability in the equipment are likely to become essential characteristics for next generation intralogistics. In order to cope with these new requirements, modern intralogistics should combine the high quality of service of automated systems with the high flexibility of manual systems (Schmidt and Schulze, 2009). In other word, 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, Nobbe and Schwab, 2011).

Increasing autonomy and complexity in processes of today's supply chain requires new and innovative deci-

DOI: 10.2195/lj_Proc_gueller_en_201602_01
URN: urn:nbn:de:0009-14-43308

sion-making approaches, which allow a fast response and adaptation to dynamic environment. The ability of a system to respond effectively changes in a market 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 and Wright, 2010) (Caplice and Phadnis, 2013). The concept of anticipation introduced by Rosen (1985) is a general concept used in several fields. 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 this context, this study presents a systematic decision-making framework based on the anticipatory system approach to support the decision process of intralogistics under turbulent market conditions. The developed framework integrates the simulation for the quantitative assessment and the efficiency of framework is evaluated by considering a new intralogistics technology called the Cellular Transport System (CTS).

2 OVERVIEW OF ANTICIPATORY SYSTEMS

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 relating to the perception of change is a general concept that has been widely studied within numerous different fields such as physics (Dubois, 2000), biology (Louie, 2009), sociology, economy, political science (Karinen and Guston, 2010) and business management. The important aspect of anticipatory systems is not only the ability of looking ahead, but it also refers to an action or decision that is taken based on a prediction in preparation for some future event (Rhodes and Ross, 2009). In this concept, 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).

An anticipatory system is diagrammatically illustrated in Fig. 1, where an anticipatory system is composed of three parts: a dynamical system S (running in real time), a model M of S, and an effector device E via which M and S interact with each other (Zamenopoulos and Alexiou, 2004). The main condition is that the model M should be able to run faster than the system itself (S) and therefore M can predict future behavior. In this way, the state of M at time *t* provides information about the state of S at some time later than *t* (Rosen, 1985). In addition, M is equipped with a set E of effectors which converts input information from M to some specific modifications of the dynamics of S. If S is modified, the effector E must also update the states of M to match future states of S. Rosen (1974) explains via an example how predictions should be used to modify the properties of S as follow:

"*Let us imagine the state space of S (and hence of M) to be partitioned into regions corresponding to "desirable" and "undesirable" states. As long as the trajectory in M remains in a "desirable" region, no action is taken by M through the effectors E. As soon as the M-trajectory moves into an "undesirable" region (and hence, by inference, we may expect the S-trajectory to move into the corresponding region at some later time, calculable from a knowledge of how the M- and S-trajectories are parameterized) the effector system is activated to change the dynamics of S in such a way as to keep the S-trajectory out of the "undesirable" region*".

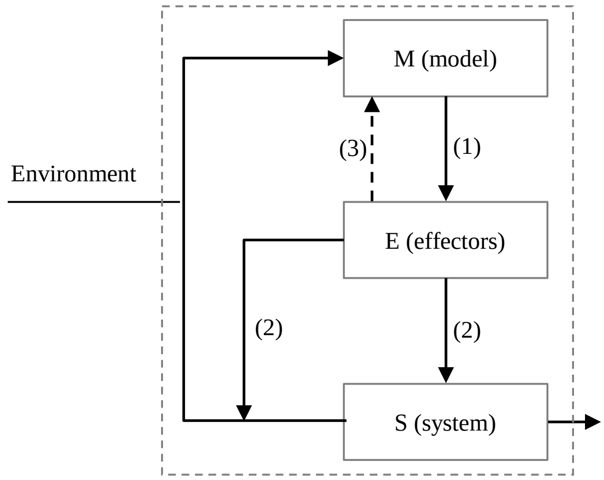

Figure 1. The basic architecture of an anticipatory system as illustrated by Rosen (1985)

From the definition of Rosen, Davidsson (2003) defines a simple architecture for implementing an anticipatory agent. When implementing an anticipatory agent, one of the different components used in the model is the reactor that corresponds to S and some kind of reactive systems. The reactor provides a response and translates this response into data propagated to the effectors, which carry out the desired actions(s) in the environment. The world model is an abstract view of the agent's environment based on data collected using sensors. Sensors component collect data from the agent's environment and propagate it to update both the world model and the reactor. The anticipator, which is an active component, uses the world

DOI: 10.2195/lj_Proc_gueller_en_201602_01
URN: urn:nbn:de:0009-14-43308

model to make predictions of future situations and its goals in order to decide whether (and how) to change the dynamical properties of the reactor. Thus, it modifies the reactor to avoid undesirable predicted world state (Bouraqadi and Stinckwich, 2007). Note that the behavior of the reactor in each situation is determined by situation-action rules (Davidsson, 1995).

