Printing House Paper Reel Management: An RFID Enabled Information Rich Approach

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Abstract

In recent years the print industry has been facing constant and increasing competition from the double onslaught of the Internet and the proliferation of television channels. In order to survive as a viable industry, print enterprises must streamline and exploit up-to-date economizing measures. A key cost element in the print industry is paper, representing between 20% and 30% of total printing expenditures. Thus, any improvement in the operational efficiency of paper reel management has the potential of yielding considerable cost savings. It is in this context that we analyze the effect of enhancing the available paper reel supply chain information through the use of semi passive Radio Frequency IDentification (RFID) technology. Focusing on the printing house, we develop both simulation models and formulas that forecast savings from having better information. Thereafter we implemented the system and compared the forecasts to actual savings. Using standard economic evaluation techniques we unequivocally show the economic imperative of introducing semi passive RFID technology. Even though this study was carried out in a specific printing house, we argue that its implications are far wider, affecting other industries.

Keywords: Supply chain management, Information rich, RFID, Value of information, Inventory management

1   Introduction

In recent years the print advertisement industry has been facing constant and increasing competition from the double onslaught of the Internet and the proliferation of television channels. This competition has forced printing companies to become more operationally efficient, and likewise, is driving them to relentlessly improve their systems so as to preserve company profits. A key cost element in the print industry is paper, representing between 20% and 30% of total printing expenditures [17]. Even though worldwide demand for paper has diminished, the shutdown of production lines has pushed the price upward. The net result is that today there is a worldwide over-demand. To illustrate this point, consider that the 2003 price for one ton of paper was $400 and in 2006 it was $650. The price at the beginning of 2008 was $700 per ton. Labor, another key cost element is labor in general, and labor associated with paper management in particular accounts for 30-40% of total cost [10]. The results of our analysis indicate that by changing the state-of-the art in the printing house significant savings are possible and the implementation of our suggested improvements proved that these savings are attainable.

Paper is supplied to printing houses on reels (paper wound around a central core). These reels are typically 0.8 – 2.5 meters high, 1.0 – 1.5 meters wide and weigh 0.5 – 2.5 tons. In addition to size differences, reels differ in both the quality and color of the paper they hold. Finally, due to the fact that the paper deteriorates with time, reels should be used on a first in first out (FIFO) bases. The paper reel supply chain that we consider begins with ordering the paper (categorized by type, size, and supplier), which signals the first of many transfers for each reel. Briefly, once ordered, reels are transported from the paper mills (usually via an international shipper), received at the company's warehouse, placed in storage, moved to an intermediate storage facility, conveyed to the different production floors, used on various machines, and finally, the spent reels are sold. These processes are reviewed in more detail in the following sections.

Today reels are usually tracked using standard barcodes—a labor-intensive task. This method is expensive, not 100% accurate and due to its intrinsic imperfect implementation does not provide all the needed information. In addition, whereas it may not seem to be the case to the uninitiated, paper reels are delicate especially when considering their weight. A simple bump equivalent to that of a hammer blow can result in the need to discard a few centimeters from the diameter of the reel. As a result of using manual labor and forklifts, paper reels are often damaged when their barcodes need to be accessed and read.

The problems with the barcode based system are well known and summarized in [10], [17]. These reports motivated our current work. In our current paper we compare the actual cost associated with the barcode system with an alternative developed by us. Our alternative is based on the development of an information rich system, i.e. a system that has more and better information available. When making the comparison we include only the direct costs (e.g. readers and tags) of the new system. Other hidden costs are not included in the analysis. Our results as presented in this paper show a potential savings of about $30,000 per year for the representative printing house that we studied. Given the fierce competition in this market these cost savings are very significant and result in a return on investment (ROI) of 75% with a payback period (PBP) of about two years.

In this paper we look at Radio Frequency IDentification (RFID) technology as one way to streamline and cut the costs of paper reel management. Using this technology, items are uniquely identified by means of a tag that broadcasts radio signals to designated receivers posted up to tens of meters away. This information is further shared with the company information system via internet connections. In this way the paper reels join the Internet of Things (IoT). This technology accomplishes more than barcode technology and thus, in many opinions, eliminates the need for barcodes and their scanning. The RFID tag readily identifies an item to the receivers and thus physically reading a barcode placed on the item is considered unnecessary.

Previous researchers tried to develop models for paper stock management [12], as well as investigate RFID technology's suitability for this purpose and for print workflow [22]; however, comprehensive studies in the area of paper reel supply chains are virtually non-existent. Section 2 reviews the few that can be found. . Our paper includes detailed investigation of the effect of using RFID technology for paper reels in the printing house by using semi passive tags that enable high accuracy of reading.

Though the complete paper reel supply chain includes many players—paper mill, transportation providers, printing house, and paper reel salvagers, as noted above—we only examine the printing house. This is a conservative restriction since the savings due to the RFID enabled information over the whole supply chain can only be greater than the savings at the printing house. Likewise, we restrict our investigation and do not include the reduction of the total inventory level that is possible as a result of the additional information provided by RFID technology. We develop simulation models and formulas that forecast the savings from having better information available in the printing house. Thereafter we implemented the system and compared the forecasts to actual savings in the printing house. Using standard economic evaluation techniques (e.g., Net Present Value (NPV) and ROI), we unequivocally demonstrate the economic viability of our proposed approach.

Printing House Paper Reel Management: An RFID Enabled Information Rich
Approach

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As already stated, our study concentrates on the printing house. We used the *Yedioth* printing house to verify that our methodology can be implemented on a real supply chain. We use *Yedioth* as a lab like environment where we implemented and tested the model developed in this research. In Section 5 we explain that this medium sized printing house located in Israel did not have fully automated paper reel transportation systems, but did have a barcode based system operated by manual labor. It is in this system that we implemented a RFID based system. Furthermore, we report the results of the implementation. We believe that our study is widely applicable and the Yedioth implementation verifies the applicability of our methodology. Unlike traditional case study based research, the focus of this study is on model development and not on analysis of a specific situation (a snapshot). Moreover, printing house paper reel supply chains have characteristics that are quite common to other industries and other characteristics that are unique to it alone. When we analyze the financial aspects we will argue that the majority of the cost savings come from the common characteristics and thus this study is relevant for other industries as well.

The rest of the paper is organized as follows. In Section 2 we review the relevant literature. In Section 3 we describe, in detail, the current barcode based system used in the printing house and our proposed information rich system. In Section 3 we discuss the various cost savings available from the proposed information rich system. In Section 4 we describe our simulation models of both the present and the proposed information rich system. We also describe our simulation experiments, analyze the results, and perform economic analyses to demonstrate the profitability of the proposed information rich system. In Section 5 we compare our predictions to the actual savings in the printing house, and finally, we present our conclusions in Section 6.

