

EMULATION AS PART OF AN INTEGRATED LOGISTICS LEARNING ENVIRONMENT

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ABSTRACT

To meet the expectations towards future logistics education, an integrated learning environment (ILE) will be implemented at German-Kazakh University Almaty. Developed by Otto-von-Guericke University Magdeburg, the ILE will enable students to design, implement and verify logistics processes along a supply chain. The ILE includes a physical, miniaturized, automated material flow system with PLC and RFID, a self-developed Excel-based Control Centre and material flow simulation. Main emphases of this paper are the learning approach of process design with predefined process modules and the development of a discrete event emulation model as virtual commissioning tool for process control validations.

Keywords: Logistics Education, Material Flow Laboratory, Virtual Commissioning, Emulation

1. INTRODUCTION

Customization and regionalization of products are trends in today's industry. Together with service quality and schedule flexibility requirements, the resulting product diversity is overstressing the capabilities of classical production and logistics systems (Bauernhansel, ten Hompel, and Vogel-Heuser 2014). That is especially true for the all-connecting material flow systems and its controls. The concept "Industry 4.0"/"Internet of Things" is addressing these challenges by digitalizing and connecting all elements in the material flow (Schenk 2014). These decentralized control systems need clear identification before a decision process can take place. RFID is an approach to solve this dilemma.

Beside technological changes, the shifting of worldwide production volumes towards East Asia will establish new hubs in the global logistics networks. One of these hubs could be Kazakhstan as it is located on the shortest overland connection between Europe and East Asia. In its long-term development plan "Kazakhstan 2030" the country aims at building a powerful transport infrastructure. The strategy paper recognizes that beside the investments into infrastructure and technical solutions the education of logistics specialists is a critical success factor (Nazarbayev 1997).

The world bank is ranking the individual logistics competence of relevant employees in Kazakhstan only on the 81st place (Arvis, Saslavsky, Ojala, Shepherd, Busch, and Raj 2014).

In order to exploit this fallow potential, the LogCentre project was established in 2014. As a cooperation between leading German logistics research/education institutions (e.g. Otto-von-Guericke-University Magdeburg, Fraunhofer IFF Magdeburg) and the German-Kazakh University (DKU) in Almaty, it is a nucleus for up-to-date logistics education, consulting and industry-related research in Kazakhstan. The LogCentre is sponsored by the German Federal Ministry of Education and Research. The Centre's education services are aiming at logistics and telematics students of DKU as well as industry practitioners.

A practical and accessible didactics concept and an appropriate learning environment can address the challenges in modern material handling systems and can include Industry 4.0 solutions in logistics education. Main objectives of the teaching should be a deep understanding of intralogistics processes (design, implementation and verification) and the key technologies used (Material flow automation, RFID, simulation and ERP integration).

Today's industrial engineering education is addressing the linking role of logistics with a broad training program. Engineering basics, first insights into automation technology, the usage of ERP systems and simulation software are mostly done with the help of abstract tasks. Especially the context and the interaction between the different elements (e.g. the key technologies identified above) of a logistics systems are lost in the class structure. While all of these separated classes help the student to understand how wide and complicated the field is, it is a challenge to impart practical experience and understand the possible synergies between process and technology (Baumgarten and Hildebrandt 2008).

The approach described in the following is to integrate computer simulation and automation technology to form an innovative learning environment which enables

students to design, implement and verify logistics processes along the whole supply chain.

2. CREATING AN INTEGRATED LEARNING ENVIRONMENT

To understand complex problems and to develop future-oriented solutions, students (and other users of the LogCentre education services) need to think beyond the borders of the curriculum. Bringing together normally separated fields of technology can help to trigger this cross-border thinking.

Beside the class content, the new complexity is also challenging the classical, lecture oriented teaching methods. The needed depth as well as the required breadth of study can only be archived with a mixture from theory-based lectures, involvement-provoking seminars and tutorials, and, most important, excursions and project works (Baumgarten and Hildebrandt 2008).

