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THE USE OF RFID SENSOR TAGS FOR PERISHABLE PRODUCTS MONITORING IN LOGISTICS OPERATIONS

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ABSTRACT

Transportation of perishable products increased in volume in the last decades and imposes new challenges to today's logistics operations. Because of the spoilage risk of the transported items, certain conditions (e.g., temperature, humidity, vibration, etc.) must be maintained during the transportation phase. Failure to maintain the required conditions may lead to product spoilage and delivery disturbances. This work considers a multi-echelon supply chain model composed of one producer and multiple customers and contrasts the performance of the logistics operations when RFID and sensing technologies are employed and when they are not. The simulation models of the two scenarios result in as much as nine different outcomes, which are presented in the form of good practice recommendations.

1 INTRODUCTION

Transportation of perishable products imposes new challenges to today's logistics systems. Generally, the quality of the items is checked at customer level without having any information about the status during transportation. Failure to monitor transportation conditions may have poor results to both producers and customers who, consequently, push for the adoption of new strategies to cope with this problem.

Jedermann et al. (2006) declare that the maritime transportation of refrigerated products reached about 57.1 million tons in 2005. In another work, Gunders (2012) mentions that 40 percent of the food in the United States, which is the equivalent to $165 billion, is wasted every year. The study also mentions that food loss in North America ranges from 20% for milk to 52% in the case of fruits and vegetables. These losses get incremented at each stage of the supply chain from production and postharvest losses to distribution and consumer losses, resulting in estimated distribution and retail losses of 9.5% for seafood and 12% for produce. Losses in distribution are attributed to inadequate transportation and handling, such as keeping produce at the improper temperature. The criticality of the perishable products transportation for both the producers (competitiveness and public image) and consumers (confidence in supply chain) imposes new challenges and requires new solutions. One of these challenges addressed in literature is the quality of the transported products. Osvald and Stirn (2008) model the logistics problem between distribution centers and retailers as a vehicle routing problem where the objective function includes the number of vehicle used, the traveled distance, and the loss of quality of transported products. When the loss of quality was considered in the objective function, the reported results show a significant average reduction of the loss of quality, which offers higher savings than incurred costs because of the increased distance traveled. A thorough review of the literature related to in-transit perishable product inspection is provided by Cheong (2011).

Advances in the RFID and sensor networks technologies equip both producers and customers with the necessary tools to better approach this problem. RFID technology consists of storing product data in a tag attached to the product for identification purposes. Data can be written or retrieved using a RFID reader that communicates with the tag via an antenna. Sensor networks consist of a set of deployed units with sensing, measuring and communication capabilities. Both technologies have many applications that include manufacturing and logistics (Mejjaouli and Babiceanu 2014). The integration of the two technologies presents many opportunities to improve the logistics of perishable products where specific required conditions have to be maintained during transportation. With the implementation of these technologies, required conditions can be monitored and recorded when products are in transit. Lee and Ozer (2007) provide a critical review of the current RFID literature and identify supply chain visibility and operational prevention as the core values that an RFID-enabled supply chain model could bring to practitioners. However, the authors argue that there is still a credibility gap related to the value of RFID, and that solid operations research methodologies are needed to fill that void.

The model proposed by Abad et al. (2009) introduces an RFID smart tag developed for tracking and monitoring of cold supply chains. The RFID system consists of a smart tag equipped with light, temperature and humidity sensors, a read/write unit and an antenna for communication purposes. The RFID system was used for an intercontinental fresh fish logistics system operation from South Africa to Europe where fish loads are transported by refrigerated trucks from processor to airport, then to the destination airport in Europe, and finally to retailers using refrigerated trucks. The RFID system modeled is able to collect temperature and humidity data during the transportation time and store them. The benefits of the system are summarized, as follows: the system is able to check whether the required temperature ranges were maintained during transportation from producer to consumer, provide traceability information to different supply chain links and ensure safety and quality control.

Wang et al. (2010) present a real-time monitoring system for perishable products during transportation and uses it to design a specific solution for a Chinese transportation company with the objective of reducing losses during transportation. The deployed temperature, humidity and vibration RFID sensors enable the company to make in-transit decisions such as changing containers or vehicles at nearest stations to cope with any emergencies. Based on technologies like RFID, GPS and GIS, the model reported by Cheung et al. (2007) proposes a framework for a vehicle management system that takes into account the dynamic changes in the data and can update the routing plans whenever new information is available. Currently, transportation companies try to take advantage of the advances in RFID technologies and offer new services to their customers. As an example, DHL is offering DHL Thermonet which is a service that enables its customers to track the transportation of drugs and life-sciences goods with the help of RFID temperature tags applied to containers. Alerts are sent to customers whenever measured temperature values go above certain thresholds (RFID Journal 2013).

Ketzenberg and Bloemhof (2009) address the value of RFID-enabled supply chain for a random lifetime perishable product, subject to stochastic demands and lost sales. Their work focuses on improving the shelf-life of the product and the value of information provided by the RFID technology. Our current work attempts to fill the gap identified in the literature, related to perishable products transportation and re-routing decision making, by introducing a generalized supply chain model that uses an RFID-based monitoring system. The model is equipped with a real-time decision making module and can be used to monitor perishable products during transportation. It is designed to cope with the consequences resulted from equipment failures or other emergencies, which change the required transportation conditions.