2   Literature Review

Before detailing our contribution we first consider the work of others in this field. Our literature review comprises three parts. In the first part we consider the state-of-the-art research in the area of supply chain management of paper reels. In the second part we consider research addressing RFID technology in supply chains. We note that RFID technology is currently the way many organizations achieve an information rich system. However, most research we review (as well as our research) is equally valid if the information richness is achieved in another way. In the third part of our literature review we look at the intersection of the first and second parts, i.e., research in the print industry that has examined the use of RFID technology. Our research falls in this last area, providing insight into the value of information for the management of paper reels in the printing house.

2.1   Supply Chain and Inventory Management in the Paper Reel Industry

The print industry is a traditional industry that has been facing increasingly stiff competition. In response, some researchers have sought to improve the paper reel supply chain as a way of obtaining a competitive advantage.

[12] presented a solution for storing and handling paper reels in printing house storerooms. Their solution is based on a genetic algorithm for the paper reel warehouse layout design. The contribution of the work is a comprehensive algorithm for storing paper reels in the printing house.

[27] investigated a production optimization problem in a paper-converting mill. They investigated the question of how to produce a set of different paper reels from a single, big row reel and then transport and store these reels in the paper mill.

The IFRA (INCA-FIEJ Research Association) group (an international publishing organization with more than 3000 members) carried out one of the most important practical works in the field of paper reel management [10]. This work was the first to cover the full paper reel supply chain. It included the basic rules for the use of barcodes, for handling and moving paper reels from the paper mill to the printing house and then to the printing area. It also considered how to handle spent reels. It is worthwhile noting that many (if not most) printing houses and paper suppliers around the world adopted IFRA's proposed method.

A comprehensive discussion on Supply chain planning models in the pulp and paper industry is presented in [6]. They describe the different components in the supply chain and the relationships between these components. Other authors focused on specific aspects of the supply chain. For example [4] presented Integer Programming models for supply chain optimization in the pulp mill industry. [20] developed models for supply chain optimization in the paper industry and [16] examined international factors in the design of supply chains in this industry. [11] focused on the development of scheduling solutions for this industry. An integrated approach aiming at maximizing value creation in the industry was also investigated [26]. In addition [2] presents a case study of implementing RFID in a printing house.

2.2   RFID Technology and Implementation in Supply Chains

RFID technology has generated an enormous amount of interest among supply chain researchers and the ways it can be used to improve current practices. It enables inventory to be tracked more accurately, thereby reducing labor costs and streamlining the complete supply chain from supplier to end-user. Through simulation [15] quantitatively

explored the impact of RFID on generic manufacturer–retailer supply chains. By analyzing the dynamic and stochastic behaviors of supply chains that are affected by RFID deployment, they showed that inventory levels can be decreased by 23-26% in a manufacturer retailer environment. In another work, [14] summarized previous research on the effect RFID might have on each part of the supply chain. Then they examined labor costs, service improvement (for the supplier), inventory accuracy, and inventory levels to qualitatively study how RFID would affect a generic supply chain. [28] looked at item level RFID visibility in a manufacturing environment. The model the benefit of RFID visibility as reduced randomness in the system.

[1] presented models to estimate the value of additional information regarding discrepancies between the inventory record and physical stock. They analyzed three different sources of inconsistencies: shrinkage, misplacement and transactions error. They considered a single-item periodic review inventory control problem in which inventory records are inaccurate. Their models showed how different error sources lead to inventory discrepancies. [1] quantified the value of inventory visibility and the value of improvement that can be achieved by deploying RFID technology.

[5], [7], and [9] all investigate coordination in the presence of RFID technology. They looked at how to share the costs and the benefits of RFID in general and how to coordinate the supply chain in the presence of RFID in particular.

2.3 RFID in the Print Industry

In 2006 IFRA studied the option of using RFID technology in the print industry [17]. The report examined all the print industry processes in which RFID can be implemented, including paper reel conveyance and storage, plate making, ink tank handling, mail room activities and final product (e.g., newspaper) distribution. Each process was examined to see if RFID deployment was possible and, if so, how it should be done. The report's examination of the paper reel supply chain was very general, i.e., it did not attempt to examine the particulars of each part of the chain. However, it was the first work that studied implementation of RFID technology in the print industry and provided a good general overview.

Several popular articles on the application of RFID technology in the Paper Reel Industry have been published including an article regarding this work at Yedioth [3]. Other reports include the Mondi report on Using RFID to Track Paper Rolls [23] and early pilots at International Paper [24]. For a review of more recent RFID applications including many from various industries see [21] and the references therein. In particular see [18], [19], and [25].

Based on the above review of the application of RFID technology in the supply chains of companies in this industry to improve their processes and thus achieve better utility is not new. Our approach, to use simulation and to define cost formulas in each of the stages identified for the paper reel supply chain for the printing industry and finally its implementation in a real case study constitutes an original and innovative contribution. We show that it is possible to take from the theory of these ubiquitous technologies and of emerging e-commerce towards their proper application in industry with very good results.

3 Current and Future Operational Systems

In this section we present descriptions both for the current barcode system (Section 3.1) and the proposed information rich system (Section 3.2). Both descriptions are given to detail what is occurring or what will occur in a printing house. In particular, no optimization is included; the systems are judged solely by how much information and insight they afford regarding the value of the information rich system. We discuss the differences between the two systems and the resulting monetary consequences in Section 3.3.

3.1 Current Barcode Based System and Associated Problems

The state-of-art in today's paper reel management (as employed at Yedioth) uses traditional barcodes and their associated optical readers. Currently, paper reel suppliers place a barcode label that meets IFRA standards [10] on both the outermost part of the paper reel and on the outermost layer of the wrapping that is placed on the paper reel. The barcode contains all the relevant details about this reel (i.e., manufacturer, factory, machine, weight, length, paper type, and paper whiteness). The barcode is read at every station along the supply chain, as long as it remains on the reel, and the organization's computer system is updated accordingly.

The paper reel passes through many stations along the supply chain. We begin with focusing on the paper reel as it is unloaded at the printing house. At this point an employee checks each reel's quality, reads its barcode, and updates the stock level. The paper reel is then moved by forklift to the main storage area where it is stored until needed. However, due to the bulkiness of paper reels and the storage method (deep stacks), a paper reel may have to be moved or shifted before going to the next station in the supply chain. This is especially true if the printing house is looking for a misplaced paper reel.

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When a specific paper reel is needed, its location is identified by the information system. If the information system is accurate, then the reel is quickly located and its identity is confirmed by reading its barcode. If the information system is inaccurate, then a search is conducted for the *lost* reel until it is *found*, during which many reels may be moved. Once located, a forklift moves the reel to what is called the daily storage area. Here the reel is unwrapped and left to acclimatize (with respect to temperature and humidity) for at least twenty-four hours. When the reel is needed for printing, its barcode is read again and a forklift moves the reel to the printing press. Here the reel is documented and the printing operation begins. Since the barcode is only on the wrapping around the paper reel and on the outermost part of the paper reel, the reel's identity is often lost at this stage of the chain. Thereafter one of three scenarios takes place:

1. *Final Depletion*: If the printing operation depletes the reel as much as possible, it is taken to be weighed, and then it and the unusable paper remaining on it are sold for scrap. Due to mechanical limitations the paper on the reel is never used or depleted completely.

