Proposal of a traceability model for the raw Brazilian sugar supply chain using RFID and WSN

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Abstract

Brazil is the world's major sugar exporter. Current traceability problems involve batch mixing, difficulty locating contaminated batches, and lack of adequate automatic and real time systems usage. This paper proposes a traceability model that allows for automatic product monitoring. Its main impacts and implementation issues are discussed.

Keywords: RFID, sugar, traceability, WSN

Introduction

Brazil is one of the largest agricultural commodities producer of the world. Its exports encompass a whole range of products, from beef, fruits and vegetables to bulk agricultural products such as soybeans, corn, sugar and ethanol. Among these, sugar is one of the most important products, due to the high volume exported. It is estimated that, in the 2013/14 sugarcane harvest, the country will export 26.2 million tons of sugar, or 47% of the world market for this product (USDA, 2014).

Sugar is exported in two different forms, each with their own processes and equipment for transportation and storage: raw sugar and refined sugar. The former is transported in the bulk form, and the latter is packaged and transported using containers. The use of big bags to export sugar is not usual. Because raw sugar corresponds to 79% of the total sugar exported in 2013 by Brazil, a volume of 21.5 million tons, this product will be the object of study of this research (MDIC, 2014).

Raw sugar is a product with low added value and it is transported over long distances, mainly using the roadway mode. For this reason, transportation costs are highly significant for the competitivity of the companies involved in its supply chain (SC). The logistics costs to export bulk agricultural products in the country can reach 60% of the price of the end product, twice as that observed for manufactured products (MARTINS; CAIXETA-FILHO, 1999; FRIEND; LIMA, 2011).

Logistics is a multidisciplinary field that focuses on improving products, information and money flows by analyzing three processes: facility location, product transportation and warehousing. The concept of supply chain management, on the other hand, expands the scope of the solutions studied, considering the efficiency and efficacy of all the companies involved in satisfying the consumers' demands for a specific product or service (BALLOU, 2006).

In the scientific literature, it is possible to observe a lack of studies of Brazilian bulk agricultural products SCs. Their logistics aspects are not well defined, making it difficult to identify the main bottlenecks that limit the competitiveness of these SCs in the world market (KAWANO et al., 2013).

One important bottleneck, though, is related to traceability systems. These have high importance to the end consumers, both in terms of guaranteeing the origin and processes applied to a determined product, and in supplying real time information related to production, processing and the product quality along the transportation and warehousing activities.

Both factors are important for a number of reasons: they allow consumers to trace product related information; they allow different links of the SC monitor the transportation and warehousing activities to identify quality issues sooner; and they enable the companies to identify defective products early, avoiding the need for consumer recalls later.

According to Metzner, Cugnasca and Silva (2014), the main technologies used for traceability purposes are: electronic spreadsheets, bar codes, quick response codes (also known as QR codes) and radio frequency identification (also known as RFID). Among these technologies, RFID is the only one that can be fully automated, allowing companies in the SC to monitor the product, boxes, pallets, containers or batches of bulk products with minimum human intervention. If implemented together with the wireless sensor networks (WSN) technology, it allows monitoring the environmental variables related to the product. These are mainly: temperature, humidity, lightness, vibration and mechanical shocks.

The main objective of this paper is to develop a proposal of a traceability model for the raw Brazilian sugar for exportation purposes that allows collecting and accessing information in real time by the different SC actors, resulting in a more effective traceability system for this product.

Agricultural products traceability

Traceability can be defined as the capability to monitor a specific product throughout the whole SC, allowing the identification of critical control points (JURAN; GODFREY, 1999). The Hazard Analysis and Critical Control Points (HACCP) approach can then be used to define which actions should be taken to avoid future quality problems (SMITH et al., 2008).

In case problems do occur, a well-established traceability system allows the company in charge to identify their source and to take corrective actions to avoid their reoccurrence. Juran and Godfrey (1999) define traceability as the ability to track the record, processing parameters and the places a product has been, storing the information in a system.

