Energy Efficiency in Logistics – SmartKanban as an Intelligent Intra-logistics Architecture for Kanban Scenarios

Energieeffizienz in der Logistik am Beispiel von Kanban-Szenarien

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Summary Information technology offers a high potential in achieving the climate protection goals by encouraging the reduction of energy consumption associated with a decrease of greenhouse gas emissions. This article shows how processes in logistics can be optimized by means of information technology. Using the example of SmartKanban, the additional energy consumption caused by information technology is compared to achievable potential energy savings. ►►► **Zusammenfassung** Die Informationstechnologie bietet im Hinblick auf die Erreichung der Klimaschutzziele ein großes Potenzial durch die Unterstützung von Energieeinsparungen und somit einer Verringerung der Produktion von Treibhausgasen. In diesem Artikel wird dargestellt, wie im Bereich der Logistik Prozesse durch die Informationstechnologie effizienter gestaltet werden können. Am Beispiel der SmartKanban Lösung werden die zusätzlichen Energieaufwände durch die Informationstechnologie möglichen Einsparungen gegenübergestellt.

Keywords J [Computer Applications]; JIT, Just-in-Time, Kanban, e-Kanban, Smart Logistics, M2M, ICT, Low Power Wireless Network ►►► **Schlagwörter** Energieeinsparung, Treibhausgase, Logistik, Informationstechnologie, Optimierung

1 Introduction

Energy efficiency in intra-logistics often means to account for direct energy savings such as those achievable through the use of energy efficient drives, lighting or heating [1].

A more holistic view upon energy efficiency in logistics through the use of information technology considers all underlying processes with regard to their potential for direct and indirect energy savings.

All of the actions that result in a reduction of carbon dioxide emissions by optimizing or decreasing traffic enabled through information technology in logistics are subsumed as Smart Logistics [2].

Furthermore, the increasing connectivity through information and communication technologies (ICT) within the scope of Machine-to-Machine communication (M2M) and an Internet of Things (IoT) up to the vision of smart cities [3], in which all processes along the six axes Smart Economy, Smart People, Smart Governance, Smart Mobility, Smart Environment and Smart Living closely interact by the use of ICT, requires to look at the processes in their entirety.

This article will give a view on how the use of an intelligent intra-logistics platform is able to achieve energy savings by using information technology for a holistic consideration of the appropriate processes.

At the beginning of this article, a short introduction to Just-in-Time (JIT) production as a currently used production philosophy and its associated Kanban production technology is given. Then, the categorization of goods in inventory planning and how to manage their supply accordingly in Kanban solutions are shown. Following this, the new SmartKanban solution is characterized. Thereby, the additional energy consumption caused by the additional functionality of the SmartKanban solution is estimated and their potential impact on energy savings is observed using the example of designated application scenarios. Finally, the SmartKanban solution is classified in the context of Smart Logistics.

2 Just-in-Time

Nowadays, modern production strategies like JIT, which dates back to the 1950's efforts of the Japanese industry to improve their production, demand for specialized processes. In related literature, JIT is also known as Toyota Production System (TPS).

We first give a short overview of some of the key issues in order to provide a basic understanding of the JIT concept. Details of JIT are covered in publications [4] and [5].

As one of its main objectives, the JIT strategy implies the elimination of over-inventory. This requires a well organized production process minimizing the stocks of material as far as possible. A prevention of over-inventory leads to cost savings and a more efficient production.

In order to achieve this, JIT comprises a demand-based philosophy. This means that a product is assembled when it is needed by the customer and in the required quantities [6].

According to [7], the "Coordination of the JIT process is clearly critical and this is influenced, in turn, by effective communication along the production chain. A simple system of cards called Kanbans is normally used to send signals between production workers."

Managing the production process in compliance with the Kanban technique is discussed in the next paragraph.

3 Kanban Production

As already mentioned, the demand-based Kanban delivery process is organized by the use of signal cards, which signal to the upstream production stage in a multi-stage production process that additional parts have to be delivered.