2. *Partial Depletion*: If the printing job is completed before the reel is depleted, it is taken off the printing press and in most cases, is left in the printing area until it is needed again.

3. *Paper break*: During the printing operation the paper can tear and result in what is called a *paper break*. Paper breaks are generally the result of a human error, a technical problem in the printing press, or (of most concern to us) defects in the paper reel. This situation is expensive for the printing house since it means that the printing operation must be stopped and valuable time lost. Note that the printing operation is not stopped when going from a spent reel to a new one. It is only stopped for a paper break or when the printing operation is completed. After a paper break occurs the paper must be rewebbed through the printing press and only printing resumes. If the paper break is due to a defect in the paper reel, compensation is available from the paper supplier; however, the reel must be fully identifiable.

The present state of affairs, i.e., the use of barcodes to track paper reels, has a number of drawbacks. These drawbacks were identified and investigated jointly by us and the management of the *Yedioth* printing house. These drawbacks are:

- *Cost of labor*: Significant amounts of human resources are invested in reading barcodes, i.e., manually taking a barcode reader, finding and reading the barcode on the reel. In addition, to be able to uniquely identity a paper reel after the printing process begins (i.e., after the last barcode is removed), a paper record must be maintained. A log is kept by manually filling in status forms at each and every subsequent stage.

- *Information loss*: As mentioned above, once the printing process begins the reel can no longer be identified by its barcode. If perfect records are not kept, then the reel's identity is lost. This loss of identity presents a problem when a defect that is assignable to the paper manufacturer is discovered, especially if it causes a paper break. When a manufacturing defect is found and the identity of the reel is known, then a reimbursement claim can be submitted to the manufacturer for both the defective material and other losses. Moreover, the supplier quality can be analyzed with an eye on influencing future purchases.

- *Defects and flaws*: As mentioned above, despite their size, paper reels are delicate. In fact, defects or flaws can be created in the paper anytime they are handled. With the current barcode based system the exact location of each reel is not always known with certainty and thus there can be extensive handling of reels with a forklift. For instance, it is not uncommon that a reel is moved for printing, only to discover that it is the wrong reel, which must then be returned. Alternatively, a certain reel may be sought, but its storage location is unknown. In such an event, reels must be moved with a forklift to *find* the desired reel. All this handling has its cost in the quality of the paper that eventually makes its way to the printing press.

- *Inaccurate inventory monitoring*: Since barcodes are read manually, human error will occur and thus it happens that a reel enters and/or is retrieved from storage without being registered. Additionally, reels that are only partially consumed do not appear on inventory lists. The combined result is that inventory records do not always accurately reflect what is in the paper warehouse.

3.2   The Proposed Information Rich System

In order to improve the printing house paper reel supply chain in general and to address the problems with the current barcode based system in particular, we propose to implement an information rich system through the deployment of semi passive RFID tags on the paper reel cores. In general, there are three types of RFID tags:

1. *Passive tags*: These tags do not broadcast data but can reflect back a unique identifying signal with information after being activated by a radio wave sent by a transmitter. Since passive tags do not have their own power supply they have an essentially infinite lifespan and are inexpensive. However, and for the very same reason, their signal is very weak, generally limited to a range of tens of meters.

2. *Active tags*: These tags have their own battery and are thus capable of broadcasting information. However, since they generally broadcast on a continuous basis their lifespan is limited. Due to battery cost and limited capacity these tags are both expensive and have a limited lifetime. The main advantage offered by these tags is their range, which can extend beyond one hundred meters.

3. *Semi passive tags*: This is the newest type of RFID tag and can be thought of as a hybrid of passive and active tags. These tags use a printed battery-assisted chip. The RFID remains dormant (using negligible battery power) until activated by a radio signal. At this point the RFID uses the printed battery to broadcast a signal that has a range between the passive and active tags. These tags are both cheaper and have a longer lifespan than active tags.

In brief, semi passive RFID tags will be placed on the reel core by the paper manufacturer before the paper is wound onto the core. In this way the reel can be tracked at every stage of the printing house paper reel supply chain and the tag will never be separated from the reel. Moreover, this means the paper's position can be identified anywhere there is a monitoring point, dispensing with the need to physically approach the paper reels.

The system employs two antennae: one for transmitting a request for data and the second for receiving the data from the tag. The signal of the semi passive tags is strong enough to transmit information through the paper reel radius (0.5–0.7 meters) plus an additional four meters of open space. This is enough signal strength to enable the use of forklift gates and the mapping of a warehouse by placing readers at regular intervals throughout the warehouse. In addition, semi passive tags are much less expensive than their active counterparts. Each tag can store all the information presently contained in the barcodes as well as any additional information that is needed. This information can be placed on the tag at any time. In other words, it can be updated to include information about the paper reel that becomes available after the paper is wrapped around the core. We chose not to use passive RFID tags since the signal reflected by the passive tag is not strong enough to transit though the paper reel radius [8].

