Using Innovative Transportation Technologies and Automation Concepts to Improve Key Criteria of Lean Logistics

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ABSTRACT

Decreasing or entire eliminating all kinds of waste in production systems is one of the main goals of today´s companies implementing lean management. Wastes can be found in material warehouses or facilities, all production and logistic processes and in finished products warehouses. The 4th industrial revolution, widely known as Industrie 4.0, delivers many innovative technologies. All of these solutions are significantly helping to reduce waste and make the company lean. These have to be compared to existing technologies in cases of energetic or time efficiency. The contribution describes two logistics technologies – the AirMove system and Automatic Guided Vehicles. The paper further deals with the comparison of the two logistic technologies in crucial aspects of lean management quality-cost-time. Therefore measurements of energy consumption, time or volume aspects are the necessary tools which are providing needed information. The objective is not the discrediting of one of the technologies, but the relaying of the relevance of lean thinking, drawn by a fundamental comparison of the two technologies. The research will be performed in the experimental and digital factory at Chemnitz University of Technology.

1. INTRODUCTION

The life of present-days companies is characterized by the goals in two ostensibly remote areas. The first one deals with adaptability of production and handling equipment. It tries to increase mechanization and automation of whole production and creates highly value added processes. The production philosophy which accurately describes it calls Industrie 4.0. The second area deals with ergonomics, resource efficiency, added value across whole value chain. The main goal can be described shortly to reduce or completely eliminate all non-value added processes and activities. It is called Lean management.

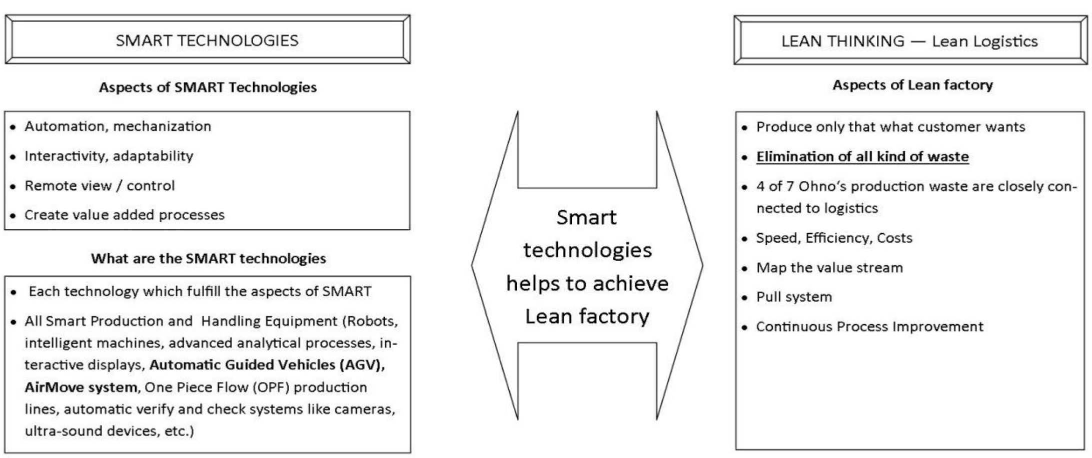

Figure 1. Smart technology and Lean thinking, created according [3], [4].

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The article is based on the description and comparison of the two production philosophies Industrie 4.0 and lean management scope. Therefore, several experiments were carried out with two smart handling technologies to recognize advantages in terms of lean management to. The approach of the research is shown in Figure 1.The goal is an exemplary comparison of two transport technologies, but not the proof of superiority of one of these technologies. Experiments, aiming the evaluation of specific optimization criteria such as time, space requirements or energy consumption, are carried out. Industries should be sensitized on the relevant criteria for lean logistics and which intelligent technology is the most appropriate to be implemented.

2. LITERATURE REVIEW LEAN – SMART RELATIONSHIP

2.1. LEAN MANAGEMENT

The concept of lean manufacturing has been used first in Toyota Production System (TPS). The main goals of lean activities are elimination of waste, increasing speed and making continuous production flow. According to it the activities and processes can be split in to two groups. The activities for which the customer is willing to pay and transform the raw material in to the final product – value added activities (VA). All other activities which decrease speed or disrupt flow are the sources of poor quality and can be found as a source of waste. They are called non-value added activities (N-VA). The latter should be reduced or eliminated completely (e.g. unnecessary transports, handling or storing) [1], [2].

