CONDITION MONITORING IN LOGISTICS – A NEW APPROACH FOR MAINTENANCE

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Abstract
In modern times, far-reaching changes especially in production have taken place. Lean manufacturing systems require delivery strategies such as just-in-time or just-in-sequence that are synchronized with production demand to make sure the optimal amount of inventory is on hand at any time. This development comes along with both increasing dependence and cross-linking of in-house-logistics systems, also called intralogistics-systems, that sharply raises the probability of negative impacts of unplanned breakdowns. Against this background the importance of reliability for intralogistics-systems increases. But instead of intelligent maintenance concepts, the intralogistics industry faces this challenge by providing robust and oversized systems. Therefore, the Chair of Factory Organization in cooperation with the Fraunhofer Institute for Material Flow and Logistics (IML) approach the problem of construction and maintenance of intralogistics-systems in order to find different, more efficient ways to reliability and availability.

Keywords: Logistics systems, Maintenance, Condition Monitoring

1. Introduction
Nowadays, logistics represent an important factor in terms of competitiveness and economy for manufacturing companies as well as commercial enterprises. This mainly lies in the dynamic market development caused, among others, by globalization. Those changes result in extremely high leveled requirements towards logistics. Several industries are reducing downtime and buffer stock to zero. Therefore, complex delivery strategies such as just-in-time and just-in-sequence require one hundred percent efficient supply-chains [1]. The rule of a chain being as strong as its weakest link can be transferred to supply-chains. Consequently, the requirements concerning reliability and availability of each link increase, because logistics-services cannot be produced to stock [2]. This applies to production facilities and particularly to their intralogistics-systems, which ensure the in-house flow of material and information. Experts agree on intralogistics being the crucial element of a successful supply chain and its bottleneck at the same time [3]. The whole supply chain and the supplied industries depend on the performance of intralogistics. Unscheduled down-times and failures of the intralogistics-systems have to be avoided in order to provide a continuous and accurate material flow, which is an indispensable requirement for organizational success. Therefore, intralogistics-systems have to be reliable [2]. In practice, this required reliability is provided through oversizing and redundancies of systems and components.

2. Intralogistics-Systems – A Disambiguation
The term logistics has a wide range and is often believed to merely refer to transportation of goods from point A to point B. But the main potential for cost reduction and innovation is within the in-house sector of organizational logistics, the intralogistics sector [1]. According to the common definition, intralogistics include the organization, control, execution and optimization of the in-house material flow as well as stock turnover in industry, trade and public institutions [3]. This definition reveals the technical, economical and social importance of intralogistics. They are an important factor in different organizations of various sizes, such as factories, distribution centers, harbors, airports, supermarkets, hospitals, etc.. This definition distinguishes intralogistics from other logistical fields such as transportation logistics, which connect different organizations, and supply chain management, that is responsible for chains in procurement and sales as well as optimization of locations and inventory. Intralogistics help supplying material and information as required and ensures production of high quality products at the right time, without excessive waste and inventory buffer. Industrial production has changed immensely within recent years. Along with the developments of just-in-time and just-in-sequence deliveries, intralogistics have become one of the biggest engineering sector in Germany. The intralogistics industry is constantly working on designing innovative solutions in order to be more cost-efficient [4]. One challenge that the industry has to face is that their product, intralogistics services, cannot be produced to stock [2]. Therefore, they have to provide a high ratio of availability of the systems and the best quality possible for their logistics services. Otherwise, a breakdown or failure usually entails high follow-up costs. This background explains the great significance of maintenance of intralogistics-systems. High availability and performance that meet expectations can be achieved by applying adequate maintenance actions [5, 6, 7]. Nonetheless, customers demand reliable facilities at low investment costs but with long warranty periods. They demand equipment that does not or only rarely require maintenance, although it should be clear that this is impossible to realize. Intralogistics is an important economic and competitive factor. It ensures production in
modern production systems and they are an important export product in Germany. To make sure that it stays that way, measures have to be taken to increase reliability. And those measures have to be affordable. An elaborate maintenance concept could be a solution to this task.

3. Design and Operation of Intralogistics Material Flow Systems

The intralogistics-industry tries to meet customer demands by providing robust equipment and systems in order to achieve high availability and reliability. The basis for this strategy is already laid during the planning phase for an intralogistics-system. There are a lot of tools and techniques for planning the intralogistics-systems, but they are inexact, due to existing planning-uncertainties [8]. One uncertainty is the expected peak power of a 10-years-planning horizon. It is used as a basis to anticipate a future capacity-addition [9, 10]. In this context, it is important that reserved backup power is high enough to avoid the need for short- or medium-term addition to capacity. Neither should the backup power be excessive, because it would create extra costs [10]. However, robust construction is not the only planning principle. In addition to a robust construction, redundancies are implemented to minimize negative consequences of unscheduled failures and downtimes [11].