These cards, called "Kanban" in Japanese, contain all the information required to identify the parts and the amount needed. This pull-principle ensures that the inventory is closely related to the consumption of the parts.

According to the Kanban principle, the flow of information is reverse to the flow of material [23].

The Kanban principle requires intermediate stocks between the different stages of the production process. The different process stages interact by self-controlled meshed feedback control loops.

Different Kanban implementations based on one as well as two cards exist. In some implementations, these cards are represented directly by the boxes with the supplies. An empty box or a box with a predefined minimum stock level signals to the upstream production stage to provide for additional parts. In a one-box system, the box is filled up with new parts, whereas in a two-box system, the empty box is handed over to the upstream stage and replaced by a newly filled up box.

Crucial to the Kanban principle is the knowledge of the current inventory of each assembly.

For further studies, paper [8] provides a detailed description of the various Kanban implementations.

4 Supply Management

In order to implement a production process, an adequate supply management plays an important role.

As part of the supply management, different supply strategies like program-controlled or consumption-based strategies can be applied to the variant material types [9]. Here, a supply management compliant to the Kanban principle belongs to the category of the consumption-based supply strategies.

In order to select the right supply strategy, in many cases, an ABC analysis [9] is performed first. The ABC-analysis usually serves as a method to achieve a classification into categories. With regard to certain characteristics, materials are analyzed and classified as A-, B-, or C-parts. In the context of supply management, the materials can be classified, e. g., according to their share of the total spectrum of parts and their purchasing volume. Parts, which have a high purchasing volume, but which make up only a small amount of the total spectrum of parts, will be categorized as A-parts. C-Parts can be characterized accordingly thorough a high share of the total spectrum of parts and low purchasing volume. Though they only have a low purchasing volume, C-Parts cause high procurement costs, due to their large numbers of suppliers and high rate of orders. Therefore especially the supply processes of the C-Parts have to be considered in terms of cost efficiency [24].

Often, the ABC-analysis is supplemented with an XYZ-analysis. In addition to the ABC method, the XYZ-analysis includes the continuity of the consumption in terms of its regularity and predictability in the classification of the parts. Here, the X-classification comprises parts which have a nearly constant and predictable consumption, whereas the Z-category represents parts with a low predictability and an irregular consumption.

This leads to a matrix with categories of AX-CZ parts. To each of these part categories, an appropriate supply strategy can be applied, so that the potential for the usage of a JIT strategy can be derived. With regard to supply management, the JIT strategy principle is normally used for the AX, AY, BX and BY as well as the CX parts [10].

An automated stock level detection, which can be achieved by e-Kanban systems discussed later, opens up the chance to extend the JIT underlying Kanban supply method to categories of Y and possibly even to Z parts, since in contrast to classic Kanban implementations here a reaction to variations in consumption is feasible.

Due to the high effort required in the purchasing process, the complete C-part management should be automated as much as possible in order to decrease purchasing costs. Often, the complete C-part management is administered by the suppliers themselves. They are responsible to provide the required amount of C-parts with a predefined quality level at the right time. Therefore, they operate so-called **V**endor **M**anaged **I**nventories (VMI) located at the facility of their customers.

VMIs organized according to the Kanban-principle are required to inform the supplier with the information of the actual stock level.

5 e-Kanban

The integration of information technology (IT) in the Kanban process allows combining the classic Kanban method with the digital processes of information and material handling. These electronic Kanban processes are also known as e-Kanban [11] processes.

One of the main advantages of e-Kanban is that the Kanban method can be expanded to cover the whole supply chain. Thus, they are not limited to a local production facility. This is especially required when considering the case of VMIs.

In recent years, a number of e-Kanban implementations came up, some of which will be presented briefly hereafter.

Since the mid 1990s, the SAP Enterprise Resource Planning (ERP) system relies on the integration of IT to support the Kanban process [12]. Workers identify the actual stock level and communicate this information to the production planning tool using barcode or RFID[1] readers connected by means of WLAN[2]-equipped data acquisition devices.