There were two approaches in the classification of waste. Toyota’s chief engineer firstly categorized all sources of production waste and defined it as Seven Mudas. The second term is logistics waste. The origins of the idea can be found in the widely known phrase “You can’t make something out of nothing”. The resources and inventories are necessary to accomplish the right products in right amount and quality. But problems arise from unproductively usage of resources, applying the wrong resources, failing to tap necessary resources, or directing resources toward the wrong destination [3].

Table 1. Definition of Production Mudas and Logistics Waste.

Seven Mudas	Logistics Waste
Overproduction	Inventory
Waiting	Time
Transporting	Packaging
Unnecessary inventory	Knowledge
Inappropriate processing	Administration
Excess motion	Space and facilities
Defects	Transportation

As can be seen in Table1, at least half of logistics waste is exactly the same as Seven Mudas for production. Many changes over recent years have driven organizations to become world class organizations or Lean Enterprises. The first step in achieving that goal is to identify and attack the wastes in production and especially logistics [2].

2.2. INDUSTRIE 4.0 - SMART FACTORY

The term "Industrie 4.0" refers to the fourth industrial revolution. The basic principle of Industrie 4.0 is the connection of machines, work pieces and systems to intelligent networks along the entire value chain. Self-control of these networks is the long-termed goal of the research efforts. Industrie 4.0 is the environment which embodies the core of the industrial way of the internet of things: intelligent machines, improved analytics and people at work. Its main ambition is to achieve new perspective in the field of production and logistics, the Smart Factory [4], [5].

The Smart Factory represents manufacturing environment that can handle turbulences in real-time production. It is characterized by adaptability, resource efficiency and ergonomics as well as the integration of customers and business partners in business and value processes. This can be achieved by using decentralized information and communication structures for an optimum management of production processes [3], [4].

Characteristic are the strong customization of products under the conditions of highly adaptable mass production. The required automation technology is improved by the introduction of methods of self-optimization, selfconfiguration, self-diagnosis, cognition and intelligent support of workers in their increasingly complex work. This ideas and principles significantly help to achieve aspects of lean manufacturing.

3. Description of the Experimental and Digital Factory at Chemnitz University of Technology

The Experimental and Digital Factory (EDF) at the department of Factory Planning and Factory Management of Chemnitz University of Technology is a research laboratory, divided in a digital and a factory section. It is designed to treat issues of education, research and demonstration of factory planning and factory operation [6]. The focus of laboratory reflects current research directions as energy efficiency, the implementation of smart sensor networks to production processes and facilities and the development and testing of emerging technologies as well as research on trends for future production [6], [7], [8].

The factory section (Experimental Center) which contains facilities and processes as close as possible to real industrial factory conditions is used to perform the experiments [6]. There are installed different kinds of equipment for the representation of processes, such as machining, assembly, quality processes or logistics. Thereby assembly/disassembly, testing, manufacturing, logistics and maintenance are combined to a holistic overview for research and development and can even be focused in lean thinking [9]. This can be used for the gaining of knowledge e.g. in the fields of layout optimization, process optimization, scopes of ergonomics and also for the research on automation. Other researches are driven by the requirements out of the industries, which lead to improved or leaner technologies like new types of automated guided vehicles (AGV) [6], sensor networks [7] or even new conveying technologies, such as airflow driven conveyors [10]. The physical implementation is quiet near a real production or logistics system and contains all of the standard equipment and especially some equipment, which can be seen as lean.