Systems are usually realized with standard components that have been time-tested and approved. These standard components also help realizing short completion times that are demanded by customers [9]. The manufacturer is responsible for the accuracy of the system and the operation-time of the equipment. Thus, dimensioning of the units and the reliability of the system lies within his range of responsibility [12]. Calculation programs should help predict the availability of a system as accurately as possible. But it is just as important to maintain this availability throughout the time of operation over several years or even decades. The fulfillment of those requirements is a task of maintenance [7, 9]. Experience shows that accurately timed maintenance actions and custom-fit modernization in adequate intervals can ensure availability and performance of intralogistics-systems that meet customer requirements in a cost-effective way [12]. Intelligent concepts of maintenance should be able to detect the condition of elements and components and predict their remaining life. If this were possible, it would contribute to increasing reliability of intralogistics-systems and reducing follow-up costs. The Chair of Factory Organization in cooperation with the Fraunhofer IML research in this field to develop tools and concepts for maintenance of intralogistics-systems to increase their availability and reliability.

4. Maintenance of Intralogistics-Systems

Within the research project “SFB 696”1 at the Technical University in Dortmund a field study about maintenance of intralogistics-systems has been carried out by the sub-project C3. The field study has been conducted among manufacturers and operators to gain knowledge about maintenance of intralogistics-systems. The results were discussed and verified during a workshop with experts from the intralogistics industry. The most important result is that a considerable waste of resources is accepted during planning and operation of intralogistics-systems.

One waste of resources is the reserved backup power. This backup power is usually higher than realistically needed, because the operator cannot predict the future workload for ten years in advance. Therefore, he deliberately uses a higher amount as a basis for the construction of the system in order to avoid the necessity of a short-term expansion of capacity. As a result, the system is designed for a longer lifetime, so that there is no need for short- or medium-term modernizations to increase performance. An intralogistics-system is always a custom-designed solution but it is realized with standard components. These standard components are not designed to match the actual demand. As a consequence of oversizing, components, e.g. electric powertrains, are not working to capacity and do not reach their nominal efficiency [13]. A further consequence is a higher wear-out of mechanical components, whereas reliability and availability do not increase with oversized components [14].

The resulting robustness is intended by manufacturers, to avoid breakdowns during the warranty period, which can last up to five years. Robustness is also regarded as a manufacturer’s quality characteristic. Nonetheless, this design usually results in higher operating costs for the operator in the long term [15].

Despite the great importance of availability and reliability, the topic of maintenance of those systems has not been in the focus of attention for a long time. In production systems, maintenance has a high priority and modern techniques and tools such as condition monitoring systems are applied [16]. In contrast to that, maintenance of logistics components and systems is usually carried out breakdown- or time-based [2, 12]. This seems surprising considering how important their availability is and how much effort the manufacturer puts into providing it. However, it is not possible to completely prevent breakdowns. Consequences of a breakdown are fatal, because it can result in follow-up costs of unscheduled downtime that can be up to four times higher than maintenance costs [17]. Besides, time-based maintenance also results in a waste of resources, because components are never used long enough to reach their maximum utilization (Figure 3). How long a component could have been used instead of replacing it is usually not analyzed. Therefore, adjusting the intervals for time-based maintenance according to the wear-out of components is not possible.

A solution could be to adjust the maintenance strategy according to the actual utilization of components. It would help overcome the problems which occur as a result of the current methods. Nevertheless, a maintenance strategy that involves the actual utilization and thus saves resources is hard to apply, because neither operators nor manufacturers possess the knowledge in necessary width and depth. Hardly any knowledge exists about the interrelation between utilization and wear-out of intralogistics-systems. Although the loads of intralogistics-systems, such as the weight of a loading unit, are recorded by IT-systems, they are not analyzed.

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and used for maintenance purposes. Knowledge about the actual utilization is insufficient, which results in a lack of experience for the maintenance of intralogistics-systems. This is not only due to the practice of oversizing. But often the contact between manufacturer and operator ends with the warranty period for the system. Only lately, a demand for after sales services has begun to develop. In the future, this will change significantly and manufacturers will shift from sales to full-service-concepts and a holistic approach to intralogistics-systems. Another obstacle when realizing a concept of utilization-based maintenance is the lack of documentation and information [18]. Although technicians keep records of their performed maintenance actions, they do not keep track of the causes for the problems that have occurred. Therefore, drawing conclusions about the failure causes

In summary, it can be stated that there is a huge need for optimization in planning, regarding robustness of the systems, as well as in operating intralogistics-systems, in terms of the practiced maintenance strategy. Therefore the Chair of Factory Organization at the TU Dortmund in cooperation with the Fraunhofer Institute for Material Flow and Logistics established the Logistics Condition Monitoring Technologies Laboratory (Log CoMo-Tec Lab), which will be introduced in the following.