According to Machado and Nantes (2004), due to an increasing demand for product quality by consumers, mainly in developed countries, gathering the information related to the path followed by the product becomes essential for the companies in a SC. Consumers are worried about food contamination, such as BSE (Bovine Spongiform Encephalopathy).

Chrysochou, Chryssochoidis and Kehagia (2009) explain that the EU traceability needs were formalized by a document denominated General Food Law. Its implementation started in 2005. According to Shanahan et al (2009) and Kelepouris, Pramatari and Doukidis (2007), the General Food Law places two main demands on food SCs:

1. The traceability system must allow for the identification of food, feed, animals, and all the raw material and inputs used to produce a specific food product;
2. The supply chain agents must be able to identify all the raw material and input suppliers, and to provide this information to government authorities when requested.

Currently, the traceability of bulk agricultural products such as soybeans, corn and sugar does not allow identifying individual batches, due to multiple processes of product aggregation and segregation (THAKUR; HURBURGH, 2009). Quality control is conducted based on product volume, not on production batches. This way, traceability is lost between different stages of the SC, making it impossible to identify the farm that provided the sugarcane that was used to produce the sugar in a specific refined sugar package. An automatic monitoring system would allow the SC as a whole to improve its traceability.

Technologies for traceability

Different technologies can be used in a traceability system, such as barcodes, QR codes and RFID. Barcodes can be defined as information codified in one dimension, with intervals in between colors with different reflectivity (black and white). These are useful to improve the speed of inserting information in a system, but they do not contain information about the product itself (PAVLIDIS; SWARTS; WANG, 1990).

The QR codes were developed in Japan in 1994, and are currently used in logistics, industrial operations and sales activities. Each symbol consists of a codification region and a series of standard procedures, facilitating the location, size and inclination of the code in relation to the reader (LIU; YANG; LIU, 2008).

The RFID technology consists of tags with information about a specific product that are automatically read, without the need of visual contact between the tag and the reader. The data is then inserted in a computer system, preferably in the web, and can be viewed by different SC agents. Another important advantage of this technology is that it allows reading multiple tags at the same time, improving the process of monitoring multiple batches (SILVA et al., 2013; METZNER; CUGNASCA; SILVA, 2014).

Kelepouris, Pramatari and Doukadis (2007) describe the RFID technology as follows: first, the objects that will be identified, such as boxes, pallets and containers, receive a tag containing information about the product and the location. These tags consist of a microchip and an antenna. When the tags are in the vicinity of a reader, they are activated, and provide the information contained in them. This information is then sent to a gateway that will send it to the web. This flow can be observed in Figure 1.

Even though the RFID technology allows for a better monitoring of the movement of a product in a SC, it does not collect information related to the environment in which it was produced, transported and stored. This is essential for food products.

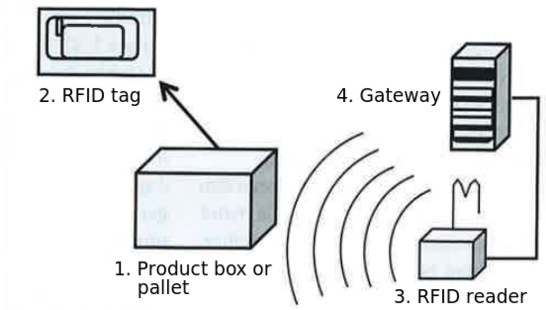

Figure 1. *Description of the use of the RFID technology.*
Source: Jones et al, 2004.

The use of sensors is important to fill this gap, allowing data collection and transmission related to temperature, humidity, vibration, pressure, gas concentration, among other variables of the environment. These can be installed in different configurations: with manual reading, with automatic reading but using cables, and with automatic reading and wireless information transmitting. The latter category, commonly known as WSN, is of the highest importance for the current paper due to its automatic data transmission.

Glisic and Lorenzo (2009) define a WSN as a large number of sensors spread over a specific area, collecting and sharing information among them and a gateway. The main advantages of using this technology, according to Wilson (2005), are: avoiding infrastructure problems related to the use of wires and cables; flexibility of the types of networks used; and easiness of information transmission.