As logistics is understood as an application-oriented science with the primary task to provide convincing recommendations for action (Delfmann, Dangelmaier, Günthner, Klaus, Overmeyer, Rothengatter, Weber, and Zentes 2011), hands-on experience is just as important as the theoretical foundation.

In this context, the combination of future technologies (e.g. RFID) and a physical material flow system with different methods from the world of computer simulation can provide an environment able to fulfill the posed standards. This environment will be called "Integrated Learning Environment" (ILE) in the following.

2.1. Learning with Material Flow Laboratories

The central and most striking element of the ILE is a material flow laboratory. While the history of laboratory work in logistics research dates back to the 1950's, there have been no studies on the effectiveness of use in (higher) logistics education (Uckelmann 2012).

With the results from other fields (e.g. engineering) in mind, it can be assumed that laboratory work is substantially different to the predominant theoretical teaching (Raghunath 2001):

"The biggest teacher is the failed experiment." Raghunath argues that not only the subject-related work is a valuable experience, but also the open way of working. Instead of repeating memorized definitions, laboratory work is about finding working hypothesis and making intelligent predictions about an (at least partly) unknown experiment outcome. Another fruit for students could be the realization that exam results do not always correlate with the results of the actual knowledge application (Raghunath 2001).

The other way around, practical work ("active learning") is improving the chances of undergraduate students to perform well in courses. Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt, and Wenderoth (2014) show that students in traditional, exclusively theoretical lectures are 55 percent more likely to fail an exam.

2.2. Learning with Computer Simulation

While the above-mentioned showed that a physical material flow laboratory has a reason for existence, the tight budgets of university teaching do not allow the providing of sufficient laboratory capacity for long, individual implementation and testing procedures (Uckelmann 2012).

The use of simulation in logistics laboratories can be a remedial action. The literature provides many examples for successful integration of simulation into education. Bruzzone, Bocca, Longo, and Massei (2007) are for example highlighting the contribution of simulation to education: increased interaction between student and system and the possibility of direct experiments (Montevechi, Leal, Miranda, and Pereira 2013) emphasize the positive motivation through interaction and are also stating improved results in the student's further project works (Rangel, Rangel, and Nascimento 2014). show the application of discrete event simulation to demonstrate operational sequences in computer network technology archiving "favorable results".

Closer to the case at hand is the education-related paper of (Cardoso, Rangel, Nascimento, Laurindo, and Camacho, 2014), describing the connection of a discrete event simulation model to a PLC. This use case of steering a simulation model with an external control system is known as emulation. Emulation can be used to find functional errors in control algorithms and to verify developed solutions (Boer and Saanen 2008).

To find error sources not included in the emulation model, it still needs a physical laboratory on site (Henke, Ostendorff, and Wuttke 2012).

Another possible risk of simulation/emulation usage in education is the misunderstanding of the reality due to the simplified modelling. In addition, familiarization with the simulation tool can be time consuming. Also, the availability of simulation tools is mentioned as a restricting factor (Bruzzone, Bocca, Longo, and Massei 2007).

Nevertheless, the usage of simulation is promising great results in education as students are showing enthusiasm when dealing with virtual, interactive learning environments (Leão, Soares, Rodrigues, Seabra, Machado, Farinha, and Costa 2012).

The benefits of a virtual over a physical laboratory are the better cost effectiveness, the higher capacity of the learning environment and the higher number of training scenarios, while the combination with a physical laboratory can eliminate most of the risks connected with simulation use.

2.3. Specification of Laboratory Scope

In logistics, it is common sense not only to think across the borders of technologies and curriculums, but also across the borders between different companies. That leads to the premise that a model for a comprehensive logistics education needs to picture a whole supply chain (Ballou 2006), including inter- and intralogistics processes from supplier to point of sale, from SCM/ERP level down to automation layer.