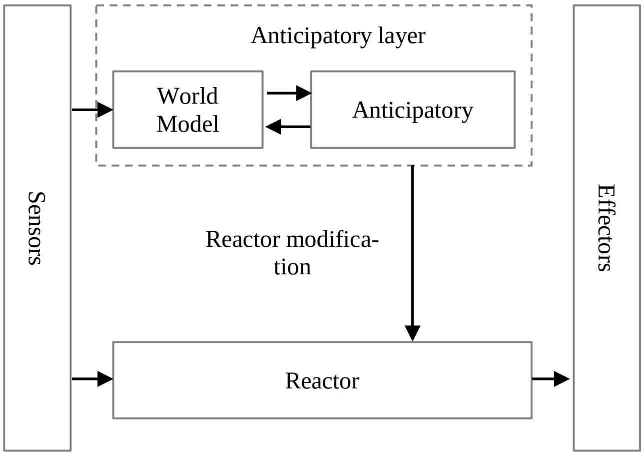

Figure 2. The Anticipatory system of an organization (Davidsson, 2003)

To provide a way of deciding when and how to change the reactor, the anticipatory agent is specified as a 4-tuple < *W, R, U, X* > by Davidsson (2003):

- *W* is the description of the environment (the world model).
- *R* is the set of situation-action rules defining the Reactor.
- *U* is the set of undesired states.
- *X* is the set of rules describing how to modify *R*.

The combination of U and X describes the anticipator. It is important to note that there is a corresponding rule in X for each element in U. This rule is applied when it is anticipated that the system has reached an undesired state.

3 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 fulfilment 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). In business context, performance of logistic processes may be characterized in terms of 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. The major challenges are that the performance in a multi-objective space is dependent on each of the single dimension and it is needed to consider these performance dimensions in corporate decision making, instead of focusing mainly on one dimension. The traditional conceptualization of system timelines does not consider impacts of different flexibility corridors on the system performance and expectations. The system has to be ensured that changes can be realized within a pre-defined and limited scope of action called flexibility corridor as shown in Fig. 3. The choices of possible actions in decision-making framework may be derived from the desired flexibility corridor of performance dimensions. In action plan under turbulent market conditions, the objective is to identify the solution that provides the best balance of time, cost, and delivery performance. In the literature, most of research regarding decision making revolves around cost.

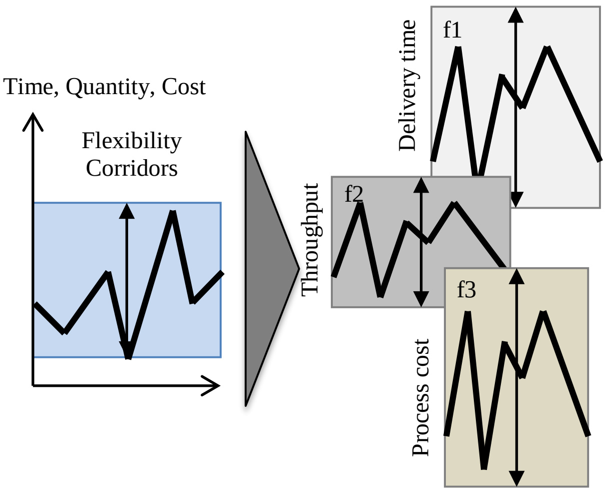

Figure 3. Flexibility corridors and performance dimensions as a decision criterion

4 PROCESS CHAIN PARADIGM FOR ANTICIPATORY CHANGE PLANNING

The process chain paradigm introduced by Kuhn (1995) is a model-based method for the visualization, evaluation and analysis of the processes within a logistic system. This model presents a process by the logical and chronological alignment of individual process chain elements alongside a timeline. Thus, it allows a time-oriented view of a business process. 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). 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. One of the main challenging tasks concerning with intralogistics is to define the changeability potentials of such a system to generate alternatives. From the process chain paradigm perspective, each process chain parameter, such as layout, means of production, space, personnel, organizational structure, etc., may also be used to specify the changeability potentials of a system.

