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Real-time data gathering in production logistics: A research review on applications and technologies affecting environmental and social sustainability

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Abstract
This paper aims to identify the challenges and issues concerning environmental or social sustainability in Production Logistics that are affected by implementing real-time data collection concepts, technologies and applications. A systematic literature review has been conducted to shed a light on sustainability aspect of real-time technologies and applications. According to the findings, few researches directly investigated how real-time data collection affect the environmental and social aspects of sustainability. Besides, the indirect effects are discussed in order to find a better picture about the relation between these technologies and sustainability.

Keywords: Real-time, Production logistics, Sustainability, Cyber-physical systems (CPS)

Introduction
Technologies for tracking and tracing, as well as industrial IoT is further expanding in use for production logistics, and enable seamless information flow as well as link information to the moving goods and material. These technologies are not only a pre-requisite for concepts like Industry 4.0 and cyber-physical systems (CPS), (Barretto et al., 2017), but also made it possible for the internal logistics operations to be more visible to the stakeholders. Visibility is one of the main steps in digitalisation of production areas (Zeller et al., 2018) and high visibility is a pre-requisite for fulfilling the Industry4.0 vision, which foresees that sensors capture all data seamlessly and in real-time in each process, facilitating the interconnectivity of different sections and units (Zeller et al., 2018). Real-time data and improved visibility has revealed several challenges related to inefficient usage of resources, often caused by low transparency of movements and low degree of digitalisation. Which again has a negative impact on related costs as well as on sustainability aspects. On the same time, these technologies also directly affect the
privacy of employees and involved stakeholders (Mettler and Wulf, 2019; Zhang et al., 2018). Other areas of impact from the emerging digital logistic paradigm on the social, environmental and economic aspects of sustainability was reported by e.g. Alfnes and Strandhagen (2017). New technologies are for instance reported to enable collaborative consumption through sharing schemes and servitization, directly linked to resource efficiency and waste generation. In addition, higher economic impact can be reached by service orientation and full value utilisation of assets. Also potential negative effects from the next generation of logistics, on the sustainability, could be argued to exist. For instance, increasing individualisation and on-demand manufacturing could potentially increase transportation activities. However, this effect might be mitigated by real-time optimization and adaptability.

As the concepts of Industry 4.0 is an elusive concept, vaguely defined and including a multitude of concepts (Hoffman and Rusch, 2017) as well as having unclear correspondence to sustainability aspects, this paper address one of its more well-defined components - real time data gathering - and relate this to anticipated performance outputs, focusing environmental or social sustainability. The focus of this paper is to analyse existing information on the real-time technologies and their logistics applications, as well as to analyse the impact on some aspects of social and environmental sustainability.

**Definitions and description of terms**

This paper relies on a study of the connection between real-time components and sustainability performance applied on production logistics, where production logistics concerns the resources, planning and control of material and information flow within the production facility. Hence, it is central to define these two terms of real-time data gathering and sustainability, as they are used in this paper.

Real-time data gathering: there is no unique definition, but Cambridge dictionary defines real-time as “communicated, shown, presented, etc. at the same time as events actually happen”. In this paper, real-time is considered as one of the main elements in any cyber-physical systems that enables decentralised decision-making and interoperability of agents (Kagermann et al., 2013). Real-time data gathering refers to any methodology that enables gathering data as events actually happens in any production logistics system which has the potential to support production logistics practices such as Just-in-time and Just-in-sequence (Hoffman and Rusch, 2017; Zeller et al., 2018; Huang et al., 2008).

Traditionally, sustainability consists of three main categories: economical, environmental and social. “World Commission on Environment and Development” defined sustainability as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland Report, 1987). This paper focus on the two aspects environmental and social sustainability.

