APPLICATION OF AGENT-BASED SUPPLY CHAIN MODELLING IN INTRALOGISTICS SYSTEM DESIGN AND OPTIMISATION

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Abstract

Intralogistics refers to managing material flows along the entire supply chain as well as the internal flow of materials between different logistics nodes in a company. It requires a multi - disciplinary expertise, encompassing a diversity of core competencies that include mainly strategic planning and logistics design; process engineering and analysis; facilities design and automation; systems design, integration, and implementation and material handling technology. When designing or optimizing an intralogistics system a model of the processes and products is often required. In contrast to traditional process systems where artefacts with physical and chemical interactions are the key constituents, intralogistics systems similarly to supply chains are best thought of as socio - technical systems where complex production technologies interact with distributed, intelligent, autonomous entities. My personal experience with supply chain modelling and optimisation shows that better than the application of a set of balance equations similar in structure to those used to model for example chemical processes is to adopt an alternative modelling paradigm when dealing with supply chain dynamics. This new paradigm is called agent - based modelling. The aim of this article is to describe an application of agent - based modelling in a real intralogistics system design and optimisation. The system consists of a warehouse ensuring storing and dispatch of products coming from machinery industry. With help of an agent-based model realized in Witness dynamic simulation environment the internal organization of warehouse is designed and optimized taking into account planned 10 - 100 % material flow intensity increase per year. The outputs of the simulation support mainly the decisions about optimal warehouse layout; warehouse storage and material handling equipment and warehouse management system.

Key words: Supply Chain Management, Logistics, Agent – Based Modelling, Dynamic Simulation, Optimisation

JEL Code: C53

Introduction

It's hard to think of another business area that offers companies such huge scope for rationalization and savings as the materials handling and logistics sector. Intralogistics refers to managing internal flow of materials between different logistics nodes in a company. It requires a multi-disciplinary expertise, encompassing a diversity of core competencies that include mainly strategic planning and logistics design; process engineering and analysis; facilities design and automation; systems design, integration, and implementation; material handling technology (storage, conveyor, and sortation). Intralogistics systems in the forms of automated distribution and fulfilment centres often achieve leaps in operational productivity through the integration of information processing and material handling technologies that optimize fulfilment processes and better utilize both labour and equipment resources.

When designing or optimizing an intralogistics system a model of the processes and products is often required (Cameron, Ingram, 2008). In contrast to traditional process systems where artefacts with physical and chemical interactions are the key constituents, intralogistics systems similarly to supply chains are best thought of as socio-technical systems where complex production technologies interact with distributed, intelligent, autonomous entities, each with their own dynamics, goals, desires and plans (Van Dam et al., 2009).

My personal experience with both intralogistics systems and supply chain modelling shows that better than the application of a set of balance equations similar in structure to those used to model for example chemical processes is to adopt an alternative modelling paradigm when dealing with supply chain dynamics. This new paradigm is called agent-based modelling.

The aim of this article is to describe an application of agent-based modelling in a real intralogistics system design and optimisation. The system consists of a warehouse ensuring storing and dispatch of products coming from machinery industry. With help of agent-based model realized in Witness dynamic simulation environment the internal organization of warehouse is designed and optimized taking into account planned 10 - 100 % material flow intensity increase per year. The outputs of the simulation support the decisions about warehouse layout, warehouse equipment with storage racks and warehousing trucks, warehouse management system.

1 Theoretical background of research

Supply chain is considered as integrated process which involves a set of business entities, e.g. suppliers, producers, distributors etc. Their collective goal is to find a solution to efficiently meet customer requirements such as high product variety, high quality, and short lead times (Stank et al. 2005; Talluri, Baker 2002). Supply chain is characteristic with a forward flow of materials and a backward flow of information (Mentzer 2001).

