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Paper Reel Management with RFID Technology – A Case Study

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A must read for: Managing Directors/CEOs/Chairmen, Technical Directors, Purchasing Managers
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Foreword

The technology of Radio Frequency Identification (RFID) is not really new as such. It is new that the use of RFID becomes more interesting and economical in more application areas every year. In the past only military and large industrial applications were possible. Today RFID has already an established position in many B-to-B businesses. It is used where large numbers of product identifications have to be performed safely in high speed and large volumes without manual intervention.

Trading companies and warehouses as well as department store chains are making use of RFID and drive the further development of this technology. The WAN-IFRA Technical Committees "Production" and "Materials and Environment" visited the Metro Group RFID Innovation Center and European Electronic Product Code (EPC) Competence Center in Düsseldorf-Neuss in March 2009 and saw many examples of actual and future applications.

IFRA published a Special Report on "The Use of Radio Frequency Indentification in Newspaper Production" in 2007 [IFRA 06] when this technology was still a novelty for the newspaper industry. Since then we see a constant development of RFID. Components get smaller and device prices drop with growing numbers. Today RFID tags or parts of them can even be produced by special printing techniques ("Printed Electronics").

Time was right to run a real life case study with RFID tagged newsprint paper reels in newspaper printing environment. Our committee member Assaf Avrahami suggested to report about the case study he and his colleagues from the largest Israeli publisher Yedioth ran in co-operation with paper suppliers and RFID technology providers.

The Technical Committees "Production" and "Materials and Environment" acted as assisting working groups during the review process of this report. The committee members are listed for information as appendix F of this report.

WAN-IFRA thanks the authors and the supporting companies for sharing their reports and findings! We also thank the committee members who were very instrumental and supported the publishing of the report with their valuable comments!

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① Introduction

The "Yedioth Ahronoth Group" is a major media house in Israel. Its newspaper flagship is the daily newspaper "Yedioth Ahronoth". Yedioth has created a special IT company, called "Yedioth Information Technologies (YIT)" that develops and supplies solutions to the group but also to the general market. Assaf Avrahami who is the CEO of Yedioth Information Technologies is a member of the IFRA Technical Group Production. He and his team have developed the sources for this Special Report.

This Report is not specifying a new IFRA standard of reel identification. It is a report on a case study that refers to the experiences of paper reel handling in the printing houses of Yedioth Ahronoth and on the developments regarding RFID tagging and RFID based IT systems at Yedioth IT. The study aims to deliver an analysis how in the future RFID could be used technically and economically for paper reel tracking and management. This study is also based on the assumption that in the future RFID tags will gain in performance and lower in cost.

A key cost element in the newspaper printing industry is newsprint, the paper used for print production, representing between 20 % and 30 % of total printing expenditures [IFRA 04]. The price of printing paper is developing along economic developments. In recent years we could see that paper prices went up according general price levels of raw materials. In the current world economic crisis this trend has stopped, but experts expect that in the long-term newsprint prices will be on a relatively high level. This is no surprise since energy costs develop in the same direction and paper making is an energy intense process.

There is no doubt that any increase achieved in operational efficiency in the area of paper management will yield considerable cost-savings, thus improving the firm's bottom-line.

The supply chain of paper reels begins with the ordering of the paper (categorised by the different types, sizes, and suppliers). The reels undergo many transfers in their lifetime. They must be transported from the paper mills (often via an international shipper), received at the printing company's warehouse, placed in storage, moved to an intermediate storage facility, conveyed to the different production floors, used in various machines and finally, the paper remnants and reel cores are sold.

Usually the reels are tracked using standard barcodes. IFRA published a reel identification specification already in 1987 [IFRA 87][1]. The IFRA barcode is an industry standard today used by many mills and newspaper printers all around the globe. A barcode on a paper reel can either be read by a simple hand-held barcode reading device or by a fully automatic barcode identification system that is equipped with automatic reading devices installed along the paper workflow in the production facility.

However, there are two disadvantages of the IFRA barcode system. First, the barcode is typically attached to the reel wrapping. As soon as the wrapping is taken off the reel the barcode identification is no longer connected to the reel. This can be an issue especially for those printing companies that want to track and control the paper workflow even after the unwrapping stage, for example tracking partially printed rest-reels. Today this is normally tracked by the reel management system. The advantage of the RFID only applies, if no tracking system is available, or the control got lost e. g. due to manual transports.

The second disadvantage was no problem in the beginning but developed into a practical restriction today. The IFRA barcode combines the reel identification number with information about the reel, such as grammage. Nowadays buyers want to know much more information about the paper than a barcode can ever contain. IFRA has often been approached since the last years with requests to include one or the other piece of information into the code structure of the barcode. Unfortunately this as not possible any more since the limited size and structure of the barcode does not allow any further information extension. The WAN-IFRA Technical Committee Production and Materials and Environment decided in spring 2009 to initiate a project called "Reel Code 2020" to develop a new reel ID with extended content that shall be independent of the coding technology used, by this covering bar code and RFID.

In order to prepare for future developments it makes much sense to look into technical alternatives for product identification. The electronic "Radio Frequency Identification" (RFID) method is developing strongly since a number of years. Different kinds of RFID tags have been developed and with the first mass market applications manufacturers of those tags could bring prices down year by year. These were reasons enough for IFRA to study the basics of RFID and its possible area of applications for

1 In the issue of January 1987 the IFRA magazine "newspaper techniques" reported that the IFRA Newsprint Committee had decided in favour of a 16-digit bar code for reel wrappings. The code selected was the numeric Interleave 2/5. Contained in the 16 digits was the manufacturer identification code, as demanded by newspapers, as well as further information, such as the specific weight of the paper.

publishing houses. The result was a first Special Report on this issue published in 2006[2].

Since this first report things have further developed. Yedioth Information Technologies (YIT) has, in co-operation with others, developed a prototype system that works with a new kind of RFID tag powered by a low-cost printed battery and has conducted first field tests and implementations tests.

The full "Supply Chain Management" (SCM) of paper reels includes also the part of the chain that takes a place in the paper mill and contains all the different parts and stages of the product in the paper manufacture production floor. In the actual study we will cover only the paper workflow in the printing plant.

A possible future alternative to barcodes is Radio Frequency Identification technology (RFID). RFID marks items with a tag that broadcasts radio signals to designated receivers.

This technology today offers different operation methods. The model used in this study integrates semi-active tags as tools for the management of the paper reel supply chain. Although attempts have been made to develop models for the management of paper stocks [LAI 02], as well as to investigate RFID technology's suitability for this purpose [WIN 04] and for print workflow [IFRA 06], research studies in the area of paper reel supply chains management – from the ordering stage to the handling of paper remnants and reel cores – are limited in number and fields of interest covered. The few studies that exist cover the area only partially.

