

Intelligent Products in the Supply Chain - 10 Years On

Duncan McFarlane*, Vaggelis Giannikas*, Alex C.Y. Wong**, Mark Harrison*

*Institute for Manufacturing, University of Cambridge, 17 Charles Babbage Road,
Cambridge CB3 0FS, UK (Tel: +44 (0)1223 338069; contact email: [dcm, eg366, mark.harrison@eng.cam.ac.uk]

**RedBite Solutions Ltd, St John's Innovation Centre, Cowley Road,
Cambridge, CB4 0WS, UK (Tel: +44 (0)1223 421611)

Abstract: Ten years ago the intelligent product model was introduced as a means of motivating a supply chain in which product or orders were central as opposed to the organizations that stored or delivered them. This notion of a physical product influencing its own movement through the supply chain was enabled by the evolution of low cost RFID systems which promised low cost connection between physical goods and networked information environments. In 2002 the notion of product intelligence was regarded as a useful but rather esoteric construct. However, in the intervening ten years there have been a number of technological advances coupled with an increasingly challenged business environment which make the prospects for intelligent product deployment seem more likely. This paper reviews a number of these developments and assesses their impact on the intelligent product approach.

Keywords: supply chain, intelligent, product, agent, logistics.

1. INTRODUCTION

In 2002 several of the authors presented an alternate vision for the way in which supply chains might work based on the emerging notion of product intelligence (Wong et al., 2002). At the same time other researchers were working on a similar approach (Kärkkäinen et al., 2003b). The model described supply chain operations in which parts, products or orders (collections of products) would monitor and potentially influence their own progress through the industrial supply chain. At this time, issues of development and wide-scale adoption of the internet and also RFID (Radio Frequency Identification) technologies were receiving significant attention (Sarma, 2001). The supply chain model based around product intelligence provided a conceptual focus for these developments. Also, from an operational perspective, the model promised the potential for greater flexibility and versatility, although at the time more emphasis was placed on improving efficiencies and reducing costs in an increasingly global supply chain environment.

Ten years on, the reason for revisiting this work (and the subsequent numerous developments in Kärkkäinen et al., 2003b; Kiritsis, 2011; Valckenaers, 2009; Ventä, 2007 etc.) is to chart its progress and to examine whether shifts in the industrial landscape now make the intelligent product model a more or less compelling approach. We will particularly examine the impact of both the development of key enabling technologies and also the rise of a series of operating challenges that are faced by the business environment today.

2. INTELLIGENT PRODUCTS IN THE SUPPLY CHAIN - CIRCA 2002

This section provides a brief overview of the 2002 model for intelligent products in the supply chain. In Wong et al. (2002), and subsequently in McFarlane et al. (2003) a definition for an intelligent product is provided:

Definition 1: Intelligent Product (Wong et al., 2002)

An Intelligent Product is a product (or part or order) that has part or all of the following five characteristics:

1. *Possesses a unique identity*
2. *Is capable of communicating effectively with its environment*
3. *Can retain or store data about itself*
4. *Deploys a language to display its features, production requirements etc.*
5. *Is capable of participating in or making decisions relevant to its own destiny*

Although this could be implemented in many ways, the particular implementation of that model discussed in that paper reflected developments at the time in the Auto ID Centre (Sarma, 2001). Specifically, it involved a unique ID on a low cost RFID tag attached to the product, where the ID can be resolved to network pointer to a linked database and decision making software agent. A simplistic example of an “intelligent” spaghetti sauce jar was provided to illustrate the notion (see Figure 1).

This is a machine-readable rendering of a working paper draft that led to a publication. The publication should always be cited in preference to this draft using the following reference:

- McFarlane, D., Giannikas, V., Wong, C. Y., & Harrison, M. (2012), Intelligent Products in the Supply Chain - 10 Years On in '14th IFAC Symposium on Information Control Problems in Manufacturing', pp. 655-660, Bucharest, Romania.

This material is presented to ensure timely dissemination of scholarly and technical work. Copyright and all rights therein are retained by authors or by other copyright holders. All persons copying this information are expected to adhere to the terms and constraints invoked by each author's copyright. In most cases, these works may not be reposted without the explicit permission of the copyright holder.

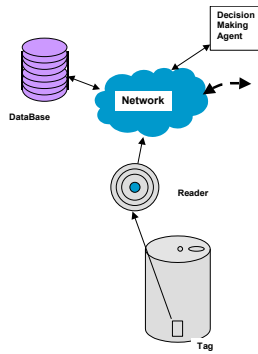


Fig. 1. Intelligent jar of spaghetti sauce (Wong et al., 2002)

Also, in the 2002 paper, two clearly defined levels of product “intelligence” were proposed, associated with that model.