Another e-Kanban solution has been built up as a pilot project by Logis.Net [13]. This e-Kanban implementation of a two-box system makes use of a mechanical switch at the shelves as a sensor to acquire the stock level automatically. Each time the second box with the supplies slides into the position of the previous, now empty, box the switch is activated. The production control system is notified by radio communication that the second box is in access and thus obtains information on the remaining stock level. Several variants of the Logis.Net implementation exist.

The award-winning turn-LOG e-Kanban system [14] has been especially designed for the management of C-goods. Each box is divided into a main zone and a zone which contains the safety margin for the stock level. In case of an empty main zone, the box will be turned in the shelf by 180 degrees so that an RFID tag now mounted in front of the box is able to communicate with a reader device in the proximity. The Tag ID received by the reader device identifies to the production planning system those boxes that have only the safety margin left.

Common to the above mentioned e-Kanban solutions is that the actual stock level is unknown. Only the information that a certain predefined threshold has been reached is transferred to the production planning system.

This leads to one main disadvantage of these methods: A minimum stock level has to be predefined and has first to be evaluated in a planning phase, so that the ability to react to changes in the production process by adapting the minimum stock levels is limited. In an ideal scenario, the minimum stock level is calculated such that there is a sufficient amount of parts left until a new delivery. In a real production process, an additional safety margin is needed in order to make the production robust against disturbances.

The inventory solely needed for the safety margin and never being assembled contributes to the energy used for its production. This is even true in the case of a multi-staged production process taking an integral view to the overall energy consumption. However, the amount of energy needed cannot be calculated here due to the lack of appropriate data.

Thus, methods that provide a more accurate and actual information on the inventory help to decrease the inventories through fitting them dynamically to the production process without having a negative impact on it. Generally, the prevention of over-inventory is one means that shows in which ways IT is able to contribute indirectly to the improvement of energy efficiency in Kanban Scenarios.

Hereafter, it is shown how additional efforts in energy efficiency can be achieved due to the use of IT in logistics taking SmartKanban as an example of an e-Kanban implementation.

6 SmartKanban

The SmartKanban [15] approach[3] goes one step further and provides a more sophisticated integrated e-Kanban

[1] Radio Frequency Identification

[2] Wireless Local Area Network

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solution with application areas not only limited to pure Kanban scenarios.

Similar to the Bossard SmartBin e-Kanban solution [16], SmartKanban relies on an inventory control by weighting the content of the Kanban boxes. Using weight information combined with information on the weight per unit of the goods contained, the connected Warehouse Management System (WMS) is able to calculate the actual stock level. Unlike the SmartBin system, Smart-Kanban connects the sensor technology, which here is integrated in the boxes themselves, to the WMS by means of a low power wireless network. As a consequence, the boxes are capable of determining the weight of the content on their own and are not fixed to a certain position in the shelf like the boxes in the SmartBin system. This opens up new applications where the boxes are mobile within the area covered by the wireless network, providing a permanent monitoring of the stock level.

In contrast to the other abovementioned e-Kanban solutions, SmartKanban allows a dynamical design of the Kanban process with mobile boxes and a permanent transparency of the stock level.

In terms of energy efficiency, the SmartKanban system is characterized by an efficient ultra low-power wireless network technology as well as an ultra low-power sensor technology. The wireless network technology further provides the locations of the mobile boxes in the warehouse.

In the following, we give a rough estimate of the additional energy consumption in operation caused by the proposed SmartKanban system compared to conventional e-Kanban systems, where the stock level information is acquired by the use of WLAN connected barcode scanners.

The energy consumption of the wireless network and the sensor technology is calculated for a scenario with the assumption that the system consists of 200 boxes, 10 routers and one gateway with 8760 operating hours per year in a permanent 24/7 operating scenario.

Intending to equip the boxes with rechargeable batteries, the energy consumption during operation time can be calculated using the battery capacity provided after each charging cycle. The energy consumption caused by the production process and the charging process itself are not considered, since they depend on the battery type and the charging equipment used [17].