Agent-based modelling (ABM) is the computational study of social agents as evolving systems of autonomous interacting agents. ABM is a tool for the study of systems from the complex adaptive system perspective. From this perspective, the researcher is interested in how macro phenomena are emerging from micro level behaviour among a heterogeneous set of interacting agents. Agents have internal states. These internal states can be represented by discrete or continuous variables. Given the choice of an agent's state variable(s), the agent's behaviour can be represented as a state-determined automata (or finite state machine): a state transition occurs whenever the agent interacts with another agent. However, more sophisticated ABM applications need to move beyond state-determined automata with the inclusion of random-access memory capabilities. That is, agents can engage with their environments beyond concurrent state-determined interaction by using memory to store descriptions and representations of their environments. They can also have access to shared knowledge among the members of their particular agent society (Macal, North 2010). Applications of agent-based modelling span a broad range of areas and disciplines. Applications range from modelling agent behaviour in the stock market (Arthur et al 1997) and supply chains (Macal 2004) to understanding consumer purchasing behaviour (North et al 2010).

To adopt the principles of ABM successfully dynamic simulation environment is usually used. Dynamic simulation can be defined as the process of designing a mathematical-logical model of a real system and experimenting with this model on a computer. The experiments with the model enables user to discover logical connections among the parties involved in processes and to propose and evaluate the performance of many different structures in a relatively short time. Simulation has much to offer any organization. The role of simulation is to evaluate alternatives that either support strategic initiatives, or support better performance at operational and tactical levels. Simulation provides the information needed to make these types of decisions. The simulation approach supports multiple analyses by allowing rapid changes to a model's logic and data and is capable of handling large, complex systems; such as, a manufacturing facility or a supply chain.

2 Dynamic simulation of warehouse using ABM

Škvor and Dyntar (2013) suggest a complex model of designing or redesigning supply chains tries to find answers on how many distribution centres to select; where to place these objects; what is an appropriate storage capacity of these objects; how to deliver goods to customers and how to control stock level in distribution centres while minimizing the distribution costs in compliance with requiring level of services mainly in the form of lead time. They upgrade the model into the form of Supply Chain Spread Sheet Simulator (SCSS) and discuss its basic functionality simulating a real task dealing with the redesign and optimisation of the distribution system for goods coming from chemical industry in the Czech Republic. SCSS is based on agent – based modelling using four types of agents controlled by a set of algorithms.

Despite SCSS is primarily designed for entire supply chain optimisation, its basic principles can be easily adopted in intralogistics systems optimization. I decide to employ SCSS basic framework to create a model of a warehouse ensuring input storing and deliveries to production lines as well as a dispatch of finished products to final customers. Warehouse simulation is realized using Witness dynamic simulation software environment supported by MS Excel for input data loading and outputs upgrading. Proposed solution consists of four types of agents such as:

- Production agent.
- Storage agent.
- Transportation agent.
- Retailer agent.

These agents are controlled by a set of algorithms in a way ensuring required performance of warehouse.

2.1 Basic framework - agents

Production agent delivers materials to warehouse according to a purchase plan or a plan of manufacturing. These materials are provided to transportation agents that ensure their placement to the storage racks. In the simulation production agents represent suppliers delivering input materials to warehouse and operators ensuring deliveries of final products from production lines to warehouse.

Storage agent represents storage racks in warehouse. These storage racks are characteristics with a storage capacity determined to store different types of materials differing in weights and proportions.

Transportation agent ensures the placement of input materials and finished products to storage racks and order picking for both final customers demanding final products and production lines demanding input materials for manufacturing. It is characteristics with a speed of movement, a time consumption spent on operations connected with order picking or storing and a transportation capacity.

Retailer agent demands items stored in a warehouse. In simulation it represents final customers demanding final products and production lines demanding input materials for manufacturing.