Regarding the use of these technologies, Silva and Cugnasca (2011) did a literature review, focusing on the use of RFID together with WSN in different supply chains. Although some contain traceability models, none was found for bulk agricultural products, and the models proposed for other products cannot be easily adapted to them. The following list contains the most important papers analyzed by those authors:

- Jedermann et al. (2006): development of a system using RFID and WSN to monitor the transportation of containers;
- Jones (2006): a RFID system that considers the movement of a product along the supply chain, focusing on automation;
- Jedermann, Moehrke and Lang (2010): online monitoring system for exporting bananas using containers. The main technologies used were RFID and WSN;
- Timm-Giel et al. (2006): RFID and WSN system that uses a modem in a truck to send information to the web, where it can be viewed by different actors in the supply chain.

Brazilian raw sugar supply chain

According to Daskin (1985), logistics is the science that studies how to best transport and store the different raw and final products, resulting in deliveries at the right time, place, and quality, with the lowest possible cost. Ballou (2006) uses a similar definition, but focusing on providing the highest profit possible to the company.

The concept of SC applies the knowledge obtained in the logistics area along the whole chain of companies that go from raw material production to end consumer demand satisfaction, considering all the companies involved, directly or indirectly. In a SC, the flows of products, money and information are analyzed.

A series of studies has been performed on the raw sugar SC, the most significant ones being: optimization of sugar distribution (COLIN et al., 1999); location problem applied to railway transshipment terminals (OLIVEIRA, 2005); and evaluation of the economic and environmental impacts of using railways in sugar exporting (KAWANO et al., 2013).

Table 1 shows the importance of the raw sugar exports for Brazil in comparison to refined sugar. It corresponded to 80% of the total sugar exported by the country in 2013.

Table 1. *Brazil sugar exportation in 2013, divided into raw and refined sugar*

	2013		2012		2011	
Product Type	US$ (thousands)	Ton	US$ (thousands)	Ton	US$ (thousands)	Ton
Refined sugar	2,686,945	5,647,447	2,836,534	4,908,725	3,392,877	5,206,237
Raw sugar	9,155,515	21,506,859	10,008,338	19,433,571	11,548,786	20,152,913
Raw sugar / Total	77%	79%	78%	80%	77%	79%
TOTAL	**11,842,460**	**27,154,306**	**12,844,873**	**24,342,296**	**14,941,663**	**25,359,150**

Source: MDIC, 2014.

According to Silva et al. (2010) and Kawano et al. (2013), the Brazilian raw sugar SC can be divided into five stages or SC links. At the first stage, which occurs inside the farms, inputs and resources are used to produce sugarcane. Due to the current state of the art of sugarcane production in the country, it is possible to grow this crop in any of its regions. After the harvest, the sugarcane enters the second stage of the SC: its transportation to the industry. This is done using trucks owned by the industry, due to their specificity.

The third stage happens inside the industry. Its main activities are: sugarcane cleaning, crushing, and processing. The results of these activities are the production of ethanol, raw sugar, and bagasse, which is normally burnt to generate electricity.

If the sugar main market is the domestic one, it will be refined and sent to the industries in big bags, or it will be packaged and sent to the wholesalers and retailers' distribution centers. If the main destination is the world market, the next stage of the SC is the transportation of the raw sugar, in bulk form, to the harbors. This normally happens using the roadway mode, although the railway mode is increasing its importance. The vast majority of vehicles is outsourced and, if the ships cannot be loaded immediately, the product will be stored in a warehouse (OLIVEIRA, CAIXETA-FILHO, 2007).

The last stage is related to loading the raw sugar into the ships at the harbor, and its transportation to the product final destination. Maritime transportation also uses outsourced ships.

The product quality control begins after the industrial processes, with samples collected in warehouses, transshipment terminals, and at the harbors. These are stored, and their information is inserted manually in the companies' computer systems. Because the monitoring of the product and the samples is not automatic, the traceability of the product may suffer problems due to errors in data insertion. The traceability model described herein aims to solve this problem.