Data for the energy consumption of rechargeable batteries in the different phases of their life cycle is difficult to obtain, so that the estimation of the energy consumption has to be limited here to the consumption during system operation. There is also a growing relevance of the operation phase to the calculation of the overall energy consumption with an increasing number of recharging cycles.

The abovementioned assumptions imply an energy consumption for all 200 mobile boxes of about 4 kWh/a with an estimated battery lifetime of 3 years per charging cycle[4]. The lifetime has a strong dependency on the frequency of stock level changes and, with the estimated 3 years lifetime, resides at the lower end of the scale.

Looking at the infrastructure for the wireless network, the estimation of energy consumption for the mains powered gateway and router devices results in an energy consumption for all 10 router devices of about 32 kWh/a with a power dissipation of less that 0.5 W for each router in continuous operation. To compare, the regulation of the European Commission related to Energy-Using Products defines for instance a limit of lower than 1 W in standby mode [2]. The gateway device dissipates about 1 W in continuous mode and therefore requires a total amount of around 9 kWh/a.

With the summed up energy consumption, the additional CO_2 emissions caused by the SmartKanban technology can be derived from the current German energy-mix data [18] with a value of about 26 kg CO_2 each year [5].

It has to be clarified that only the contribution of the additional functionality has been considered and that the SmartKanban-specific processes will be integrated virtually on the existing WMS server, so that energy consumption of these processes does not have to be included in calculating the carbon footprint. The results imply that in terms of energy savings, the implementation of a SmartKanban system should be considered if the carbon footprint of the energy savings exceeds the value calculated above.

7 Application Scenarios

Following the calculation of the carbon footprint, now potential energy savings due to the SmartKanban solution will be analyzed. Therefore, the VMI and the location of forklifts serve as possible application scenarios.

How can the SmartKanban solution contribute or enable the achievement of energy savings in a VMI?

A VMI is usually located at the facility of the buyer of the goods and the vendor is responsible to ensure that supplies are maintained with a predefined quality level. This requires the vendor to know each stock level in order to perform an efficient route planning and scheduling for the delivery of the supplies. With the support of an e-Kanban system, the vendor directly receives the stock-level information by use of IT, so that he is able to remotely monitor the inventory. Conventional e-Kanban solutions often require the interaction of employees to acquire the stock levels, which is sometimes error-prone. Furthermore, these workers are not being employed by the vendor, so that it is preferable to have automatic stock-level detection. Therefore, SmartKanban provides a solution that is not only able to monitor certain limits

[4] Here the self-discharge with the use of i.e. NiMH rechargeable batteries is included in the calculation of the energy consumption by an additional recharging cycle during the estimated lifetime.

[5] We apply a conversion factor of 0.57 kg CO_2/kWh (2008)

but also allows acquiring the exact actual stock level. This enables the vendor to adapt his delivery cycles dynamically to the real needs without having any negative impact on the delivery reliability.

On the contrary, if the vendor knows that certain goods have not yet reached their stock limit, but are about to reach their limits, he can decide to fill up the stocks ahead of time. This may save an additional delivery tour. The VMI scenario is similar to the scenario of a vending machine, which is mentioned in the Carbon Connections report [19] as an opportunity in the sector of Smart Logistics to reduce carbon emissions by the use of wireless telecommunications.

With the carbon footprint calculated above and the footprint of a ton-kilometer [20], which amounts to 104 g CO_2 per ton-kilometer for freight transport by road [21], this results in a break-even point of about 250 km each year[6] for the SmartKanban solution. This implies that the saving of only a few deliveries through the use of the SmartKanban system already has a positive impact on the energy consumption.

In addition to these direct effects on emissions and energy consumption, there are always secondary effects which come into effect due to a reduction in traffic, such as the prevention of traffic congestion, cost savings in road maintenance and a reduced need for new roads.

In case of the forklift location scenario, an innovative location solution allows guiding the forklifts in the warehouse by combining the current forklift position information with the SmartKanban-based location information of the goods to transport.