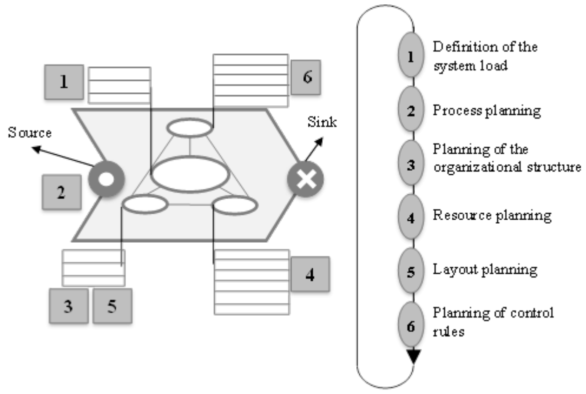

Figure 4. Iterative planning steps

One of the most important assets of a successful organization is how the organization deals with the uncertainty. Changes and uncertainties in the environment lead to a need for the organization to have a novel management concept in order to prosper in the future. In general, a proper planning framework is critical to reach organizational performance. To coordinate decision-making for determining a set of decision alternatives, Kuhn (2007) and Beller (2009) present a systematic decision framework for the factory planning which consists of three planning levels, covers five planning phase and describes six iterative planning steps as shown in Fig. 4. The iterative process involves data collection and analysis, searching among the possible solutions, evaluating alternatives and the choice of the best solution combination. is an organized way to factory planning. First of all, it is necessary to analyze data and to identify the characteristics of systems load in terms of type and quantity, and the desired performance. Once the essential characteristics of system load are known, their influence on the system performance is analysed. The influence is evaluated with a scale in defined period called performance corridors as shown in Fig. 3. The process planning level deals with characterization of all required sub-processes in order to manage the previously determined system load. The next step of iterative process is the planning of the organizational structure. The task of this step is to identify an efficient organization and areas of responsibility based on the defined processes. In the fourth step, decision maker has to determine 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 deals with the

DOI: 10.2195/lj_Proc_gueller_en_201602_01
URN: urn:nbn:de:0009-14-43308

layout planning and it is a static planning of intralogistics 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 to control and manage the logistics processes.

In order to implement organizational changes effectively, it is necessary for the decision-makers to engage in anticipatory management. The systematic anticipatory change planning with the iterative planning process is a framework used to arrange an intralogistic system under dynamic environmental conditions (Fig. 5). In this framework, each iterative step (level 2) provides a possible solution. In order to evaluate the effectiveness of each solution, the different alternatives are compared with the help of a simulator. A simulation model is an easy way to represent real life scenarios and to enhance system performance under different scenarios in terms of productivity, process cost, resource utilization, cycle times, delivery times, etc.

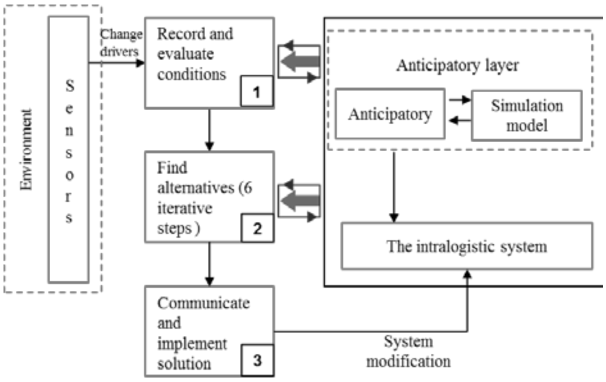

Figure 5. Simulation-based anticipatory planning for intralogistics systems

For the assessment of iteration process, the major decision criteria used in this study are time, quantity and cost. The time-related performance of a process is determined by the sub-criteria delivery time and the quantity-related performance is determined by the throughput within a defined period. Each solution alternatives may have a different impact on performance dimensions (see Fig. 6). For example, possible solution in the organizational structure planning may have a very high influence on the process cost. On the other hand, it may have not enough to keep the system in performance corridors in terms of throughput and delivery time. Moreover, changeability potential at the forth step of iteration process (resource planning), the desired throughput may have been reached while the delivery time performance is still out of scale. Changing layout at next iteration process with resource planning also affects these performance criteria. The iteration process continues until all performance expectations are met.