Methodology

According to Cooper and Schindler (2001), this paper can be considered an exploratory research, because it will elaborate a structure that will be tested in future studies, with a case study nature, because it analyzes a topic in depth.

The methodology used can be divided into three steps: (i) literature review, aiming to understand: the state of the art in the traceability of bulk agricultural products, and the current researches being made that apply RFID and WSN to these SCs; (ii) data gathering from primary and secondary sources to characterize the raw sugar SC and to identify its major traceability problems; and (iii) development of a traceability model that considers using these technologies to solve the current traceability problems of the raw sugar SC.

At step (i), a systematic literature review was made of the Web of Science database, following the bibliometric review methodology, and considering the most relevant scientific journals and events. Software BibExcel, VosViewer and Microsoft Excel were used, and this will be described in more detail in another paper, along with the main results. The tags used were related to traceability, logistics, SC management, RFID and WSN.

The knowledge obtained in step (i) was used to guide the data collection at step (ii). The main secondary sources used were scientific papers and government databases from Brazil, the EU and the USA. The primary sources used were: research groups, such as Embrapa (Brazilian Agricultural Research Company, a state agency) and ESALQ-LOG (Agroindustrial Logistics Research Group, part of the University of São Paulo), and one of the main companies in the sector. The raw sugar SC was then characterized, and its main traceability problems and quality control points were identified.

The last step of the research was applying all the knowledge acquired to develop a proposal of a traceability model for the Brazilian raw sugar SC, focusing on export. This was conducted together with researchers from the Agricultural Automation Laboratory (LAA, part of the University of São Paulo) and the Knowledge Engineering and Decision-Support Research Center (GECAD, part of Porto Polytechnic Institute).

Results and discussion

The main traceability problems in the raw sugar SC identified in this research were:

- Product contamination: for years there have been problems related to sugar mixed with other products at the harbors. This occurs mainly during the stage that involves transporting the product from the industry to the harbors (REUTERS BRASIL, 2009);
- Mix between batches with different product characteristics: due to the difficulty in identifying the products characteristics without laboratory analysis, batch mixture can occur along this SC. The current traceability model does not allow the identification of where this might have happened, and it does not provide the tools to identify which link must account for it;
- Product theft: cases of product theft were identified, with the most common ones occurring during the transportation and warehousing stages. This also has interaction with the first problem identified, because in most cases the thieves replace the product with sand;
- Difficulty in determining a specific batch in the case of a product recall: because the current traceability model is mostly manual and incomplete, it is highly complex to identify the source of a quality problem in the SC. For this reason, it is difficult to identify which specific batch should be recalled, and the most common response is to recall multiple batches, generating losses for all the SC links;
- Lack of systems that allow for complete, real time and automatic product traceability;
- Lack of coordination between the agents of the SC: as each agent seeks only to maximize its own profits, without considering the negative impacts this may have on the other links of the SC, the main problems of a non-coordinated SC may occur. This leads to inefficiency and a higher total SC cost.

The traceability model developed considers how these problems could be solved, in a cost-effective way, applying state of the art knowledge from both the logistics and SC management areas. The RFID and WSN technologies are essential for this to be possible, because they allow an automatic monitoring process, improving the efficiency and effectiveness of the SC agents in dealing with disruptions and quality problems.

The proposed traceability model, illustrated in Figure 2, is based on a series of assumptions founded both on the scientific literature and on information obtained from the primary sources:

- The warehousing model adopted, both for silos and adapted warehouses, is the First In, First Out (FIFO) model, which means that the batches leave the warehouse in the same order as they entered it;
- Sugarcane crushing in the industry is managed using a FIFO model to avoid quality losses;
- In the case of batch mix at a transshipment terminal, the content of the wagon will be considered to be composed of equal parts of the initial batches;
- Due to its very low volume, big bags and packages export will not be considered by the model, only bulk products;
- There should be no additional quality control points because this would increase the complexity of adopting the traceability model proposed;
- The use of humidity sensors in the vehicles and wagons can reduce the unloading operation time because it allows the detection of product aggregation beforehand.