The printing house's information system can collect data from all the monitoring points at any time. A rough schematic of the information flow is shown in Figure 1.
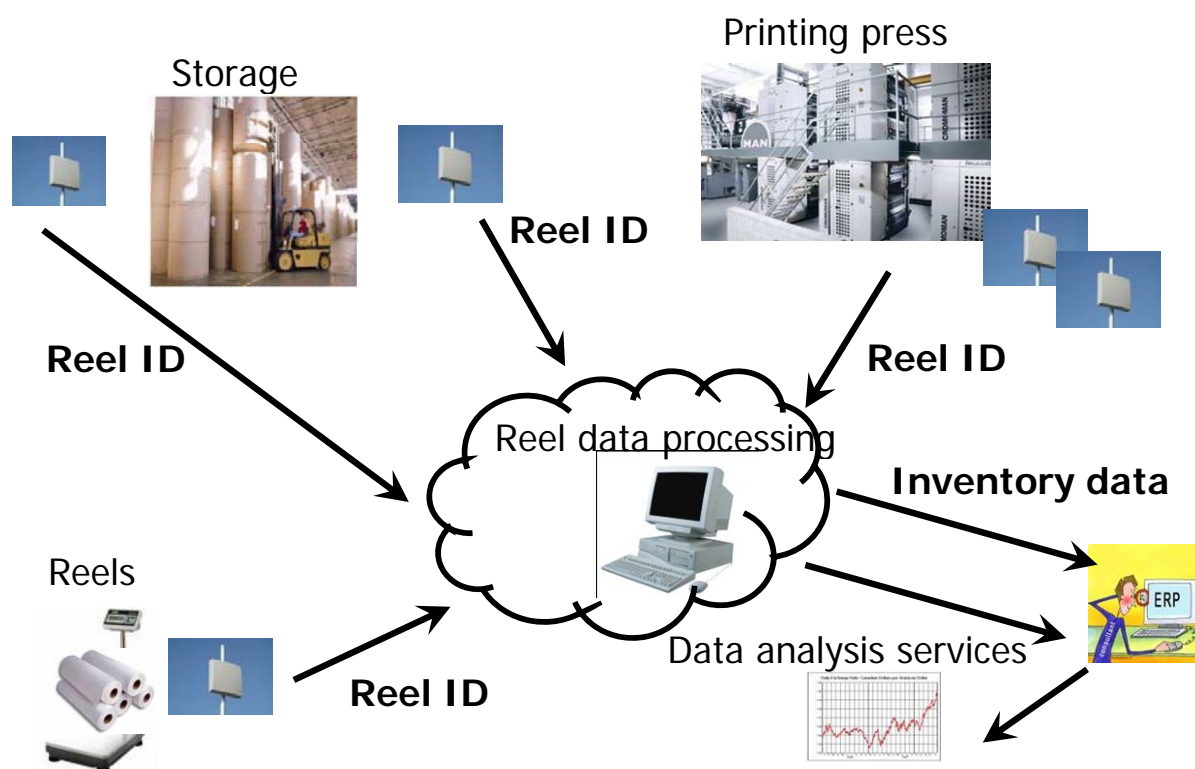
Figure 1: Information flow in the proposed system

In figure 2 we show the layout structure of the printing house in very general terms. There are a total of four readers: at the entrance to the paper reel storage area, in the transfer from paper reel storage area to daily storage area, in the transfer from the daily storage area to the printing area and at the exit from the printing house. Note that the paper is vertically stacked in the paper reel storage area and is horizontally stored in the daily storage area.

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Figure 2: Printing house layout

3.3 The Paper Reel Management Cost Components and How the Proposed Information Rich System Affects Them

We now analyze each stage in the paper reel printing house paper reel supply chain within the printing house in order to investigate the effect on the costs of using our proposed information rich system compared to the current barcode based system. For each cost component we first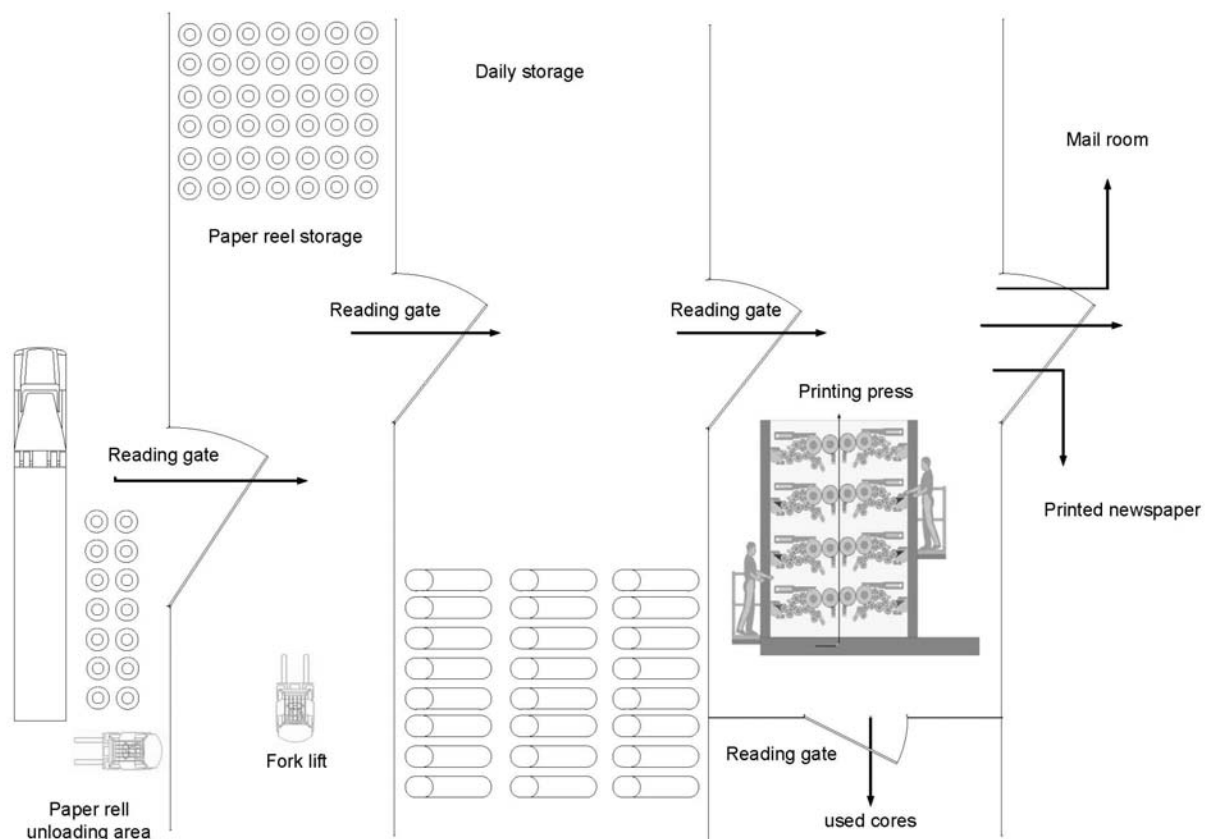 give an expositional analysis of how our proposed information rich system affects it and then, where appropriate, we quantify the savings with a formula. The notation that is common to the various cost components is:

N – number of reel types

n – index indicating the type of reel being considered $n = 1, \ldots, N$

R_n – number of reels of type n processed per unit time

1. *Ordering*: When employing a reorder point ordering policy, as is the practice in the Yedioth system, an order is placed when the stock drops below a specified level. Ordering can be done either manually or automatically using the printing house's information system. With the proposed information rich system, stock levels can be checked in real-time and can include stock in the production process. Whereas automated ordering can take place with the current barcode based system, such a system will not include reels whose barcodes have been removed, i.e., reels that are in the production process or that have been only partially consumed. The system has no way of knowing how much and which type of paper is on these reels. Due to the conservative nature of inventory management, with the current barcode based system the inventory in these areas is assumed to be zero, thereby essentially skewing the inventory and ordering systems. The average on-hand inventory is increased by the average inventory after the barcode is removed. However, if semi passive RFID tags are used, the printing house saves money because the on-hand inventory is reduced. We illustrate the savings formally by letting L_n. represent the average inventory

(reels) of type n to which the ordering system has no access i.e., knowledge of, at an arbitrary point in time and letting h_n be the holding cost of a reel of type n per unit time, the cost savings per unit time is $h_n L_n$.