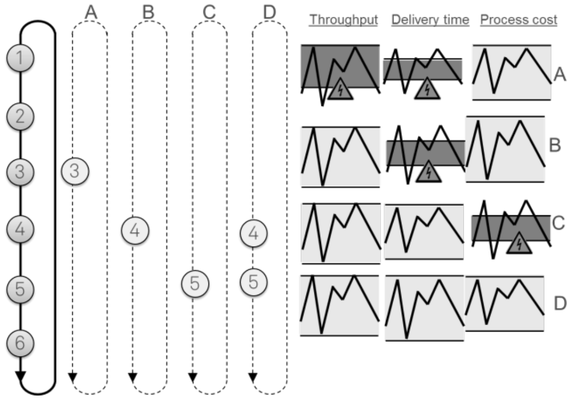

Figure 6. Iterative planning steps with flexibility corridors

5 CASE STUDY

The applicability of the framework was proved in a case study at an e-commerce small-sized distribution centre which uses a new automated material handling technology called the Cellular Transport System (CTS). 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. 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. The system is triggered by orders that enter the system at any time. Customer orders can have one or more order lines (product line), where each order line consists of a particular item type and quantity of the requested orders. Each of these items can be created as a separate line item, which rolls up into one order. 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. Other assumptions used in the simulation model are summarized below:

DOI: 10.2195/lj_Proc_gueller_en_201602_01
URN: urn:nbn:de:0009-14-43308

- The sample problem is considered with approximately 600 storage positions.
- The model is run for 15 independent replications and one day shift (8 hours length).
- Customer order arrivals in the system follow an exponential distribution with the arrival rates 60 per hour.
- The order size varies between 1 and 6 units and is generated from a uniform distribution.
- The transactions are served by MSMs on a first-come first-served (FCFS) rule.
- The system uses pure random storage policy. According to this policy, the probability that a retrieval transaction is required in a certain storage point is identical for each point.

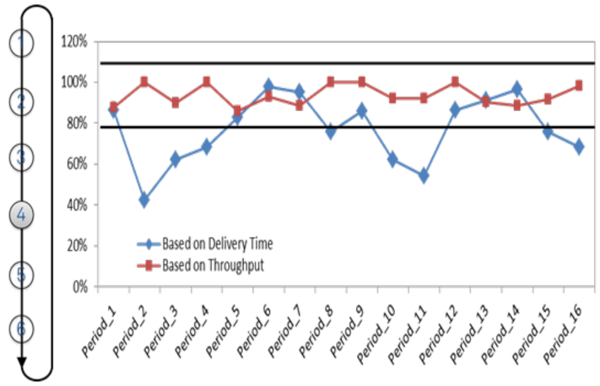

Figure 7. The impact of resource planning on performance dimensions

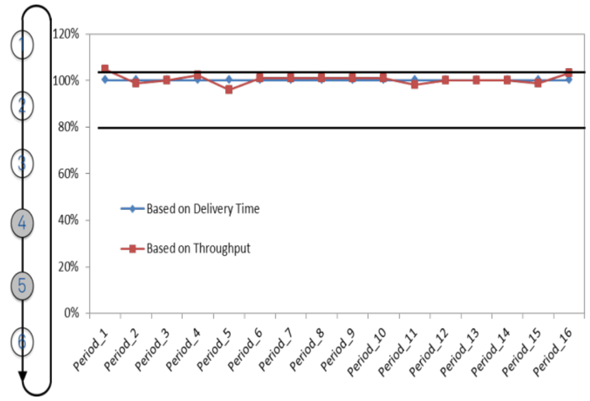

Figure 8. The impact of layout planning with more MSMs in the system on performance dimensions

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 increasing number of MSMs on the system performance in terms of throughput and delivery time is illustrated at the Fig. 7. In the next step of the iterative process, the layout planning and resource planning is analysed together. We consider different layout of order picking system under a higher number of MSMs. As expected and shown in Fig. 8, the throughput and on-time delivery performance measures are in the target scale.