5. Logistics Condition Monitoring Technologies Laboratory
The Log CoMo-Tec Lab was implemented in 2009 at the TU Dortmund. The Fraunhofer-Gesellschaft realized the enormous research potential in this field and accepted the total acquisition costs. In the Log CoMo-Tec Lab the interrelation between utilization and wear-out of components of intralogistics-systems will be researched sui generis by the use of condition monitoring technologies. Condition Monitoring (CM) is the targeted monitoring of components concerning critical trends as well as the forecast of the time of failure [16]. Condition Monitoring is also the basis for a condition-based maintenance. The monitoring of the condition of components can be carried out by different techniques, e.g. vibration diagnosis, torque measurement, lubrication analysis or thermography. The use of condition monitoring pursues the goal of decreasing downtimes and increasing availability [7]. Further it contributes to optimized energy efficiency, because the efficiency of components is checked continuously [19]. The following components are examined: an automated guided vehicle system (AGV), roll conveyors and a miniload automated storage and retrieval system (ASRS). The ASRS consists of a vertical conveyor that moves two autonomous shuttles between the particular storage levels
and the prestorage area. The miniload storage system may store up to 120 small load carriers (SLC) which contain three sandbags with 5 kg (~11 lbs) each. The system is designed for a payload of 15 kg (~33 lbs).

After being taken out of store, the SLCs are moved via roll conveyors either to the transfer station of the AGV or via further roll conveyors back to the prestorage area. The AGV covers a distance of approximately 15 m before it delivers to another transfer station (receipt of goods) of the roll conveyor. From there the SLCs also get to the prestorage area.

In the pilot system different technologies for condition monitoring of components are being used: Vibration analysis, torque measurement, power consumption measurement and a thermography camera. In addition to that, it is also planned to integrate an ultrasonic analysis.

There are sensors installed both at all drives of the roll conveyor and the AGV to perform a continuous vibration analysis (Figure 3). Vibrations within the drives are recorded and sent to an online monitoring system. In this way, possible damages can be recognized due to variations in the vibration behavior. Besides the continuous analysis (on-line CM), off-line measurements (off-line CM) are conducted in the laboratory with additional mobile vibration analysis systems. Data are summarized and assessed in a vibration diagram with the help of Fourier transformation.

A sensor at the drive of the vertical conveyor is used for torque investigations. An increased torque may have the following causes: either the vertical conveyor is overloaded which means the payload is higher than the permissible maximum weight of 15 kg or the rolling bearing of one of the components appears to be damaged so that due to more friction a higher movement force is needed. This can also be monitored by the current power consumption measurement since a damaged drive has an increased demand for power.

In addition to the technologies described so far, further investigations can be done with the help of mobile thermography cameras (Figure 4). By doing this, separate drives can be compared as well as damages recognized. Damages related to wear out due to increased friction are shown in elevated temperatures.

With the help of the described condition monitoring technologies installed in the Log CoMo-Tec Lab, data about thermal and dynamical impacts on the intralogistics system should be extracted and evaluated. Various technologies for condition monitoring are used, as experience from other industries has shown that the combination of different types (i.e. vibration analysis and thermography) provides much more precise statements about the condition of machine elements, components and systems. Additionally, there are mutual influences of technologies in an overall system. To determine the optimal combinations as well as mutual influences and trying to exclude them respectively, experiments with different combinations are necessary.

6. First Results

In Figure 5, different results emerged from the vibration analysis of two different drives of the roll conveyor are illustrated. The upper diagram without any periodical vibrations belongs to a drive of the intralogistics-system. In contrast to that, the lower diagram belonging to another drive is characterized by periodical peaks indicating the damage frequency of the rolling bearing implemented in the drive motor. Hence, an upcoming failure can be perceived early enough to counteract an unplanned breakdown.

Another result of the experiments in the laboratory will be the knowledge about the correlation between utilization and wear of components in intralogistics systems. This knowledge will help to realize an utilization-based maintenance.

Not least, the demonstration and proving of condition monitoring technologies will also lead to the development of new control strategies. The training of maintenance staff in use of CM-technologies will help to increase the availability of intralogistics systems significantly. At the same time, current redundancy
concepts for availability protection could be revolutionized and partially removed. These new strategies and concepts could have some influence in the usual modernization process of those systems.

Furthermore, it is possible to remove identified efficiency losses in the framework of modernization for instance by replacing a standard drive with a highly efficient one.

7. Conclusion

The basic task of intralogistics is making processes more efficient, planning capacities and performance and using them in a better way. For this reason it contributes to environmental protection and improved profitability and competitiveness of organizations [20].

Unpredictable market developments can thwart any planning. In addition, robust intralogistics-systems query optimal modernization intervals. Availability could be also achieved with adequate maintenance techniques and actions instead of costly redundancies and oversizing. Maintenance actions could be carried out conserving large amounts of resources and unscheduled downtimes could be reduced, while requirement-based components would help save energy. Furthermore, modernizations at the right time bear the potential to generate large savings in terms of needed optimization. Due to fast changes in technical areas as well as in costs for resources such as steel and energy, it might be reasonable to shift from robust construction of intralogistics-systems to intelligent maintenance concepts in order to insure the demanded reliability.

There is still a high potential in the planning and operating of intralogistics-systems with regards to their efficiency. The Chair of Factory Organization and the Fraunhofer IML accept this challenge. The Log CoMo-Tec Lab is an adequate reference system for further research activities and is also a part of the EffizienzCluster: LogistikRuhr, the biggest European logistics research project.

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9. References