2. *Unloading*: The current barcode based system and our proposed information rich system for this stage are equally efficient.

3. *Registration and quality control*: Obviously, quality inspection of arriving reels also continues in the proposed information rich system. However, since the identity of the reel is known automatically, the RFID technology reduces the time needed and thus costs will be reduced. Letting c_n^1 be the reduction in registration and quality control costs for a single reel of type n, we obtain a total savings per unit time of

$$\sum_{n=1}^{N} R_n c_n^1.$$

4. *Moving the reel to its storage location*: This operation also exists in the proposed information rich system. Nonetheless, since the proposed information rich system automatically identifies the location of the reel (as opposed to trying to find the reel based on the records of the current barcode based system), reels will no longer be misplaced. See the next point *Cost of handling stock* for a discussion of the cost implications.

5. *Cost of handling stock*: In the proposed information rich system stock is handled in the same way as in the current barcode based system, i.e. by forklifts. However, the quality and accuracy of the information provided by the proposed information rich system will reduce handling time. For example, in the proposed information rich system reels will not go missing; should a reel be placed in the wrong location, the system immediately and correctly identifies its actual location and online records reflect this. Possibly more importantly, and for the same reason, reels will be handled less. Recall that each time a reel is handled, it may be damaged. Letting c_n^2 be the average direct reduction in handling cost of a single reel of type n and c_n^3 be the average saving in damage costs per reel of type n, we obtain a total savings per unit time in the cost of handling stock of $\sum_{n=1}^{N} R_n c_n^2 + \sum_{n=1}^{N} R_n c_n^3$.

6. *Moving to daily storage*: There is no difference between the current barcode based system and the proposed information rich system for this stage.

7. *Cost of acclimatization*: In order to absorb humidity, each reel needs to remain in the daily storage area for at least twenty-four hours. Under the current barcode based system operators never know precisely the exact number of reels in the daily storage area and how long they have been there. Consequently, they may transfer a reel for printing before it is fully acclimatized. This contributes to the incidence of paper breaks and their associated costs, including production halts. These stoppages are expensive (time, human resources, rewebbing, etc.). Implementation of the proposed information rich system with its associated inventory visibility would reduce the occurrences of such events. Letting c_n^4 be the reduction in the percentage of reels adversely affected multiplied by the cost of a paper break for reel type n, the total cost reduction per unit time due to proper acclimatization becomes $\sum_{n=1}^{N} R_n c_n^4$.

8. *Moving to production floor*: There is no difference between the current barcode based system and the proposed information rich system for this stage.

9. *Updating the inventory information system*: The current barcode based system requires an employee to update the inventory system manually. The proposed information rich system automatically updates the stock levels as the paper reels move through the printing house. Letting c_n^4 be the reduction in the cost of manually updating the information system per reel of type n, we obtain a total savings per unit time of

$$\sum_{n=1}^{N} R_n c_n^5.$$

10. *Cost of weighing*: The current barcode based system necessitates the weighing of spent reels that are sold for scrap. The proposed information rich system will provide—without weighing—all the information needed about the spent reels, thereby saving all costs related to weighing. Letting c_n^5 be the cost of weighing a reel of type n, we obtain a total savings per unit time of $\sum_{n=1}^{N} R_n c_n^6$.

11. *Keeping records of the spent reels sold*: This cost will also be eliminated in the proposed information rich system. The identity of each spent reel sold and removed from the plant will be recorded automatically, i.e. without employee action. Letting c_n^7 be the cost of record keeping of a reel of type n, we obtain a total savings per unit time of $\sum_{n=1}^{N} R_n c_n^7$.

12. *Cost of handling complaints to the supplier*: At times during the printing process a defect is found in a paper reel (in approximately two percent of reels). The printing house should document, clearly identify and uniquely link each defect to the associated reel. Well documented complaints, filed with the supplier, result in adequate compensation. In the current barcode based system considerable activity is required to document each defect and identify the associated reel. Moreover, if a reel has entered the printing process, this means its barcode has been discarded, and so it may be impossible to uniquely identify it. Consequently, the printing house cannot file a complaint. This is especially true of reels that are partly used, removed from the printing press, and then reloaded onto the press. The proposed information rich system will enable the immediate identification of the reel at any stage of the printing process and thereby allow the preparation of well documented complaints. Letting c_n^8 be the average additional compensation available per reel due to the proposed information rich system, we obtain a total savings per unit time of $\sum_{n=1}^{N} R_n c_n^8$.

Putting these various savings together we obtain an average savings per unit time as a result of implementing the proposed information rich system of:

$$h_n L_n + \sum_{n=1}^{N} \sum_{i=1}^{8} R_n c_n^i \qquad (1)$$

Evaluating the various parameters used in the above equation is a non-trivial task. For example, c_n^4, which is defined as *the reduction in the percentage of reels adversely affected multiplied by the cost of a paper break for reel type n*, cannot be readily estimated. A paper break not only has its associated direct costs, but it also starts a chain reaction of events including a delay in completing the printing operation, a delay in withdrawing paper reels from the daily storage area, a delay in moving reels to the daily storage area, an increased chance of a paper break due to the reel not spending enough time in the daily storage area. Thus in order to evaluate the benefit of the proposed information rich system, we built a simulation model of both the current barcode system and the proposed information rich system.

4 Simulation Study to Demonstrate and Verify the Advantages of the Proposed Information Rich System

In this section we will describe our simulation study that demonstrates and verifies the advantages of the proposed rich system. We do this by building a simulation model, running it with various parameters settings and finally by analyzing the results.

4.1 The Simulation Models

In this section we describe the simulation models that we developed to investigate the stochastic nature of the printing house paper reel supply chain, i.e. the paper reel process inside the printing house, in general and the benefits of our proposed information rich system in particular. In line with our discussion above, we consider only the printing house and thus we focus on all operations from the ordering of new reels to the selling of spent reels. The simulation models were developed using ARENA software.

In our model of the printing house paper reel supply chain all activities (e.g., forklift time) were assumed to be stochastic in nature. Moreover, the results of actions (e.g., damage due to movement and paper breaks during printing) were also stochastic. We obtained the parameters used as input for the simulation of the current barcode based system from measurements done in the Yedioth newspaper printing house (see Table 1). The simulation included nine different paper reels. The demand for these reels was independent and deterministic. The characteristics of the reels differed with respect to the demand (50 – 500 tons per month), the probability of a paper break (1% – 3%). The replenishment method used was fixed order quantity when the inventory reached a fixed reorder point.

