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Manufacturing and Logistics Information Systems

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INTRODUCTION

Logistics information systems (LIS) are specially designed to support all elements of logistics processes, including coordination of logistics activities, material flow, and inventory replenishment (Douglas M. Lambert, 1998). By necessity, this involves a combination of hardware and software in addition to supporting data exchange and capturing technologies, supported over the interconnected manufacturing and logistics phases between different companies by specialised manufacturing and logistics information systems (MLISs). It is recognised that overall supply chain performance can be improved by using information technology (IT) and while many firms have enabled transactional processing, they still request improvements to enable IT to support improved planning and decision-support applications (Sundarakani, Tan, & Over, 2012). They have been used by both specific firms, as well as being a core enabler for many third-party logistics (3PL) firms to whom other companies outsource their logistics requirements (Srivastava & Wood, 2011).

This article examines individual elements of MLIS (relating to identification, warehouse management systems, transport management systems, quality management, information exchange, and enterprise resource planning (ERP) systems) and its key use to both capture and process transactions and support improved decision making. This is aided by the resurgence of interest in Radio Frequency Identification (RFID) technologies to support identification and tracking of inventory. Finally, we examine the weaknesses and challenges of MLIS and discuss future trends and approaches that will offer value in the near future.

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BACKGROUND

Effective management of the movement of physical goods largely rests on the ability to rapidly and easily identify what a particular physical item is. Thus, the ability to identify and track physical items and record movements becomes crucial to the success of a MLIS.

Identification Systems

Firms have developed many approaches to tracking and management of the movement of goods. Identification of materials is crucial in three main logistics processes: (1) the tracking and handling of materials during logistics processes, (2) the tracking and consolidation components or packages from multiple parties including third Party Logistics (3PLs) providers, and (3) the monitoring and handling of materials at point of sale (POS) in the retail environment. Initial attempts to identify inventory related to providing an identification code to different batches, which may take the form of a physically adhered label with a job or batch number written on it.

In contrast, barcode technology translates the identification number into machine-readable graphical representations (Figure 1). These can be interpreted using an optical reading device that captures the image, extracts the information, and converts it into useable data (i.e., unique identification number). It improves the speed and accuracy of reading labels and identifying items and reduces error rates. The technology supports picking orders, tracking orders and materials, and as part of the loading/unloading process (Shamsuzzoha, Ehrs, Addo-Tenkorang, Nguyen, & Helo, 2013). The

Figure 1. Examples of three different barcode formats

disadvantage of barcodes is the mandatory visibility of the code.

RFID (Radio Frequency Identification) does not require visibility or alignment as identification is transmitted by radio signals and does not need a line of sight. Tags also encode more information than barcodes, supporting the manufacturing/logistics process (e.g., update of manufacturing details). They can be used on items, boxes, pallets, vehicles, or animals; as well as with people when considering tracking systems in airports (RFIDs in board passes can coordinate passenger flows and identification to minimise waiting times or delays of planes). RFID technology enables firms to monitor and manage the freshness (or deterioration) of products. By knowing the state of inventories, delivery times, or whereabouts of items in transit or transportation (Pahl, 2011) firms can increase product visibility and process transparency, and use integrated and automated data capture (Liu, Tang, and Huang, 2008). The disadvantage of increased cost for the tags is compensated by several benefits; e.g. simultaneously reading every item in a pallet; faster scanning process; recording sensor data (e.g., humidity, temperature); and improved response and traceability capabilities. Effective use requires significant investment in infrastructure to support the introduction and implementation of a continuous tracking of RFID tags. Moreover, there is no globally accepted RFID standard.

Low-cost RFID tags can be integrated in labels during their production. However, GPS tags require an integrated source of energy to send their position to the controlling system with every movement. Thus, GPS tags are generally used in items of high value or which have a power source (e.g., vehicles or cooling containers). Another option for GPS usage is in combination with barcodes or RFID, where information about the materials come from the tags and the location from GPS devices installed in the transportation vehicles; thus increasing the accuracy of all information without the overhead of an infrastructure. Examples for such systems can be found in airline management (Reiners et al., 2012) or container depots (Ngai, Cheng, Au, & Lai, 2007).