2.2 Control elements – algorithms

Control elements ensure effective interaction among agents in a way leading to required performance of warehouse. These algorithms are based on following principles:

- Requirements on finished products dispatch or input materials handling to production lines are satisfied prior to the requirements on input materials or finished products storing.
- Transportation agents place finished products or input materials to storage racks according to the frequency of the requirements on their dispatch or handling to production lines.
- Transportation agents place finished products or input materials to storage racks to achieve the maximum of space utilization.
- Transportation agents move among storage racks trying to reach the maximum savings of travelled distance.
- Transportation agents observe FIFO during order picking.

2.3 Input data to simulation

To achieve the aim of simulation, following set of input data is used:

- Input materials and finished products characteristics – weight, shape, proportions, frequency of order picking and dispatch in a certain period of time.
- Material flow intensity in a certain period of time.
- Warehouse layout.

- Information about available material handling equipment – capacity, average speed, time of loading and unloading.
- Information about available storage racks – loading capacity, proportions.

2.4 Simulation performance indicators

To support the decisions about warehouse layout, warehouse equipment with storage racks and warehousing trucks outputs of simulation in the form of performance indicators are used. Material handling equipment utilization describes amount of time the equipment is idle or busy during the simulation run. Storage racks utilization describes average occupancy of storage bins by input materials and finished products. Time of fulfilment of the material handling requirement describes how much time passes from the moment the requirement emerges till it is satisfied by a material handling equipment. Indicators describing stock levels during the simulation run are used in the form of minimal, average and maximal stock and stock turnover. And finally the success rate of the placement of input materials and finished products to zones according to the frequency of order picking is calculated in the form of no additional material handling rate.

3 Machinery industry warehouse design and optimisation

To discuss basic functionality of proposed simulation and to assess its performance a real machinery industry warehouse is designed and optimised taking into account planned 10 - 100 % material flow intensity increase through warehouse per year (see Table 1).

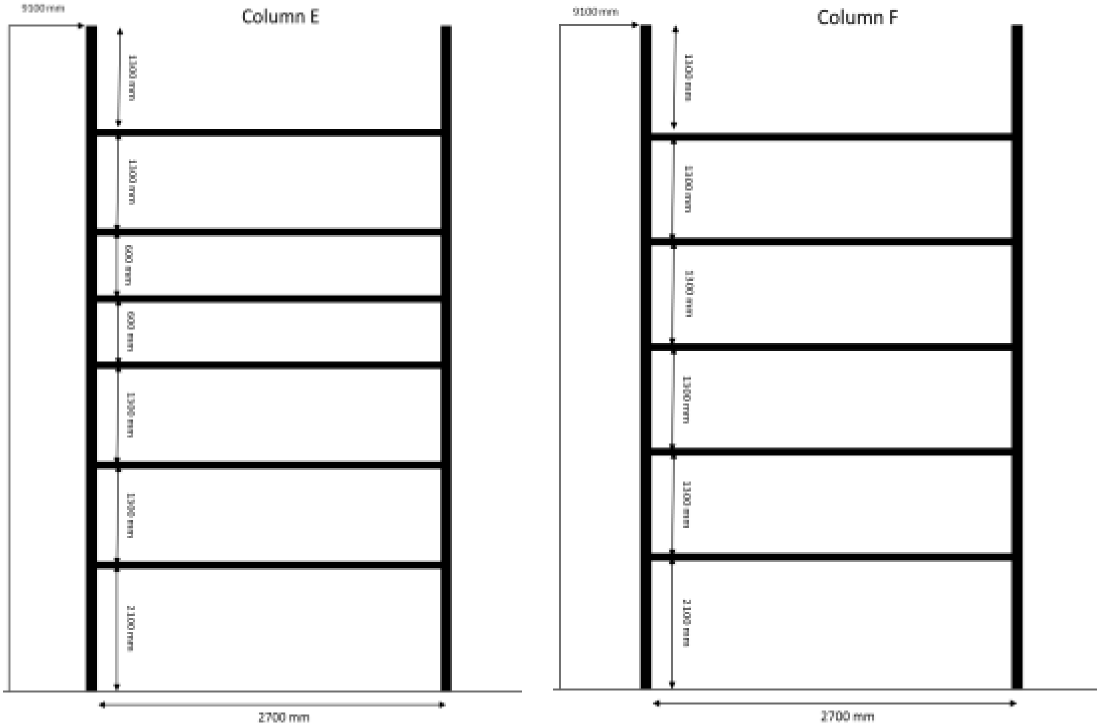
Tab. 1 Material flow intensity increase – simulated varieties