Goals of the case study research

The research of this study aims to meet the following goals:

- Development of a model that forecasts the newspaper printer's savings in paper reel SCM (supply chain management) through the implementation of an automatic reel tracking system based on RFID technology in comparison to the actually existing paper handling workflow.
- Development of a simulation model that helps forecasting more efficient management of the supply chain of paper reels, thus saving unnecessary expenditure.

2 IFRA Special Report 04.2006, Moritz Müller: "The Use of Radio Frequency Identification in Newspaper Production", Darmstadt 2006

② Literature review

Supply chain and inventory management in the paper reel industry

Few studies that describe paper reel inventory management in a printing house and the SCM of paper reels have been published so far.

Lai, Jue Xue, Guoping and Zhang [LAI 02] described an optimal solution for storing and handling paper reels in printing houses. Their solution is based on a genetic algorithm for layout design of a paper reel warehouse with a two stage heuristic approach. The work proved that this algorithm enables the design of an optimal layout for storing paper reels. The target function was minimised clamp truck handling of the stored reels. The work related to unloading the reels, moving them to the storage facility and later on transporting them to the production area. They considered a paper reel storage layout problem where different classes of paper reels need to be placed in the cells of the warehouse. Each paper class has a different reel type and each reel type has its own inventory level and demand. In their study they solved the problem of locating each reel in the warehouse, so that the total transportation time would be minimised. The contribution of the work is a comprehensive algorithm for storing paper reels in a printing house.

Another study by Westerlund and Isaksson [WES 98] dealt with solving a production optimisation problem in a paper-converting mill. In this paper the problem to be solved was how to produce a set of different paper reels from one big tambour reel and then transport and store these reels in the paper mill. This work is important since it deals with the paper suppliers' part of the SCM process.

One of the most important works in this field was carried out by the IFRA Newsprint Committee and was published in 1993 under the title "Newsprint and Newsink Guide" [IFRA 93][3]. This work includes the basic rules for tagging paper reels with traditional barcodes in the paper mill according to one standard and for reading these barcodes at each stage of the SCM process. The work introduced the best practice method whereby reels are wrapped and arranged in the paper mill, loaded into a shipping container, unloaded from the container at the printing house, stored in the optimal way and then supplied to the printing area later on. The method also considers how to handle the core and the paper waste at the end. This research represented first time that one work covered the full process of paper reel SCM for the printing industry. It is very basic and simple and uses generic models from industrial engineering, applying them to this specific field. Later on most printing houses and paper suppliers around the world adopted the IFRA proposed method.

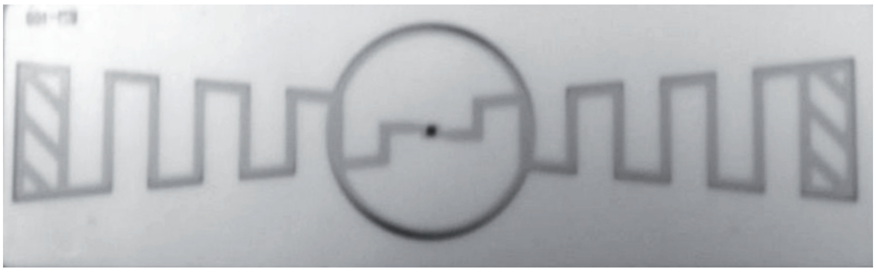

Figure 1: A typical passive RFID tag

3 "IFRA Newsprint and Newsink Guide", Darmstadt 1993. This 530-page guide is intended to serve as an information source for printers, pressroom supervisors and technical management, providing up-to-date facts and advice for dealing with these every-day materials. The guide has been compiled and approved by the IFRA Newsprint Committee.

RFID technology and implementation in generic SCM

RFID technology is a means for marking items with a tag, which broadcasts radio signals to designated receivers posted up to tens of meters away. This technology aims to replace other product identification methods and can be based on one of the following RFID tag technologies.

Passive RFID tags (100–135 KHz)

Passive tags do not broadcast data but just reflect back a signal with information after being sent a radio wave by a transmitter. Such passive tags are not equipped with a power supply, and as a consequence their lifetime is relatively long and they are relatively inexpensive. On the downside of this, their electronic signal is relatively weak. They are able to transmit signals only up to one meter of distance.

Active RFID tags (860–950 MHz)

Active RFID tags are typically equipped with a battery, capable of broadcasting additional data compared to passive tags. Their lifetime is limited because the battery's life is limited. Due to their battery such types of RFID tags they are more expensive than passive ones. The advantage however, offered by these tags, is their strong signal that can transmit over a distance of up to one hundred meters. The tag reading system in a gate for example is equipped with a proximity sensor that is used to identify the tags which are passing through. So the reading system can distinguish between the tags it has to read and those which are just sitting in the store attached to storage items.

Figure 2: Example of an active RFID tag

Semi-Active RFID tags (860–950 MHz)

The idea of the development of semi-active RFID tags is to combine the advantages of passive and active tag technologies. Semi-active tags should be as inexpensive as possible (comparable to passive tags) but also as powerful as possible with regard to signal strength (comparable to active tags).

Semi-active tags use a battery-assisted chip. In order to keep costs low, this battery is not a conventional device but a printed battery that gives the tags an up to two-year life-span and a signal that reaches up to ten meters. Such tags also cost much less than active tags, but more than passive tags. At the time when this report was written the price per semi-active tag could be up to 20 times lower than the price of an active tag.

The emerging RFID technology has generated and enormous amount of interest in the general supply chain area. Using this technology, inventory can be tracked faster and more accurately, labour costs can be saved and the complete SC from supplier to end-user can be improved.

In the paper industry however, you also find a lot of scepticism regarding the use of RFID for reel tracking. Paper manufacturers argue that the cost of the tag is far higher than the current label costs. This would – in the case of one paper supplier – represent millions of dollars per annum, which could be pushed onto the publishers. Another paper supplier reported that they hardly found sufficient benefits to justify the introduction of RFID reel identification. Other paper suppliers are investigating the use of RFID and run pilot tests together with customer and developers.

There is also some hesitation on the supplier side regarding the placement of the semi-active tags on the reel core. One supplier reports about test results: “We attempted the tag placement as described (in this report; the author) and stopped because of winding issues. Placing the tag in each core was very labour intensive. The only winder that the tag could work on is a wind belt.” There are other technical questions regarding the tag placement as well. One of them is how to make sure that the tag is not damaged by cutting large tambours into single reels. In such a case you need to know the sizes of the individual reels created later in advance, before placing the tags onto the tambour’s reel core. Another question is how large the reel diameter can be so that the tag signal still transmits through the paper to the outside. Currently there is a trend to use reels of a higher diameter; 1.5 m can frequently be found nowadays. RFID tag signals have to be strong enough to transmit through a paper reel of 1500 mm diameter. Further development of RFID technology will certainly provide such requested signal performance.