The following process layout was created by analyzing problem fields of today's process design, especially in the context of RFID usage. All flow objects (goods, pallets and trucks) are RFID tagged and tracked/traced along the whole supply chain. The stock levels in the different supply chain stages are recorded and can be used to control the system, e.g. automatically reorder products.

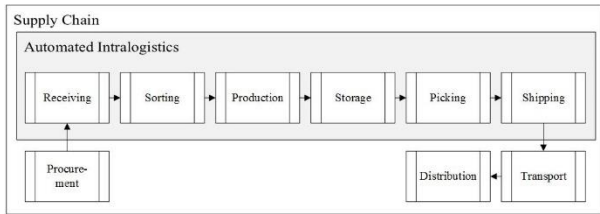


Figure 1: Process Structure of the ILE Supply Chain

2.4. Automated Intralogistics

The main part of the model is the automated intralogistics technology depicted below (Higher quality pictures and other project related media can be obtained from <http://www.logcentre.ovgu.de>). It shows all the main processes inside a production system in a miniaturized manner: goods receiving, transport, sorting, automated storage, production, goods dispatch. The processes are automated. The user is only needed to feed palletized products into the system and to sort goods on the picking stations.

The conveying mechanics are made by the company Fischertechnik, which is producing a construction kit under the same name. Coming with a high individualization potential, the kit can be complemented by different supplementary materials (e.g. steel bars) which positively influence the durability in the tough environment of a learning laboratory. Several vendors are offering pre-assembled industrial modules, including numerous intra-logistics relevant elements like the ones shown above.

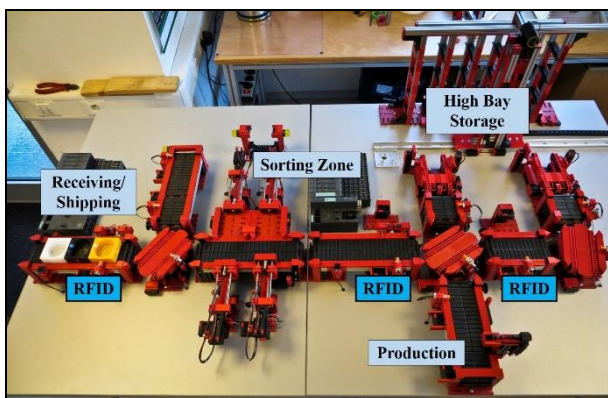


Figure 2: Automated Intralogistics in the ILE

2.5. Supply Chain Periphery

After leaving the automated material flow system, goods are transported down the supply chain to the distribution part represented by an outlet. The store has

a two-step layout, consisting of a storage area and a sales area. The transition points transport to storage area, storage area to sales area and sales area to the point of sale are equipped with RFID gates.

The main RFID processes in commerce can be demonstrated here: Automated bulk checkout, first-in-first-out assurance and the implementation of refined reorder procedures.

3. CONTROL SYSTEMS

The material flow along the modeled supply chain is managed by a number of tools which are also controlling the automated intralogistics.

Figure 3 shows the line-up of the software and hardware components installed in the ILE. Intersystem communication is done via the Control Centre (CC). Read from the top to the bottom, the structure shows a hierarchy similar to the automation pyramid (Heinrich, Glöckler, and Linke 2015).