In the following paragraphs, a description of the proposed traceability model will be provided. This will include the description of the information to be collected and the technology that will be used for that purpose, the way it will be transmitted and how it may influence the operations of that specific SC link.

At the first stage of the traceability model, which comprises the production of sugarcane at the farms, most of the processes will be inserted in a spreadsheet at the farm computer system. This will be connected, via internet, to the cloud, where the web server that contains all the traceability information is located.

The farmer will then enter the production dates, crop varieties, inputs used and their quantity, and the main processes considered important for traceability purposes. In an ideal condition, the information inserted in the spreadsheet will be automatically synchronized with the cloud, minimizing transcription errors.

The first stage ends with the harvesting and transportation processes. At the second stage, the sugarcane is transported to the industry using the industry's own vehicles that will each have an RFID tag containing information about the driver and the truck number. When the truck enters the industry to unload its cargo, it will go through a gate with an RFID reader that will automatically link the information on the truck with the information inserted by the farmer.

The data related to the product quality is also inserted in the Enterprise Resource Planning (ERP) of the industry, allowing it to monitor the origin of the inputs during the processes of crushing and sugar production. This will be performed automatically due to the FIFO rules already described: the first batch that enters the industry will provide the raw material for the first batch of sugar produced.

The third stage is related to the transportation of the raw sugar from the industry to the harbor. Two transportation modes can be used: roadway or railway. In the first one, the product is directly sent to the harbor. In the second one, it is sent to a transshipment terminal, stored, loaded into wagons, and then sent by railway to the harbor.

In both cases, to maintain the traceability of the product batches, RFID tags will be placed at each truck and wagon. Information related to the batches will be transmitted to the cloud by the industry, and the software will link the wagon or truck to the original batch. When the vehicle arrives at the harbor, it goes through a gate with an RFID reader similar to the one at the entrance of the industry and this will link the product being unloaded at the harbor with the original batch.

The fourth stage is related to the maritime transportation between the origin and destination harbors. As the ships loading and unloading processes follow a Last In First Out (LIFO) management model, in which the last batches loaded will be the first ones to be unloaded, batch identification will be made automatically when unloading the cargo at the destination harbor.

The fifth stage comprises the transportation of the product from the harbor to the sugar refining plant. Normally, the product is transported using trucks, but it can also be transported using trains. Gates with RFID readers will be placed both at the exit of the sugar terminal at the harbor and at the entrance of the food industry, to allow the identification of the product.

After the sugar refining process, this will be packaged and sent to retailers and wholesalers. The transportation is performed using boxes placed on pallets. One RFID tag will be used in each box and pallet, allowing individual packages to be automatically linked to the original raw sugar batch.

The last stage is related to the product consumption, and no data will be collected in this link of the SC. The challenge in this case is to provide useful and easy to access information to the end consumer, who will be able to access it online, through a web portal, using information contained in a tag at the refined sugar pack.

WSNs will be mounted along the SC links, in three different configurations: processing points (raw sugar producing industry and sugar refining plant), during transportation (inside the trucks, wagons, and ships), and in stationary points (warehouses, wholesalers and retailers).

In categories one and three, both temperature and humidity will be monitored, because they can influence both the operations and the final product quality. In the case of category two, just humidity will be monitored, because the most serious problem detected was product aggregation due to high levels of humidity.

