Shelf Replenishment with RFID-ERP-Kanban System: A case study in large distribution

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Abstract: Although the current development of supply chain (SC) management techniques had a rapid progress with new technologies, inconsistency between production data and customer demand may still plague SC managers. The present study investigate how RFID systems can be combined with lean production concepts, through a Kanban-driven production system connected with an Enterprise Resource Planning (ERP) system. Efficiency measures regarding the implementation of such system are developed within 3 aspects: i) accuracy of production and real time information with visibility; ii) effectiveness of operational processes in shelf replenishment and production confirmation; iii) reduction of manual operations. Within the case study, the possible RFID solutions for the improvement of replenishment operations between backroom warehouse and shop floor are investigated. Key Performance Indicators are defined for each tier of the SC. Their values are assessed and addressed to the potential benefits of joining the RFID systems within a lean production context.

Keywords: SC; RFID; Kanban; Shelf Replenishment

1. Introduction

Albeit the recent advances in information management and progress of SC, there may be still inconsistencies among information and effective customer demand. In order to maximize customer satisfaction, optimal alignment strategies are developed based on new information technologies, such as RFID, among supply chain stages (Sana, 2013). In general, certain SCs may be affected by inaccurate information such as inaccurate inventory levels and big amount of stock keeping units (Sana, 2011; Lee and Ozer, 2007; Raman et al., 2001; Savino et al., 2014). In addition, mismatch information between physical flow and information flow may lead to the missing of over the 3% of stocks (Rekik, 2011). As well known, RFID technology is an automatic inspection and real time data capturing technology obtained by tags, middle ware and RFID readers (Ngaiet al., 2008). Moreover, it is often used for shelf replenishment optimization (Szmerekovsky et al. 2011). The main concept is to monitor inventory and replenishment stock levels through real time data communication. Thus, RFID deployment may provide an advanced way to get accurate and convenient information for backroom monitoring (BM) in real time. There are a number of reasons for use RFID in BM, the main two are i) Backroom has more inventory storage capacity which means more profits compared to shop floor buffer inventory; ii) Backroom inventory need to be improved for keeping higher service and guarantee enough sales space and shelf space for more reliable capability of products .

During products replenishment in supply chain, inefficient and erroneous operations often become direct reason of profits decline and efficiency reduced. Because of these problems, a combined RFID-ERP-Kanban system is studied in this paper for the efficient management of replenishment operations.

The structure of this paper is as follows. Section 2 presents a review of RFID researches in manufacturing logistic, while section 3 provides structures of deployment model include the replenishment policies. Section 4 offers the discussions, based on the case study results. Section 5 concludes this study and suggests of future research directions.

2. Literature Review

Currently, RFID applications in SC have increased for inventory management, component or asset tracking, product identification & location, transportation and environmental monitoring of logistics industry, retailer, health care program, in addition to automotive manufacturing (Provotorov A. Et al., 2015; Mark et al., 2016; Martin et al., 2017).

RFID can contribute in SC management with information visibility through powerful tool of advanced identification and real-time communication properties. It mainly aims for process accuracy and automation, stock information visibility, loss prevention (Elisa et al., 2015). Particularly, through programming code of each tag and easy scanning, RFID realizes operations with higher accuracy and speed which leads to products with better trace-ability and visibility in SC (Zhou et al., 2009). RFID may also contribute in reducing stock-outs by compressing lead time and distribution costs (Rekik, 2011; Li. et al. 2006), and efficiency of current supply chains (Lee et al., 2011).
Through combination of operating part with unique code, RFID enables industrial products to be informative at all

manufacturing stages and steps. Thereby, the accuracy and operation speed are improved with manufacturing trace-ability and processes visibility (James et al., 2013; Juan et al., 2012; Savino et al., 2015).

Inventory inaccuracy is one of the main problems of certain SCs. The relationship between inaccurate inventory and retail performance in the supply chain not only affects the demand, but it also reduces sales levels and overall profits (Fleisch & Tellkamp,2004). Inventory levels and material information may be not accurate due to lower process quality and products lost by theft. Thus, material inventory and information need to be adjusted and update in real time. Some literature findings (Dalvi and Gangurde, 2012) show that the actual inventory and information systems need to be aligned at the end of each sale-cycle to eliminate inventory inaccuracies, which may increase supply chain costs and insufficient inventory. These authors show nine alternative methods that can be used to collect data from the shop floor to the ERP system to adjust the accuracy of the data on time.