Nowadays reel core suppliers offer cores with integrated passive tags, which are worked into the reel core multiple times. The tags are repeatedly positioned after a certain distance along the reel core, so that later cutting of the tambour into single reels has no negative effect on RFID tag functionality and availability. This is even true in case it happens that one tag is damaged by the saw.

Paper is often shipped under extreme climate conditions. It is no exception that reels are loaded and transported at a temperature of – 30° Celsius (e. g.

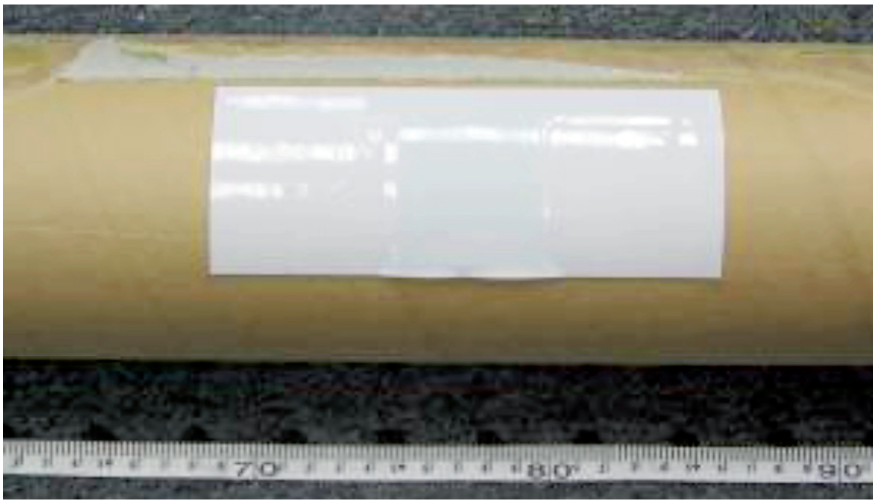

Figure 3: Example of a semi-active tag, glued onto a reel core in a paper mill.

shipments from Canada in winter time). It will need clarification and tests to ensure that RFID tags can work reliably under such harsh environmental conditions. It also has to be checked if and how the batteries of semi-active tags and their life-time are affected by very low temperature.

Lee and Cheng [LEE 04] explored the impact of RFID on a generic supply chain. They developed a simulation model to study how RFID can improve supply chain performance by modelling the impact of RFID in the manufacturer-retailer supply chain. Their paper provided a quantitative analysis for measuring the potential benefits of RFID. They modelled a simple manufacturer-retailer supply chain in a consumer product business. They then analysed the dynamic and stochastic behaviours of supply chains that are affected by the deployment of RFID. They presented two simulation models, one without RFID and one including the use of RFID. The results of their work was that inventory levels in the process decreased by 23 %–26 % in the RFID-assisted supply chain.

Another work by Lee and Ozer [LEE 07] studied whether RFID could affect generic supply chains. They summarised previous research related to RFID and the effect RFID might have had on each part of the supply chain. The paper related to labour cost, improvement of service (for the supplier), inventory accuracy and inventory levels.

Printing industry

Research studies regarding the development of the international publishing industry indicate that newspaper circulation has dropped in the last five years at the range of 5 %–10 % (including free newspapers). Nevertheless, newspapers remain leading media and account for 44 % of the advertising market-share worldwide, while in Israel they represent 50 % of the market [TGI 06].

These competitive changes mandate that the printing companies take the necessary steps to become more operationally-efficient and constantly improve their systems, in order to preserve publishers' revenues and profits.

Paper breaks have a major impact on the effectiveness of the printing process. When a paper break happens during printing, the print process is stopped and valuable time is lost by having to re-web the paper in the press. Paper breaks are generally the result of one of the following: a human mistake, wrong machine settings or false materials handling, a technical problem in the printing machine or a defect in the paper reel.

RFID in the printing industry

IFRA studied the option of using RFID in the newspaper printing industry [IFRA 06]. The report reviewed the printing industry processes in which RFID can be implemented, including paper reel conveyance and storage, plate making, ink handling, mailroom activities and distribution. Each stage was examined to see if deployment of RFID was possible and meaningful now and in the future, and, if so, what the optimum effect could be.

Regarding paper reels this work studied the effects of RFID in very general terms without getting into each part of the paper reel supply chain management process. It was the first report that studied the implementation of RFID in the newspaper printing industry and gave a good general overview of using RFID in the printing process.

Based on and in addition to this first IFRA report, the results of the actual RFID case study were presented at a Focus Session during IFRA Expo in Vienna in October 2007 [AVR 07].

③ Present situation and problems observed

What did we compare in this report? We compared a non-automatic system with a potential automatic system based on RFID technology. Modern automatic tag recognition is compared with manual barcode reading or with a half-automatic system.

You could argue that only a comparison of a fully automatic barcode based system with a fully automatic RFID based system would make technical sense. Indeed, there are companies who use fully automatic barcode systems without disturbances during delivery and within the production value chain.

On the other hand, the idea of this case study report was not so much to provide a comparison on the highest level of automation between barcode and RFID but to open the eyes of many average newspaper printers who typically do not run the utmost in reel tracking systems. In order to touch those potential readers of the report we decided by intention to compare an average or even below average reel tracking system with a fully automatic system. This automatic system could be either barcode or RFID based. In both cases the leap-frog would be comparably large. However, we decided to use the RFID based solution because we believe in the future of this technology and we actively help developing this technology for newsprint reel tracking.

To say it in short: We did not intend to argue against a barcode based solution, but we wanted to promote fully automatic tracking systems in contrast to incomplete tracking systems, which are still a reality in many cases.

Our reference point for this case study is a medium-size newspaper printing house equipped with a barcode system. This print plant has a paper consumption of 20 000 tons per year. It has no automatic reel handling system and uses one main big paper storage in the printing house. The barcode system is used for manual reading with hand-held devices. They use a manually controlled clamp truck system. As far as we know from experience in our country's market, on the spectrum of "no automation at all" on the one hand side up to "fully automated systems" on the other hand side many of the cases are like this.

Today, paper reel supply-chain management in the printing industry is performed using two methods:

1. Completely manually, with no tools or marking devices (manual lists are used for managing the complete process).
2. Traditional barcodes and barcode optical readers.