Definition 2: Levels of Product Intelligence (Wong et al., 2002)

- *Level 1 Product Intelligence: which allows a product to communicate its status (form, composition, location, key features), i.e. it is information-oriented.*
- *Level 2 Product Intelligence: which allows a product to assess and influence its function (e.g. self-distributing inventory and self-manufacturing inventory) in addition to communicating its status, i.e. it is decision-oriented.*

Level 1 essentially covers points 1 to 3 of Definition 1. In 2002 it was anticipated that such developments had the potential to be deployed and provide benefits in the short term (2-5 years). Level 2 however involved points 1 through to 5 of Definition 1. It was estimated in 2002 that achieving Level 2 functionality was a long-term prospect for deployment of the order of 5-10 years. (Wong et al 2002).

3. DEVELOPMENTS IN INTELLIGENT PRODUCTS

In this section we briefly review the main developments in product intelligence over the last ten years. For a more detailed review, the reader is referred to the very thorough review by Meyer et al. (2009).

3.1 Definitions & Origins

As was pointed out in Section 1, the notion of product intelligence emerged independently from at least two different research activities. Intelligent products were first presented in the context of innovative manufacturing and supply chain control systems. These systems arose through the availability of Auto-ID technologies and multi-agent systems (McFarlane, 2002, Wong et. al, 2002), as well as the emergence of distributed, intelligent decision making models in manufacturing control (McFarlane et al., 2003). At the same time as the concepts were being developed, a different group of researchers independently presented similar concepts, introducing *product individuals* (an alternative term for intelligent products) as a solution for the challenges that project-delivery-chains faced (Kärkkäinen et al., 2003b). In this case, product individuals were the means for the

implementation of what they referred to as *inside-out control* or *product-centric approach* (Kärkkäinen et al., 2003a) which seemed to offer a certain number of benefits in the management of complex supply chains. This coincidence led to the introduction of new control architectures that shared common ideas, although they used different terminology.

3.2 Constructing Intelligent Products

There are conceptually two main ways to implement an intelligent product: by putting intelligence *at the object* or *through the network* (e.g. Meyer et al., 2009). Research so far has focused on the second option -though not exclusively- for cost and technological reasons. In particular the cost of specialised hardware required for the first option can be very high. The second option uses Automatic Identification and Data Capture (AIDC) technology attached to the product to allow it to be identified by a computer system. These technologies enable the automated identification of objects, the collection of data about them, and the storage of that data directly into computer systems (Sarma et al., 2000). Through this network, the computer system can a) access or write information in databases about the product and b) link with a software agent which is responsible for the communication and decision-making features (Främling et al., 2003).

The aforementioned issue - the enabling technologies of intelligent products - is perhaps the most well studied one in the literature and there are many remarkable review papers available (Främling et al., 2007; Meyer et al., 2009; Kiritsis, 2011), also from the literature of smart objects (López et al., 2009). Nevertheless, there are still some open questions for these technologies such as the specification of what information should be gathered, stored and distributed and how it should be managed during the lifecycle of the product (Baña et al., 2009), the linkage of new hardware and software systems with current ones and existing architectures, the development of appropriate and cheap hardware to be placed on products etc.

3.3 Deploying Intelligent Products

Regarding the latest developments on the intelligent product notion, current research is moving towards exploring its applications in real-life problems (Brintrup et al., 2011; Holmström et al., 2009) as well as the identification and measurement of its benefits in them. Apart from the literature that deals with the quantification of the benefits of AIDC-based information systems (which can be considered to use Level 1 intelligent products), researchers are now trying to evaluate the core concept behind the intelligent product approach. That is, a distributed decision-making process where products, instead of their owners, take control of their destiny. Although there is still little evidence for the value of such a process, increased robustness and effective management of disruptions seem to be the main areas which can benefit from an intelligent product (Meyer, 2011; Meyer et al., 2011; Pannequin et al., 2009; Sallez et al., 2009).