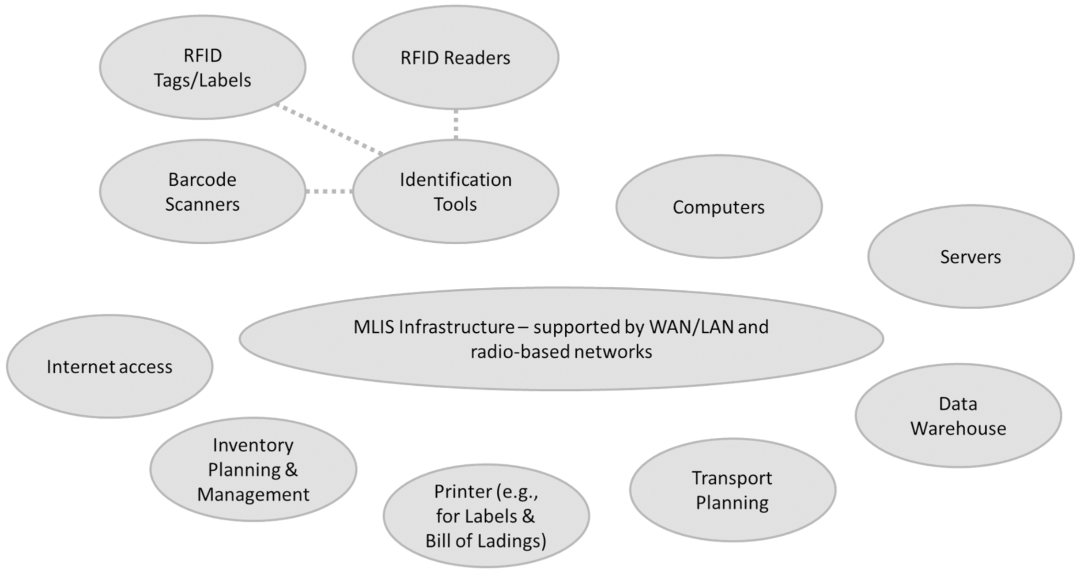
Logistics Information Systems

LIS can be configured to work in different scenarios and often support warehousing and transport management by optimising processes and tracking locations and inventory movements. The LIS acts as a transactional system attempting to capture all information changes and material movements such that it is accessible to all stakeholders at all times. Figure 2 provides an overview of MLIS components.

Warehouse Management System

Warehouse Management Systems (WMS) support the management of the warehouse, particularly the flow of materials (incoming, storage, internal movement, and dispatching), monitoring of the progress, and the communication between stakeholders in the system. Users of WMS can receive and see relevant information on computer terminals about allocated tasks and locations of materials. The tasks are optimised, managed, and assigned by a central controlling and management system. A common task in a warehouse is to pick up a requested pallet and move it (or parts of it) to a new location. The tracking of each step can be done by (automatically) scanning barcodes; i.e., barcodes on the shelf to report the location, barcodes of each removed item to verify that it is the correct material and to keep accurate stock counts. If the pallet is transported completely, only the barcode of the pallet should be scanned as the WMS keeps track of pallet-material-associations. The process is repeated at the destination and at all intermediate stations. Hidden

Figure 2. Logistics information system components



or obscured barcodes can cause delays as they require manual scans with potential physical shifts of items.

While barcodes usually encode product information, RFID tags can include further information about due dates, handling information, or hazard codes. While a barcode can be used to track an entire pallet, RFID readers are also able to automatically track all separate items on the pallet to ensure that the pallet carries the right materials in the right quantity. The RFID reader automatically captures all information about the materials from the attached tags, allowing rapid and easy input into the system. Strategically, readers need to be placed in such a way that all movements will be captured and recorded. This allows, for example, a reader on a forklift to receive all information about the pallet and the items on it. Additional readers on shelving can be used to register removal or insertion of pallets, at gates or warehouse entrances, or along driving paths; together, this allows all inventory movements to be captured.