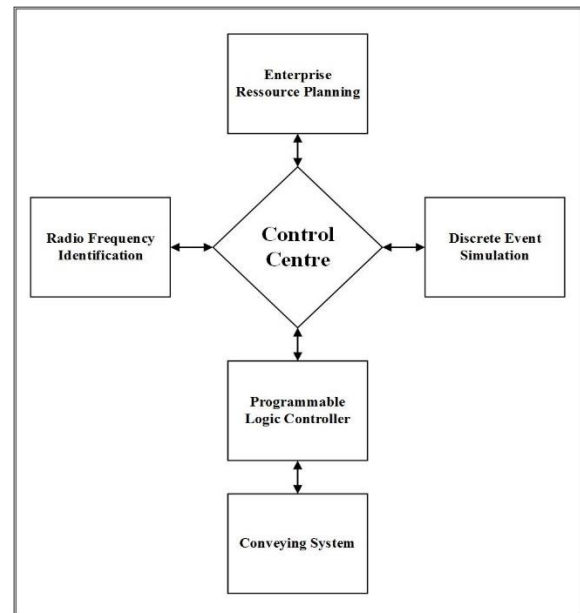


Figure 3: The Technical Components of the ILE

3.1. Control Centre

The Control Centre is the all-connecting knot in the material flow control. It receives RFID readings, manages the data base, processes user inputs and communicates the resulting process commands to the PLC.

The CC is integrated in an .xlsm file, consisting of several sheets and VBA code. As Excel is a standard tool used extensively for the most different kinds of business tasks, most students have been using the software before. In connection with VBA as programming language, which is close to natural language and a good starting point if the student was programming never before, it is easily accessible.

Excel seems to be a unique choice for a material flow control software but communicates very well with all other software elements of the ILE. That simplifies the

development of interfaces to the existing elements and ensures the future upgradability.

3.1.1. Usage of the CC to Demonstrate Processes

The CC is the user interface of the system. All main system routines are triggered by purchase orders which can be placed through user forms on the main control sheet. The user is guided through the order placing with the help of self-explaining input boxes. A short user guide describing all processes and how to trigger them is provided.



Figure 4: New Order User Form Screenshot

If the ILE is used for demonstration purposes only, nothing about the detailed functioning of the system needs to be known. In this way, teachers not directly involved in the project can use the material flow laboratory in their courses, too.

3.1.2. Usage of the CC to Modify Existing and Develop New Processes

However, for the main field of application the manipulation of the process sequences in the CC is elementary. It was necessary to choose an easily accessible programming approach that allows students to change the existing process structure and to implement new functionalities. While parts of the target group, especially the telematics students, are expected to have a solid IT knowledge, some of the logistics students as well as other users might not have a lot of experience in programming.

To face this challenge, an approach using graphical programming was developed. The students only need to combine elementary, pre-defined process modules to process groups, which in turn are linked to process chains through VBA-coded decisions.

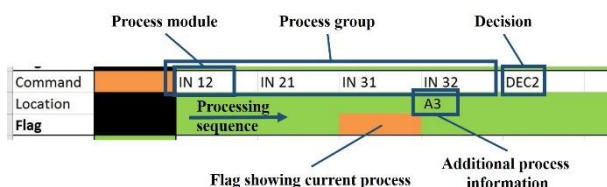


Figure 5: Screenshot Graphical Programming

Figure 5 shows an example line from the graphical programming sheet. The process module identifier above the flag is read by a superordinate VBA method and communicated to the PLC. Once the PLC confirms the successful execution of the process module, the flag jumps to the right follower. If additional information is needed to carry out a process (e.g. a location in the high bay storage) it is communicated in the field below the process module name. At the end of the process group, a decision method realized in VBA is called. This decision method chooses the next process group depending on the system status, e.g. RFID readings and the stock situation.

The single process module is clearly defined. It has a starting point and an ending point. The process module is reported as successfully executed once the good was transported to and detected by the physical ending point sensor.

Every possible process chain in the automated intralogistics part can be described as a sum of process modules.

3.2. PLC

The process modules described above are intended to simplify the design of process groups and process chains as well as to serve as commands from the CC to the PLC.

The PLC code is structured into different function blocks. These blocks are called by the communicated process module identifiers. The cyclic program sequence of the PLC is first checking for the active process module, then checking the system status represented by sensor readings and finally setting the actuators needed to complete the process module execution.