**Methodology**

A structured literature review (SLR) has been applied to identify the direct and indirect effects of real-time data collection technologies and applications on production logistics sustainability. SLR was chosen as it helps to bring together relevant studies regardless of their location or even disciplinary background. By keeping the research process transparent and unbiased, readers can have a clear conclusion and provide new opportunities for other researchers to have new experiment by knowing the exact details of the study performed according to SLR. In addition, properly managed, an SLR can shed a light on one specific aspect of the reviewed studies (Thorpe et al., 2005). In this case, the SLR identifies how technologies that have developed during recent years - in
the context of Industry 4.0 - can be related to real-time data collection and sustainability aspect. The connection between this aspect of Industry 4.0 and sustainability has not been investigated previously, to our knowledge, so a SLR can be an effective method to deal with this question. This systematic literature review is based on Tranfield, Denyer and Smart (2003) suggesting to use three stages process to perform a systematic literature review: planning a review, conducting a review, and reporting and dissemination.

Planning the review

This first stage concerns planning the review of literature covering real-time technologies and applications in production logistics that affect sustainability. To perform the review, Scopus and Primo are used as search engines. These databases have rich material regarding production logistics, sustainability and related technologies. The strategy to the review consists of two main parts. First, technologies, application and use cases are identified. Secondly, the effects of technologies on sustainability are searched.

Conducting the review

To initiate the study, it was needed to investigate the existence of real-time data collection in the literature on production logistics. In order to do so, search queries created by using following key word groups: (1)Real-time and (2)Production logistics, internal logistic, material handling, material movement, internal logistic, internal supply, production supply, manufacturing supply.

Following string was used to make the search query in titles, abstracts and keywords followed by truncation and wild card rules:

(A) "Real time" AND "production logistic*" OR "Internal logistic*" OR "material handling" OR "material movement" OR "Internal logistic*" OR "Internal supply" OR "production supply" OR "manufacturing supply"

To be more specific, it was needed to narrow down the search query by identifying the real-time technologies and applications within production logistics. In order to do so, technologies, applications and use cases were focused. So, in stage two, a third key word group was defined as follows: “Technolog*”, “application*”, “appl*”, “us*”, “method” and following strings were used to perform the next step in the SLR:

(B) "Real time" AND "production logistic*" OR "Internal logistic*" OR "material handling" OR "material movement" OR "Internal logistic*" OR "Internal supply" OR "production supply" OR "manufacturing supply" AND "technolog*" OR "application*" OR "use case*" OR "appl*" OR "us*" OR method

After finding the relevant technologies and applications, it was needed to map them toward sustainability and then analyse the effects each technology has on environmental and social aspect of sustainability. Following is the search query used for environmental aspects:

(C) "Real time" AND "production logistic*" OR "Internal logistic*" OR "material handling" OR "material movement" OR "Internal logistic*" OR "Internal supply" OR "production supply" OR "manufacturing supply" AND "technolog*" OR "application*" OR "use case*" OR "appl*" OR "us*" OR method AND incident* OR energy OR resource* OR utili* OR circular* OR emission OR recycl* OR packag*

The following search query was used for identifying social aspects of sustainability:

(D) "Real time" AND "production logistic*" OR "Internal logistic*" OR "material handling" OR "material movement" OR "Internal logistic*" OR "Internal supply*"
The final stage of a SLR is the reporting and dissemination of the results, which is presented on the next section.

Analysis of the systematic literature review
The emergence of real-time concept and production logistics in the literature during the last 50 years is identified, 1072 documents in total. Using search string (A) above, shows that the concept of real-time data collection has emerged since 1970 and has gradually increased overtime despite its fluctuations.

Narrowing the literature from search (A) into publications regarding real time applications, technologies and use cases within production logistics, Figure 1(a) shows the number of publications on this matter during the last 50 years, 927 documents in total. Since the period is rather long, it is decided to choose the publications in the last 5 years. The number of publications reduced to 323.

As illustrated, real-time concept has been gradually attracted more and more researchers and has almost been doubled from 2009 to 2018. This further emphasise the importance of this subject for doing research.