As a consequence, the processes will be improved. The routes of the forklifts in the warehouse are optimized by assigning the transport order to the forklift next to the location of the goods to transport. The position of the forklifts can be visualized and their routes are logged in order to identify optimization possibilities and improve their load factor.

This may lead to a reduction in the total number of forklifts required as well as an optimized usage of forklifts, i. e., using the diesel or gas lift trucks for far routes in the outdoor area instead of electrically driven ones.

The intelligent forklift guidance system supports the saving of resources and increases efficiency by preventing empty runs and reducing the driving routes.

Thus, IT generates savings effects since transport orders will not be executed in arbitrary, freely selected routes, but in guidance by the system. The forklifts follow an intelligent navigation. As a long time effect, a reduction of the fleet capacity is possible.

In summary, in case of the VMI scenario, the SmartKanban system helps to save energy through the reduction of deliveries. In intralogistics, the location of forklifts in relation to the position of the material offers additional potential for energy savings.

8 Smart Logistics

A series of studies deal with the subject of the reduction of carbon emissions by using telecommunication [2; 19; 22].

There are different key areas identified like Smart Buildings, Smart Grid, Smart Motors, Dematerialization and Smart Logistics, which provide for potential savings of carbon emissions related to information technology.

The term “Smart Logistics” refers to all the information technology-based activities, which have a positive impact in case of the optimization of traffic and logistics [2]. Here, the savings related to information technology use mainly have an indirect character.

According to the “Smart2020 Addendum”, amongst all areas considered, Smart Logistics is the one with the most potential emission savings, estimated to about 85 Mt of CO_2.

The Carbon Connection study [19] assigns a similar classification as the Smart2020 study. However, it is more focused on the wireless telecommunications and specifies 13 specific opportunities providing savings of carbon emissions. In case of Smart Logistics, there are five opportunities designated and analyzed. Significant savings are expected here in the domain of traffic avoidance. One of these five opportunities is remote supply control by means of wireless telecommunications.

SmartKanban aims exactly at this specific activity by integrating sensor technology to remotely monitor the stock-level and providing the supplier with appropriate inventory information by using a wireless machine-to-machine (M2M) communication in order to adapt his deliveries. On the whole, this leads to possibilities to achieve savings related to delivery tours.

9 Related Work

Within the scope of e-Kanban implementations, the abovementioned SAP e-Kanban solution follows up on the idea to integrate the Kanban process into their Enterprise Resource Planning (ERP) system with the help of IT. One main drawback of this e-Kanban system is that there is no automatic stock level detection implemented, so that human interaction is always required to obtain the stock level by special reader devices and hand it over to the ERP.

Further developments in the field of e-Kanban replace the human interaction by the use of appropriate sensors in order to maintain the supplies.

[6] Using primary batteries of LR6 type (AA size) instead of rechargeable batteries results in a break-even point of nearly 425 km with an estimated battery lifetime of 3 years (Mobile boxes: 200 km, Gateway + Router: 225 km). The contribution of a LR6 battery can be derived from [25] with a carbon footprint for its entire life cycle equivalent to the CO_2 emission of a conventional car for a driving distance of 1 km. The calculated carbon footprint of the other system components comprises only the energy consumption during operation time.

The Logis.Net AMS[7] e-Kanban plattform provides an automatic detection that a certain stock level limit is reached and notifies the production control system by means of radio communication technologies. The automatic stock level detection is based on different sensor types (mechanical shelf mounted sensors, RFID Kanban cards, Call-Button) depending on the applied system option. Common to these sensors is that they do not allow to acquire the exact current content level of the Kanban boxes. In the case of the mechanical shelf mounted sensor system option, the Kanban process is limited to the two box Kanban process variant.

Similar to the abovementioned e-Kanban solutions, the turn-LOG system relies on RFID technology to detect that a predefined safety margin of the box content is reached. The turn-LOG solution is bound to prepared shelves but requires no wiring. With the constraint of a specialized shelf infrastructure, the turn-LOG system is not limited to a fixed location.