Conveyor systems for materials supply are essential in logistics and contain a big potential for optimization of logistical processes, facilities or objects. Standardization is one proper way to support lean thinking. The transportation of material can be done with standardized small load carriers [11], that can be taken up by one of the cheap and lean automated guided vehicles (AGV). In addition to the investigation of lean structures and processes, also some other conveyors are presented in the EDF, which consider the Lean thinking or even can be compared to each other. Material storage of the named small load carriers can be done by the automated high rack. Again, studies on space, storage strategy, etc. are possible. Next to the storing and/or transportation of small parts in standardized boxes, parts can be delivered in some other smart systems. The EDF includes also unconventional transportation system the airflow driven conveying system called “AirMove”. Material is supplied in required quantities to the demanding places (e.g. assembly lines) by air flow via a pipe system. This technology was built up in May 2013 and is aimed to transport individual parts in the specific amounts without any usage of small load carriers. It can be seen as lean technology, because of the missing packing and unpacking processes, what can save time and space.

4. Logistics systems / Handling systems descriptions

Material handling equipment is equipment that relate to the movement, storage, control and protection of materials, goods and products throughout the process of manufacturing, distribution, consumption and disposal. Material handling equipment is the mechanical equipment involved in the complete system. It can be generally divided in to the four main categories: storage and handling equipment, engineered systems, industrial trucks, and bulk material handling [12]. Among material handling equipment we can include resources as [13]: Storage and handling equipment, conveyors, robots, AGV´s, industrial trucks or bulk material handling systems. Some of the main logistic and handling equipment which face the smartness of factories and Lean management are AGV and certain kinds of bulk material conveyors. The next section will focus on the description of AGV’s and the AirMove system, which are both installed in the Experimental and Digital Factory of Chemnitz University of Technology. Both technologies are comparable in e.g. energy consumption, throughput or time issues. Those parameters are facing to the Mudas defined before. It is mentioned, that an optimized part of a logistic system can lead to more holistic process optimization in lean logistic. Therefore users of technologies shall find Mudas in their system, in the usage of it and in the technology itself. Following this, two selected lean technologies out of the EDF are described in short issues. Figure 2 shows some available facilities in the laboratory EDF like AGV as well as the installed AirMove system.

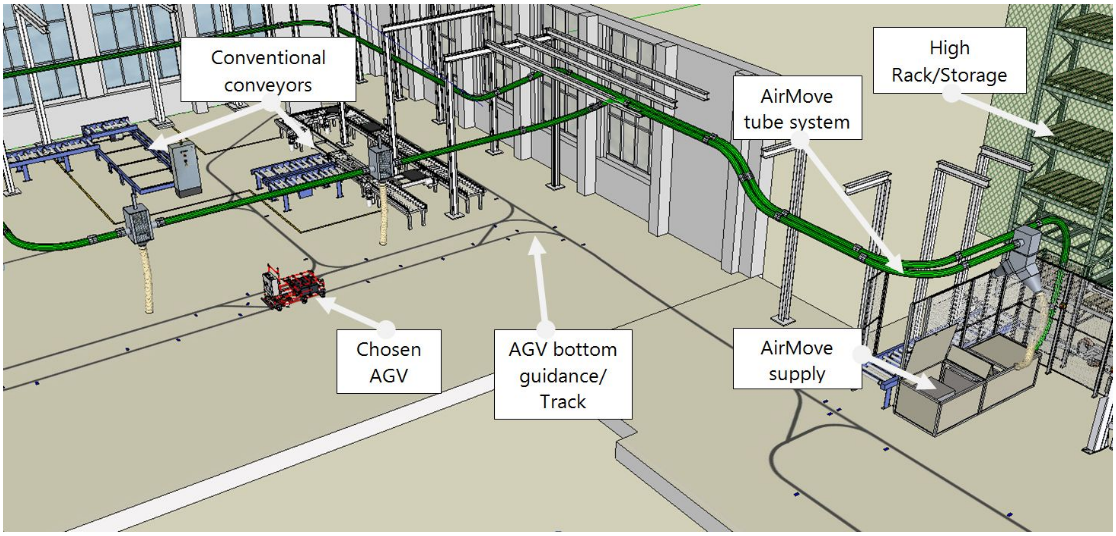

Figure 2. EDF with selective facilities like AirMove and AGV.

4.1. AUTOMATIC GUIDED VEHICLES (AGV)

AGV's are floor-bound conveyor systems that can automatically supply production lines or carry finished goods. The delivering is predictable at all exact times, the reduction of headcounts in material delivering or the availability and reliability are some benefits. Other benefits include the ability to transport a wide variety of goods, adaptation to fluctuating transport performance requirements, change in the delivery order and high transparency. AGV can be classified by e.g. their load volume or their transportation characteristics and should be optimized by facing the common habits of logistics and lean thinking [14].