2 IMPLEMENTATION OF THE RFID-BASED MONITORING SYSTEM

This work considers a multi-echelon supply chain composed of one producer and multiple customers. Because of the spoilage risk of the transported items, certain required conditions (e.g., temperature, humidity, vibration, etc.) must be maintained during the transportation phase. Failure to maintain the required conditions when the items are transported downstream the supply chain may lead to items spoilage and delivery disturbances. The model considers that extra costs are not limited to the spoiled items only (i.e., items production cost, disposal cost, etc.), but they also include the following costs:

- Transportation cost of the items shipped from producer to customer.
- Penalty cost imposed by the customers for late delivery.
- Lost sales cost, which includes the profit that would have been made if the items were not spoiled when transported.

Therefore, monitoring the status of transported items is crucial to protect the producer's public image and boost customers' satisfaction. The model presented in this study attempts to investigate the benefits of implementing an RFID-based monitoring system within the multi-echelon supply chain. The proposed monitoring system consists of:

- RFID sensor tags traveling together with the shipped items for monitoring purposes. The RFID sensor tags are responsible for sensing, collecting and storing data about the monitored transportation conditions.
- RFID check points deployed along the transportation path. The RFID check points are equipped with RFID readers that retrieve the stored data and check whether the required conditions were maintained or not.
- A decision module responsible for analyzing the data retrieved by the RFID readers. The decision module is able to make operational decisions based on predefined goals.

Figure 1 presents the architecture of the proposed RFID-based monitoring system corresponding to each customer, with several RFID checking points and RFID sensor tags traveling with the individual case or pallet. The model considers three types of decisions that depend on the retrieved data. At the RFID check points, data is analyzed to determine whether a failure has occurred or not. When a failure occurred, the following time measures are to be determined:

- The failure time F_t measured when the required conditions begin to deviate from the desired levels (i.e., when the measured parameters begin to exhibit values above a certain threshold).

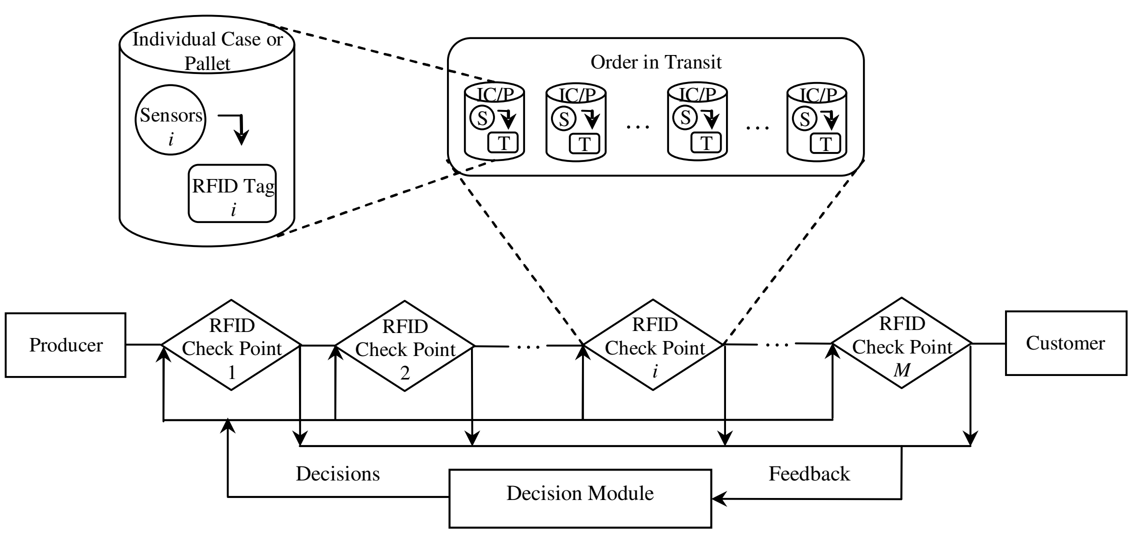

Figure 1: Architecture of the proposed logistics RFID-based monitoring system, with several RFID checking points and RFID sensor tags traveling with the individual case or pallet.

- The spoilage time S_t measured when the items become spoiled after the failure occurrence. After the measured time S_t, the items will not be accepted by the customer because of degraded quality.

Once the values of F_t and S_t are obtained, a decision is made based on the following scenarios:

- If no failure has occurred, the transportation will be continued.
- If a failure has occurred and the items can be delivered to the customer before the spoilage time, then transportation will be continued.
- If a failure has occurred and items cannot be delivered before the spoilage time, then:
  - If the items can be delivered to another customer before being spoiled, then the model re-routs the shipment to the corresponding customer.
  - If the items cannot be delivered to another customer before being spoiled, the transportation is stopped and spoiled items are disposed.

2.1 Supply Chain Model

In order to present the functionality of the proposed model and identify its potential benefits, an illustrative example is depicted in Figure 2. The example involves one producer and is limited to only two customers, whom transportation paths are equipped with a set of RFID check points. Furthermore, the number of RFID check points is equal to two for Customer C_1 and one for Customer C_2. The resulting transportations times between the different transportation network nodes are presented in Table 1.