Thinking one step further, the knowledge of the exact amount of content left in the Kanban boxes enables the WMS to organize the supply process more efficiently. The Bossard SmartBin e-Kanban solution picks up this idea and adds a scale to each box position in the shelf. This allows to detect the accurate content of each box by using the weight per unit of the box content.

Due to the fact that each box requires a separate scale, the system is expensive and demands a high wiring effort especially with regard to modifications of an existing infrastructure. Another drawback relates to the acquisition of the weight information. In the case that the boxes are in access, they do not necessarily reside on the scale in the shelf. Weight changes can not be detected until the box is placed on its appropriate scale in the shelf.

SmartKanban improves the detection of the content level by integrating the sensor technology into the box itself and ensures that each change of content is detected by the box itself and notified to the WMS by a low power wireless network. Additionally, the constraint of the Bossard solution that the boxes are fixed to a certain position in the shelf does no longer exist by using the SmartKanban solution.

10 Conclusions

This article shows, by referring to commonly used production methods in logistics, how the use of information technology is able to achieve savings in case of carbon emissions.

Business processes can be organized more efficiently with the use of IT. Often, besides improved procedures, this also leads to energy savings. On the basis of the forklift location scenario, where the correlation of forklift position and material position provides an optimization of the forklift routing, and the scenario to remotely monitor the stock-level, it has been demonstrated how wireless information technology within the scope of the proposed SmartKanban solution works as an enabler technology for the savings of carbon emissions. This increasing connectivity of processes by the usage of information technology implies as a drawback the risk that single failures have negative effects on the whole process chain. Here, a compromise between the benefit of the increased connectivity by the usage of IT and the degree of dependencies between the processes has to be found.

[7] Automatisches Materialnachschub Steuerungssystem

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References

[1] Fachhochschule Osnabrück Fachgruppe Logis.Net, RIS Kompetenzzentrum für Zukünftige Energieversorgung e.V. Oldenburg. *Praxisleitfaden "Grüne Logistik"*. Osnabrück und Oldenburg 2010. http://www.ris-logis.net/Gruene_Logistik/pdf/Praxisleitfaden.pdf (31.05.2011).

[2] The Boston Consulting Group GmbH, Deutsche Telekom, Huawei, SAP, Siemens. *Smart 2020 Addendum Deutschland: Die IKT-Industrie als treibende Kraft auf dem Weg zu nachhaltigem Klimaschutz*. http://www.gesi.org/LinkClick.aspx?fileticket=X7m82qhz%2F6o%3D&tabid=60 (31.05.2011).

[3] J. M. Hernandez, Telefonica R&D. *Smart cities, the silent IoT revolution MONAMI* 2010. © 2010 Telefónica Investigación y Desarrollo, S.A. Unipersonal. http://mon-ami.org/2010/docs/JMHernandez-Smart_Cities-The_Silent_IoT_Revolution-MONAMI2010.pdf (11.12.2011).

[4] D. Arnold, H. Isermann, A. Kuhn, H. Tempelmeier und K. Furmans (Hrsg.). *Handbuch Logistik*, 3. Auflage. Springer Verlag 2008.

[5] H. Wildemann. *Das Just-In-Time-Konzept Produktion und Zulieferung auf Abruf*, 5. Auflage. München 2001.

[6] J. G. Siegel and J. K. Shim. *BARRON'S Accounting Handbook*, 4th edition. © 2006 Barron's Educational Services Inc, 2006. Pages 120f.

[7] A. Chambers and G. Rand. *Operational auditing Handbook: Auditing Business and IT Processes*, 2nd edition. © 2010 John Wiley & Sons Ltd. Page 196.

[8] H. Lödding. *Verfahren der Fertigungssteuerung*, 2. erweiterte Auflage, Springer Verlag 2008. Seiten 177ff.

[9] F. Eisenführ. *Einführung in die Betriebswirtschaftslehre*. Schäffer-Poeschel Verlag 1996, Seiten 229f.