In modern warehouses, a variety of additional technologies are applied including pick-to-light systems (Ramaa, Subramanya, & Rangaswamy, 2012) or 'smart' conveyor belts that integrate scanners to capture the identification of transported materials before consolidating orders by adjusting the flow of materials from the main belt to a 'staging station' as appropriate. The WMS integrates this extension of the traditional transactional system by inclusion of advanced algorithms to manage this flow (Boysen, Briskorn, & Tschöke, 2013). The real-time information from the tracked materials is used to optimise the subsequent activities and, therewith, the overall system.

Transportation Management Systems

Another area that requires LIS is the movement of goods between facilities. This is supported by Transportation Management Systems (TMS) which allow automation of the tasks relating to the transportation planning (Li, Taudes, Chao, & Hanping, 2011), optimisation (Suzuki, 2012), vehicle loading (Zhang et al., 2012), routing (Suzuki, 2012), payments (J. Liu, Yang, Wu, & Zheng, 2012), and execution (Barbosa & Musetti, 2010). Initially, transport systems were developed using heuristics and estimated distances to supported effective transportation modelling (Sankaran & Wood, 2007; Wood & Sankaran, 2004); recently, extensive data from GPS and RFID together with Geographic Information Systems (GIS) allow the support of real-time analysis to understand the flow of traffic (Leung, Lim, Tan, & Yu, 2012) and the on-the-fly adaption of logistics in response.

Quality Management

Supply chain quality management is enabled by Information Systems support (Lin, Kuei, & Chai, 2012), as at the core, the focus of quality management is about aggregating information, traceability, analysis, and decision-support. By this, it is possible to identify a potential problem to prevent the occurrence of similar problems in the future. Aided by hazard analysis and critical control point (HACCP) as well as tracking technology like RFID or GPS, LIS can trigger the reverse logistics flow of materials (Kumar & Budin, 2006). The expanding emphasis on supply chain quality management will require an evolution towards a network of firms, connected virtually, facilitating management of any quality issues over a supply chain of co-dependent enterprises (Xu, 2011).

Enterprise Resource Planning

While ERP software was originally perceived as a transaction-oriented management system, it has expanded to support integration and standardisation of processes and sub-systems over enterprises and supply chains. ERP can incorporate existing MLIS while also extending the functionality from a pure transactional system towards an enterprise solution offering greater decision support. Integration across supply chains enables use of real-time information to support making decisions and granting vendors and customer access to relevant information. ERP systems comprise broadly of supply chain planning components (e.g., modelling and simulation, sales and operations planning (S&OP), optimisation, and procurement), distribution (e.g., warehouse management system and transport management systems), operations (e.g., scheduling, materials management, and inventory management), marketing and sales (e.g., demand planning and customer relationship management). In supply chains it is critical to effectively and efficiently exchange information and documents while minimising overhead. Electronic data interchange (EDI) provides a standardised method to exchange data between firms without requiring human intervention.

Prediction and Optimisation Characteristics

MLIS have been improved to not only capture data but also to effectively use the data to enable more effective, efficiently movement of materials or vehicles (Fink & Reiners, 2006). Now, algorithms ensure that the fastest, most accurate, movement of goods occurs. As firms become larger and face significantly more challenging logistics problems on a global scale, improved algorithms enable firms to react in real time.

At the core of this approach is the use of advanced planning systems (APS) (Stadtler, Kilger, & Meyr, 2010). APS analyses demand, inventory holdings (over multiple levels, while accounting for risk-pooling benefits), production, and transport costs and speeds to help the organisation plan their production and logistics activities and manage their inventory to help support their business objectives. While single-location or single-tier optimisation of inventory is relatively simple, the ability for a large multi-national firm to manage inventory over perhaps thousands of retail and distribution centres and warehouses is far more complex.

Supply Chain Event Management

An important concept in the integration of logistics and supply chain partners is supply chain event management (SCEM), addressing the identification of deviations from a plan and its execution across the supply network, while providing corrective actions according to predefined rules in order to improve decision making (a full review is provided by Pahl, Voß, and Mies (2005)). SCEM aims to render supply chain processes more transparent (‘visible’), safeguard them from unexpected events as they occur, and identify and eliminate inherent system (process) problems. SCEM can be linked with other planning and management software (e.g., APS) to improve the quality of production plans supporting the avoidance of unexpected events; e.g., capacity bottlenecks or transportation delays (Straube, Vogeler, and Bensel, 2007). Especially in Just in Time (JIT) management, SCEM provides an alerting system (mechanism) regarding unplanned events that enable companies to quickly - even automatically - respond to those events at an early stage of disruption providing information based action opportunities (Pahl et al., 2005; Zimmermann & Paschke, 2003). Companies can experience 20% of inventory cost reduction and 30% supply chain cycle time reduction (Vernon, 2004).