For almost all changes and process developments in the material flow laboratory, the PLC code does not need to be reconfigured. However, if the lecturer/the student wants to include PLC programming into his/her project, the system provides a state-of-the-art development environment. A Siemens Simatic S7 hardware PLC was chosen to control the automated intralogistics. This is the current industry standard for material flow automation. The used PLC programming environment is Siemens TIA Portal. It is supporting all commonly used PLC programming languages.

The communication between the Excel CC and the S7 was implemented by using an Industrial-Ethernet connection and the LGPL-rated communication library "libnodave.dll".

3.3. RFID Integration

RFID is one of the trending topics in the last decade's logistics research. Advantages are contactless and fast bulk reading without handling the goods (Gartner 2012, Kortmann 2006). Automated systems need this fast and reliable identification.

13.56 MHz USB readers with a suitable read range of 5-7 cm are in use in the ILE. The readers are positioned on seven points. Three are part of the intralogistics

automation, while the other four are keeping track of stock movements along the supply chain. All flow objects are equipped with passive tags for identification. The tag ID refers to the object's details which are saved in a central database. The reading data is written into the Control Centre. The data is used for tracking/tracing goods along the supply chain and, more important, for picturing the system status and deciding for the next process group.

4. INTEGRATING EMULATION INTO THE ILE

As mentioned above, the described physical laboratory does not offer sufficient capacity for all students as only one student after the other can implement and verify the developed process design. On the other hand, interaction with the system during the control development was identified as one of the central success factors for the laboratory.

Cardoso, Rangel, Nascimento, Laurindo, and Camacho (2014) showed the use and the usefulness of emulation models in automation engineering classes. Transferring this approach to the higher level of process control development solves the mentioned problem.

To test the developed process logic, an emulation model of the automated intralogistics and the supply chain periphery was created. This model is connected to and controlled by the Excel CC. This approach is known as high-level emulation and is typically used for virtual commissioning (Zhang, Le, Johnston, Nahavandi, and Creighton 2012).

The commissioning model emulates the physical part of the material flow model including PLC, conveying elements and RFID reader, emulating its input/output behavior towards the CC.

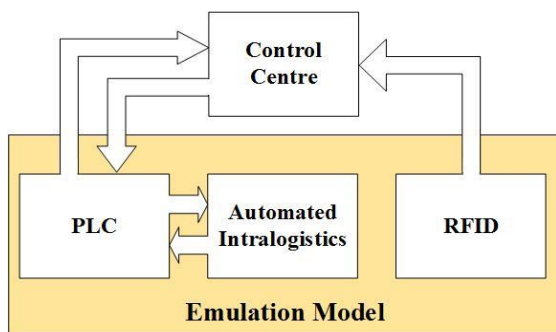


Figure 6: Structure of the Emulation Model

The implemented model does not emulate on sensor-actuator level (as not the PLC is connected) but the process level control done by the CC. Base for the emulation model were the planning outcomes: Flowcharts, conveyor layouts, the pre-defined interface CC to PLC and the pre-defined interface RFID to CC.

As part of the LogCentre, workstations with the simulation software ExtendSim are available for the students. The ExtendSim implementation of the model has the main objective to visualize/animate all

necessary information for the verification of the process sequence programmed in the CC. For this purpose, a special ExtendSim object library was created and custom made blocks were provided with a special animation behavior. In the simulation model, all of the physical components were modeled in a simple way in 2D, including material handling technology with conveyor belts, rotary tables and the production facility as well as goods and pallets with their attributes Tag ID and type. The high-bay storage is visualized by animating the information about put away goods that is written into a database table. The stock levels of the virtual HBS as well as the stock in other supply chain steps can be initialized with the currently defined stock levels from the CC.