Misappropriation, dislocation and non-sellable items may lead to inventory inaccuracies, thus reducing the SC performances. Regarding the impact of RFID technology, especially under economic perspective, Sarac et al. (2008) conducted a return on investment analysis and evaluation. These authors investigated also the impact of different RFID technologies for different products to provide a different level of labels. Their results show that different technologies can improve the performance of different proportions of supply chain. As a result, the return on investment for RFID applications is highly dependent on the device application strategy.

The core idea of this study is to investigate the economic impact of shelf replenishment based on RFID inventory control strategy, and combined with RFID hardware used to detect the store between the background and sales layer. Consistent with the study of Elisa et al. (2015), who gave detailed statistics of RFID projects, the contribution of this paper is mainly about inventory accuracy and shrinkage reduction. In the replenishment with BM and hardware testing, Condea et al. (2012) did not consider that the main inaccurate information comes from the product location mismatch caused by manual errors, not just the inaccuracy due to product thefts. Furthermore, regular evaluations in case studies are in contrast with the traditional policies programs with stochastic demand, sales losses and shrinkage.

3. Methodology

The study is conducted in three main steps. First, the RFID implementation framework is built to eliminate manual inventory checks and realizing automated replenishment. Here, RFID-ERP-Kanban is used to detect the movements between the warehouse and the shop floor, rather than directly observing the inventory at item level on the shelves. Then, considering the economic and rationality of RFID applications, we searched also how to optimize RFID reading rates, costs and stock-out impacts. The third step consist in comparing the management of traditional regular manual checks with the implementation of RFID management strategies. The case study aims to quantify the complimentary strategies for RFID, thus resulting in possible valuable conclusions.

3.1 RFID implementation framework

With respect to traditional replenishment process, in the RFID case the manufacturing supervisor cannot carry out a manual inventory operation with periodic review (PR) policy, when a low inventory is detected at the sales level. In contrast, with RFID, the readers are installed between the backdoor and the shop floor of the supermarket, where products equipped with RFID tags can be detected by two-way movement between these two tiers. RFID is characterized by higher quality inventory information in terms of accuracy and timeliness, but it may result in new cost factors such as the hardware cost of the RFID transponder. In addition, RFID values as optimizing the control parameters of RFID can impact the system economic.

In order to investigate the role of RFID in retailing stage of fashion and apparel, relations of retailing and shop floor management are highlighted by Elisa et al.(2015). Chatfield et al. (2004), simulate a raw material warehouse consisting of a real unrestricted rear chamber and a workshop with a limited number of shelves space. The model assumed that the store is operated with a fixed number of items. Any excess case that arrives at the sales floor during the replenishment process will be returned to the backroom. The customer demand is assumed to be the Poisson process model of the rate □ per day (Chatfield et al., 2004). The confirmation point (POC) is recorded the inventory level is updated.

The model also considers that the contraction of the items leaving the system (for example, due to theft) is not detected on the POC, which can be seen as an invisible demand. The degree of shrinkage □ is expressed as part of the aggregate demand (Condea et al., 2012). In the period T, we observe Key Performance Indicators (KPI) as : (i) the total cost of the store manager (ii) the product service level.

3.2 Shelf Replenishment Process

With manual periodic review policy, transhipment receipts (TR) should be provided to the backstage shop whenever material is required. When the customer receives the product, the item is loaded into the tray for delivery, there will be a delay time of dC to the POC. Then, the item is recorded in the ERP and delivered.

Mostly, the owner uses POC data to monitor and track inventory, but this activity cannot determine the exact number of items on the shelf. Thus, for each r time, the worker manually checks the shelf level behind the shop. In the supermarket, the shelves have the maximum capacity of Sz. Whenever the shelf stock level is less than or equal to a threshold, the replenishment should be triggered to the owner. But the actual replenishment will take place after the delay dR because more time is needed to pick, transport and load the product from the backstage to the shop. The quantity of each replenishment is considered to be a multiple of the number of *u* items added to the shelf.

Calculation of the total cost of the retailer's replenishment operations, including shelf allocation cost *ca*, review cost *ci*, replenishment cost *cr*, and penalty cost *cp*, for which lost sales happen when a customer face an empty shelf for that particular product. The output parameters in the replenishment period T include the customer arrival quantity *nc*, the number of sale units *ns*, the detection number *ni*, the shelf replenishment amount *nr*, the products mismatch which causing non-sellable *nd* and the number of products damaged or theft during sales process, *nf*. The total cost of periodic review Tc_{PR} is calculated[1] as (1).

$$Tc_{PR} = c_i n_i + c_r n_r + c_d n_d + c_a S \cdot T + c_p (n_c - n_f - n_s - n_d) \quad (1)$$