4.2. AIRMOVE SYSTEM

The AirMove is a conveying system which is an air-flow-based conveyor system, that can be mounted in nearly every existing production system (e.g. on walls, ceilings). Therefore it is adaptable to every given structure. The goods are transported in a pipe system by a stream of air, generated by fans. The system is efficient and durable and especially suited for small parts. Low follow-up and maintenance costs are caused by the modular design of the AirMove system and the resistance of its components. In the EDF the technology is installed on an approximately 75 meters track with several separators. Distances of up to 100 meters can be achieved with optimal pipe diameter by a single fan. Flow rates of up to several million parts per day can be achieved. By moving the transport routes in unused levels of production, some more space is available and can be used by value adding work. The facility can be fully automated: "Once programmed, intervention is only necessary in exceptional cases." [14]. The transportation takes not place in an enclosure - in AirMove the parts are moved directly by the air flow, so that the lean thinking is supported by the decimation of handling or packaging processes.

5. EXPERIMENTAL DESIGN

For the operated experiments two kinds of parts were chosen (as shown in table 1) and used for the transport issues and measurements. Both are functional parts, coming out of the automobile industry. Part A is firmly attached in auto bodies and serves to hold cables through it (prevention of attrition). Part B is also mounted in the car body it holds cables in their position (serves for positioning). These parts are being assembled in huge amounts, so that it is very evident to analyze their transportation characteristics facing the defined Mudas. The comparability between both technologies is given by the assignment of transportation processes to both kinds of parts. To follow the link between smart technologies and lean logistics it was necessary to define experiments, which are exactly facing the given Mudas. The technologies are assessable by the survey of two key criteria: time needed for distance and energy consumption per time.

The Energy consumption depends on the transported goods (e.g. weight, geometry, amounts). So there were needed to define specific parameters for both technologies. For AirMove technology, this is especially the fan speed driven by its motors power. For the AGV it is the transportable box size and maximal amount of boxes which can be loaded on a one trailer or rack. To make all experiments comparable, both parts were measured by their weight, geometry and amounts needed to fill one transportation box (RL-KLT 3215). Its dimensions are 30 cm x 20 cm x 14.7 cm, the volume 5,3l and their own weight is 570 g. For all measurements were used the same boxes (RL-KLT 3215) full of corresponding parts. Therefore the time consumption belongs to one box and to the distance along which the parts has to be transported.

Table 2. Correlated input quantities.

	Part A	**Part B**
		
Average Transportation Time AirMove [s]	Apparent power AirMove for secure transportation [W]	Space requirements of facilities on ground [m^2]
27.3	1500	~3… 5 m² *
34.5	1500	

5.1. Experiments on AirMove

The AirMove system installed in the EDF has got a fan with 2.5 kW of maximum power, it´s tube systems diameter is 125 mm and it´s exactly length is 73 meters. The fan speed can be chosen continuously in a range of min = 0.6 kW to max = 2.5 kW and defines the speed of the transportation air stream. The experiments on AirMove were performed in 5 dependent experiments for each parts type. All of them are determined by optimal speed of fan which are corresponding to the chosen parts. All parameters were measured as soon as the AirMove behavior settled down and were slightly oscillating around the mean value with negligible standard deviation. Power consumption depends only on the fan speed which is influenced by size and weight of parts and transportation length. For the chosen parts the fan speed had to be experimental and firmly set to an apparent power of 1.5 kW for an assured transportation of the parts amounts. Currently doesn´t exist any equation for analytical determination of electrical parameters. Fixing these optimal parameters and after stabilization of the whole system, the cycles on AirMove for each part were measured by time consumption. The transportation time was measured between the point the first part fell in and the point, the last part completed the circle in transportation range. The results are stated in table 3 below.

Table 3. Realized measurements for both parts types on AirMove.