Table 1: Calculated transportation times for the supply chain model.

	RCP_1	RCP_2	RCP_3	C_1	C_2
Producer	t_1	$t_1 + t_2$	t_4	$t_1 + t_2 + t_3$	$t_4 + t_5$
RCP_1	0	t_2	-	$t_2 + t_3$	t_6
RCP_2	-	0	-	t_3	t_7
RCP_3	-	-	0	t_8	t_5

As shown in Figure 2, if the producer is shipping items to customer C_1, then the following scenarios will be considered at the RFID check points:

- At RCP_1:
  - If items reach RCP_1 at time t_{now} and no failure has occurred, then transportation will be continued to RCP_2.
  - If items reach RCP_1 at time t_{now} and data show that a failure has occurred, then spoilage time S_t will be determined. Depending on S_t, one of the three decisions will be made:
    * If $S_t > t_{now} + t_2 + t_3$, then transportation is continued to customer C_1.
    * If $S_t < t_{now} + t_2 + t_3$ and $S_t > t_{now} + t_6$, then shipment is rerouted to customer C_2.
    * If $S_t < t_{now} + t_2 + t_3$ and $S_t < t_{now} + t_6$, then transportation is aborted and shipment is disposed.
- At RCP_2:
  - If items reach RCP_2 at time t_{now} and no failure has occurred, then transportation will be continued to customer C_1.
  - If items reach RCP_2 at time t_{now} and data show that a failure has occurred, then spoilage time S_t will be determined. Depending on S_t, three decisions can be made:
    * If $S_t > t_{now} + t_3$, then transportation is continued to customer C_1.
    * If $S_t < t_{now} + t_3$ and $S_t > t_{now} + t_7$, then shipment is rerouted to customer C_2.
    * If $S_t < t_{now} + t_3$ and $S_t < t_{now} + t_7$, then transportation is aborted and shipment is disposed.

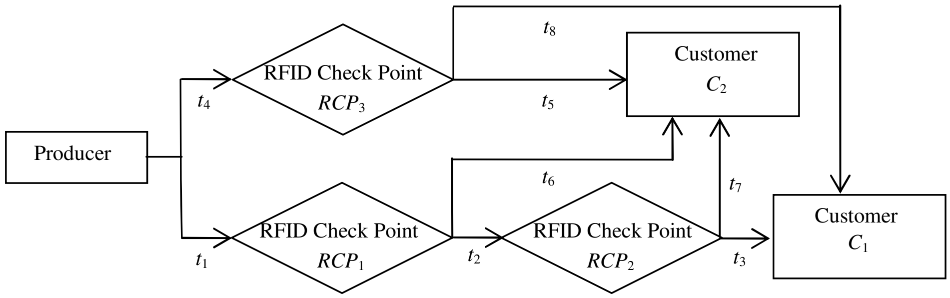

Figure 2: Supply chain model including RFID check points and potential transportation routes.

If the producer is shipping items to customer C_1, then the following scenarios will be considered at the RFID check points.

- At RCP_3:
  - If items reach RCP_3 at time t_{now} and no failure has occurred, then transportation will be continued to customer C_2.
  - If items reach RCP_3 at time t_{now} and data show that a failure has occurred, then spoilage time S_t will be determined. Depending on S_t, one of the following three decisions will be made:
    * If $S_t > t_{now} + t_5$, then transportation is continued to customer C_2.
    * If $S_t < t_{now} + t_5$ and $S_t > t_{now} + t_8$, then shipment is rerouted to customer C_1.
    * If $S_t < t_{now} + t_5$ and $S_t < t_{now} + t_8$, then transportation is aborted and shipment is disposed.

3 SUPPLY CHAIN SIMULATION MODELS

In order to conduct a cost benefit analysis of the proposed RFID-based monitoring system, two models were developed.

- A multi-echelon supply chain consisting of one producer and multiple customers which does not include the monitoring system.
- A multi-echelon supply chain consisting of one producer and multiple customers which includes the monitoring system.

A quantitative analysis including the cost, net profit and customer satisfaction was conducted to assess the transition from the first model to the second one. To conduct the quantitative analysis, the following costs are considered.

- Item production cost: a linear cost profile is considered, where c is defined as the item unit cost. If the firm is shipping d items to customer C_i, the cost of items will be cd.
- Transportation cost: a linear cost profile is considered, where r is defined as the transportation cost per time unit per item unit. If the firm is shipping d items to customer C_i and the transportation time is t, then the transportation cost will be drt.
- Lost sales cost: a linear cost profile is considered, where l is defined as the lost sales cost per item. If the firm is shipping d items to customer C_i and that shipment fails to reach the customer, then the lost sales cost will be ld. In this case, l is considered as missed profit which is the difference between the selling price and the production cost.
- Inventory cost: a linear cost profile is considered, where h is defined as the inventory cost per item. If d items are rerouted to customer C_i and that shipment is used after t units of time, then the inventory cost is htd. Because of the re-routing option, customers may receive shipments they did not order. If a customer receives a shipment which was not ordered, then that shipment will be added to customer's inventory. In this case, the producer will be responsible for the inventory

cost of the rerouted shipment. The inventory cost corresponds to the time spent in storage from the delivery date until the usage of the items to fulfill partly or fully a periodic demand.