Currently, each reel is labelled on its outer wrapping with an IFRA Barcode that contains relevant details for this paper reel (manufacturer, paper mill, weight, paper type) [IFRA 93]. Many mills also print the CEPI Unit Identifier code (UIB) on the belly of the reels that can be used for easy identification. In the places where the reel management system uses barcode reading, it is read in every station along the supply chain and the organisation's computer system is updated accordingly with the reel status.

Printing plants we have studied in our country's market showed a number of handling problems:

1. Cost of labour – large amount of human resources was invested in manually reading of the reel barcodes and in appropriately filling in their status on forms in each and every stage, as will be further described.
2. Information loss – once the reel wrapping was removed, the reel could no longer be identified (the barcode is available only on the reel wrapping). The wrapping was generally removed as the reel entered the production process (printing). Defects were occasionally found in reels, or a defect in the reel caused the paper to break during the production process. When such defects emerged during the process, and if the reel barcode was lost or not recorded, there was no way of knowing which reel was flawed. Therefore, the factory

couldn't ask the paper supplier for concrete help.[4] Another observed problem was that since the supplier was unknown, the paper quality could not be fully analysed according to suppliers. Such analyses would have helped when making decisions regarding future buying of paper from specific sources.

3. Traditional barcodes do not allow the location of specific reels paper in the warehouse to be identified. Hence there were instances when a reel was moved for printing, but it turned out to be the wrong reel. Alternatively, a certain reel e. g. was sought, but its storage location was unknown. In any such event, reels had to be moved with a clamp truck and any such shift might damage the paper.
4. Inaccurate inventory monitoring could be observed as well. All the reel reading was done manually; a reel may enter and/or be retrieved from storage and not be registered due to human error. Additionally, reels marked as retrieved for production (printing) did not appear in inventory lists even if they were only partially consumed. These issues mean that the inventory lists were false and inaccurate and did not reflect what was actually sitting in the paper warehouse.

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4 If the diameter of the remaining rest reel is not too small you should be able to read the reel number, which is printed onto the side of the reel. (The same is true for the manufacturer information.) In a well organised printing plant the reel consumption sheet tells you which reel number ran on which reel-stand, so that you still can identify the reel even if the barcode is gone.

④ Paper reel tracking with RFID technology

Figure 4: Applying the tag at the paper mill

Figure 5: Reading the RFID tag at the wrapping station in the paper mill

We tested the use of RFID semi-active tags on paper reel cores in a pilot installation at Yedioth Ahronoth printing plants in Israel. This system should allow the paper movement to be monitored automatically. The monitoring system comprises two antennas: one for transmitting and one for receiving the signal from the tag. Our solution uses s semi-active tag, which on one hand is strong enough and able to transmit the information through the paper reel radius (0.5 m–0.7 m) and more up to four meters through the air, which is the distance needed to be bridged for a clamp truck gate. On the other hand the semi-active tag is by factors less expensive than an active tag. Each semi-active tag, to be applied at the paper mill as shown in Figure 4, includes a unique identification number for the reel.

The reason for having the tag attached to the reel core is to enable reel tracking at every stage. The tag will not disappear when the reel wrapping is discarded.

Figure 6: Reading gate in the printing plant

In the next stage the paper is wound onto the core. At the last station in the paper mill – the wrapping station – the reel tag identification number is read for production tracking reasons of the paper mill. This procedure is shown in Figure 5. At each control point in the printing plant you will need a reading gate as shown at Figure 6. The information from all the reading points will be collected by the information system that will apply the studied supply chain model.

⑤ The cost components in the paper reel supply chain

Below we describe all steps of the paper reel supply chain and their cost excluding those in he paper mill. Each stage is examined to see if it can be streamlined and improved by using RFID as opposed to using a barcode system.

1. Ordering – When the stock drops below a specified minimum, the order can be automatically issued to the supplier (subject to the supply schedule). Automatic ordering depending on the stock level does not depend on the use of RFID. It can be done with another product ID system as well. It needs a system that allows automatic reading of IDs and automatic processing. You can find so called "chaotic paper storage systems" that are able to do this, although the reels are just marked with traditional barcodes. However, RFID is a modern and future oriented method of helping to solve this problem.
2. Data indicating that stock is dropping below a minimum level will be given in real-time by means of an RFID stock analysis (which will include stock in the production process, which cannot be done manually). If your current way of record keeping does not allow for verification of stock quantities, paper reels will not be ordered on time. With an automatic system such as a system based on RFID, it will be possible to effectively update stock-levels, according to the historical data on paper reel usage collected. This will allow the updating of stock levels of different types of reels, at any stage and "on the move".
3. Land and sea transportation – no difference between manual and RFID based recording.
4. Unloading – no difference between manual and RFID based recording.
5. Registration and quality control – manually registering each reel means registering each one individually and manually identifying each reel on the delivery note. These labour costs are avoided with an RFID system.
6. The use of barcodes is not automatically identical with a manual registration. There are IT based barcode systems that do many of the processes automatically. It depends on the complexity of the system employed.
7. Handling to point of storage – no difference between manual and RFID based recording.
8. Cost of stock – no difference between manual and RFID based recording.
9. Moving to day storeroom – no difference between manual and RFID based recording. The day storeroom is the place where the reels expected to be used in the next 24 hours are kept.
10. Moving to production floor – no difference between manual and RFID based recording.
11. Detraction from stock – manual record keeping requires an employee. Use of RFID saves this cost.[5]
12. Cost of acclimatisation – each reel has to remain (still wrapped) for 24 hours in the day storeroom, in order to adapt to the right printing temperature. This common practice is useful if high differences in temperatures exist between the main warehouse and the day storeroom In case the reels were exposed to very low temperatures during transportation they should have an even longer acclimatisation time. Due to the fact that by manual record keeping it is difficult to know the exact number of reels in the day storeroom, as well as whether more are needed, it happens that a reel may not be fully acclimatised. This could cause paper breaks during printing, halting production. These stoppages cost money (time, labour, resetting, etc.). Absorption (implementation) of RFID would reduce the occurrence of such events.[6]
13. Cost of weighing – manual record keeping requires weighing of the reel-ends sold. A press control system that keeps track of the amount of paper on the rest reels can, in conjunction with a fully automatic RFID or barcode based reel identification, provide information about the weight of the rest reels to be sold without weighing. Therefore cost related to the weighing of rest reels can be saved.
14. Record keeping of the number of cores of each type sold – this cost will also be avoided. The exact number of reels sold and removed from the plant will be made available by RFID, without employee intervention.
15. Cost of handling complaints to supplier – at times, during the printing

5 Automatic storage systems can well track every reel that is coming in and every reel that is going out. RFID is one method to identify the reels, but bar-coding is another method. And there are a number of different fully automatic barcode reading systems.