Figure 1(b) depicts the number of publications of real-time technologies and applications in the context of production logistics and their connection to sustainability. Even tough, sustainability has almost same trend but it has gained more attention in the last few years compare to the figure 1(a).

Direct effects of real-time technologies and applications on sustainability
In further, defining environmental sustainability in a production logistics setting, following keywords have been used: Incidents, Energy, Resource, Packaging, Utilization, Circularity, Emission and Recycling. In a similar manner, social aspects of sustainability
in the context of production logistics has been detailed by the keywords: Ethics, Accidents, Injury, Ergonomy and Lifting.

Among all the searched results, only 10 publications have directly investigated the effects of real-time technologies and application on sustainability in PL context. 29 other papers have focused on the economical aspect. These 10 papers report on different social and environmental aspects related to operators’ injuries, ergonomic analysis and emission reduction. (Qu et al., 2012) applied Radio Frequency Identification (RFID) for managing material distribution in a complex assembly shop floor. This leads to some behavioural change for material movement operators. For instance, they have to use portable RFID-Gateway to bind materials with containers and pallets instead of merely marking the loading quantity on papers. Battini et al., (2014) introduced and discussed new integrated full-body system for the real-time ergonomics evaluations of manual material handling in warehouse environments. Inertial motion capture system and Wi-Fi connection are the main technologies and the implementation results show increase in productivity and ergonomics improvements both in the redesign of the warehouses and in the training of human in the execution of the most critical manual logistical tasks. Real-time analyses of already existing activities, using standard cameras for material handling is an application investigated by Del Fabbro and Santarossa (2016). Just like the previous research, they also intended to help operators by decreasing accidents and injuries by deploying optical sensors. Cherradi et al., (2018) have tried to minimize the overall risk of hazardous material transportation and their potential consequences by using emission source, accident location and real-time meteorological data near to the sources, to provide necessary and accurate results rapidly. In-vehicle sensors and wireless communication are the main technologies used in the research. Kousi et al., (2018) developed a SoA that would enable the real-time scheduling of material supply operations in an assembly system that can plan and operate without human interaction. This can be considered as a negative effect since it will reduce human from the process. Trkov and Merryweather (2019) quantified the weight of an object during lifting and carrying, lift frequency and lift duration during manual material handling in real-time. The work aimed to minimise operator injuries while performing logistical activities. Optical motion capture system and wearable sensors have been used as R&D technologies.

Regarding the environmental aspect, Huang et al., (2008) have tried to increase Adaptivity within production logistics by means of CPS-based smart control model for real-time material handling to enhance the efficiency of material handling and reduce the delivery cost and time through implementing RFID tags. According to their research result, material planning has improved which can be considered as a positive effect of implementing these technologies. RFID, Wi-Fi and sensor networks and cloud computing are the main technologies in this research. Pang et al., (2015) used auto-ID/RFID technologies in industrial parks to create a smart work environment for enhancing real-time information sharing throughout the process of material handling. As a result of their work the average paper consumption dropped by more than 70%. However, it had some impacts on operators’ behaviour. For example, operators must use various auto-ID devices to update resources and job progress status rather than record resource information on paper. Guo et al., (2017) proposed a timed-colored Petri net simulation-based self-adaptive collaboration method for Internet of Things-enabled production-logistics systems. The method combines the schedule of token sequences in the timed colored Petri net with real-time status of key production and logistics equipment. The key equipment is made ‘smart’ to actively publish or request logistics tasks. A comparative study is implemented and the result indicates that the proposed method outperforms the
event-driven method in improving the overall efficiency of the production logistics systems and reducing electricity consumption.

Zhang et al., (2018) have focused on integrating production and logistics into a smart control system such that it is capable of exception identification, self-organizing configuration, and self-adaptive collaboration. One of the result of their research is reduced energy consumption.

**Discussion about indirect effects of real-time technologies and applications on sustainability**

Rest of the researches have no direct connection with environmental or social aspects of sustainability. Thus, authors have decided to discuss if these researches might have indirect effect on the mentioned aspects of sustainability. These researches have tried to solve the following challenges and issues within production logistics.