Variety	Flow In [pal]	Flow Out [pal]	Initial stock [pal]	Total increase of palette flow [%]
1	25 364	26 168	4 242	-
2	28 988	28 785	4 242	10%
3	33 818	34 622	4 242	33%
4	38 046	38 850	4 242	49%
5	40 582	41 386	4 242	59%
6	46 500	47 304	4 242	82%
7	50 728	52 336	4 242	100%

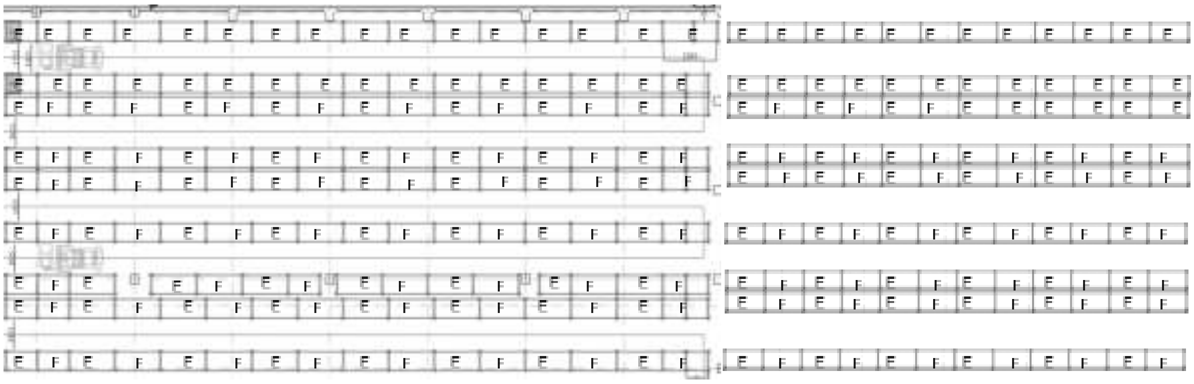
Source: Author

Input materials and finished products are represented by 2817 items placed in 12 types of palettes differing in proportions. With help of simulation warehouse layout is proposed and storage racks and material handling equipment is designed. Storage racks consisting of 2 types of columns (see Figure 1) and are sorted in storage racks layout as it is shown in Figure 2.