6 Conclusion

The presence of uncertainty in future outcomes and decisions that must be taken under multi-criteria contributes to the complexity of a decision making system. A reliable decision-making system requires a means to understand its surrounding environment and possible alternative decisions as well as the consequences of these decisions. Moreover, in a decision making process, decision makers must select an action or a set of actions among a set of possible solutions whose consequence depends on uncertain future state. In this regard, anticipatory system can be engaged with the decision making process as the strategy that enable decision makers to respond robustly to future scenarios. In recent years, the ability to respond to real time changes in operations, agility in the turbulent market environment, and reconfigurability in equipment are likely to become essential characteristics for next generation intralogistics systems to deal with the dynamic environment. However, the ability of a system to respond effectively uncertainties depends more on the decisions taken before the event than those taken during or after.

This paper describes a simulation-based anticipatory change planning framework for intralogistics system in order to cope with turbulences and dynamic conditions in future states. The roles of anticipation and of performance dimensions on systematic multiple criteria decision-making processes under uncertainty are investigated. The simulation offers an environment to test and quantify the alternative strategies as well as the analysis of performance availability in terms of the degree of fulfilment of customer requirements. Furthermore, the process chain paradigm with iterative steps for the planning of logistics systems is integrated with the framework to define the changeability potential on a logistic system. The methodology is applied 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 and performance dimensions, 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.

Acknowledgment

The paper is based on the research results from the project “Paketantrag 672 Logistics on Demand- Subproject C4 – Simulation-based Anticipatory Change Planning of Intralogistics Systems” funded by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG).

References

Adaev, K. (2012). Factors influencing planning process design and their impact. *The 16th Cambridge International Manufacturing Symposium.* Cambridge.

Aksoy , A., & Öztürk , N. (2012). The Fundamentals of Global Outsourcing for Manufacturers. In F. Aziz, *Manufacturing System.* INTECH.

Allgood, G. (2000). Mapping function and structure for an anticipatory system: what impact will it have and is it computationally feasible, today? *Systems, Man, and Cybernetics, 2000 IEEE International Conference on,* (S. 2198 - 2203). Nashville, TN.

Beller, M. (2009). *Entwicklung eines prozessorientierten Vorgehensmodells der Fabrikplanung.*

Bouraqadi, N., & Stinckwich, S. (2007). Towards a generic anticipatory agent architecture for mobile robots. In P. Sapaty , & J. Filipe (Ed.), *Proceedings of the 3rd International Workshop on Multi-Agent Robotic Systems* (pp. 102-106). France: INSTICC PRESS .

Caplice, C., & Phadnis, S. (2013). *Strategic Issues Facing Transportation:Scenario planning for freight transportation infrastructure investment.* Washington, D.C.: National Academy of Sciences.

Davidsson, P. (1995). A linearly quasi-anticipatory autonomous agent architecture: Some preliminary experiments. *Proceedings of the First Australian Workshop on DAI: Distributed Artificial Intelligence: Architecture and Modellin* (pp. 189-203). London: Springer-Verlag.

Davidsson, P. (2003). A framework for preventive state anticipation. *Lecture Notes in Computer Science, 2684,* pp. 151-166.

Dubois, D. (2000). Review of incursive, hyperincursive and anticipatory systems-foundation of anticipation in electromagnetism. *AIP Conference Proceeding* (pp. 3-30). Belgium: American Institute of Physics.

Furmans, K., Nobbe, C., & Schwab, M. (2011). Future of Material Handling – modular, flexible and efficient. *IEEE International Conference on Intelligent Robots and Systems.* San Francisco.

Goodwin, P., & Wright, G. (2010). The limits of forecasting methods in anticipating rare events. *Technological Forecasting & Social Change*(77), 355–368.

Güller, M., Hegmanns, T., Henke, M., & Straub, N. (2014). A Simulation-based Decision Making Framework for the Anticipatory Change Planning of Intralogistics Systems. In T. Blecker (Hrsg.), *9th HICL Conference on Next Generation Supply Chains: Trends and Opportunities* (S. 200-223). Hamburg: epubli GmbH.