Parts type	Amount of Parts	Transportation way AirMove [m]	Average Transportation Time AirMove [s]	Apparent power air Move [W]	Energy consumption [kWs]	Space requirements for AirMove [m²]
A	305	73	27.3	1500	40.95	~3… 5 m² *
B	620	73	34.5	1500	51.75	

The transportation time was measured between defined start and stop points during the energy consumption was watched, concerning energetic stability. Crucial on AirMove is the input into the whole system. By using too narrow input the parts stuck at the input. Therefore first segment which has to be properly designed at AirMove is the parts input. The problem was solved by using wider entry cone and putting parts in smaller batches – by continuous part supplies. The space requirements depend on the usage and counts of e.g. noise abatement facilities, the geometry of cone, fan or the used feeding technology.

5.2. Experiments on Automatic Guided Vehicle

The used AGV is created by the company Trilogiq S.A. and is already defined here as lean technology by its producers. This AGV is powered by 2 batteries with each 120 Ah each, that are combined to one 24 Volts block. It is processed by a very simple control and can carry a max load of 500 kg in bearing mode or max 1000 kg in dragging mode. It´s energy consumption depends on the carriage and some physical parameters of its operation. The average energy consumption can be determined by the measurement of AGV in different states. Operating states differentiate from each other by its speed and weights. The power consumption is mediated by measurement of decrease of AGVs battery power. Final goal of those previous researches was the creation of so called energy cards for the visualization of characteristic energy consumption [15]. The experiments were focused to adjust optimal setting in different operation types, transport mass (counts of trailers/load) and speed setting, frequency of starting operations in consequence to disturbances (as stops). The biggest information value has shown long-term experiment which simulates usual working processes. The overall results corresponding to the chosen conditions of conveyed material, 30m/min, 70m length track) are stated in the following table 4. As can be seen the main power consumption for AGV is driven by the transportation itself. The calculations were performed without computing standby or waiting mode.

Table 4. Experimental results for AGV power consumption.

Operating state	Operating time [hours]	Operating time [%]	Energy consumption [Wh]	Energy consumption [%]
Standby	1,2 h	6,9%	18 Wh	1,7%
Waiting	0,6 h	3,5%	15 Wh	1,4%
Transport	16,1 h	89,7%	1034 Wh	96,9%

For experiments a characteristic industrial medium speed of 30m/min was set. Out of the long term experiment results that the AGV consumes by driving at average 60W depending on its load and one circle takes 204s/circle [15]. This is used for the overall calculation for the chosen transport. This means the AGV consumes 3.6W each 204sec and within the 16.1hours the AGV drove more than 280circles. The length of one circle was approximately 70m what is almost the same distance as AirMove system. Therefore the delivery time and the specific energy consumption could be compared between both systems because the corrected transportation time was also measured for AirMove. Table 5 shows the operated measurements for AGV.

Table 5. Realized measurements for both parts types on AGV.

Parts type	Amount of Parts	Transportation way AGV [m]	Average Transportation Time AGV [s]	Apparent power consumption AGV [W]	Energy consumption [kWs]	Space requirements for AGV on ground [m²]
A	305	70	204	60	12,24	~ 75 m²
B	620	70	204	60	12,24	

Different load volumes and physical characteristics have to be centered to evaluate in smooth dimensions even for other types and amounts of parts or different tracks. The apparent power consumption depends mainly on the AGV's modes, load and length of circle. It was chosen an average power consumption of 60W which was gained out of the long-term testing and simulating standard working operation. Space requirements depend on the count of shelves and the track. Needed space was counted by following formula - single space plus the space for loading and for AGV guidance tracks. Exact calculations are A1 = (AGV + single rack) = 1.035 m², A2 = A1 * guidance track length = 70 m, A3 = loading station (acceptance = A1 = 1.035), A_sum = A1 + A2 + A3 ~ 75 m² (counting: one-way course = 1 cyle).

5.3. COMPARISON OF BOTH EXPERIMENTS

The comparability was ensured by selecting proper box, amount of material and similar distances for delivering material (even the same length tracks). These facts served as premises for following evaluation. Therefore the experiments were evaluated according their energy consumptions, average transportation times, space requirements and specific energy consumption per each part because there were different amounts of parts conveyed (table 6).

Table 6. Numerical comparison of both experiments.