3.1 Supply Chain Model Unequipped with the RFID-based Monitoring System

In this first model, the supply chain is not equipped with the monitoring system. The customer determines the periodic demand, checks the inventory level for demand fulfillment and places an order to the producer if demand cannot be fulfilled by the existing inventory. This order placement process, as shown in Figure 3, works the same for both models.

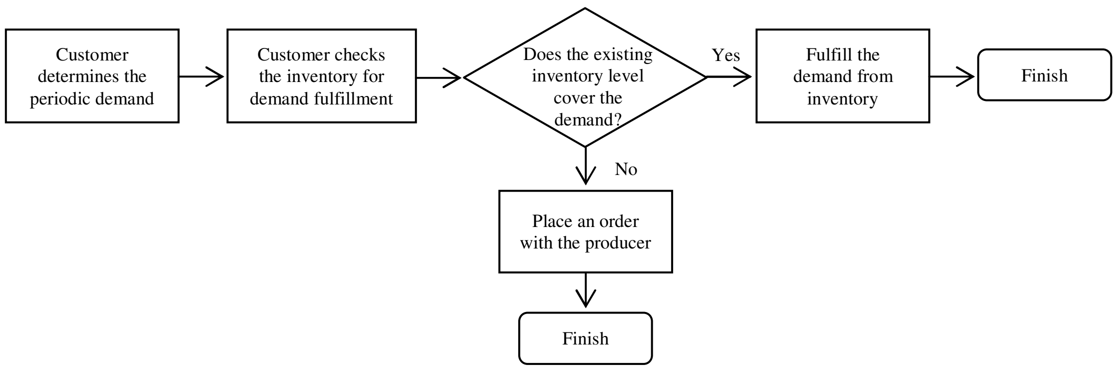

Figure 3: Supply chain models: order placement process.

After placing the order, the corresponding shipment is prepared and transportation starts. In this model, items are delivered to customers without being checked during transportation, as shown in Figure 4. At the time of delivery, the items status is checked by the customer. If a failure has occurred and items were spoiled, then the items are disposed and the customer demand is not fulfilled; otherwise, the customer demand is fulfilled. The items check process at the customer level is depicted in Figure 5.

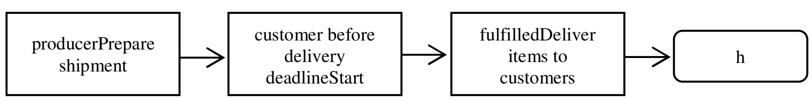

Figure 4: Supply chain model without the monitoring system: shipping process.

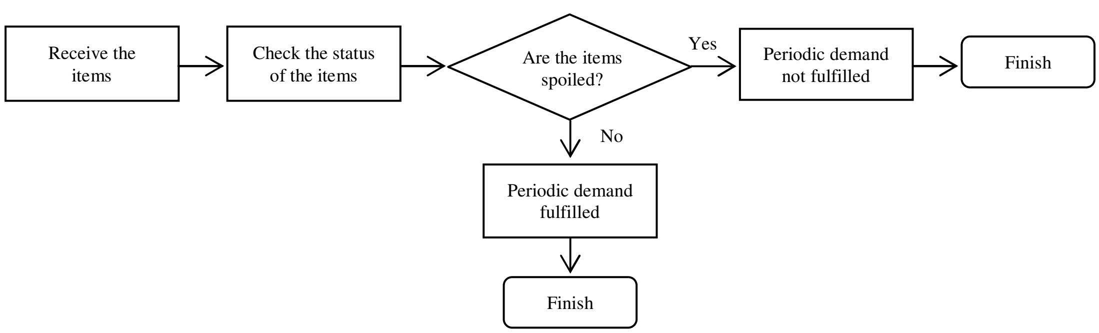

Figure 5: Supply chain model without the monitoring system: items status check process.

3.2 Supply Chain Model Equipped with the RFID-based Monitoring System

After placing the order, items are prepared and transportation starts. In this second model, the transportation path is equipped with RFID check points where the status of the transported items is checked. If no failure has occurred, then transportation continues; otherwise, the decision of whether to reroute the shipment to another customer or stop the transportation and dispose the shipment is made.

Also, the customer who ordered the shipment is alerted about the spoilage of the shipment. The shipping process and the different scenarios for this second supply chain model are shown in Figure 6.

When receiving an alert, customers wait until the delivery deadline to consider the periodic demand as not fulfilled. In the meantime, if another shipment that was intended to another customer was rerouted to the corresponding customer, then the periodic demand will be partly or fully fulfilled, as in Figure 7.