The relevant output from the simulations (both of the current barcode based system and the proposed information rich system) are:

- Paper damage (tons)

- Forklift hours

- Person hours

- Average stock level (tons)

- Number of paper breaks with an assignable cause

- Number of paper breaks for which we cannot uniquely identify the paper reel

Table 1: The results of our observation at the Yedioth printing house

Action	Average (seconds)	Standard Deviation
Unload	42.4	8. 5
Record stock level	14.5	4.5
Transfer to storage	30.0	6.3
Transfer to daily storage	56.9	5.3
Detract from storage	14.5	4.5
Detract from daily storage	14.5	4.5
Transfer to printing	85.1	12.7
Preparation	398.1	15.5
Record paper information	40.1	1.9

4.1.1 The Current Barcode Based System

We begin by describing the simulation model that reflects the current barcode based system. The simulation model includes four modules: inventory management, order management, demand management, and production management. We describe each one in turn.

1. *Inventory Management*: The Inventory Management module initializes the system inventory at the beginning of the simulation and updates the inventory quantities when orders arrive. This module represents part of the system's logic and does not represent any real world physical activities.

2. *Order Management*: The Order Management module is responsible for initiating orders based on the system's physical inventory information. The ordering policy is based on the EOQ (Economic Order Quantity) model with lead times. That is, the module compares the current information on the stock level to the minimum stock level (reorder point) that is predetermined for each product. If the level is below the reorder point, an order is placed for a predetermined EOQ based order quantity.

   This module also contains the functions of receiving orders and represents the physical functions of performing quality control checks and transferring the reels to the warehouse.

3. *Demand Management*: The Demand Management module is responsible for creating the daily paper reel demand. Accordingly, it also represents the physical moving of the reels from the warehouse to the daily storage area. The logical operation of reducing the known stock level is also performed by the module when the reel is removed from the daily storage area. This logical operation is performed when the reel is removed from the daily storage area (and not when the paper is consumed) since the identity of the reel is lost after this point.

4. *Production Management*: The Production Management module is the largest of the four simulation modules and includes all the processes through which the reel goes once it reaches the production floor. The module includes both the logical functions and the representation of the physical functions associated with the production operations including: moving reels from the daily storage area to the print press, documentation at the print press, removing spent reels from the printing press, weighing and disposing of spent reels, removing partially spent reels from the printing press, moving partially spent reels from the printing press back to the daily storage area, finding and handling defects in the paper reel, and paper breaks and their associated recording and compensation procedures.

The flow of the simulation conceptually starts with the Order Management module. As the physical inventory is depleted the system the Order Management module replenishes inventory so that printing demands can be met. When a replenishment order arrives the receiving functions are handled by the Order Management module as well. The update of the printing house inventory is handled by the Inventory Management module. Paper reels remain

untouched until the Demand Management module indicates that there is a need to use them for printing. At this point in time they are conceptually removed from the warehouse and conceptually put in the daily storage area. The printing functions in the Production Management module are driven by the Demand Management module which takes care of *using* the paper reels and incurring all the printing related costs. With the demand of the paper reels, the loop is closed and once again the Order Management module makes a replenishment order when needed.

4.1.2 Changes Made to the Model to Simulate the Proposed Information Rich System

We now describe the simulation model that reflects the proposed information rich system. Instead of describing the system anew, we concentrate on the differences between the proposed information rich system and the current barcode based system.

- *Manual recording eliminated*: We removed from the simulation all activities that reflect the manual recording of information. In particular, we modified the quality control check and the transfer to warehouse in the Order Management module, the move to the daily storage area in the Demand Management module, and the move to the printing press and all the documentation at the printing press in the Production Management module. Note that the physical moves associated with the above activities were not eliminated from the simulation model as they are carried out in the proposed information rich system too.

- *Improved inventory information*: In the proposed information rich system the point at which the inventory is removed from the known stock level (in the Demand Management module) is carried out when the paper is actually used and not when it is removed from the daily storage area. This provides a more accurate representation of the inventory level in the printing house. The proposed information rich system makes this change possible since the reel's identity is not lost when printing begins.

- *Reduced paper reel handling and damage*: Since the location of each reel is known with certainty in the proposed information rich system, less forklift transportation in the Demand Management module will occur. As a result, the paper reels will be in better shape when they reach the printing press. Thus there will be fewer damaged reels and fewer paper breaks in the Production Management module.

- *Better control of daily storage*: Since each reel will stay in the daily storage area for the entire time needed to acclimate (because the information rich system will know how much time the reel spent in the storage area), the paper reels that reach the printing press will perform as they should. Thus fewer paper breaks will occur in the Production Management module.

- *Improved information on quality of reels*: The semi passive RFID system allows the reels to be located and identified at all times, including when they are partially used. Thus compensation for quality defects can be claimed from the paper supplier no matter when a defect is discovered. This additional compensation is accounted for in the Production Management module.

4.2 Simulation Experiments

We performed a series of experiments aimed at investigating the following two hypotheses:

H1: The simulation model of the current barcode based system correctly simulates the current situation. This can be viewed as model validation.

H2: The simulated cost performance of the proposed information rich system outperforms the simulated cost performance of the current barcode based system. Moreover, this improvement indicates that the information rich system is economically justifiable (see Section 4.4).

All simulations used the models described in Section 3. We used a six-month warm up period and a twenty-four month data collection period. A simulation run (warm up and data collection) required approximately one hour. Wherever appropriate, we used common random number streams as a variance reduction technique.

In order to test Hypothesis H1, i.e., that the simulation model of the current barcode based system actually reflects the current situation, we ran the current barcode based system simulation model and recorded the simulation output (see Section 3) at the end of each month. In the next section we compare this output with what actually occurred in a printing house (obtained from the organization's information system). We then compare the two outputs (simulation and actual) using t-tests.

In order to test Hypothesis H2, i.e., that the proposed information rich system is better than the current barcode based system, we ran both simulation models with common random number streams. We recorded the simulation output at the end of each month of the data collection phase of the simulation runs. Again we used t-tests to evaluate the statistical significance of the differences between the simulation models, and by extension, the anticipated difference between the systems.

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4.3   Simulation Results and Analysis

In this section we test Hypotheses 1 and 2, presented in Section 4.2, by comparing three different outputs; see Table 2.

1. The actual data of the printing house (obtained from the printing house's ERP system), including the monthly values of all but average stock levels in the system over the past two years. The average stock level in the system was not obtainable from the ERP system. These values are in the columns marked *Act.* (for actual) in Table 2.

2. The data produced by the simulation of the current barcode based system. These are the values from the twenty-four month data collection portion of the simulation run. These values are in the columns marked *BC* (for barcode) in Table 2.

3. The data produced by the simulation of the proposed information rich system. These are the values from the twenty-four month data collection portion of the simulation run. These values are in the columns marked *IR* (for information rich) in Table 2.