	Transportation way [m]	Average Transportation Time [s]	Energy consumption [kWs]	Specific energy consumption [Ws/1pc.]	Space requirements (max) [m^2]
AirMove – part A	73	27.3	40.95	134	5
AirMove – part B	73	34.5	51.75	83	
AGV – part A	70	204	12.24	40	75
AGV – part B				20	

The advantages of AirMove can be seen in the high transportation speed and the space requirements contrary to its significantly higher (specific) energy consumption. When the process of optimal material filling was reached the average transportation time over nearly the same distance was much lower than the transport time by the AGV (up to 7times). The AirMove got its own infrastructure and therefore the transport speed do not subject to any safety regulation. Each technology has to be installed or used somewhere to the production space and takes away very valuable floor space. As can be seen, the space needed by AirMove is 15 times lower than the space needed by AGV. The advantages of AGVs are drawn by a higher transport capacity for (different) parts in one transportation cycle depending on conditions of high material requirements and suitable layout. This fact is caused due to the AirMove needs only space for central station, which could be situated in the warehouse. Other infrastructure is firmly attached to the ceiling and there are further no elements touching floor.

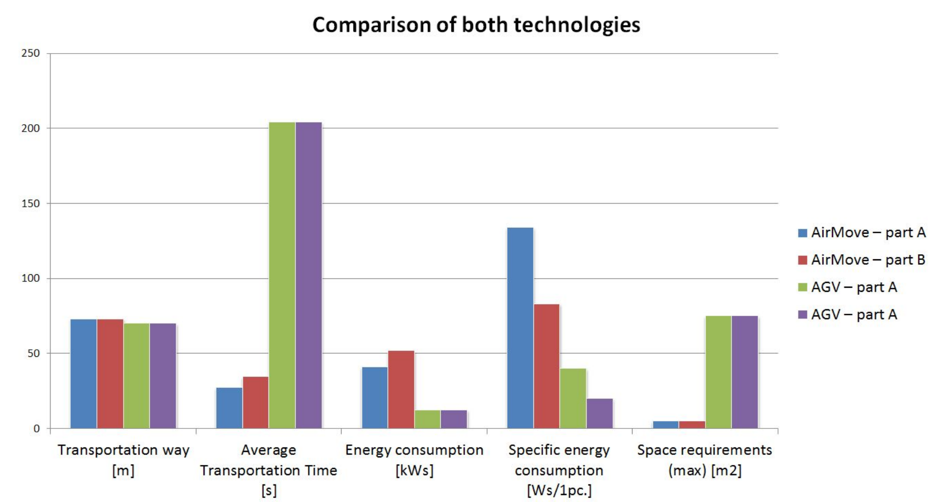

Figure 3. Comparison of both technologies depending on the conveyed parts.

6. CONCLUSION

The comparisons made before shows that AGV's looks much more energy efficient but AirMove spares time and valuable production space. Therefore both technologies could be seen as lean, because of their specific waste reduction – each with its own advantages and disadvantages in case of lean production. To release the global optimization in lean thinking, those and other technologies have to be adapted to their optimal operating points and behaviors in production and logistic systems. For this it is necessary to examine additional relationships.

The advantage of AirMove to be more speedy/time saving should be compared to its disadvantage of e.g. buying additional automated feeding technologies. Other optimization criteria have to be watched in a more holistic way. Especially if the energy consumption is not the most important or the only criteria, some other criteria should be separated. For example the simultaneous handling of different parts can only be given by AGV – AirMove will provide a more complex control technology for it. Saving packing/unpacking processes in warehouses takes time and also needs staff for it. Furthermore researchers shall handle the time consumption in manual handling boxes to the AGV and the energy consumption by carrying empty boxes to their starting point. Future research should consider material handling to get a more holistic overview for the comparison of the shown technologies. New developments of facilities shall be driven by the holistic optimization criteria. The goal will be, to determine relations directly between energy consumption, kind of parts and main technologies/consumer loads and not to loading devices or bypass processes. Advantages of the AGV, such as the simultaneous transport of all kind of materials or larger amounts of material should be weighed against the advantages of AirMove as well as the transported parts shall be watched on quality aspects.

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