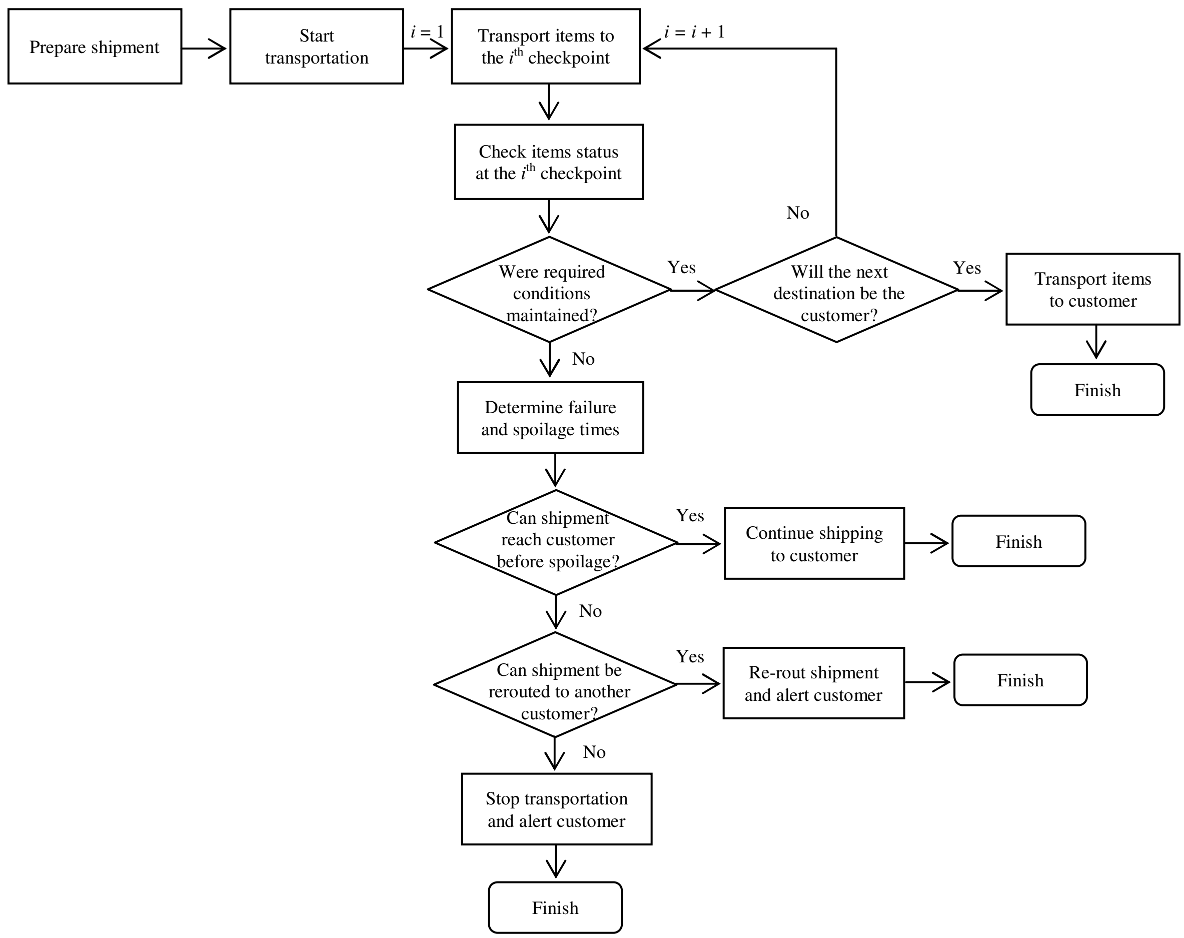

Figure 6: Supply chain model with the monitoring system: shipping process.

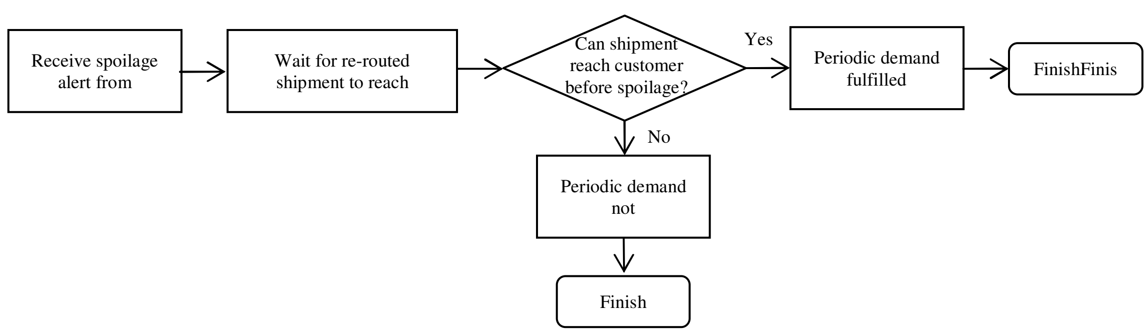

Figure 7: Supply chain model with the monitoring system: alert management process.

4 SIMULATION RESULTS

For the two simulation models, the example introduced in Section 2 consisting of one producer and two customers is considered. The objective of the simulation is to gain insight on the operation of the proposed model that will help to better evaluate the added value of the proposed system to the entire supply chain composed of the producer and the set of customers. The following assumptions are made:

- Only one product type is considered.
- Customer C_1 transportation path is equipped with two RFID check points.
- Customer C_2 transportation path is equipped with only one RFID check point.
- Re-routing is possible from any RFID check point to any customer.
- Disposal cost is ignored.
- Shipments to both customers C_1 and C_2 are in same quantities.
- Each shipment corresponds to 10,000 items.
- Transportation cost per hour per item is the same for both customers ($0.002).
- Inventory cost per hour per item is the same for both customer locations ($0.001).
- Failure incidents follow a uniform distribution U[0,200].
- Spoilage time is equal to 8 hours.
- Production cost is equal to $2 and selling price is equal to $3.