**Monitoring**

In order to be able to track and monitor all the movements of material and production, researchers have done different types of researches. Oh and Park (2008) used RFID to control material movement and inventory classification in real-time. Röhrig and Spieker (2008) have used Real-time locating system (RTLS) to monitor the manual transportation processes of goods in a warehouse aiming to update the database automatically in real-time. Qu et al., (2013) used RFID for material distribution management. Mejjaouli (2014) have implemented RFID and wireless sensor networks to perform real-time condition monitoring for in-transit perishable items. Bortolini et al., (2015) have used RTLS and Ultra wide band (UWB) to trace the material flow in real-time. Mészáros, et al., (2016) have used RFID, sensor network, wireless connection and Global Positioning System (GPS) to monitor certain aspects like temperature, humidity, quantity, or location. Freitas et al., (2017) benefit from RFID to deal with misplacement of material, line stoppages, unattended material turning outdated and obsoletes. Qu et al., (2017) implemented Wi-Fi connection and RFID to control high operational dynamics in production logistics. Mészáros et al., (2018) have used RFID and drones to support the monitoring of intra-logistical processes in real time.

In general, technologies that support monitoring and increase visibility can have positive effect on sustainability metrics (Ahn and Lee, 2014). According to the studies mentioned in above, tracking and monitoring of materials and equipment result in having a better control over buffer, warehouse, ordering and precise localisation of equipment. In addition, it will help to follow logistical rules and procedures. Better control on buffer, inventory level and warehouse, will reduce unnecessary ordering of material and less transportation, which might reduce energy consumption, emission reduction and better resources utilization. Real-time technologies will help to follow up logistical activities to be in line with rules and regulations, which might decrease accidents and injuries. In case of inventories’ classifications (Oh and Park, 2008), it might help the operators to reduce the re-work caused by wrong classification. Knowing the precise localisation might help to avoid accidents and improve the ergonomy for operators. On the other side, it might have negative impact on integrity for operators since they will be tracked during their work.

**Adaptive scheduling**

The research work of Wang et al., (2013) concerned RFID-enabled real-time manufacturing information for scheduling and rescheduling in an agent-based manufacturing system. Qu, T. et al., (2017) have implemented sensor networks and RFID
to capture real-time information from PL processes and dynamically trigger adaptive plan correction. Qu et al., (2017) used sensor networks and RFID for capturing real-time execution dynamics and rely on plan (re)scheduling and cloud-based resources reconfiguration. Nagy et al., (2018) have used RFID and sensor networks to realize real-time scheduling for designing the milkrun.

Dynamic scheduling of material planning might optimise the production order in case of volume, but it is not clear if it will reduce the transportation as well. Therefore, this can have both positive and negative effect on energy consumption, emission and even accidents. Considering the social aspect, dynamic rescheduling might have effect on drivers’ workload and work habits. It is not clear if it will increase their stress level or decrease due to more clear work instruction.

Optimisation
Joe et al., (2014) used sensor network to control the framework to improve the flexibility and responsiveness of material handling systems in real-time. Alias et al., (2015) used sensor networks and Bluetooth for optimization of forklifts utilization. Al Hazza et al., (2016) used RFID and Automated Guided Vehicle (AGV) to enhance and improve the utilization of the production line through improved material handling. Guo et al., (2017) used RFID to collect real-time data and used a timed colored Petri net simulation-based self-adaptive collaboration method to actively publish or request logistics tasks.

In case of Joe et al., (2014), transferring steps are minimised so it can have a positive effect on energy consumption and emission reduction in addition to have better resource utilization. Optimised material handling within the production line might reduce energy consumption and avoid creating wastes. Optimisation of requesting logistical tasks can have positive effect to emission reduction since unnecessary movements will be omitted. The same argument is true if forklifts benefit from optimised utilisation so they have less unnecessary movements and it might even help the operators to have less stressful job.