3.4 Parallel Developments

The characteristics of an intelligent product and the fundamental ideas behind it can also be found in other emerging technological topics, such as *smart objects* (López et al., 2009), objects in *autonomous logistics* (Hülsmann and Windt, 2007) and the *Internet of Things* (Fleish, 2010). Unfortunately, using different terminology for similar concepts or (less often) mixing different concepts using the same terminology is a very common phenomenon in the relevant literature. However, during the last couple of years, a number of researchers have realised this problem and they are investigating how these concepts can merge together or benefit from each other (Främling and Nyman, 2008; Kiritsis, 2011; McFarlane, 2011; Morales-Kluge et al., 2011; Uckelmann et al., 2010).

4. THE CHANGING INDUSTRIAL & INFORMATION ENVIRONMENTS 2002-2012

In 2002, the Intelligent Product approach was used to provide an alternative vision for the way supply chains might work. It provided impetus for the development of new low-cost RFID and internet-based technologies and solutions. It also provided support for the notion of greater flexibility/versatility in the supply chain, but at the time more emphasis was placed on efficiencies. So in 2002, there was only a limited amount of commercial momentum supporting the development of environments that could support intelligent products. Any such development would have required a completely new information system environment for deployment and would have faced difficult business justification as its impact on normal steady state operations of the supply chain were limited. In this section we examine recent developments which impact on both the business and technological landscape that an intelligent product solution would be required to operate in and consequently examine the impact on the potential for supply chain deployments of intelligent products in 2012.

4.1 Changes In The Business Landscape

As mentioned above, intelligent product based solutions tend to support supply chain environments where versatility and flexibility are core requirements. We comment here on the rise of a series of business challenges that increasingly make versatile supply chains a necessity rather than a possibility:

(a) *energy price constraints*: the rising price of hydrocarbon based fuels is placing an enormous strain on today's supply chain operations. Long haul practices are reviewed and options such as back-hauling, cross-docking, multi-modal logistics routes are being used (Apte and Viswanathan, 2000; Konings et al., 2008).

(b) *environmental constraints*: Similarly to the above, CO₂ emission constraints are beginning to change the way supply chains operate, requiring providers to more carefully consider the use of vehicles and routing options. In addition there is a need for greater recycling of materials used within the supply chain (Srivastava, 2007).

(c) *tighter traceability regulations & practices*: Laws for the full traceability of consumer goods have been introduced in the past ten years into food, pharmaceutical industries. Additionally, industries such as aircraft manufacturing and luxury clothes & goods have voluntarily sought to tighten the regulation of goods in their supply chain as counterfeiting practices have become more sophisticated and widespread.

(d) *supply chain disruptions*: Tighter, more efficient supply chains with less inventory ironically means a greater vulnerability to natural and man-made disruptions and need for greater resilience (Sheffi, 2007).

(e) *internet-based shopping*: The surge in internet-based shopping has led to a significant increase in the numbers and variety of small, individual item orders. In order to compete on performance, many online retailers now offer next day guaranteed service levels placing further strain on the supply chains they use.

(f) *multi-modal logistics*: Today's logistics service providers are ready to examine many different logistics paths for achieving an effective delivery route. Integrated rail, road and sea models are commonly in use, and some organizations are beginning to consider the need for dynamic route planning.

In summary, these challenges faced by today's supply chains require that the underlying logistics operations be (a) flexible & adaptable to meet fluctuating demand while operating under significant constraints and rapidly changing supply models, (b) resilient, able to provide performance in the face of significant disruptions and (c) accountable in the sense that guaranteed levels of delivery performance and product integrity are provided.

4.2 Technological Advances

Coupled to the changing business landscape, in the last ten years there has been a rapid development of many of the technologies and systems which make Intelligent Product deployment distinctly more of a possibility than in 2002:

(a) *RFID Systems*: RFID is now deployed in many of the world's logistics environments and provides item-level or consignment-level tracking for a range of goods. Predictions are that by 2020 there will be 125 billion RFID tags deployed while in 2010 there were only 2.4 billion (Harrop, 2010). Additionally, through the work of the GS1 community, coherent and compatible global open standards exist for networked RFID and barcode numbering systems (EPCglobal, 2005).

(b) *Object and Vehicle Location Systems*: GPS based location systems are now ubiquitous, and are deployed by most logistics providers in their transport fleet. This capability combined with (a) and with the availability of affordable 3G/GPRS data traffic has the potential to provide for real-time location information of unique items and/or orders.

(c) *Order Tracking Software*: Order tracking systems which support customer access to order progress are now commonplace in areas as diverse as airline baggage, express

parcels and food delivery. These systems directly make use of the RFID and location technologies above, and provide the customer with a level of visibility that would have been unheard of ten years ago.

