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Removing the blinders: A literature review on the potential of nanoscale technologies for the management of supply chains

Marcus Bowles [a,1], Jianjun Lu [b,*]

[a] Australian Maritime College, University of Tasmania, Launceston 7250, Australia
[b] College of Economics and Management, China Agricultural University, Beijing 100083, China

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ABSTRACT

Supply chain management requires more intelligent technology in the future; however, the current sensor technology is causing a bottleneck in the development of an intelligent supply chain. The emergence and development of nanosensors provide a good opportunity to improve the complex technical issues that supply chains need and may bring revolutionary changes to supply chains in the future. This paper reviews the current and potential application of nanosensors to every aspect of supply chains, including the SCM system, packaging, storage and distribution, supply chain safety, tracking and tracing. The particular focus will be on removing the blinders to the true potential technologies on the nanoscale for the future, not just for the management of supply chains but for firms seeking to become more competitive. This review will shed light on the profound impact nanotechnologies could have in augmenting or replacing the existing radiofrequency identification (RFID) tags or bar-code technologies.

1. Introduction

Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and logistics management [1]. Raw materials or parts enter a manufacturing organization via a supply system and are transformed into finished goods. The finished goods are then supplied to consumers through a distribution system [2]. Automation can improve supply chain visibility and efficiency and yield higher turnovers [3–5].

A decade ago, wireless sensor networks (WSNs) were identified as being among the most important technologies for the twenty-first century [6,7] and the MIT Technology Review considered them to be one of ten emerging technologies that will change the world [8]. Basically, a WSN is a wireless network consisting of small, spatially distributed autonomous devices using many scattered sensors to monitor cooperatively environmental or physical conditions, such as temperature, vibration, pressure, location, or motion, at different sites [9,10]. Through the use of low-cost, smart devices possessing multiple microsensors deployed in large numbers over wide areas and networked through wireless links and the Internet, an unprecedented capability exists for automatically monitoring, tracking, and controlling goods or items of interest.

Nanotechnology and nanoscale materials constitute a new and exciting field of research [11]. An emerging area of biosensors is based on the use of structures provided by recent advances in nanotechnology, such as nanowires, nanotubes, and nanopores. Among them, the integration of natural nanopores, such as ion channels, with electronics is a promising approach to developing rapid, sensitive, and reliable biosensors [12]. The inherently small size and unusual optical, magnetic, catalytic, and mechanical properties of nanoparticles, not found in bulk materials, permit the

* Corresponding author. Tel.: +86 137 1770 6659; fax: +86 10 6273 7830.
E-mail addresses: mbowles@amc.edu.au (M. Bowles), ljjun@cau.edu.cn (J. Lu).
[1] VET and Industry Research, Australian Maritime College, University of Tasmania, Launceston 7250, Australia. Tel.: +61 3 6324 9561; fax: +61 3 6324 9720.

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development of novel devices and applications that were previously unavailable. Nanosensors are any biological, chemical, or surgical sensory points used to convey information about nanoparticles to the macroscopic world [13,14]. Remarkable progress has been made in the last two decades in the development of optical sensors and their utilization in environmental protection, medicine, space science, agriculture, et al.

Nanosensors hold great promise for the supply chain management business. Nanosensors can be attached to crates, roll containers, pallets, and shipping containers to function as so-called active transport tracking devices. These devices can actively monitor the transportation process and verify the proper handling conditions of goods, like temperature for fresh foods. Furthermore, these devices can detect damage due to sudden shocks, the opening of containers, and other forms of contract breach. These abilities result in a significant quality of service improvements and greater efficiency, which in turn lead to lower transportation costs [3]. However, the potential of nanosensors can be anticipated to extend beyond such devices. As nanotechnologies are embedded into packaging and even the product (e.g. placed into a pill), the potential able to be realized in the next decade increases exponentially.

As improved sensor technology, the nanosensor technology equally offers a great deal to the supply chain field. However, the appreciation of the opportunity for nanosensor applications in the supply chain is at best embryonic. This paper will review the application of nanosensor to the supply chain management.

To complete the review, this paper is organized as follows. In Section 2, an overview of the state of the art in nanosensor technology is provided, in particular relating to details of the research and the main application of nanosensors. In Section 3, the current application of nanosensor technology to primary aspects of the supply chain is reported through a review of the current research. Based on Section 3, a discussion of the potential able to be derived from the application of nanosensor technology in the supply chain is undertaken in Section 4. Finally, the paper concludes in Section 5.

2. Nanosensor technology

Nanotechnology enables the development of devices on a scale ranging from one to a few hundred nanometers. At this scale, novel nanomaterials and nanoparticles show new properties and behaviors that cannot be observed at the microscopic level [15,16]. The aim of nanotechnology is to create nanodevices with new functionalities stemming from these unique characteristics; it is not solely about developing miniaturized versions of classical machines [17]. One of the early applications of nanotechnology was in the field of nanosensors [11,18–21]. Nanodevices and nanosensors have enjoyed increased scientific and public attention [22,23]. While many variations and types exist, for the convenience of study, nanosensors will be systematically classified into physical (mechanical and acoustical, thermal and radiation, optical, magnetic) and chemical (atomic and molecular energies) categories.

Nanosensors are nanotechnology-enabled sensors characterized by a range of variations Table 1.

Presently, there are several proposed ways to make nanosensors, including top-down lithography, bottom-up assembly and molecular self-assembly [13].

As nanosensors become cheaper and easier to synthesize, their presence may become ubiquitous. While there are many positive implications associated with this upsurge, there are also some more sinister consequences. They could be used to spy on people almost anywhere. There is no indication that the current trend for surveillance will end any time soon, much to the chagrin of some optimistic futurists. It is likely to become even worse as the technology improves at a rapid pace. Eventually nanosensors could be placed almost anywhere and would be difficult to detect or destroy. Even if some of them were to be eliminated, a wireless network could still be upheld through any remaining sensors. As this technology matures, new possibilities will arise that could have far-reaching ramifications.

Supply chains are the series of links and shared processes that exist between suppliers and customers, which involve all the activities from the acquisition of raw materials to the delivery of finished goods to the end-consumers [2]. Applying a new technology to a supply chain, generally, first concerns the fields that need more technology in the supply chain, consequently improving the supply chain management and performance [29–32]. We searched the literature from the "Web of Knowledge" and conducted a Google search based on the keyword "nanosensor" and this topic in total produced several hundred papers and reports. Then, we summarized and classified these items. Judging by the surviving literature, the aspects of supply chains that will potentially receive the greatest impact from nanosensor technology are concentrated in the SCM system, packaging, storage and distribution, supply chain safety, tracking and tracing; in this paper, we review the potential application of nanosensors to SCM from the perspective of these aspects. A large amount of literature exists on the potential applications of nanosensor technology in the supply chain; due to the paper's space limitations, we have just reviewed the representative literature.

3. Nanosensors in SCM

It has been well recognized that supply chain management (SCM) is strategically vital to corporate competitiveness and profitability in today's more complex and dynamic operating environment [33]. The successful coordination, integration, and management of key business processes across the entire supply chain determine the ultimate success of all supply chain members [34].

With the recent development of nanosensor technology, nanosensors have shown their great potential in different areas. Therefore, it is necessary to evaluate how this state-of-the-art technology can be applied to supply chain management [34]. In the following, nanosensor applications in supply chains are reviewed from several key aspects.

3.1. Nanosensors in supply chain management systems

Successful supply chain management (SCM) requires a change from managing individual functions to integrating activities into key supply chain processes. Although current wireless sensor network hardware platforms are suitable as