Fig. 1 Columns E, F proportions in storage racks



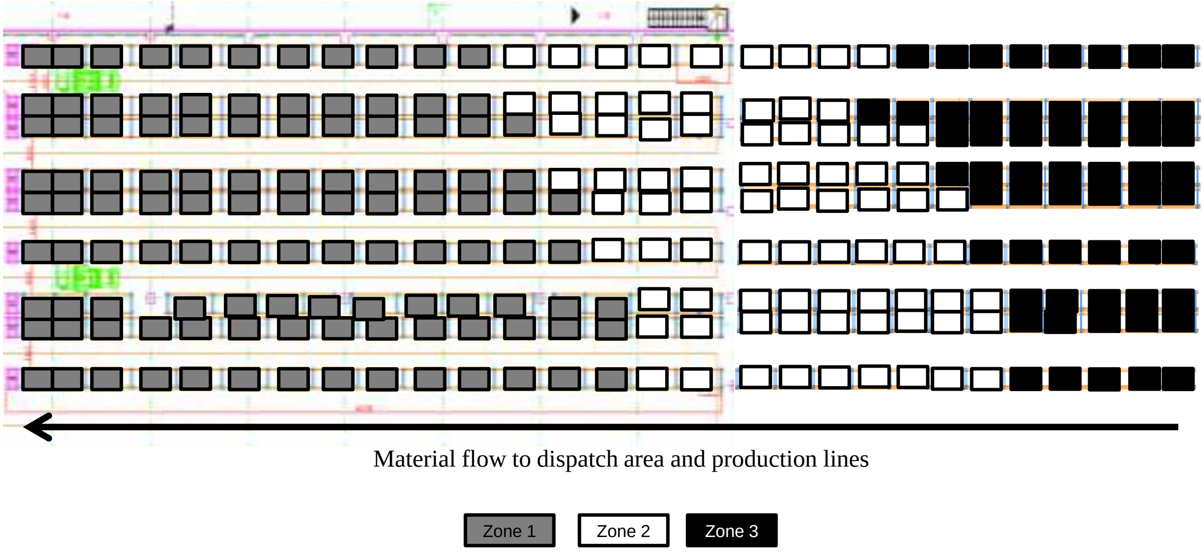
Source: Author

Fig. 2 Storage racks layout

Source: Author

To handle input materials and finished products through warehouse order picking stackers are used. Order picking stackers represent industrial trucks with a lifting operating platform, and can be used both as order pickers and also for putting load units into and out of stock. For the purpose of simulation average speed of order picking stacker is suggested to be

5 km/hour with time of loading and unloading ranging from 0.5 to 3 minutes per material handling requirement. Material handling requirement is represented by both whole palette and a part of palette manipulation. Palettes with input materials and finished products are placed to storage racks in 3 zones according to the frequency of order picking (see Figure 3). To Zone 1 items with 80% of order picking requirements are placed, Zone 2 with 15% and Zone 3 with 5% come after.

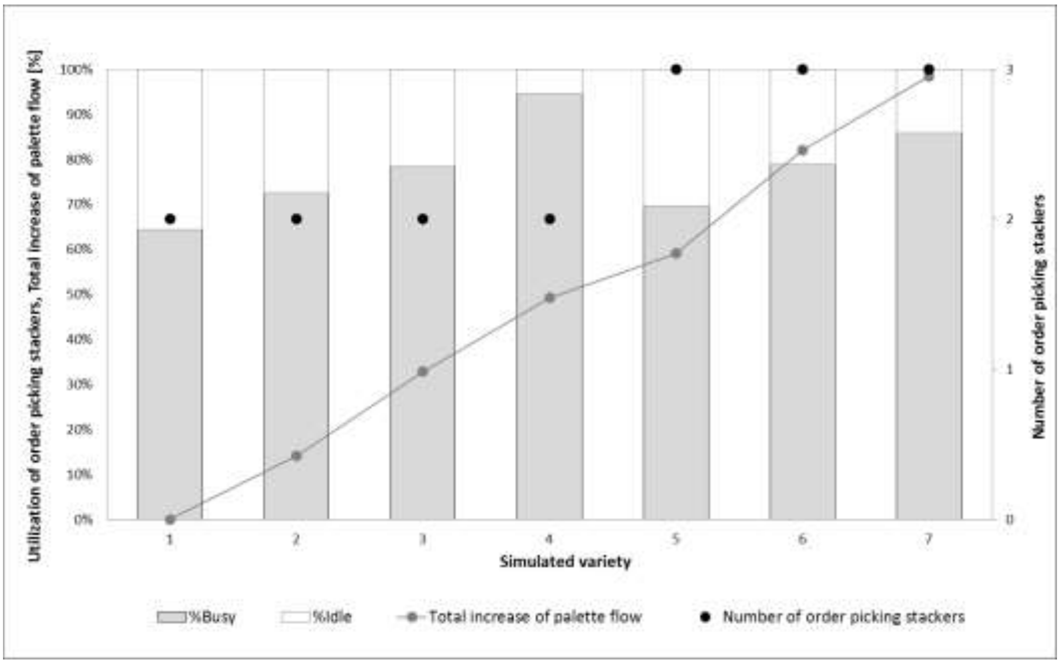
Fig. 3 Zones for placing items to storage racks according to the frequency of order picking



Source: Author

For proposed storage racks optimal number of order picking stackers is evaluated using the outputs of simulation (see Figure 4).