SCEM has evolved from process control (Marabotti, 2005) and is often perceived as being an additional component in existing SCM systems and is linked with real-time applications such; e.g., RFID (Pahl et al., 2005; Graf & Tellian, 2011). An underlying process represented by milestones and its advancement are controlled by emitting and comparing state notes of tracking and tracing systems to the plan.

The concept of SCEM is generally implemented as a feature-functionality subset of SCM suites. Unfortunately, these SCM suites transfer their underlying problems and weaknesses to SCEM; e.g., data quality. Therefore, companies focus on enhancing these underlying environmental problems. For instance, approaches to integrating SCEM into supply chains include Petri nets (R. Liu, Kumar, & Van der Aalst, 2007) and agent-based technology (Zimmermann & Paschke, 2003). Moreover, Straube et al. (2007) provides an overview of the current SCEM research with a special focus on RFID integration. Graf and Tellian (2011) examine the integration of real-time transportation information via GPS tracking and tracing systems using smartphones. This enables the design of a technology platform to manage innovative information and supply network delivery processes in a manner that also supports optimisation planning and (accurate) calculation of truck fill rates and transportation lead times to minimise (waiting) times and utilised capacities.

Weaknesses and Challenges in the Use of MLIS

Despite the importance of RFID technology in supporting MLIS use, the uptake of RFID technology has been slower than initial estimates (Thiesse, Staake, Schmitt, & Fleisch, 2011). In recent years, uptake has increased and extended beyond previous levels and now frequently occurs at the item-level. However, it is still proving difficult for supply chains to integrate the technology and gain the full benefit from the information sharing. An approach where a large and powerful supply chain actor mandates adoption of technology may catalyse widespread RIFD adoption in particular supply chains; the influence of large organisations is often required implementation of policies or technology (Jeeva & Wood, 2012).

There are further weaknesses within MLIS and areas that remain challenging in practical application.

- **RFID is expensive:** Requiring extensive investments in both tagging and infrastructure. SMEs find it challenging to reach the break-even point and many firms struggle to measure the value of information provided by RFID, making it difficult to create a business case.
- **Standardisation of RFID:** Who should define the standards and at what cost? The not-for-profit organisation GS1 (www.gs1.com) established and administers the global barcode standards and has worked towards RFID standards; however, no standard has been unanimously adopted.
- The *quality of information* from underlying systems (ERP, APS, etc.) is problematic as the SCEM systems draw on and use these data. This is true for both transactional data and especially so for planning- and forecast-related information.
- Hardware and software systems facilitate information sharing through supply networks. Nevertheless, there are *significant costs related to these systems* (e.g., investment in systems, implementation and learning costs due to process changes) and the *benefits of information sharing are distributed asymmetrically* along the supply chain. A suitably challenging topic for Operations Researchers is examining how to symmetrise the distribution of benefits (e.g., decreases in costs or the increase in profits driven by improved information sharing) between partners to ensure that all partners have a motivation in applying appropriate SCM tools.
- The *transactional nature of ERP* has limited it as a planning support tool. APS provides planning tools; however, these fail to account for important operational elements; e.g., load-dependent lead times, or other real-world problems regarding production capacity bottlenecks. There are still limitations on the relative size and complexity of problems that APS can address.
- *Real-world studies* on the *effectiveness of MLIS remain rare*. Challenges lie in developing methods to study the effectiveness of MLIS in supporting overall supply chain improvements; e.g., emphasis on cost decreases due to enhancements in the quality of information. Advances from Operations Research professionals have

been stymied as many organisations remain unwilling to provide data to validate new models and approaches, stunting progress in this area.