In what follows, Model 1 refers to the supply chain simulation model equipped with the RFID-based monitoring system, while Model 2 refers to supply chain simulation model unequipped with the RFID-based monitoring system. All transportation times selected for the two simulation models are depicted in Table 2, and the reported results are based on 1000 runs using the Arena® simulation environment.

Table 2: Calculated transportation times for the supply chain model.

	RCP_1	RCP_2	RCP_3	C_1	C_2
Producer	24 hrs.	48 hrs.	24 hrs.	72 hrs.	48 hrs.
RCP_1	0	24 hrs.	-	24 hrs.	30 hrs.
RCP_2	-	0	-	12 hrs.	2 hrs.
RCP_3	-	-	0	50 hrs.	24 hrs.

4.1 Result 1: RFID Monitoring System Increases the Number of Fulfilled Demands

Customers with shipments that were spoiled during transportation will benefit from the re-routing option. The customers that receive the rerouted shipments before the delivery deadline will be able to fulfill their periodic demand which increases the number of fulfilled demands. For example, the producer was able to increase the average number of fulfilled demands for customer C_2 from 40.52 to 41.14 because of the rerouted shipments from customer C_1 (Figure 8). However, customer C_1 kept the same level of fulfilled demands (35.31) because no shipment (intended to C_2) witnessed a failure and could reach customer C_1 before being spoiled. For both customers, running the 1000 simulation replications of both models provided the results with half-widths no larger than 0.23, which makes the difference between the average number of fulfilled demands for customer C_2, while small in actual magnitude, still significant from the statistical point of view.

4.2 Result 2: RFID Monitoring System Results in Extra-Costs for Holding Rerouted Shipments in Inventory Until Used by the Corresponding Customer

When rerouted, shipments will be kept in customer inventory until used to fulfill customer periodic demand. Since the rerouted shipment will serve to fulfill the next periodic demand or replace a spoiled shipment, an extra cost pertaining to hold the shipment in inventory is incurred. For the first simulation model, rerouted shipments to customer C_2 resulted in a cost of \$2070.78. No shipments were rerouted to customer C_1, which did not incur any inventory costs (Figure 9).

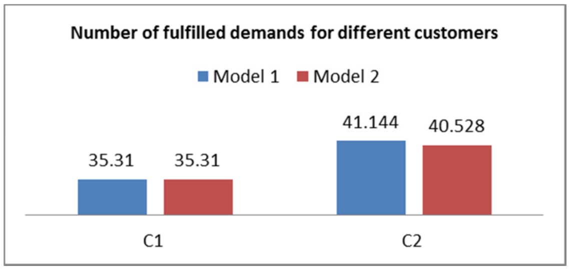

Figure 8: Fulfilled demands for different customers.

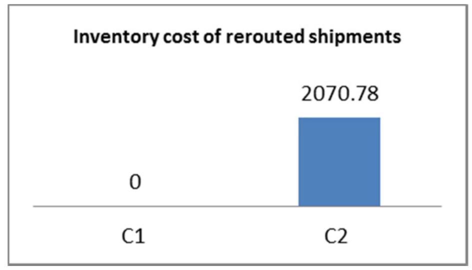

Figure 9: Inventory cost of rerouted shipments.

4.3 Result 3: RFID Monitoring System Results in Cost Savings for Items in Rerouted Shipments

Instead of being spoiled and disposed, the re-routing option will save the shipments that experienced a failure which results in cost savings corresponding to the items cost. For the first simulation model, savings pertaining to rerouted shipments to customer C_2 are equal to \$31,300 (Figure 10).

4.4 Result 4: RFID Monitoring System Decreases the Lost Sales Cost

Because of the rerouted shipments, more demands were fulfilled which decreased the lost sales cost. The lost sales cost pertaining to customer C_2 decreased from \$114,720 to \$108,560. However, the lost sales cost pertaining to customer C_1 did not change because no shipments were rerouted (Figure 11).

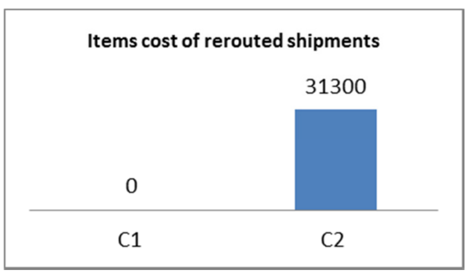

Figure 10: Cost of rerouted shipments.

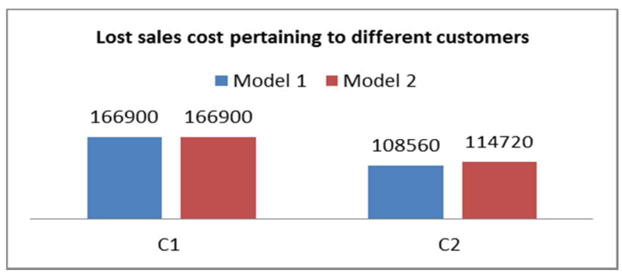

Figure 11: Customers' lost sales cost.