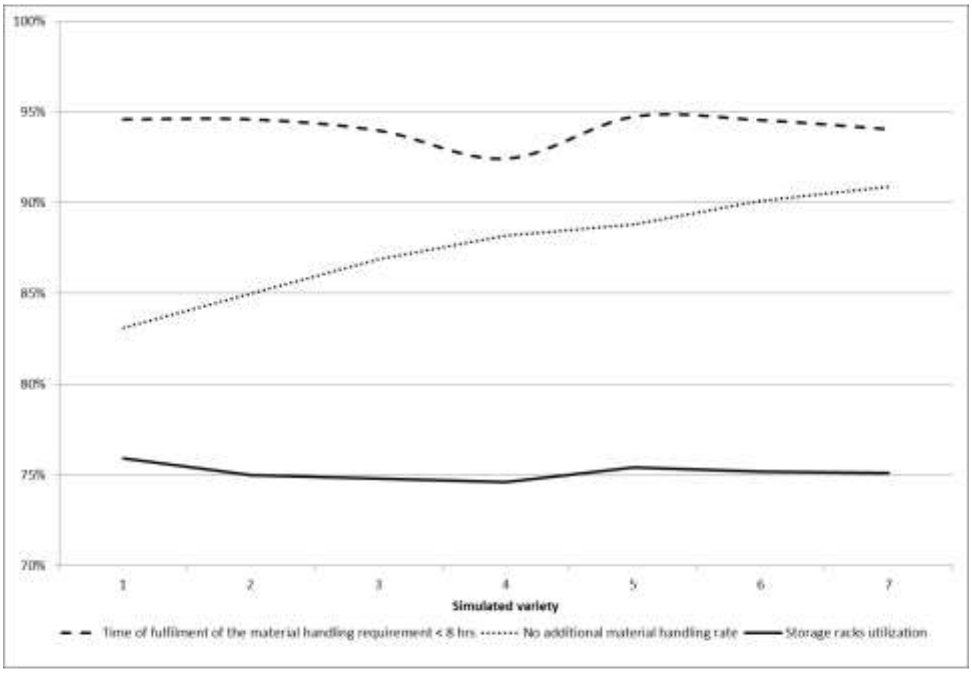
Fig. 4 Order picking stackers utilization



Source: Author

To assess performance of proposed solution represented by warehouse layout, warehouse equipment with storage racks and warehousing trucks outputs of simulation in the form of performance indicators are used (see Figure 5 and Table 2).

Fig. 5 Simulation performance indicators



Source: Author

Tab. 2 Stock levels, stock turnover

Variety	Minimal stock [pal]	Minimal stock [pal]	Maximal stock [pal]	Stock turnover [days]
1	3 437	4 352	4 599	51
2	3 438	4 309	4 607	47
3	3 434	4 298	4 618	40
4	3 431	4 287	4 622	36
5	3 438	4 331	4 628	33
6	3 438	4 320	4 636	30
7	3 438	4 319	4 641	27

Source: Author

Conclusion

The basic framework of simulation in the form of four available agents can be successfully applied in both supply chain and intralogistics systems modelling and optimisation. With help of performance indicators such as material handling equipment utilization or time of fulfilment of the material handling requirement decision making about warehouse layout, warehouse equipment with storage racks and warehousing trucks outputs can be supported. For companies, that means the possibility to assess performance of many different varieties of an intralogistics system structure in a relatively short time. Furthermore outputs of simulation provide the companies with the possibility to select optimal solution before investment

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