Table 2: Results for the actual (act.) system, simulation results of the barcode system (BC), and simulation results of the information rich (IR) system

Mo.	Paper damage (tons)			Forklift hours			Person hours			Average stock level (tons)			Assignable paper breaks			Unknown paper breaks		
	Act.	BC	IR	Act.	BC	IR	Act.	BC	IR	Act.	BC	IR	Act.	BC	IR	Act.	BC	IR
1	1.75	1.22	0.53	54	56	36	120	120	36	*	5178	5008	24	25	22	3	4	2
2	1.78	1.24	0.54	55	55	37	119	118	37	*	5179	5007	25	24	23	3	5	3
3	1.79	1.25	0.52	54	54	38	118	118	38	*	5176	5006	23	23	24	2	2	2
4	1.65	1.27	0.53	55	55	36	122	122	36	*	5178	5009	22	26	21	3	3	3
5	1.6	1.22	0.52	56	56	36	119	119	36	*	5175	5010	21	24	20	1	2	2
6	1.5	1.24	0.53	53	54	37	120	129	37	*	5174	5007	20	23	22	3	3	2
7	1.75	1.23	0.56	54	46	37	121	120	37	*	5173	5006	28	22	23	3	3	2
8	1.7	1.24	0.54	54.5	55	38	117	118	38	*	5172	5005	24	24	21	5	4	2
9	1.72	1.22	0.55	55	55	35	122	121	35	*	5170	5005	22	22	22	4	4	2
10	1.8	1.22	0.52	56	56	34	119	119	34	*	5178	5009	21	25	23	4	5	3
11	1.85	1.25	0.54	53	53	37	119	119	37	*	5179	5101	22	23	21	5	5	2
12	1.9	1.22	0.53	55	55	35	118	118	35	*	5178	5009	23	22	23	3	3	3
13	1.8	1.24	0.52	54	56	34	118	118	34	*	5173	5010	25	20	23	5	3	1
14	1.8	1.23	0.55	54	55	38	120	119	38	*	5173	5004	20	21	22	2	2	3
15	1.9	1.23	0.52	54	54	36	120	119	36	*	5171	5003	20	26	21	2	2	2
16	1.9	1.22	0.51	53	54	37	121	121	37	*	5178	5002	22	28	22	0	1	3
17	1.85	1.23	0.53	53.5	55	38	117	118	38	*	5178	5006	23	22	23	3	3	2
18	1.85	1.22	0.54	55	55	37	120	120	37	*	5180	5008	22	24	21	6	3	2
19	1.83	1.23	0.53	54	55	36	121	121	36	*	5181	5008	26	25	23	3	4	2
20	1.82	1.22	0.52	55	55	37	122	122	37	*	5178	5011	26	26	21	2	2	2
21	1.84	1.21	0.51	53	55	38	117	117	38	*	5174	5012	24	24	22	1	1	2
22	1.86	1.21	0.53	54	54	34	118	118	34	*	5175	5009	25	25	23	4	3	3
23	1.83	1.22	0.55	55	55	35	119	118	35	*	5174	5012	24	23	21	3	4	2
24	1.8	1.22	0.53	54	55	37	119	119	37	*	5174	5008	22	24	22	3	3	3
Aver.	1.78	1.22	0.53	54.3	54.5	36.4	119.6	119.4	36.4	*	5175.8	5011.5	23.1	23.8	22.0	3.0	3.1	2.3

In order to test Hypothesis H1 we conducted two-tailed t-tests to compare the actual current situation (the columns marked *Act.* in Table 2) to the results from our simulation of the current barcode based system (the columns marked *BC* in Table 2). We conducted a separate t-test for each system output separately, i.e., five t-tests (since we did not have information on the actual average stock level in the current situation, no t-test was possible for this output). For

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all but one of the outputs, the t-tests failed to find a statistical difference, even for a level of significance of 0.1. The only system output that demonstrated a statistically significant difference (p value <<0.01) was *paper damage.* The actual system had significantly more paper damage than the simulated barcode based system. We conjecture that the reason for the discrepancy is that our model omits situations where paper damage can occur.

The next step was to determine if the information rich system simulation model outperformed the current barcode based system model, i.e., the first part of Hypothesis H2. In order to do so we conducted one-tailed t-tests comparing the results from the current barcode based system simulation (the columns marked *BC* in Table 2) to the proposed information rich system simulation (the columns marked *IR* in Table 2). We did this for each of the six outputs separately. In all cases the proposed information rich system had statistically superior performance (p value of <<0.01). In other words, the simulation data supported our hypothesis that the current barcode based system is inferior to the information rich system. Our next objective was to analyze the economic aspects of the difference between the two systems.

Since our simulation models describe the operation of systems whose day-to-day operations are unaffected by cost parameters, calculating the sensitivity of our simulation results to these cost parameters is a trivial task. For example, if labor costs increase by $1 from $20 to $21 (see Table 3), the total cost increases by $996.96.

Note that the savings for forklifts and people are based on hours and not whole units. Clearly, forklifts come in whole units. Assuming that a forklift can be used K hours a week, a savings of a single forklift hour is unlikely to result in needing fewer forklifts. However, using the same logic, saving $K-1$ forklift hours is likely to result in the need for one less forklift. Less clear are people. Since workers are often hired on an hourly basis, as is the case at Yeioth, the saving of a single person hour can be easily turned into the hourly savings for that person. Finally, since both forklift and workers are shared between departments it is the policy to consider the saving to be proportional to the number of hours saved knowing that the actual savings may be a bit more or a bit less.

Another issue with the savings is the ability to aggregate the savings. If the work time is simply turned into idle time then there are no real savings. A minute saved here and there have no effect unless these minutes can be aggregated. As discussed above, when a worker receives a shipment of paper reels, there are savings associated with each paper reel. After the worker finishes processing the first reel she can immediately go on to the second. No waiting is needed in the proposed information rich system. Thus the individual savings on each reel can be aggregated to a savings on the shipment. This is also the nature of the other savings and thus they too can be aggregated.

Table 3: Yearly savings/expenditures from using the proposed information rich system over the cost of using the current barcode based system

Area of savings/expenditure	Quantity	Price per unit ($)	Savings ($)
Paper damage (tons)	8.28	600	4,968
Forklift hours	217.56	30	6,527
Person hours	996.96	20	19,939
Average stock level (tons)	164.34	50	8,217
Assignable paper breaks, first order effects	21	200	4,200
Additional refund from supplier due to being able to identify the reels after a paper break (tons)	9.48	600	5,688
Tags	20,000	0.5	(10,000)
Gates & software maintenance			(10,000)
Total			29,539

4.4 Economic Aspects

In this section we examine differences we found between the current barcode based system model and the information rich system model in financial terms, i.e., we test the second part of Hypothesis H2 (Section 4.2). The estimated yearly monetary savings from implementing the proposed information rich system come from the simulation runs and thus are based on Table 2. In Table 3 we present the yearly cost savings and yearly costs for tags and maintenance. The *price per unit* column of the table is taken from the company's (Yedioth) database cost as they relate to the savings. The costs of the system are actual costs of the installed technology. In addition, in order to implement the proposed information rich system, some initial one-time expenses are required. In particular, we need to purchase and install software that would allow the RFID information to be used by the system and purchase the RFID gates needed to read the semi passive RFID tags. These expenses are summarized in Table 4. Other *hidden* costs are not included in the analysis. Whereas the expenses summarized in Table 4 are one-time in nature, the software and equipment are not designed to last forever. Even though we estimate the system will last five years, we conservatively assume a lifetime of four years. Note that software and equipment maintenance is included in the yearly expenditures.