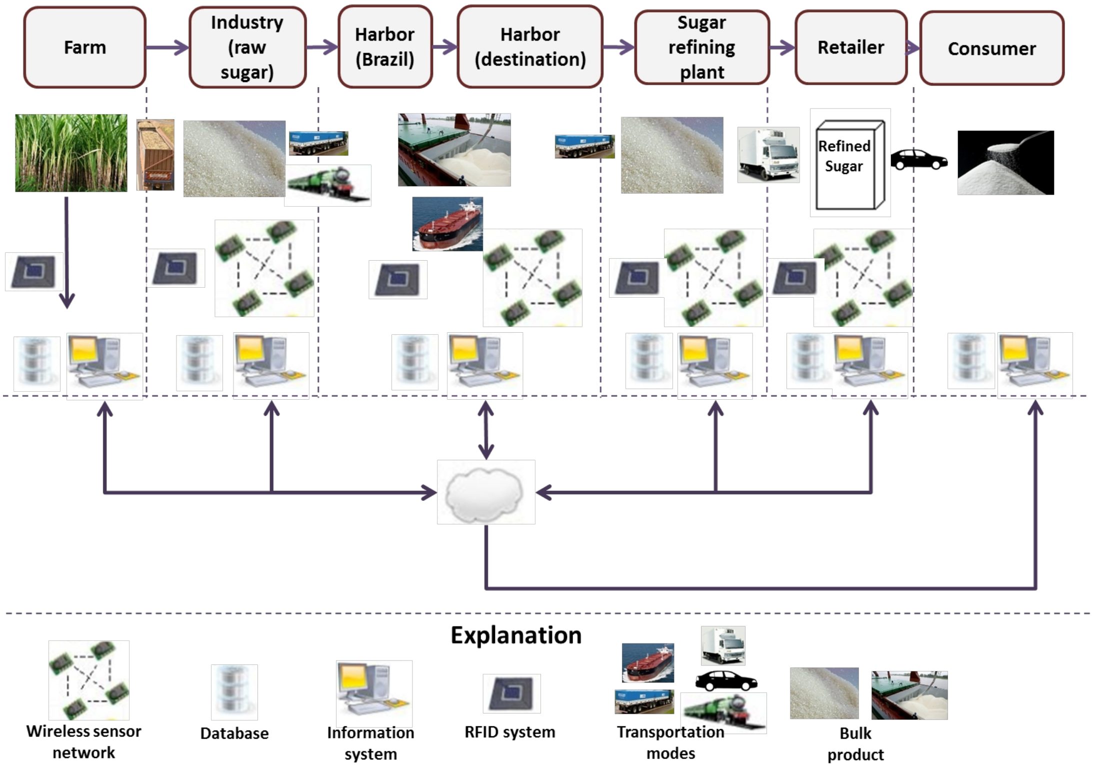

Figure 2. *Traceability model for the raw sugar SC*
Source: the authors, 2014.

The data collected by the sensors will be sent to the server at the cloud at periodic intervals. If any of the values measured are out of the expected ranges, resulting in an anomaly in the product quality control, the responsible link of the SC will receive warnings via email and Short Message Service (SMS).

This early warning system allows the companies in the SC to take corrective actions faster, improving their responses to problems of contamination and product recalls, for example. An additional advantage is the possibility to re-route the product to another market, which will accept the lower quality product.

Regarding product contamination, the model proposed can improve the companies' responses in two different ways: avoiding product contaminations and reducing the impacts of a batch contamination, in the case it occurs.

In the first case, the main advantage of the proposed model is that it allows a more accurate quality control of the processes and interactions between the companies, allowing the identification of quality control points and transmitting information faster among them.

In the second case, if a contamination of the final product is detected, the model enables the companies in the SC to easily locate which batch originated the contaminated product, leading to a more effective product recall. As observed by Thakur and Hurburgh (2009), this is currently not possible in the SCs of bulk agricultural products due to multiple batch aggregation and segregation activities.

One important point considered when developing this traceability model is that the information at the company's ERP that is useful to other companies in the SC can be shared, but the information it considers confidential will not. Thus, the traceability model can improve SC coordination while maintaining essential strategic information confidential.

Limitations and future research

The main limitations observed when conducting the research were the following: the technologies of RFID and WSN are not widespread, especially in the agro industrial products SCs; the companies on this specific SC are not easy to contact for research purposes; and there are few traceability models available in the scientific literature for these specific products.