4.5 Result 5: RFID Monitoring System Decreases the Spoiled Items Cost

The shipments that experienced failures and have been discovered at RFID check points during transportation were rerouted which decreased the spoiled items cost. For the first simulation model, customer's C_1 shipments that witnessed a failure and could reach customer C_2, were rerouted which reduced the spoiled items cost pertaining to C_1 from \$333,800 to \$302,500, amount equal to items cost of rerouted shipments to C_2. Also, the spoiled items cost pertaining to customer C_1 decreased because some demands were fulfilled from inventory which decreased the risk of losing those shipments during transportation (Figure 12).

4.6 Result 6: RFID Monitoring System Decreases the Transportation Cost

In the second simulation model, all shipments spoiled during transportation were discovered at the customer level. However, shipments can be discovered at RFID check points in the first simulation model where transportation can be stopped, which results in transportation cost savings. Also, some periodic demands will be fulfilled from inventory which results in more transportation cost savings (Figure 13).

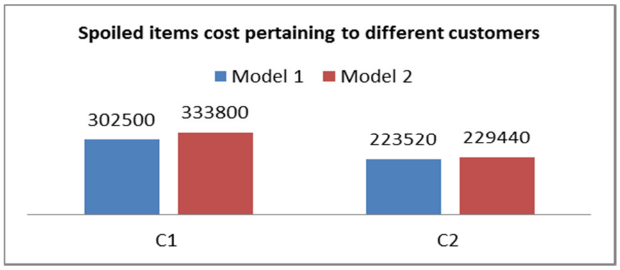

Figure 12: Cost of spoiled items.

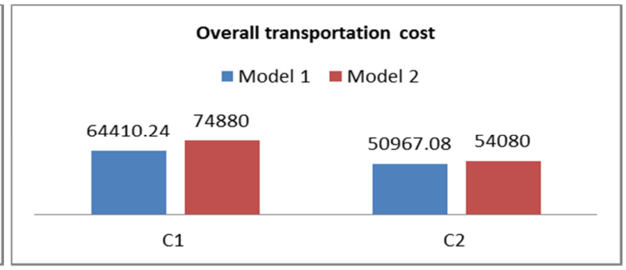

Figure 13: Overall transportation cost.

4.7 Result 7: RFID Monitoring System Decreases Overall Cost and Increases Customer Satisfaction

In light of results 1-6 above, the overall cost defined as the sum of items cost, transportation cost, inventory cost and lost sales cost will be decreased. For the simulation example, the overall cost decreased by 1.68% (Figure 14). Also, customer satisfaction level defined as the ratio between the fulfilled demands and number of orders placed was improved. For instance, for customer C_2 the satisfaction level was improved by more than 1% (Figure 15).

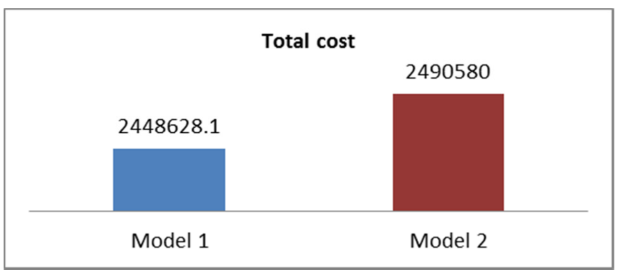

Figure 14: Total transportation cost.

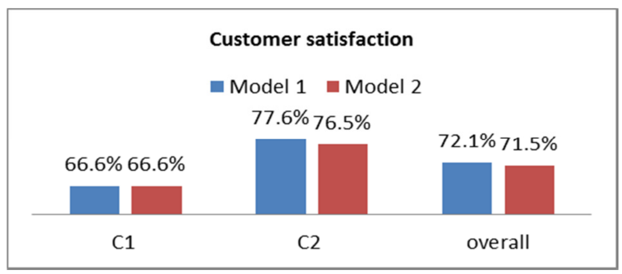

Figure 15: Customer satisfaction levels.

4.8 Result 8: RFID Monitoring System Has More Value When the Failure Probability is Higher

The models also investigated the effect of failure probability on RFID monitoring system value by changing the failure probability and record its effect on the total cost decrease and customer satisfaction increase. The results show that the RFID monitoring system has more value when the failure probability gets higher. In fact, as the failure probability increases, the spoilage risk gets higher which results in more spoiled shipments and less fulfilled demands. Therefore, total cost reduction and customer satisfaction increase will be higher when the RFID monitoring system is implemented. From the results below, we can see that total cost decrease changed from 1.68% to 2.29% and 3.34% for failure probabilities corresponding to U[0, 200], U[0, 140], and U[0, 80], respectively (Figure 16). Also, the customers' satisfaction increase changed from 0.81% to 1.86% and 9.01% for failure probabilities equal to U[0, 200], U[0, 140], and U[0, 80], respectively (Figure 17).