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Table 4: One-time expenses required to implement the proposed information rich system (actual purchase prices)

Area of expense	Number	Price ($)	Total ($)
Software	1	25,000	25,000
Reading gates	10	3,500	35,000
Total			**60,000**

Next we examine the proposed information rich system as an investment, using the standard investment evaluation techniques of NPV, PBP and ROI. Table 5 presents details of the data used and a summary of the results.

- *Net present value*: To calculate the NPV we assume an annual interest rate of 5% and an investment lifetime of four years. Performing a sensitivity analysis, we determine that the NPV for an interest rate of 2.5%, 10%, and 20% is $51,125, $33,635, and $16,469. In fact the NPV is positive as long as the interest rate is less than 33.9%.

- *Payback period*: We can see that the PBP is very short. In just over two years we start to earn money from the investment in the RFID technology.

- *Return on investment*: To calculate the ROI we again use an annual interest rate of 5%, and obtain an ROI of 75%, i.e. the percentage gain from the investment after taking into account the cost of capital.

Table 5: Summary of calculations to assess the economic viability of the proposed information rich system

	Time 0	Year 1	Year 2	Year 3	Year 4
Investment ($)	60,000	0	0	0	0
Savings ($)		29,539	29,539	29,539	29,539
Total ($)	-60,000	29,539	29,539	29,539	29,539
Total in present value (5%) ($)	-60,000	28,132	26,793	25,517	24,301
NPV	$44,744				
PBP	2.03 years				
ROI	75.08%				

As discussed in the introduction, on the one hand the printing house paper reel supply chain has characteristics that are common to supply chains of many other products, e.g., the use of labor and forklifts to move products. On the other hand, it has characteristics that are somewhat unique to paper reels, e.g., the paper reels are easily damaged. It is informative to note from Table 3 that most of the cost savings are from the aspects that the paper reel supply chain has in common with other supply chains. For example, a full 40% of the savings come from labor costs, which are by no means unique to the printing house or even especially predominant.

5   Implementation of the Information Rich System

As the result of this study the Yedioth newspaper printing house decided to install the information rich system as described above. As in this study, the first stage of implementation includes only the printing house. The company chose semi passive RFID tag technology. The hardware (reading gates) were purchased and installed. Moreover, software was developed to allow exploitation of the information obtained.

The printing house has so far received over 1900 paper reels embedded with semi passive RFID tags. The printing house ran for a month almost exclusively using these reels. Information on the outputs of interest is reported in Table 6. For the clarity of presentation we also include the average results (last line) from Table 2. Again, information on the average stock level was not gathered. The results are very encouraging. The outputs from the month of implementation closely paralleled the values generated by the simulation. Moreover, the actual cost of the equipment was as described in Section 4.4. This means that the economic analysis presented in Section 4.4 is validated by the implementation. In particular, the investment in the information rich system is expected to pay for itself in two years and the investment as a whole is worthwhile.

As is the case with any implementation of new technology, the Hawthorne effect [13] cannot be ruled out, given that a blind test of the information rich system is not possible. However, we note that the learning affect was not taken into account. We expect that as time progresses the printing house will become more adept at using the technology and performance will improve further. As a whole, the evidence is very strong that the system is beneficial.

Table 6: Monthly values for the actual barcode system (*act.* from Table 2) system, simulation results for the barcode (BC) system, simulation results for the information rich (IR) system, and actual information rich system

	System			
	Actual	Predicted	Predicted	Actual
Outputs	BC	BC	IR	IR
Paper damage (tons)	1.78	1.22	0.53	0.57
Forklift hours	54.3	54.5	36.4	33.3
Person hours	119.6	119.4	36.4	33.3
Assignable paper breaks	23.1	23.8	22.0	20.0
Unknown paper breaks	3.0	3.1	2.3	2.0

6   Summary, Conclusions and Discussion

For the print industry, paper constitutes its major raw material expenditure. Costs related to this raw material (including labor) have a direct influence on the financial health and strength of the print industry companies. Our analysis demonstrates that adopting the proposed information rich system, enabled by RFID technology, is undeniably worthwhile and offers the industry considerable savings. We found that for a relatively small investment and a reasonable yearly outlay, a significant cost saving as well as a very reasonable investment recovery result.

In the exposition above we repeatedly used the term *proposed information rich system* and avoided using the term *RFID*. This was not an oversight. We view RFID technology not as an end in itself, but rather as a means of obtaining greater system inventory visibility. In short a way of realizing the concept of IoT in the printing house. If tomorrow another method for achieving this inventory visibility were to be developed, this research would be no less applicable. In fact, there are non-RFID systems that give us the same information rich environment. For example, many automatic material handling systems are no less capable of tracking and identifying the location of parts. However, these systems do a lot more and cost a lot more. If the desire is an information rich environment requiring a modest investment, then at present no substitute for RFID technology exists. Our research does not preclude the possibility of a more complicated barcode system that would yield something akin to the information rich environment that we have investigated. However, it is our experience that barcodes fall short of this goal.

In this paper we only considered the first order benefits of creating an information rich system. We expect that other second order benefits, e.g., an improved procurement mechanism, would be just as significant as the first order effects that we studied. Moreover, the added information available from the information rich system will reduce errors in the inventory record and thus increase second order benefits. In contrast, we only considered direct costs in our analysis. Changeover costs and similar *hidden* costs were not considered.

Even though this study dealt only with the printing house, the actual paper reel supply chain contains other components. We expect that the same RFID tag embedded in a paper reel will create an information rich environment at the paper reel manufacturer as well and possibly also at the paper reel shipper. These other components will no doubt benefit from the paper reels joining the IoT. We did not consider the savings (and costs) at these stages, but have no doubt that they would add to the attractiveness of this technology. We also did not consider the supply chain after the spent reels are sold. Here we do not foresee any costs or savings.

Finally we point out that the printing house paper reel supply chains have some characteristics that are quite common to other industries. For example the need to track large raw material units as they make their way through the facility is common, e.g. in the automotive industry. The approach in this paper can be used to identify the benefits of an information rich system in these industries as well. Of course there are characteristics in this study that are unique to the printing house. Nonetheless, our analysis of the financial aspects indicate that the majority of the cost savings come from the common characteristics and thus this study is relevant for these industries as well.

Acknowledgments

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