Future research is related to the discrete event simulation of the proposed traceability model, considering its impacts in terms of time, costs, and error frequency. The following operations will be considered: internal movement of raw materials and products in each link of the SC; the sugar production process; product transportation and storage; transshipment operations; and end product distribution.

Conclusions

Traceability is an essential process to guarantee food quality and safety, and its importance has increased over the last years. It is currently a consumer demand for most of the agricultural products, excluding the raw material that will be further processed, such as soybeans and raw sugar. If a contaminated batch is found, it is very hard to identify where the raw materials came from, making it difficult to trace back the contamination.

In this paper, an analysis of the Brazilian raw sugar SC was performed, and a traceability model considering the use of the RFID and WSN technologies to allow real time product monitoring was proposed. This model meets both current and future traceability needs, and can be extended to other bulk agricultural product SCs with a few modifications.

The next steps of the research, currently in development, are related to the elaboration of a simulation model that considers the impacts of the model proposed in terms of costs, times, and error frequency, in comparison to the current situation.

Bibliography

Ballou, R. H. 2006. **Gerenciamento da Cadeia de Suprimentos**. Editora Bookman, Porto Alegre – RS.

Chrysochou, P., Chryssochoidis, G., Kehagia, O. 2009. Traceability information carriers. The technology backgrounds and consumers' perceptions of the technological solutions. **Appetite**, 53, 322-331.

Colin, E. C., Cualberto, L., Shimizu, T. 1999. Otimização do Custo de Transporte na Distribuição-Armazenagem de Açúcar. **Produção**, 9 (11), 23-30.

Cooper, D. R., Schindler, P. S. 2001. **Métodos de pesquisa em administração**. Porto Alegre: Bookman.

Daskin, M.S. 1985. Logistics: an overview of the state of the art and perspectives on future research, **Transportation Research - A**, 19A (5/6), 383-393.

Friend, J. D., Lima, R. S. 2011. Impact of transportation policies on competitiveness of Brazilian and US soybeans: from field to port. **Transportation Research Record: Journal of the Transportation Research Board**, 2238, 61-67.

Glisic, S., Lorenzo, B. 2009. **Advanced Wireless Networks**. Second edition, John Wiley & Sons Publishing Company, United Kingdom.

Jedermann, R., Behrens, C., Westphal, D., Lang, W. 2006. Applying autonomous sensor systems in logistics – combining sensor networks, RFIDs and software agents. **Sensors and Actuators A**, 132, 370-375.

Jedermann, R., Moehrke, A., Lang, W. 2010. Supervision of Banana Transport by the Intelligent Container. **In:** Kreyenschmidt, J. (ed.): Coolchain-Management, 4th International Workshop. University Bonn, Bonn, Germany, 75-84.

Jones, P. 2006. Networked RFID for use in the food chain. **In:** IEEE Conference on Emerging Technologies and Factory Automation, 1119-1124.

Jones, P., Clarke-hill, C., Shears, P., Comfort, D., Hillier, D. 2004. Radio frequency identification in the UK: opportunities and challenges**. International Journal of Retail & Distribution Management**, 32 (3), 164-171.

Juran, J. M., Godfrey, A. B. 1999, **Juran's Quality Handbook**. Fifth Edition, McGraw-Hill Publisher, USA.

Kawano, B.R., Mores, G.V., Silva, R.F., Cugnasca, C.E. 2013. The exportation of Brazilian raw sugar: an analysis of economic impacts from railway mode**. International Journal of Logistics Systems and Management (Print)**, 14, 315-328.

Kelepouris, T., Pramatari, K., Doukidis, G. 2007. RFID-enabled Traceability in the Food Supply Chain. **Industrial Management & Data Systems**, 107 (2), 183-200.

Liu, Y., Yang, J., Liu, M. 2008. Recognition of QR Code with Mobile Phones. **In:** Chinese Control and Decision Conference (CCDC), 203-206.

Machado, J. G. C. F., Nantes, J. F. D. 2004. A visão institucional do processo de rastreabilidade da carne Bovina. **In:** Congresso Luso-Brasileiro de Tecnologias de informação e comunicação na agro-pecuária, 1., Santarém, Portugal. Anais..., Santarém: Associação Portuguesa para o Desenvolvimento das Tecnologias de Informação e Comunicação na Agricultura, 1-11.