6 A sophisticated paper reel management and tracking system can control all this even without RFID identification. Only if you lose track of a reel you have to count the number of reels in the day store room. But if you keep track, you do not have to count the reels in the stock over and over again.

process, different types of defects can be found in the paper reel (the number of such cases can be defined by percentages). Each defect must be documented, clearly identified and linked to the respective reel. Well documented complaints filed with the supplier allow for adequate compensation. In manual record keeping much energy is required to document each event and identify the respective reel. If the reel is in the process of printing, it is virtually impossible to identify it, making it impossible to file a complaint. Implementation of RFID technology will enable the identification of the reel – as well as retrieval of its quality data – at any stage of the printing process, allowing the preparation of an adequate complaint. This also includes reels that were partly used and loaded back to the press for printing. In such cases without an RFID tag, the reel identification and quality information is lost.[7]

Basic Formulas

The basic formulas for costing paper reel SCM may change after adding RFID.

1. Effects of stock-reduction on total cost (TC):

   $TC = AD / Q + CD + hQ / 2$

   where:

   A Fixed cost per order

   D Demand per time-unit

   Q Ordered quantity

   h Cost of stock per unit

   C Cost per unit.

   This value represents the overall cost per time-unit (including the cost of raw material) according to the "Economic Ordering Quantity" (EOQ) model. Excluding the cost of raw material:

   $TC = AD / Q + hQ / 2$

   The following cost will be relevant for each item in stock:

   $$\sum_{n=1}^{N} TC_n = AD_n / Q_n + hQ_n / 2$$

   Type of items in stock is n = 1, 2, 3, ...

2. R_n – reel

   C – Costs of registration and quality-control

3. R_n – Reel.

   C_1 – Cost of registration at delivery

   $$\sum_{n=1}^{N} R_n \cdot C_1$$

4. B_R – Number of paper breaks with RFID

   B – Number of breaks without RFID

   C_B – Cost of a paper break

   $B \cdot C_B - B_R \cdot C_B$

5. W_n – Number of reel-end weighing events

   C_3 – Cost per weighing event

   $$\sum_{n=1}^{N} W_n \cdot C_3$$

6. R_n – Reel.

   C_2 – Cost of sale registration

   $$\sum_{n=1}^{N} R_n \cdot C_2$$

7. (%) D_1 – Number of defects per reel found before usage

   (%) D_2 – Number of defects per reel found during usage

   C_4 – Cost of defect documentation per reel

   C_5 – Compensation received per defective reel

   $$D_1 \cdot \sum_{n=1}^{N} R_n \cdot C_4 + D_2 \cdot \sum_{n=1}^{N} R_2 \cdot C_5$$

7 It is true that the reel ID is lost as soon as the barcode is taken off with the wrapping. However, there are automatic reel handling systems which take care of the reel when it enters the production area. They put the right reel into the right reel stand on time. They also take the rest reel off after printing. They even know how much paper is left on the rest reel and they store it and use it again in case it fits the production requirements. All this can be done independently of the coding system (barcode or RFID). Maybe it can be done easier in case of RFID coding, but still, it can also be done without RFID, because the paper logistic system knows which reel has been put into which place. It is all a matter of investment and how much you want to spend for your automatic paper logistic system. In real life mainly large printing houses invest into such complex systems.

⑥ The simulation model

Non-automated reel management process

In a case study we compared a non-automated process of paper reel tracking and control with a possible fully automated process of reel identification, tracking and control. Our assumption was that the automated process would be based on RFID technology.

We developed a model that simulates the process undergone by each paper reel in the printing house from ordering to selling of the cores. The simulation model was developed using ARENA software. The model includes four different parts:

- Inventory management – includes the mechanism that is responsible for adding new orders and the orders that have arrived to the stock level.
- Orders – compares the actual stock level to the minimum stock level that was predetermined for each product, and if the level is lower, then determines that an order for a specific quantity (Q) should be prepared/issued.
- Demand – includes the demand for every reel type. This demand is determined and known.
- Production – includes all the processes through which the reel goes once it arrived at the production floor.

Each part includes the mathematical rules and actions that belong to this stage. These mathematical rules and actions can not be described in detail in this report.

In order to input the data for each process we conducted a time study to check how long every process takes and what resources are used in this process. Appendix A shows all the measurements that were taken for each of the activities.

Automated reel management process

Below we describe the changes in the model if an automatic and RFID based system is used.

1. Generally the need of manual recording of the reel is eliminated in the automatic process.
2. The effective order point changed so the known stock inventory now includes the real stock level in the entire printing plant (including daily storage and printing room).
3. Since the location of each reel is known there will be less transportation and less paper damage. This also means that the transportation working time and the degree of paper damage is reduced.
4. Since – based on improved reel tracking and control – each reel will stay in the day storage for the time needed to acclimate, the reel condition will be optimised and there will be less paper breaks. We could reduce the percentage of total paper breaks.
5. Reels that were only partly used can now be identified as well as those of substandard quality. This information can be used in the communication with the paper supplier.

⑦ The experiment

We performed a series of model executions aimed at examining and verifying the following two hypotheses:

1. The non-automatic model correctly simulates the current situation.
2. The automatic and RFID based model is economically worthwhile compared to the non-automatic version.

In order to examine the first hypothesis we took the following steps:

1. We used collected data of the resources consumed during management of the supply chain as they appear in the organisation's IT system.
2. We measured the times of the various processes for the non-automatic model (Appendix A) and fed this information into the various stages of the model.
3. We simulated the non-automatic model by software, processed it and sampled the output of each resource at the end of each month.
4. We validated the non-automatic model by comparing its data with the actual data. This comparison was done using a T-test. The T-test is a statistical tool that compares sets of data and finds out if there is a correlation between them.

The second part of the experiment examined the second hypothesis (does the automatic RFID tag based model consume fewer resources than the non-automatic model?). In order to perform this test we took the following steps:

1. We ran the non-automatic model for 24 months in the computer simulation program, checking the resource consumption at the end of each month.
2. We ran the automatic model, checking the resource consumption at the end of each month.
3. We compared the non-automatic model to the automatic model using a T-test, and found the differences between.

8 Results

The results can be broken down into three different parts. The first part is the real situation existing at the printing house. This data was taken from the printing house's IT system. It includes the value for each month and for each parameter over a period of two years.