4.9 Result 9: RFID Monitoring System Has More Value When the Spoilage Time is Higher

The models also investigated the effect of failure probability on RFID monitoring system value by changing the spoilage time and record its effect on the total cost decrease and customer satisfaction increase. The results obtained show that the RFID monitoring system has more value when the spoilage time gets higher. In fact, as the spoilage time increases, more shipments can be saved and rerouted to nearer customers. In our case, some of the shipments that could not be rerouted to customer C_2 will be now rerouted and delivered before being spoiled which will result in less spoiled shipments and more fulfilled demands. Therefore, the total cost decrease and customer satisfaction increase will be higher when the RFID monitoring system is implemented. From the results below, we can see that total cost decrease changed from about 0.5% to about 3% when the spoilage time changed from one hour to 14 hours (Fig. 18). Also, the customers' satisfaction increase changed from 0% to 1.3% when the spoilage time changed from one hour to 14 hours (Fig. 19). Actually, the customers satisfaction level did not increase when spoilage time is fixed at one hour because no shipment can be rerouted from the RFID check points due to transportation time that is greater than the spoilage time.

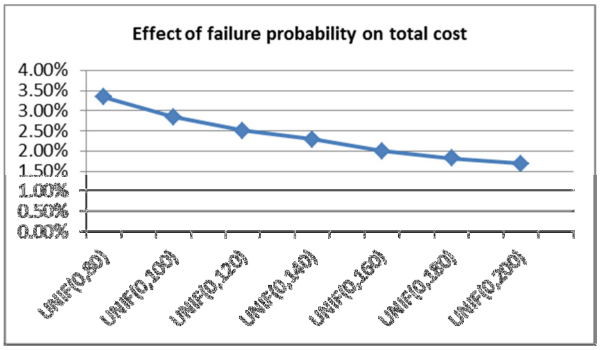

Figure 16: Failure probability and total cost.

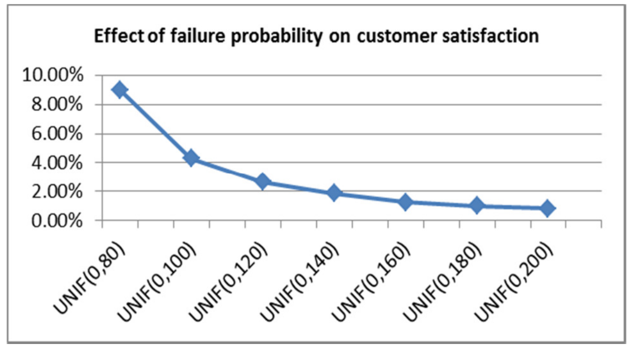

Figure 17: Failure probability and customer satisfaction.

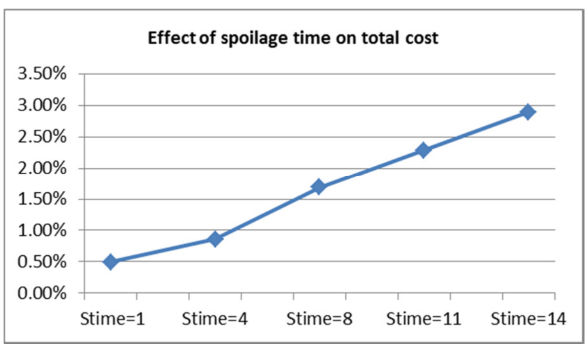

Figure 18: Spoilage time and total cost.

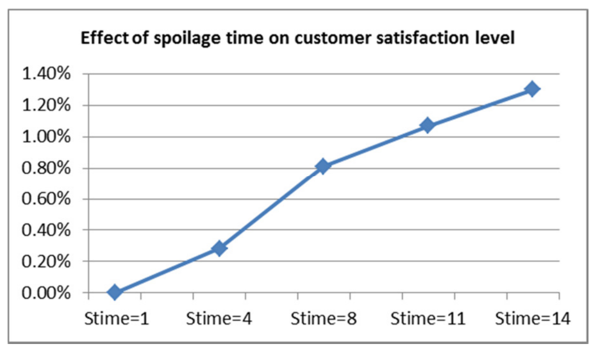

Figure 19: Spoilage time on customer satisfaction.

5 CONCLUSIONS AND FUTURE WORK

This work investigates the benefit of implementing an RFID-based monitoring system in the transportation operations of perishable products. The results of running the simulation models with a set of predefined decisions executed by the decision module, show the benefits of the supply chain model equipped with RFID check points and sensor tags. The main contribution of this work is directly related to the transportation operations by providing solutions for rerouting or interrupting the shipment of perishable products based on real time data received from the RFID tags. Overall, the proposed method can help reduce the costs associated with the shipment of perishable products that are accumulated due to issues during the transportation. While the results provided by the two simulation models show only a small improvement for the performance measures under study in this work (number of fulfilled demand, lost sales cost, spoiled item cost, overall transportation cost, and others), this behavior can be attributed to the small scale of the model considered. From this point of view, the models developed in this paper, work as a proof of concept. It is expected that larger models will provide a sizeable improvement when the RFID-based monitoring system is considered.

Future work will include the extension of the proposed model with a larger number of customers with the objective of identifying the optimal number of RFID check points and their location. A more sophisticated decision module where decisions at RFID check points are made using a set of algorithms and predefined objectives (i.e. minimize the total cost, increase customer satisfaction, etc.) will be explored. Also, a cost benefit analysis of implementation of the proposed system will be conducted, with the total cost of implementation and the savings resulted from it functioning as main cost contributors.

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