Martins, R. S., Caixeta Filho, J. V. 1999. Subsídios a tomada de decisão da escolha da modalidade para o planejamento dos transportes no estado do Paraná. **RAC**, 3 (2), 75-79.

Metzner, V., Silva, R. F., Cugnasca, C. E. 2014. Modelo de rastreabilidade de medicamentos utilizando identificação por radiofrequência, redes de sensores sem fio e o conceito de internet das coisas. **In:** XXVIII ANPET - Congresso de Pesquisa e Ensino em Transportes, 2014, Curitiba, PR. Anais do XXVIII ANPET - Congresso de Pesquisa e Ensino em Transportes, 1, 1-12.

MDIC/SECEX – Ministério do Desenvolvimento, Indústria e Comércio Exterior. 2014. **AliceWeb System**. Accessed on: 01/11/2014.

Oliveira, A.M.K. 2005 Potencial da logística ferroviária para a movimentação de açúcar para exportação no estado de São Paulo: recomendações de localização para armazéns intermodais concentradores de carga. Dissertação na área de ciências, área de concentração: economia aplicada. Piracicaba: ESALQ/USP. 166pp.

Oliveira, A. M. K., Caixeta Filho, J. V. 2007. Potencial da logística ferroviária para exportação de açúcar em São Paulo: recomendações de localização para armazéns intermodais. **Revista de Economia e Sociologia Rural**, 45 (4).

Pavlidis, T.; Swartz, J.; Wang, Y. P. 1990. Fundamentals of bar code information theory, **Computer**, 23 (4), 74-86.

Reuters Brasil. 2009. Brasil reforça testes de açúcar após contaminação com areia. http://br.reuters.com/article/domesticNews/idBRSPE5900KA20091001. Accessed on 20/10/2014.

Shanahan, C., Kernan, B., Ayalew, G., Mcdonnel, K., Butler, F., Ward, S. 2009. A framework for beef traceability from farm to slaughter using global standards: an Irish perspective. **Computers and Electronics in Agriculture**, 66, 62-69.

Silva, R. F.; Cugnasca, C. E. 2011. A tecnologia de redes de sensores sem fio e a logística. In: XVII International Conference on Industrial Engineering and Operations Management, 2011, Belo Horizonte, MG. **In:** Proceedings of XVII International Conference on Industrial Engineering and Operations Management. Belo Horizonte: ABEPRO, 1, 1-15.

Silva, R. F., Bartholomeu, D. B., Caixeta Filho, J. V. 2010. Impactos ambientais de açúcar para exportação no Brasil: quantificação das emissões de GEE evitadas pelo uso do modal ferroviário. **In:** XII ENGEMA Encontro Internacional sobre Gestão Empresarial e Meio Ambiente, 1.

Silva, R. F., Ferreira, M. M., Cugnasca, C. E. 2013. O uso de modelos computacionais de simulação para avaliar a implementação de RFID em cadeias de suprimentos. **In:** XX Simpósio de Engenharia de Produção, 2013, Bauru, SP. Anais do XX Simpósio de Engenharia de Produção. Bauru: UNESP, 1, 1-13.

Smith, G. C., Pendell, D. L., Tatum, J. D., Belk, K. E., Sofos, J. N. 2008. Post-slaughter traceability. **Meat Science**, 80, 66-74.

Thakur, M.; Hurburgh, C. R. 2009. Framework for implementing traceability system in the bulk grain supply chain. **Journal of Food Engineering**, 95, 617-626.

Timm-giel, A., Kuladinithi, K., Becker, M., Gorg, C. 2006. Wireless sensor networks in wearable and logistic application. **In:** 15th IST Mobile & Wireless Communication Summit, Greece.

USDA. United States Department of Agriculture. 2014. **Sugar: world markets and trade**. Foreign Agricultural Service.