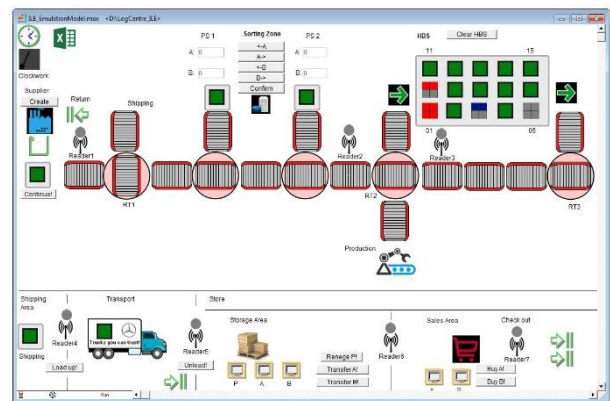


Figure 7: ExtendSim Emulation Model

The emulation model is controlled analogously to the control of the physical model's PLC: The CC transmits the ID of the process that has to be executed and further needed process information, e.g. location names for picking and put away. After successful execution of the process, the emulation model confirms the command. In addition, when passing the reader points the corresponding RFID tag IDs of the flow objects are communicated. The embedded software interfaces based on COM are used to write directly into corresponding CC database fields.

The writing of a process module execution confirmation message is triggering the next process module or a decision. In the emulation model, the execution – which means the simulation and animation of the communicated process – is released by opening the respective gates for the corresponding flow object.

Just as the physical system, the emulation needs human interaction. User inputs into ExtendSim can be done during runtime with the help of form fields and buttons. It is possible to create flow objects, to insert them into the automated intralogistics, to sort the goods on the picking stations and to move the goods down the supply chain.

CC and ExtendSim both run locally on the student's workstation. Test scenarios can be easily defined in the CC in the presented graphical way and transferred to the emulation model at the push of a button. As the solution can be tested virtually before, the work on the physical

model can be minimized to the actual implementation and presentation. That increases the number of students that can work in the laboratory.

5. USING THE LEARNING ENVIRONMENT IN LOGISTICS CLASSES

The concept presented in the preceding offers a wide range of teaching and learning possibilities. Some of these possibilities are presented to the teachers in form of learning materials, collected in an online knowledge management system. Using different kinds of media can improve the teaching results (Jensen, Wood, and Wood 2003), especially since it is respecting differences in learning habits, curiosity and experience (Mandal, Wong, and Love 2000).

The prepared tasks are aiming at different aspiration levels following the Bloom's taxonomy (Bloom and Engelhart 1976).

The easiest level is to demonstrate lecture contents with the help of the ILE. Example: The lecture "High Bay Storage" is accompanied with a practical demonstration of put away and picking processes in the automated intralogistics model. The students can *identify* and the main processes and can *compare* them to manual storage strategies.

On a medium aspiration level, the students can program a new process chain in the Control Centre. The given programming technique has to *be used* and the solution needs to *be structured* according to the material flow system layout.

The most complicated tasks are openly formulated ones. Example: A small group of students has to *develop* a RFID-stock take process for the high bay storage. The process needs to be *tested* and *evaluated*.

During the concept development, the ILE was always thought of as a living environment with constant growth and enhancement. The development of new functions through student project works and final papers is desired and makes it exceedingly attractive.

In the everyday classes at DKU, students of telematics and logistics hardly ever meet. To cross the border between the two curricula, the ILE can be used for project work in interdisciplinary teams consisting of students from both study programs. Especially for the logisticians a knowledge transfer within these projects could be essential – Industry 4.0 is asking for a firm knowledge of IT and integrated systems.

6. FURTHER RESEARCH

In later development stages an integration of virtual reality (VR) technology is considered. With the automated intralogistics part, students have a role model for constructing their first VR model. An interface between CC/PLC and VR could be used for the digital status control.

The SAP ERP learning module that is part of the LogCentre project will be integrated into the ILE. It could function as a superordinate user interface to control the material flow laboratory.

In order to measure the actual impact of the used methods, the learning progress of the students in the ILE will be tracked. Results from this study might answer the question about the usefulness of learning laboratories in logistics education.

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