Month	Paper damage (ton)	Clamp truck hours	Person hours	Average stock level	Paper breaks	Paper breaks without reel IDs
1	1.75	54	120		24	3
2	1.78	55	119		25	4
3	1.79	54	118		23	2
4	1.65	55	122		22	3
5	1.6	56	119		21	1
6	1.5	53	120		20	3
7	1.75	54	121		28	3
8	1.7	54.5	117		24	5
9	1.72	55	122		22	4
10	1.8	56	119		21	4
11	1.85	53	119		22	5
12	1.9	55	118		23	3
13	1.8	54	118		25	5
14	1.8	55	119		22	3
15	1.9	54	120		20	2
16	1.9	53	121		22	0
17	1.85	53.5	117		23	3
18	1.85	55	120		22	6
19	1.83	54	121		26	3
20	1.82	55	122		25	2
21	1.84	53	117		24	1
22	1.86	54	118		25	4
23	1.83	55	119		24	3
24	1.8	54	119		22	3

Table 1: Data taken from the IT system[8]

Paper breaks without reel identification – the total number of paper breaks where we cannot know the reel identification

Paper breaks – the total number of paper breaks in one month

Person hours – the total man hours needed for the entire process including all the stages that the reel is going through

Paper damage – the total damage that happens in the printing house because of handling the reels with the clamp truck

Clamp truck hours – the total clamp truck hours that are needed for the entire process

Month – the 24 months in which data were collected

8 There are no data in the column "Average stock level" because we did not have these data in the Enterprise Resource Planning (ERP) system.

The next two sections comprise the data generated by our simulation models. The first was the non-automated model. The results for 24 months for this model are shown in table 2.

Month	Paper damage (ton)	Clamp truck hours	Person hours	Average stock level (units)	Paper breaks	Paper breaks without reel IDs
1	1.22	56	120	5178	25	4
2	1.24	55	118	5179	24	5
3	1.25	54	118	5176	23	2
4	1.27	55	122	5178	26	3
5	1.22	56	119	5175	24	2
6	1.24	54	120	5174	23	3
7	1.23	46	120	5173	22	3
8	1.24	55	118	5172	24	4
9	1.22	55	121	5170	22	4
10	1.22	56	119	5178	25	5
11	1.25	53	119	5179	23	5
12	1.22	55	118	5178	22	3
13	1.24	56	118	5173	20	3
14	1.23	55	119	5173	21	2
15	1.23	54	119	5171	26	2
16	1.22	54	121	5178	28	1
17	1.23	55	118	5178	22	3
18	1.22	55	120	5180	24	3
19	1.23	55	121	5181	25	4
20	1.22	55	122	5178	26	2
21	1.21	55	117	5174	24	1
22	1.21	54	118	5175	25	3
23	1.22	55	119	5174	23	4
24	1.22	55	119	5174	24	3

Table 2: Data from the non-RFID-based model simulation

Table 3 shows the results of running the RFID-based model in our simulation software. Again we simulated two years of production or 24 months.

Month	Paper damage (ton)	Clamp truck hours	Person hours	Average stock level (units)	Paper breaks with reel ID
1	0.53	36	36	5008	22
2	0.54	37	37	5007	23
3	0.52	38	38	5006	24
4	0.53	36	36	5009	21
5	0.52	36	36	5010	20
6	0.53	37	37	5007	22
7	0.56	37	37	5006	23
8	0.54	38	38	5005	21
9	0.55	35	35	5005	22
10	0.52	34	34	5009	23
11	0.54	37	37	5010	21
12	0.53	35	35	5009	22
13	0.52	34	34	5010	23
14	0.55	38	38	5004	22
15	0.52	36	36	5003	21
16	0.51	37	37	5002	22
17	0.53	38	38	5006	23
18	0.54	37	37	5008	21
19	0.53	36	36	5008	23
20	0.52	37	37	5011	21
21	0.51	38	38	5012	22
22	0.53	34	34	5009	23
23	0.55	35	35	5012	21
24	0.53	37	37	5008	22

Table 3: Data from the automatic model simulation

Analysis

First, to validate our model we conducted hypothesis tests, so called T-tests, to compare our model with a real-life situation. We conducted T-tests for each variable separately. The results of the T-test show that there are no statistical differences between the two variables in each case (Appendix B). The only variable whose correlation is not clear is "paper damage". This might have happened because our model may omit a stage where additional damage could occur.

The next step was to determine if and where the automatic model and the non-automatic model differed. To this end we conducted a T-test and found that there is a difference (Appendix C).

In other words, the data confirmed our hypothesis that there is a difference between the automatic and the non-automatic model. Our next objective was to analyse the financial aspects of this difference.

9 The economical aspects

It is interesting to translate the differences we found between the two simulated models into monetary values. We calculated the total savings for one year.

The calculation was done by subtracting the outcome of one year of the automatic model from those of the non-automatic model after having calculated the average of each variable reached in the T-test (see appendix C). The price for each resource is also described in appendix D. We can see that the total savings for one year is about 50 000 US$.

The investment for the installation of an automatic and RFID based system would be as follows.

1. The cost of tagging the reels (yearly expense):
2. 20 000 reels, about 0,5 US$ per tag = 10 000 US$
3. The cost of maintenance for the gates and the software (yearly expense):
4. 10 000 US$
5. System software, one time investment: 25 000 US$
6. Installation of 10 RFID gates, one time investment:
7. 3 500 US$ per gate = 35 000 US$

The pay-back period

In calculating the pay-back period (PBP) we will consider the capital investment for the software and the gates, which sums up to a total of 60 000 US$. In order to calculate the possible net total savings for one year we have to take into consideration the cost of the tags that have to be purchased, which reduces our savings per year to 30 000 US$.[9]

Therefore the entire PBP would last two years: 60 000 US$ investment divided by 30 000 US$ savings/year = 2 years. After two years we can start benefiting from an automatic RFID based system in this hypothetical case study.

Net Present Value model

To calculate the net present value (NPV) we assumed an interest rate of 5 % for one year. We calculated the NPV for four years. We assumed that we will pay the tags at the end of each year. The cashflow for these years would be as shown in table 4.

The total NPV for the period would be 46 379 US$. The NPV at an interest rate of 7 % would be 41 629 US$ and the NPV at an interest rate of 3 % would be 49 346 US$.

Return On Investment model

We calculated the return on investment (ROI) with the data from the NPV model above. The ROI would be calculated like this: (gain-cost) divided by (gain). The ROI would be: (106 378-60 000 US$) / 60 000 US$ = 0.77.

$$NPV = 0 = Expenditures + \sum_{n=1}^{N} C_t / (1 + IRR)^t$$

In our case IRR = 0.349 = (34.9 %). This rate is better then any internal rate given by a bank.