(d) *Web/Cloud Services*: The ability to efficiently and securely host third party applications on remote servers via web interfaces has lifted many barriers to the customer or order owner playing a role in the provision of logistics services. In addition, customer-oriented web services with agent-like characteristics have begun to appear in which the customer can play an active role in business transactions.

(e) *Internet of Things*: Although still rather esoteric, the evolution of an architecture for the so called *Internet of Things* has led to the increased acceptance of an information environment which includes everyday (non electronic) objects as part of the basic infrastructure (Atzori et al., 2010).

Items (a) – (e) can provide support for much of the hardware, software and architectural requirements for an intelligent product oriented environment although we note that items (d) and (e) are by no means well established at this stage.

4.3 Implications For Intelligent Products In The Supply Chain

The 2002 paper (Wong et al., 2002) spoke of a series of potential applications for both Level 1 and Level 2 Intelligent Product deployments in the supply chain.

(i) Applications for Level 1 Intelligence: The applications based around this level are based on the ability of a product or order to be information-rich and include:

- Product-specific Status Information: The ability to monitor the status of an individual item or order
- Product Tracking Information: Location and prediction information which can be used to plan for downstream use of the order
- Product History Access: Retrieval of product data from multiple organisations enabling tracing of product history and access to design, manufacturing, usage data etc.

(ii) Applications for Level 2 Intelligence: At this level, the product is able to proactively influence its environment and its own movement:

- Product Status: Dynamic updating of price, use-by date and other environmentally sensitive status information
- Product Option Assessment / Negotiation: Dynamic assessment of potential pathways for the product or order
- Self-Managing Capability - Storage & Distribution: managing/enabling the execution of product-initiated decisions

The ability of the emerging business challenges and recent technological developments to impact on each of the two levels of product intelligence is outlined in Table 1.

Simplistically this table indicates that traceability requirements coupled with RFID and location system developments are prime movers for enabling Level 1 Product Intelligence. In the same way, disruption management and cloud/web services plus Internet of Things architectures are strong forces supporting Level 2 Product Intelligence. The relatively newness of these latter developments is in line with the fact that Level 2 Product Intelligence remains predominantly in the academic domain.

Table 1. Supply Chain Applications (derived from Wong et al., 2002)

Level of Product Intelligence	Type of Intelligent Product Functionality	Impacting Business Issues	Impact of Technological Development
1/2	Product Status	Traceability	RFID, ID standards
1	Product Tracking	Traceability, Multi modal logistics, disruption management	RFID, Location systems, Order tracking
1	Product History Access	Traceability, Internet Shopping	Cloud/Web services
2	Product Option Assessment / Negotiation	Energy, Environment Constraints, Disruption management	Internet of Things, Cloud/Web services
2	Self Managing Capability: Storage & Distribution	Internet shopping, Disruption management, Dynamic multi-modal logistics	Internet of Things, Cloud/Web services

5. TODAY'S OPPORTUNITIES FOR PRODUCT INTELLIGENCE

Focussing on logistics only, we now seek to identify the circumstances under which product intelligence as a paradigm for designing an information management environment might prove to be superior to a more conventional approach to managing the movement of a product as part of the logistical planning system of an organization. Tables 2 and 3 outline both characteristics of the logistics environment along with an explanation for why an information environment based around the intelligent product paradigm can provide a suitable supporting environment under these circumstances. We differentiate between structural issues in Table 2 and behavioural issues in Table 3.

Table 2. Suitability of the Intelligent Product model: Structural Issues

Structural Characteristic	Application	Why suitable for Intelligent Product model?
When a product or order moves between organizations in its delivery		Associating information directly with the product allows information to be cross-referenced to the unique ID of the product instance rather than solely to bilateral transaction IDs
When a specific item is part of multiple orders/ consignments for certain stages of its production/ delivery.		A customer is able to directly reflect his order requirements rather than being forced to accept a compromise based around the optimal management of all of the orders being managed.
When a customer's specific requirements for his order is at odds with the aggregate intentions of the logistics organisation.		The entire order is associated with a single logical entity and thus facilitates simpler access to and distribution of information relevant to the order among organizations.
When an order exists in multiple segments scattered across multiple organizations.		Item or product-level lookup services and event repositories enable access to information related to a specific product instance for a third party or customer which might not be available to the players.
Where the different players in the logistics chain have only partial or no information sharing facilities.		Sensor technology can be used for the collection of critical information about an item's quality/ condition (e.g. perishables) and directly linked to the item's data-file.
When an item's characteristics change over time.		