Service level □ is modified as the ratio of actual demand to customer arrival quantity, excluding shrinkage caused by lost products and/or mismatches.

$$\beta = \frac{n_s}{n_c - n_f - n_d} \quad (2)$$

3.3 Backroom Monitoring

RFID readers are equipped in the transport channel between backroom and shop floor. Hence, when shipping tray is transported from the back room to the shop floor, the product information (item information, the batch size of the *u*) is recorded to the inventory records by ERP system. After each sale of POC, the record of inventory quantity will be reduced. Furthermore, inventory management system can provide the actual inventory information such as: inventory level $I_{P,t}$ at time t. The record value in the list is only basis for the replenishment operation. But the RFID running cost depends on the RFID read rate. The parameter **ψ** is used to compare the replenishment with read rate. **ψ** ∈ [0,1] is the probability that the RFID reader detects the product. As *t* and *t'* are time between the RFID readers points and the time before the materials are delivered into the shop floor, the inventory update I_R,t□ = I_R,t+u. If there is no material or product detected, IR remains of the same value.

As a result, the manufacturing director needed more data sources to identify empty containers that were removed from the shelves during the supplement period. If it is found that the detected information does not match with the recording, the recorded shelf stock information is corrected accordingly. For example, the detection empty box processing unit is equipped with another RFID reader. If there is no change of situation detected by the RFID reader between the backroom and shelf after the supplement, the recorded shelf stock is increased by u. When the replenishment operation is triggered, the back room takes time *dO* until the box reaches the RFID gate. Another *dS* to pass that arriving at the shelf. Thus total time added is : *dO*+*dS*=*dR*. Then, extra products returns to the back room with a delay *dB*. Empty box which sent to the garbage is with delay of *dT*. Customer moves from the shelves to the POC with a delay equal to *dC*. The entire replenishment model is shown in Fig. 1.

During the monitoring operations, there is another accurate information of replenishment freezes caused by poor read rate of RFID. If the resulting error reaches the point of I_R>s, while I_P=0. The trigger of the replenishment will occur and inventory will not be further reduced. Meanwhile, the inventory status is out of stock.

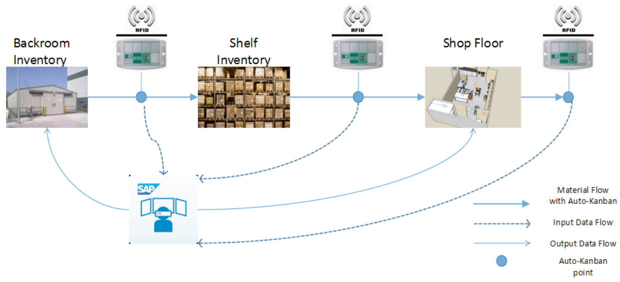

Figure 1. RFID-ERP-Kanban enabled replenishment with backroom monitoring

Unavoidable inventory information errors are due to product damage and thefts. In addition, an error occurs when products are detected in the POC. Finally, the recording system makes correction of the error and reset the inventory value as the information system inventory. In this study, new cost factors such as RFID transponder cost *ct* and inventory adjustment cost *cm* have been considered into total replenishment cost. *ym* considers the adjustments of the inventory triggered by the aforementioned strategy. The total cost BM is given by (3).

$$Tc_{BM} = c_r n_r + c_a S \cdot T + c_p (n_c - n_f - n_s) + c_m (n_m + n_d) + \frac{c_t (n_f + n_s)}{u} \quad (3)$$

4. Results and Analysis

In comparison with traditional operation flow with Kanban cards, this RFID-ERP-Kanban consists of three RFID readers connected to the ERP system with a centralized server. Backroom store is located behind shop floor, which includes supermarket shelf for inventory buffer and storage spaces. First, case study is conducted with a base case corresponding to daily consumers (machines in shop floor) demand of □=560 boxes (560x50=28000), a product that can be regarded as neither a typical fast-moving nor slow-moving good. It is assumed an in-store logistics cost of *ci=2.50* € for review, *cr=2.50* € for replenishment, and *cm=1.25* € for adjustment. In this scenario, the backroom space can hold 56 shelves and replenishment with a half in 28 days. The shelf allocation cost is reckoned at ca= 10.00 € per shelf which can take 1000 items with 20 cases per day ; penalty cost for each lost sale of cp= 1.80€. Furthermore, based on our observations of actual processes in a retail store, delays between events assumed *dO*=*dS*=15 min (i.e., *dR*=30 min), *dC*=15 min, *dB*=15 min, and *dT*=15 min. The case size is u=50 items. We consider a store that is open 24 hours per day and simulate over a horizon of T=28 days per run.