Expenditure and income calculation	Year 0 1000 US$	Year 1 1000 US$	Year 2 1000 US$	Year 3 1000 US$	Year 4 1000 US$
Expenditures	60	20	20	20	20
Income	—	50	50	50	50
Total	– 60	30	30	30	30
Total in present value	– 60	29	27	26	25

Table 4

IRR[10] model

Expenditure and income calculation	Year 0 1000 US$	Year 1 1000 US$	Year 2 1000 US$	Year 3 1000 US$	Year 4 1000 US$
Expenditures	60	20	20	20	20
Income	—	50	50	50	50
Total	– 60	30	30	30	30

Table 5

9 Costs for the application of the tags in the paper mill are not part of this calculation. In practice this cost would have possibly to be added to the calculation.

10 IRR stands for "Internal Return Rate", which is another financial indicator.

⑩ Summary and conclusions

Assimilating the RFID technology in the paper reel supply chain is worthwhile considering. Automated systems based on RFID technology can offer considerable savings. We found that for a relatively small investment and reasonable yearly outlay, significant cost savings are possible as well as a reasonable investment recovery.

This study did not deal with three additional components that must, in the future, be investigated thoroughly.

1. The cost components and overall stages of the paper reel supply chain in the paper mill must be analysed and studied. Following this, two simulation models should be built: a model based on the average current state-of-the-art practice and an automatic system based on RFID technology. It will be critical to find the costs and benefits of the current and of a possible future scenario for the paper mill and the potentials for saving in this stage.
2. Sensitivity analysis of the model presented in this study – a study should be performed to examine the influence of changes in different components on the entire model. It needs to be decided which are the model components that might change, and in what possible range. Subsequently, these changes should be gradually embedded in the model and a sensitivity analysis should be performed according to these changes.
3. Building a stochastic model with components of uncertainty – the model we presented in this study was based only on deterministic components. The resources, demands, inventory levels and processes were all known and obvious, with known expectancy. A model for a non-automatic process, when uncertainty variables are within known limits, should be built. Then a model for an automatic process based on RFID technology with stochastic components needs to be built and the difference between these two stochastic models should be determined.

This study identified the savings that can be expected by implementing automatic paper reel tracking and management systems based on RFID. It is likely that RFID technology develops further on and will be used in many more applications including identification of consumer goods. It will be worth while following this development in order to suggest the right measures for the industry at the right time.

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⑫ Appendices

Appendix A

The time study data that we had for each activity. We did not make any use of the standard deviation data.

Activities	Time in seconds	
	Average	Standard Deviation
Unload	42.40	8.48
Record to stock level	14.53	4.52
Transfer to storage	30.02	6.28
Transfer to day storage	56.86	5.30
Detract from storage	14.53	4.52
Detract from daily storage	14.53	4.52
Transfer to printing	85.09	12.75
Preparation	398.11	15.52
Recording paper information	40.10	1.89

Table 6: The average of the time study

Appendix B

The results of the T-test for the ERP data comparing to the model without RFID data. Variable 1 stands for ERP data, variable 2 for the model without reel IDs.

Paper damage	Variable 1 (ERP data)	Variable 2 (model without reel IDs)
Mean	1.786250	1.229167
Variance	0.009338	0.000199
Observations	24.000000	24.000000
Pooled Variance	0.004768	
Hypothesized Mean Difference	0.000000	
df	46.000000	
t Stat	27.946340	
P(T<=t) one-tail	8.32E-31	
t Critical one-tail	1.678660	
P(T<=t) two-tail	1.66E-30	
t Critical two-tail	2.012896	

Table 7: Paper damage

Clamp truck	Variable 1 (ERP data)	Variable 2 (model without reel IDs)
Mean	54.333330	54.500000
Variance	0.775362	3.826087
Observations	24.000000	24.000000
Pooled Variance	2.300725	
Hypothesized Mean Difference	0.000000	
df	46.000000	
t Stat	–0.380630	
P(T<=t) one-tail	0.352614	
t Critical one-tail	1.678660	
P(T<=t) two-tail	0.705227	
t Critical two-tail	2.012896	

Table 8: Clamp truck

Labour	Variable 1 (ERP data)	Variable 2 (model without reel IDs)
Mean	119.375000	119.291700
Variance	2.418478	1.867754
Observations	24.000000	24.000000
Pooled Variance	2.143116	
Hypothesized Mean Difference	0.000000	
Df	46.000000	
t Stat	0.197191	
P(T<=t) one-tail	0.422273	
t Critical one-tail	1.678660	
P(T<=t) two-tail	0.844547	
t Critical two-tail	2.012896	

Table 9: Labour

Paper breaks	Variable 1 (ERP data)	Variable 2 (model without reel IDs)
Mean	23.125000	23.791670
Variance	3.766304	3.302536
Observations	24.000000	24.000000
Pooled Variance	3.534420	
Hypothesized Mean Difference	0.000000	
Df	46.000000	
t Stat	– 1.228400	
P(T<=t) one-tail	0.112772	
t Critical one-tail	1.678660	
P(T<=t) two-tail	0.225544	
t Critical two-tail	2.012896	

Table 10: Paper breaks

Paper breaks with unknown reel ID	Variable 1 (ERP data)	Variable 2 (model without reel IDs)
Mean	3.125000	3.083333
Variance	1.940217	1.297101
Observations	24.000000	24.000000
Pooled Variance	1.618659	
Hypothesized Mean Difference	0.000000	
Df	46.000000	
t Stat	0.113449	
P(T<=t) one-tail	0.455084	
t Critical one-tail	1.678660	
P(T<=t) two-tail	0.910168	
t Critical two-tail	2.012896	

Table 11: Paper breaks with unknown reel ID

Appendix C

The results of the T-test for without RFID data compared to the model with RFID. Variable 1 stands for the model without RFID, variable 2 stands for the model with RFID.

Paper damage	Variable 1 (without RFID)	Variable 2 (with RFID)
Mean	1.229167	0.531250
Variance	0.000199	0.000168
Observations	24.000000	24.000000
Pooled Variance	0.000184	
Hypothesized Mean Difference	0.000000	
df	46.000000	
t Stat	178.423400	
P(T<=t) one-tail	2.69E-67	
t Critical one-tail	1.678660	
P(T<=t) two-tail	5.38E-67	
t Critical two-tail	2.012896	

Table 12: Paper damage

Clamp truck	Variable 1 (without RFID)	Variable 2 (with RFID)
Mean	54.500000	36.375000
Variance	3.826087	1.722826
Observations	24.000000	24.000000
Pooled Variance	2.774457	
Hypothesized Mean Difference	0.000000	
df	46.000000	
t Stat	37.694650	
P(T<=t) one-tail	1.55E-36	
t Critical one-tail	1.678660	
P(T<=t) two-tail	3.1E-36	
t Critical two-tail	2.012896	