In Table 2 it is clear that where the supply chain structure is complex and where information and physical goods are distributed across multiple organisations, the ability of a single organisation to coordinate flow of orders is limited.

Equally, Table 3 implies that under circumstances in which there are significant options for change and / or disruption there are opportunities for a product oriented information system to provide superior decision support. Such an assumption is based around the ability of the product or order to be able to communicate effectively with the multiple organisations involved on specific issues of routing. We also emphasise that although the decision-making environment might be simpler and more automated this does not mean that dynamic rerouting is always physically possible as a person or material handling system is generally needed to execute such a change.

Although the material in Tables 2 and 3 refers specifically to logistics environments much of it is directly relevant to other environments in which tailored treatment of an individual product is required or is induced due to disruption – for example in the customisation of manufactured products.

Table 3. Suitability of the Intelligent Product model: Behavioural Issues

Behavioural Characteristic	Application	Why suitable for Intelligent Product model?
When options arise frequently and unpredictably for alternative routings to be considered.		Delivery schedules can become emergent and more dynamic since the agent acting on behalf of an intelligent product [See Figure 1] can plan alternative rerouting and negotiate a new intended destination (and customer if necessary) for itself.
When disruptions are frequent and performance guarantees are difficult to achieve.		In the face of existing and potential disruptions the product oriented system can anticipate delays that will impact on its required delivery performance
When decision making about order management requires human resources that are not available.		Software agents within intelligent products could be configured with a set of rules and decision criteria, to make a decision automatically and autonomously.
When a customer's preferences change in the time between ordering and delivery.		A customer can potentially amend or update his order at any time before its final delivery.

6. CONCLUSIONS

In this paper we have examined changes to the business operating environment over the ten years since the Intelligent Product notion was introduced. For example, developments such as the increased need for food traceability or the rise of internet shopping have increased the need for an accurate understanding of the movement of individual items through the supply chain. We have also noted that a number of key technical developments are making the deployment of product intelligence a more manageable task. In particular, the internet of things architectural developments promise to provide environments naturally suited to intelligent product paradigms. We have identified that opportunities exist in the logistics and supply chain fields where more customer-oriented strategies are being sought – perhaps as a means of establishing competitive advantage.

A series of challenges for the community working in this area for the next years can be summarised under the following categories:

- *technical feasibility*: demonstrating that an intelligent product environment can be deployed within industrial scale information systems
- *economic viability*: establishing quantifiable benefits to be gained through deployment of intelligent product oriented solutions
- *operational practicality*: validating the compatibility of any such development with other existing information systems
- *cultural acceptability*: gaining acceptance from potential customers and users of the proposed solutions