Hellingrath, B. (2010). Flexibilität von Supply Chains. In U. Clausen, & M. ten Hompel, *Facetten des Prozesskettenparadigmas* (pp. 221-236). Dortmund: Verlag Praxiswissen.

Karinen, R., & Guston, D. (2010). Toward anticipatory governance: The experience with nanotechnology. In M. Kaiser, M. Kurath, S. Maasen, & C. Rehmann Su, *Governing future technologies: Nanotechnology and the rise ofan assessment regime* (pp. 217–232). Dordrecht: Springer.

Klaus, P., & Krieger, W. (2009). *Gabler Lexikon Logistik. Management logistischer Netzwerke und Flüsse* (3. ed.). Wiesbaden: Dr. Th. Gabler.

Kuhn, A. (1995). *Prozessketten in der Logistik-Entwicklungstrends und Umsetzungsstrategien.* Dortmund: Verlag Praxiswissen.

Kuhn, A., Schmidt, A., & Beller, M. (2007). Neue Vorgehensmodelle zur prozessorientierten Logistikplanung. In H. Wolf-Kluthausen, *Jahrbuch Logistik 2007.* free beratung Geselschaft für Kommunkation im Marketing mbH Verlag.

Louie, A. (2009). *More than life itself: A synthetic continuation in relational biology.* Frankfurt: Ontos Verlag.

Poli, R. (2010). An introduction to the ontology of anticipation. *Futures, 42*(7), pp. 769–776.

Rhodes, D., & Ross, A. (2009). Anticipatory capacity: Leveraging model-based approaches to design systems for dynamic futures. *International Conference on Model-Based Systems Engineering* (pp. 46-51). Haifa: IEEE.

Rosen, R. (1974). Planning, management, policies and strategies: Four fuzzy concept. *International Journal of General Systems, 1*(4), pp. 245–252.

Rosen, R. (1985). *Anticipatory Systems.* New York: Pergamon Press.

Schmelzer, H., & Sesselmann, W. (2008). *Geschäftsprozessmanagement in der Praxis* (6. ed.). München: Carl Hanser Verlag.

Schmidt, T., & Schulze, F. (2009). Future approaches to meet complexity requirements in material handling systems. *FME Transactions*.

Tang, C., & Tomlin, B. (2008). The power of flexibility for mitigating supply chain risks. *International Journal of Production Economics, 116*(1), 12-27.

ten Hompel, M., & Heidenblut, V. (2008). *Taschen-lexikon Logistik.* Springer-verlag.

VDI10. (2010). *VDI Richtlinie 4486: Zuverlässigkeit in der Intralogistik: Leistungsverfügbarkeit.* Berlin: Beuth Verlag.

DOI: 10.2195/lj_Proc_gueller_en_201602_01
URN: urn:nbn:de:0009-14-43308

Zamenopoulos, T., & Alexiou, K. (2004). *Design and anticipation: towards an organisational view of design systems.* London, UK.

Mustafa

Mustafa Güller, M.Sc. ist wissenschaftlicher Mitarbeiter am Lehrstuhl für Unternehmenslogistik an der Technischen Universität Dortmund

Adresse: Technische Universität Dortmund, Fakultät Maschinenbau /Lehrstuhl für Unternehmenslogistik, Leonhard-Euler-Str. 5 44227 Dortmund, Tel.: +49 231 231 755-5786, E-Mail: *guller@lfo.tu-dortmund.de*

Dr.-Ing. Tobias Hegmanns ist stellvertretender Leiter des Lehrstuhls für Unternehmenslogistik der Technischen Universität Dortmund und akademischer Direktor des Institutsbereichs Unternehmenslogistik am Fraunhofer Institut für Materialfluss und Logistik in Dortmund.

Adresse: Fraunhofer-Institut für Materialfluss und Logistik (IML), Joseph-von-Fraunhofer-Str. 2-4, 44227 Dortmund, Tel.: +49 231 9743-417, E-Mail: *hegmanns@lfo.tu-dortmund.de*

Prof. i. R. Dr.-Ing. Axel Kuhn ist ehemaliger Lehrstuhlinhaber des Lehrstuhls für Fabrikorganisation (jetzt: Unternehmenslogistik) und als Senior Scientist der TU Dortmund an verschiedenen Forschungsvorhaben beteiligt.