Table 13: Clamp truck

Paper breaks	Variable 1 (without RFID)	Variable 2 (with RFID)
Mean	23.791670	22.000000
Variance	3.302536	0.956522
Observations	24.000000	24.000000
Pooled Variance	2.129529	
Hypothesized Mean Difference	0.000000	
df	46.000000	
t Stat	4.253105	
P(T<=t) one-tail	5.11E-05	
t Critical one-tail	1.678660	
P(T<=t) two-tail	0.000102	
t Critical two-tail	2.012896	

Table 14: Paper breaks

Labour	Variable 1 (without RFID)	Variable 2 (with RFID)
Mean	119.291700	36.375000
Variance	1.867754	1.722826
Observations	24.000000	24.000000
Pooled Variance	1.795290	
Hypothesized Mean Difference	0.000000	
df	46.000000	
t Stat	214.370600	
P(T<=t) one-tail	5.85E-71	
t Critical one-tail	1.678660	
P(T<=t) two-tail	1.17E-70	
t Critical two-tail	2.012896	

Table 15: Labour

Paper breaks with unknown reel ID	Variable 1 (without RFID)	Variable 2 (with RFID)
Mean	3.083333	2.291667
Variance	1.297101	0.302536
Observations	24.000000	24.000000
Pooled Variance	0.799819	
Hypothesized Mean Difference	0.000000	
df	46.000000	
t Stat	3.066459	
P(T<=t) one-tail	0.001810	
t Critical one-tail	1.678660	
P(T<=t) two-tail	0.003621	
t Critical two-tail	2.012896	

Table 16: Paper breaks with unknown reel ID

Inventory level	Variable 1 (without RFID)	Variable 2 (with RFID)
Mean	5175.792000	5007.667000
Variance	9.041667	7.101449
Observations	24.000000	24.000000
Pooled Variance	8.071558	
Hypothesized Mean Difference	0.000000	
df	46.000000	
T Stat	204.995500	
P(T<=t) one-tail	4.57E-70	
T Critical one-tail	1.678660	
P(T<=t) two-tail	9.13E-70	
T Critical two-tail	2.012896	

Table 17: Inventory level

Appendix D

Total cost savings for one year			
Area	**Number**	**Price, US$**	**Total price, US$**
Working hours	995	20	19900
Clamp-truck hours	218	30	6525
Stock level (ton)	168	50	8406
Paper breaks	22	195	4300
Paper damage (ton)	8	628	5025
Refund from supplier (ton)	10	570	5700
Total cost			**49856**
Total investment			
	Number	**Price, US$**	**Total price, US$**
Tags	20000	0.5	10000
Software	1	25000.0	25000
Reading gates	10	3500.0	35000
Total investment			**70000**

Table 18. Total savings for one year and total investment

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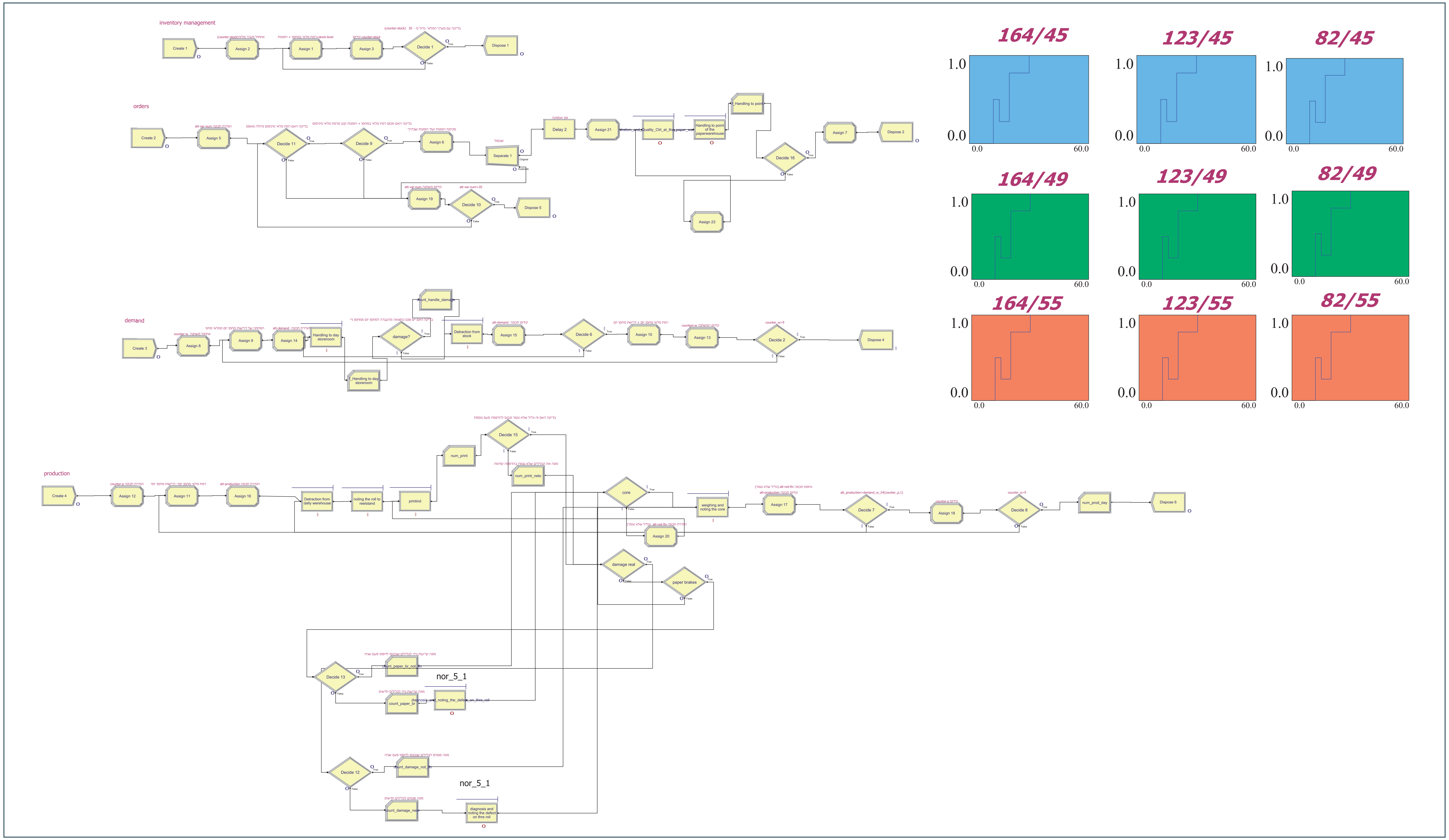
Appendix E

The drawing below shows all the different stages that the reel is going through.



Appendix F

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