REFERENCES

- Apte, U. M. and Viswanathan, S. (2000). Effective cross docking for improving distribution efficiencies. *International Journal of Logistics Research and Applications*, 3(3), 291-302.
- Atzori, L., Iera, A., and Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks*, 54(15), 2787-2805.
- Baïna, S., Panetto, H., and Morel, G. (2009). New paradigms for a product oriented modelling: Case study for traceability. *Computers in Industry*, 60(3), 172-183.
- Brintrup, A., McFarlane, D., Ranasinghe, D., López, T.S., and Owens, K. (2011). Will intelligent assets take off? Toward self-serving aircraft. *IEEE Intelligent Systems*, 26(3), 66-75.
- EPCglobal (2005). *The EPCglobal Architecture Framework*. Retrieved November 4, 2011, from http://www.gs1.org/gsm/kc/epcglobal/architecture/architecture_1_2-framework-20070910.pdf.
- Harrop, P. (2010). *The Global Market for RFID*. ID Tech Ex Ltd.
- Fleish, E. (2010). *What is the Internet of Things?* Auto-ID Labs White Paper WP-BIZAPP-05, Univ. of St. Gallen.
- Främling, K., Harrison, M., Brusey, J., and Petrow, J. (2007). Requirements on unique identifiers for managing product lifecycle information: comparison of alternative approaches. *International Journal of Computer Integrated Manufacturing*, 20(7), 715-726.
- Främling, K., Holmström, J., Ala-Risku, T., and Kärkkäinen, M. (2003). Product agents for handling information about physical objects. Technical report, Helsinki University of Technology.
- Främling, K. and Nyman, J. (2008). Information architecture for intelligent products in the Internet of Things. In V. Autere, A. et al (ed.), *Beyond Business Logistics; Proceedings of 20th NOFOMA logistic conference*, pp. 221-232. Helsinki, Finland.
- Holmström, J., Kajosaari, R., Främling, K., and Langius, E. (2009). Roadmap to tracking based business and intelligent products. *Comp's in Industry*, 60(3), 229-233.
- Hülsmann, M., and Windt, K. (2007). *Understanding Autonomous Cooperation and Control in Logistics: The Impact of Autonomy on Management, Information, Communication and Material Flow*. Springer Berlin Heidelberg, New York, NY.
- Kiritsis, D. (2011). Closed-loop PLM for intelligent products in the era of the Internet of things. *Computer-Aided Design*, 43(5), 479-501.
- Konings, R., Priemus, H., and Nijkamp, P. (2008). *The future of intermodal freight transport: operations, design and policy*. Edward Elgar Publishing, Cheltenham, UK.
- Kärkkäinen, M., Ala-Risku, T., and Främling, K. (2003a). The product centric approach: a solution to supply network information management problems? *Computers in Industry*, 52(2), 147-159.
- Kärkkäinen, M., Holmström, J., Främling, K., and Arto, K. (2003b). Intelligent products—a step towards a more effective project delivery chain. *Computers in Industry*, 50(2), 141-151.
- López, T., Ranasinghe, D., Patkai, B., and McFarlane, D. (2009). Taxonomy, technology and applications of smart objects. *Information Systems Frontiers*, 13(2), 1-20.
- McFarlane, D. (2002). Auto ID based control systems - an overview. In *2002 IEEE International Conference on Systems, Man and Cybernetics*, vol. 3.
- McFarlane, D., Sarma, S., Chirn, J. L., Wong, C. Y., and Ashton, K. (2003). Auto ID systems and intelligent manufacturing control. *Engineering Applications of Artificial Intelligence*, 16(4), 365-376.
- McFarlane, D. C. (2011). Distributed Intelligence in Manufacturing & Service Environments. In *1st International SOHOMA Workshop*, Paris, France.
- Meyer, G. G. (2011). *Effective monitoring and control with intelligent products*, PhD thesis, University of Groningen.
- Meyer, G. G., Främling, K., and Holmström, J. (2009). Intelligent Products: A Survey. *Computers in Industry*, 60(3), 137-148.
- Meyer, G. G., Wortmann, J., and Szirbik, N. B. (2011). Production monitoring and control with intelligent products. *International Journal of Production Research*. 49(5), 1303-1317.
- Morales-Kluge, E., Ganji, F., and Scholz-Reiter, B. (2011). Intelligent Products - Towards Autonomous Logistics Processes - A work in progress paper. In *International Conference on Product Lifecycle Management*.
- Pannequin, R., Morel, G., and Thomas, A. (2009). The performance of product-driven manufacturing control: An emulation-based benchmarking study. *Computers in Industry*. 60(3), 195-203.
- Sallez, Y., Berger, T., and Trentesaux, D. (2009). A stigmergic approach for dynamic routing of active products in FMS. *Comp's in Industry*, 60 (3), 204-216.
- Sarma, S., Brock, D., and Ashton, K. (2000). *The networked physical world*. Technical report, MIT Auto-ID Center.
- Sarma, S., (2001) Towards the five-cent tag. Technical Report MIT-AUTOID-WH-006, MIT Auto-ID Center.
- Sheffi, Y. (2007). *The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage*. The MIT Press, Cambridge, MA.
- Srivastava, S. K. (2007). Green supply-chain management: A state-of-the-art literature review. *International Journal of Management Reviews*. 9(1), 53-80.
- Uckelmann, D., Isenberg, M.A., Teucke, M., Halfar, H. and Scholz-Reiter, B. (2010). Autonomous control and the internet of things: Increasing robustness, scalability and agility in logistic networks. In Ranasinghe, D et al (ed.), *Unique Radio Innovation for the 21st Century*, pp. 163-181. Springer Berlin Heidelberg.
- Valckenaers, P., Germain B.S., Verstraete, P., Van Belle, J., Hadeli, and Van Brussel, H. (2009). Intelligent products; Agere versus Vesere. *Comp's in Industry*, 60(3), 217-228.
- Ventä, O. (2007). *Intelligent products and systems: Technology theme-final report*. VTT Technical Research of Finland, Finland.
- Wong, C., McFarlane, D., Zaharudin, A., and Agarwal, V. (2002). The intelligent product driven supply chain. In *2002 IEEE International Conference on Systems, Man and Cybernetics*, vol. 4, pp. 6.