- The use of *significant volumes* of information *in transport management systems*, drawn from transport-related assets, remains low. Firms are challenged to make use of this information and extract significant value. The ability to understand the status of various elements (e.g., tire-pressure or fuel levels) over a fleet of trucks, in real time, and incorporate the information into planning and execution decisions is a new problem in transport.

FUTURE RESEARCH DIRECTIONS

The key success factor for supply-chain-wide integration is the ability to manage complexity. While even the implementation of an ERP system in one organisation is often a challenge and cost-intensive project, dealing with multiple systems and infrastructure adds further dimensions of potential risks. Service-oriented architecture uses standards that allow firms to attain excellence in the business process execution and simplifies maintenance, but provides access to all data and information collected along the supply chain in the MLIS. Effective management relies on an established business process management system before a change project with service-oriented architecture (SOA). These interfaces become platform independent, allowing effective and rapid integration of new, or existing, specialised applications. Major software vendors have implemented different approaches; see Juric, Sasa, Brumen, & Rozman (2009) for an overview of different IT technologies.

An important, emerging trend is the introduction of "software as a service" (SaaS) architecture which enables firms to access particular components as required to extend their capabilities; only what is needed is used and only the required functionality is paid for. This can extends ERP suites, working on the basis of greater access to information and services delivered as required. SaaS can support effective sharing and exchange of information between trading partners, increasing supply chain integration.

CONCLUSION

Logistics information systems are increasingly becoming integrated with the enterprise resource planning systems. The approach rests on the ability to accurately capture information about the whereabouts and movement of materials, people, and equipment. This is supported through the use of barcoding, RFID technology, warehouse management systems, transport management systems, quality management, inter-firm information exchange, and incorporation into ERP packages. Together, these systems capture transactional level information and support decision-making in logistics, transport, and materials management using specialised optimisation and planning tools. Efforts are still being undertaken to connect and combine the LISs and ERPs over multiple firms to support end-to-end visibility and management of logistics and quality activities over the supply chain. This is being supported by new software approaches using SOA and SaaS, and the increasing use of RFID coupled with the ability to collect, transfer, and use RFID-related information for logistics efficiency to improve supply chain performance. Greater use of SCEM will improve firms' ability to identify and respond to disruptions and events that may cause logistics disruptions. The trend is towards the integration and coupling of logistics and materials management into other enterprise systems, enabling a more seamless decision to be made using appropriate and current information held in databases to provide advantage. Together, these technologies promise a faster, more visible flow of materials over the supply chain while reducing waste as they support having the right product in the right place at the right time.

Much work remains to be done to bring new logistics technologies (e.g., RFID and SCEM) to maturity and integrate them. Firms struggle to evaluate total costs and benefits of technology changes; if new business processes are not implemented in conjunction with the technologies, many anticipated benefits may fail to materialise. Evaluation and implementation projects must carefully consider the required benefits, how these will support existing competitive priorities, how these may fit with existing infrastructure, and what new capabilities they offer.

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KEY TERMS AND DEFINITIONS

Enterprise Resource Planning System: An integrated information management system over multiple business functions (e.g., manufacturing, logistics, sales, marketing, finance, and account) with the aim of capturing business transactions and storing data. This is a transactional system.

Logistics Information Systems: Interconnected hardware and software systems design to support logistics elements; e.g., coordination of logistics activities, material flow, and inventory replenishment.

Manufacturing and Logistics Systems: Hardware and software systems designed to support the management of inventory and production over multiple supply chain tiers or companies to achieve a balance between costs and availability.

Radio Frequency Identification (RFID): A system consisting of tags able to respond to and emit radio signals and a network of readers. Together, these enable the automated capture of business transactions relating to the movement of goods with an RFID tag near to readers.

Supply Chain Event Management: A method to address the identification of deviations between a plan and its execution across the supply network while providing corrective actions according to predefined rules in order to improve decision making.

Transportation Management Systems: Support automation of the tasks relating to the transportation planning, optimisation, performance measurement, vehicle loading, routing, payments, and execution of transport-related activities.

Warehouse Management System: Supports the management of warehouses and distribution centres; particularly, the flow of materials along the inwards goods, storage, internal movement, and outwards goods or despatch.