[1] Notations are given in Appendix.

Each setting of the control parameters was simulated with different replications to validate the simulation. The shrinkage rate is assumed to be □ =1.4% (400 damaged or theft) of the total demand.

4.1 Replenishment with Periodic Reviews

Hence, by using the above actual values from a manufacturing firm, and by considering ci=2.50€, ni=48, cr =2.50€, nr=512, ,ca=10.00€, Sz=56, T=28, cp=1.80€, u=50, for periodic review scenario, the sample calculation for total cost Tc_{PR} with (1) is given as follows:

Tc_{PR} = (2.50 x 48) + (2.50 x 512) + (10.00 x 56 x 28) + 1.80 x (28000- 400-25600)= 20680 €.

The service level of supply chain is, by equation (2), □ = 95.5%. By taking horizon T = 28 days, s = 28. The case study results under periodic review including performance metrics are given in table 1.

Table 1: Numerical results under Periodic Review

S_z	n_c	n_s	n_r	n_i	n_f	n_d	Total cost	β
56	28000	25600	512	48	400	800	20680	.955

It is seen that the shelf space is S_z = 56 which can take 56000 items. Replenishment of n_c that take a half with 28000. The sale with traditional replenishment way that is with 25600, and the service level □ is near 95-96%. In addition, product availability is only related to replenishment process not considered costs of organizational cost and technical cost.

For the RFID-enabled processes, the case study resulted in the same parameter settings for *s* and *Sz* and for the entire possible range of read rates 0.1 ≤ **ψ** ≤1 (step size 0.1), as previously. Beyond that, for each read rate, optimization has done on the adjustment threshold □. Values which are too small or too big for □ both cause sub-optimal behavior. With small values of □, adjustments are triggered more often than needed, whereas with a large □, the occurrence of out-of-stocks is unnecessarily prolonged. The range on which □ depended on the respective policy.

Total cost under the BM policy reaches its minimum within the simulated threshold domain for intermediary read rates. Because supply chain costs closely linked to values of replenishment threshold □, total cost and Read rate (Condea et al. 2012). The choice of □ for extremely low and high (perfect) read rates will be further explained following a discussion of the study results. Table 2 shows these numerical results.

As shown in table 2, sale number can increase from 25.600 € to 26.600 € with reader rate increasing. Total cost of replenishment increase when RFID read rate with lower rate. It has been observed that the replenishment efficiency drops dramatically even for slightly worsening read rates. If **ψ** (read rate) decreases, all policies show a tendency to (i) allocate more shelf space and (ii) increase the number of replenishment. This is a direct consequence of the fact that the probability of the recorded inventory IR dropping and then staying below 's' is greater with low read rates. Then, the inventory management system begins triggering many more replenishment than are actually necessary to eliminate apparent stock-out situations. The resulting growth in total cost is substantial. However, the erroneously numerous replenishment triggered to counter the hypothetical stock-outs guarantee a high service level. Consequently, □ is higher for low read rates, which initially seems counter-intuitive. This issue may also explain the choice of □ for low read rates. In such a case, policies perform best with a high □, which allows them to save, at least, on adjustment costs. For high (perfect) read rates, the optimal threshold again tends to be higher because, as a matter of principle, it is not possible to encounter replenishment freezes due to detection rate inaccuracies. Shrinkage remains the sole reason why □ is still needed in this case. Fig. 2 shows the influence of **ψ** on minimal cost for all RFID-enabled policies.

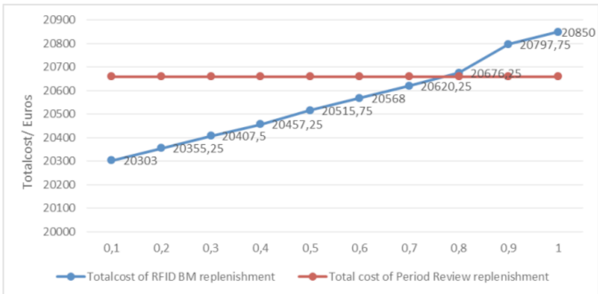

Figure 2. Total cost of replenishment considering reading rate

Using the PR policy, the execution of replenishment and confirmation was unobserved to both shop supervisor and store manager. In contrast, the RFID infrastructure allows replenishment to be identified by detecting items in transit from the store to the shop floor. The results indicate the importance of utilizing RFID data not only for estimating inventory levels but also for monitoring in-store logistics processes. As previously mentioned, the deployment of RFID technology in logistics is motivated not only by cost considerations but also by reductions in stock-outs.