Material handling
Fang et al., (2013) used RFID and barcode to control dynamic production and material handling for real-time scheduling. Vatankhah et al., (2013) implemented RFID to gain flexibility and re-configurability of material handling in FMS (Flexible Manufacturing System). Qu et al., (2014) used 2D barcodes and RFID to collect both real-time process dynamics and resource statues to realize dynamic distributed capability matching. Zhang et al., (2018) used a combination of some technologies such as Infrared sensor, ultrasonic sensor, Wi-Fi connection and Strawberry Pi to realise CPS-based smart control model for real time material handling.

Improved material handling will reduce wastes of material in production processes and might help to have better utilization of space and resources. Realisation of FMS might help to avoid over-ordering of material which lead to better utilization of resources.

Positioning
Chen et al., (2012) benefit from Computer vision system and wireless transmitter for accurate positioning of forklifts. This accuracy might reduce energy consumption while it might have negative effect on integrity for the driver.

Physical flow
Optimised material movement within production area might reduce accidents and injuries especially if agents are move around under a fleet management control. If this optimisation cause less paved distance, then it will reduce energy consumption and
emission reduction.

**Table 1 – Optimisation of Physical Flow**

<table>
<thead>
<tr>
<th>Application/Use case</th>
<th>Technology</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimization of shop floor material handling tasks through intelligent trolley</td>
<td>Intelligent trolley / RFID</td>
<td>Zhang et al., (2015)</td>
</tr>
<tr>
<td>CPS-based smart control model for real-time material handling to enhance the efficiency of material handling and reduce the delivery cost and time</td>
<td>Camera / Wifi/Sensor network / RFID</td>
<td>Zhang et al., (2018)</td>
</tr>
<tr>
<td>Improve forklift dispatching</td>
<td>Wireless Mesh / Sensor networks</td>
<td>Estanjini et al., (2011)</td>
</tr>
<tr>
<td>Deal with unforeseen adaptation needs when it comes to reliable detection of object conditions</td>
<td>RFID / Camera</td>
<td>Jung et al., (2013)</td>
</tr>
<tr>
<td>Effective transportation between the production lines to minimize the waiting time and transportation cost</td>
<td>Simulation and real time dashboard for production planning</td>
<td>Aqlan et al., (2014)</td>
</tr>
</tbody>
</table>

Table 1 shows uses cases for physical flow optimisation. By having a more clear paths and smarter vehicles, which are visible to each other, it might help to avoid accidents and injuries while it is not clear if it will reduce human from the work.

**Conclusion**

The focus of this paper was to analyse existing information on the real-time technologies and their logistics applications, as well as to analyse the impact on some aspects of social and environmental sustainability. A systematic literature review was conducted in three steps: (1) identifying real-time focused literature within production logistics, (2) narrowing down to technologies and application within the set, (3) narrowing down to environmental sustainability and social sustainability, respectively. It was found that a small but growing set of literature have discussed the effects of real-time technologies such as RFID, sensor networks, RTLS, etc. on sustainability; and they show how technologies and applications can have positive impact on environmental and social aspects of sustainability. However, most work still mainly focus only on the economic aspect. Nevertheless, it is concluded that these technologies and applications might have positive effects on many social and environmental aspects such as reducing energy consumption, better utilization of resources, emission reduction, operators’ injuries reduction and improvements on ergonomy.

The paper represent an effort of relating a central concept of Industry 4.0 – real-time information – to environmental and social sustainability. It is concluded that sustainability effects of using real-time technologies can be on three levels: (1) direct in the logistics process by e.g. energy optimization or monitoring working environment in operations, (2) indirect by supporting decisions for development of next generation logistics processes, its inputs, resources and outputs, (3) by enabling a radical renewal of the business model, including circularity and servitisation. Further studies are required in the area, detailing the implementation and end-effects of deploying real-time technologies in production logistic settings.

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