[10] R. Krüger. *Das Just-in-Time-Konzept für globale Logistikprozesse*. Deutscher Universitäts-Verlag, Reihe "Supply Chain Management – Beiträge zu Beschaffung und Logistik", Hrsg. M. Eßig und W. Stölzle, 2004. Seiten 101–110.

[11] H. H. Wannenwetsch und S. Nicolai. *E-Supply-Chain-Management. Grundlagen – Strategien – Praxisanwendungen*, 2. Auflage, Gabler Verlag 2004. Seiten 145ff.

[12] M. Habermüller. Schlanke Produktionsabläufe mit Kanban und RFID-Technik. In: *IT & Produktion*, Heft 03/2011, Seiten 38f.

[13] W. Bode. Automatisierter Materialnachschub für die Montage. In: *Hebezeuge Fördermittel*, Heft 9/2009, Seiten 420ff.

[14] D. Herrmann. Versorgung nach der Wende. In: *Logistik Heute*, Heft 11/2008, 30. Jahrgang, Seiten 54f.

[15] VDI/VDE-Innovation + Technik. *Projektinformation SmartKanban.* http://www.mstonline.de/foerderung/projektliste/detail_html?vb_nr=V3AVS032 (31.05.2011).

[16] Bossard. Smart & Lean. http://www.bossard.com/index.cfm?app_cache=070905_112726&app_action=file_open&app_Content-MenuItemID=11388&app_fileID=4360&app_source=text_file (31.05.2011).

[17] G. Scholl, W. Baumann, A. Muth. INFU. *European Ecolabel for Batteries for Consumer Goods – Final Summary Report*. Heidelberg 1997. http://www.oekopro.de/files/FIN-REP.pdf (31.05.2011).

[18] Umweltbundesamt, FG I 2.5., März 2011. *Entwicklung der spezifischen Kohlendioxid-Emissionen des deutschen Strommix 1990–2009 und erste Schätzung 2010.* http://www.umweltbundesamt.de/energie/archiv/co2-strommix.pdf (31.05.2011).

[19] Vodafone Group Plc and Accenture. *Carbon Connections: Quantifying mobile´s role in tackling climate change*, 2009. http://www.accenture.com/SiteCollectionDocuments/Accenture_Carbon_Connections_Quantifying_Mobiles_Role_in_Tackling_Climate_Change.pdf (31.05.2011).

[20] Gabler Verlag (Hrsg). *Gabler Wirtschaftslexikon*. Stichwort: Tonnenkilometer (tkm), online im Internet: http://wirtschaftslexikon.gabler.de/Archiv/84091/tonnenkilometer-tkm-v4.html (31.05.2011).

[21] Umweltbundesamt (Herausgeber), FG I 3.2., Dessau-Roßlau, März 2010. *CO_2-Emissionsminderung im Verkehr in Deutschland*, Mögliche Maßnahmen und ihre Minderungspotenziale, Ein Sachstandsbericht des Umweltbundesamtes. Tabelle 2 auf Seite 12. http://www.umweltdaten.de/publikationen/fpdf-l/3773.pdf (31.05.2011).

[22] The Climate Group on behalf of the Global eSustainability Initiative (GeSI). *Smart2020: Enabling the low carbon economy in the information age*. http://www.smart2020.org/_assets/files/02_Smart2020Report.pdf (31.05.2011).
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[23] R. Vahrenkamp. *Produktionsmanagement*, 6. Auflage, Oldenbourg Wissenschaftsverlag, 2008, Seiten 313–323.

[24] R. Kämpf und J. Boivin. EBZ Beratungszentrum GmbH, Stuttgart, *C-Teile Management*, http://www.ebz-beratungszentrum.de/logistikseiten/artikel/ctm1.html, Download am 15.01.2012.

[25] VARTA Consumer Batteries in cooperation with Aalen University. *SUSTAINABILITY REPORT 2011*, 2011. http://www.varta-consumer.com/~/media/Files/Global/Company/Recycling%20and%20Sustainability/VARTA_Sustainability_Report_2011.ashx (11.01.2012).

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