Table 2: Numerical Results for RFID-ERP-KANBAN Enabled backroom Monitoring

ψ	n_c	n_s	n_r	n_f	n_d	Total cost	β
.1	28000	26600	532	400	800	20303.00	0.9925
.2	28000	26500	530	400	800	20355.25	0.9888
.3	28000	26400	528	400	800	20407.50	0.9850
.4	28000	26250	525	400	800	20457.25	0.9794
.5	28000	26150	523	400	800	20515.75	0.9757
.6	28000	26050	521	400	800	20568.00	0.9720
.7	28000	25950	519	400	800	20620.25	0.9682
.8	28000	25800	516	400	800	20676.25	0.9626
.9	28000	25700	514	400	800	20797.75	0.9589
1	28000	25600	512	400	800	20850.00	0.9552

5. Discussion and Conclusions

The aim of this study is to analyze the characteristics of Rfid-Erp-Kanban based shelf replenishment policies in raw material store and to compare them with the traditional procedure of periodic reviews. The conclusions on the benefits of the technology are also relevant to practitioners planning to implement RFID systems in ERP-Kanban environment. First, it is proven that the RFID-enabled redesign of in-store processes holds the potential to increase process efficiency in terms of total cost and service levels, depending on data quality. Other influential factors requiring special consideration include the costs of production lost, demand rate, shelf allocation cost, and case size.

Second, it is found that the possibility of utilizing RFID as a mean of monitoring in-store logistics processes has fundamental consequences on the performance of the replenishment policies. As it is observed, the value of RFID-based estimates of shelf inventories using pure backroom monitoring is severely influenced by imperfect read rates, which makes this policy acceptable only under optimal reader performance. In contrast, RFID-based policies employing an heuristic to eliminate unnecessary replenishment are considerably less sensitive to reader performance. This result is also in line with the one of Condea et al. (2012). From these data we may also argue that the maximum benefits of RFID can be only achieved if the supervisor in manufacturing shop is able to make parallel decisions on optimal shelf space allocation and to implement replenishment processes that are not performed periodically but are flexibly adapted to customer demand by the inventory management system.

As last consideration, it is come to know that RFID does not allow for full automation of the replenishment process in the presence of shrinkage, e.g. in case of theft or missing of parts. As pointed out, the presence of shrinkage leads to inventory inaccuracies that cannot be detected by RFID alone. Consequently, the store supervisor does not avoid to adjust the recorded inventory to the physical inventory manually from time to time. The result is also concentrated on stock-outs; it did not consider consumer reactions to different shelf inventory levels. For example, supermarkets often hold more inventories on the shelves than apparently necessary, in the hope that product visibility will drive demand. Some apparel retailers, in contrast, try to achieve similar results by keeping on low level the availability of a specific item. These ones and other psychological factors are beyond the scope of the current paper (Condea et al. 2012). Although we can see the potential in implementing RFID project in manufacturing industry, but other influential factors also need to be taken care before application of project in manufacturing shop. As also proven by Lin (2009), these influential factors such as readability, adaptability by the people (willingness of SC members), strong leadership from the management, infrastructure availability, readability, system compatibility in the current supply chain, system integration are playing vital role in execution and sustainability of RFID project. Although the validation of the simulation has been made as regards to the control parameter, the system may be made more robust with a validation the data of the simulated calculation with the measured results coming from the RFID application to the specific case study.

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Appendix

Notation overview

Notation	Description
r	Review interval
s	Replenishment threshold
S_z	Shelf space
τ	Inventory adjustment time threshold
c_i	Cost of the manual inspection/review of shelf levels
c_r	Cost of shelf replenishment
c_a	Costs of shelf space allocation (per item)
c_p	Penalty costs of lost of production (per item)
c_t	Cost of RFID transponders
c_m	Cost of the inventory adjustment
d_R	Delay until shelf replenishment
d_B	Delay until excess inventory is returned to backroom
d_C	Delay until customer arrives at POC (back-flush of product)
d_T	Delay until the box is trashed into the box crusher
d_O	Delay until arrical at the RFID reader
d_S	Delay until arrival at the shelf
i_P	Physical inventory level
i_R	Recorded inventory level
n_c	Number of customer arrivals (actual demand of the product)
n_s	Number of sold units
n_r	Number of shelf replenishments
n_i	Number of manual shelf level inspections
n_m	Number of manual inventory adjustments
n_f	Number of stolen items
T	Horizon
λ	Demand rate
ψ	Read rate of RFID hardware
γ	Shrinkage rate
u	Number of units per case
Tc_{PR}	Total cost function under the PR policy
Tc_{BM}	Total cost function under the RFID-enabled policy

β	Service level