RFId systems for moveable asset management: an assessment model

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Management of moveable assets is a key issue in most industrial manufacturing companies. With the increasing complexity of production systems, characterized by numerous and heterogeneous machining centers, it becomes quite hard to carry out an effective and cost-efficient management model of the tools and fixtures needed for ensuring a correct and timely execution of the planned production cycles. A pre-requisite for a proper management of moveable assets is the adoption of identification systems to support the traceability and data collection of the most relevant pieces of information along the life cycle of an asset. Aim of the paper is to provide an assessment model for evaluating the benefits and costs related to the adoption of RFId tags as identifications systems for moveable assets, and in particular in managing machinery tools in a production premise. In order to present a practical example of applicability of the model, an industrial application is reported with an in-depth analysis of the potential benefits and issues deriving from the implementation of RFId tags.

Keywords: Machine tools, tool management, RFId, case study

1. Introduction

The recent development of smart devices has created new opportunities for reconfigurable manufacturing systems that can be more flexible and efficient (Shiraz et al. 2012). Their application in the industrial context has been favoured by the functional characteristics of these smart devices such as better interoperability, large diffusion and availability on the market at lower costs.

The adoption of suitable new technologies can reduce inefficiencies and increase the availability performances of a production system. Despite this relevance, one of the main problems is to define beforehand what are the benefits and possible savings that could justify a profitable investment. While companies are willing to adopt solutions that could improve their performance, they also need to economically quantify the expected benefits.

From this point of view, the role of a vendor of an industrial device has to be reconceived: from being a technological supplier to acting as a provider of an integrated solution for the customer, which should contribute to the enhancement of the technical and financial performance of its industrial assets (Ngai et al. 2010). Hence, if a device is commercially available, if the technical skills are widespread and the industrial applications already tested on the field, how can a provider be more responsive towards the users to ascertain the expected benefits that the solution brings into a production system?

The unit of analysis in this paper is moveable asset management as the decision-making area related to planning, scheduling and traceability of moveable assets, ranging from cutting or shaping tools, to jigs, fixtures, pallets, dies or moulds (Kwon et al. 2003). Traditionally, a lack of attention to such management issues is a primary reason for poor performance of many facilities (XuJin Yan et al. 2012). This is further exacerbated by the increasing complexity and extreme level of automation of production systems, as well as by the high variety and number of tools used in a single machining center (Turkan et al, 2007). A first pre-requisite for scaling up the level of utilisation of a moveable asset resides on the proper, unambiguous identification, traceability and prompt availability of updated information about its status, wear level and technological capability throughout its whole life cycle (Avci et al, 1996). Unavailable or unreliable information on such items can trigger delays in industrial operations, inefficient use or excess inventory, and even lead to serious damages or accidents. On the contrary, accuracy and easy accessibility of such data enable the development of a suitable scheduling and control system, which could optimise the level of utilisation and sharing of single tools (Kwon et al, 2003).

In this context, RFId technology has emerged as a valid support for enabling accurate and real-time accessible data related to an item, either a component, a final product or, as in our case, to auxiliary moveable assets. The debate on RFId technology in the last years has been characterised by some prevailing positions: from the enthusiasm and expectations sparked by its potential (Ngai et al., 2008); to the prudent stance of many professionals on its widespread implementation timing which could be quite lengthy, due to several economic (in terms of its current high unit costs if compared with traditional barcodes) and organisational hurdles yet to be overcome.

RFId remains a niche technology whose benefits have eluded its widespread and invasive adoption in many companies. Some of them have experienced a disappointing return on investments from their RFId implementation, while others have found themselves unable to overcome the technological obstacles. As a result, though it is widely acknowledged that RFId could become the primary technology for tracking products and managing inventories, companies embracing such a technology should carefully consider beforehand its long-term benefits and impact rather than myopically emulating their competitors.

Aim of the work is to fill this gap providing an assessment model for evaluating RFId implementation in tool management. This would allow practitioners to ascertain which should be the main advantages in implementing RFId techniques, not neglecting its limitations and investment costs. This paper is an advancement of a preliminary research work carried out by the same authors (Dovere et al. 2015) with remarkable improvements in the methodological and experimental phase.

The remainder of the paper is organized as follows: section 2 provides a literature review on applications of RFId in the industrial domain, with particular reference to moveable asset management. Section 3 describes the system architecture and how the

RFId can be adopted in the tool management. Section 4 shows the assessment model, whose potential is evaluated in the case study reported in section 5. Final conclusions and managerial implications are drawn in section 6.

2. Literature Review

Literature dealing with RFId has been flourishing in the last decade with applications in disparate fields and with different claimed benefits. A comprehensive analysis of state of the art on RFId application in different industrial sectors is provided by a survey conducted by Ilie-Zudor et al. (2011).

This section is rather devoted to a review of the most acknowledged scientific proposals and industrial implementations of RFId in solving those issues related to the specific moveable asset management domain. The review categorises the literature contributions according to four main classes of applications.

- *Production control*: in this class, the typical application is the insertion of an RFId tag to a part, item or assembled box under production (Higgins et al, 2006). The tag contains data related to part number, location, production line, operator, time and so on. The information registered in the tag would flow tightly with the product throughout its production process. Baudin et al. (2005) report their experience in an assembly line, where the information embedded in RFId tags enable a better traceability of items and tools to be used as well as a real time update of the single steps of advancement of the assembly unit. Another example is given by Johnson (2002), with the RFId tags applied on an automated assembly line in a Ford Motor Company premise. Johnson reports that: “as a vehicle passes through the different stages of production, a serial number is referenced on a tag, indicating what needs to be done at each station”. A similar case study is given by Pacciarelli et al. (2012)

where the RFId tags are used to manage the production schedules in a pharmaceutical packaging area: the tags are placed on the sealed bins, on the roll containing the packages and on the tools defining the blister sizes. Each tag stores information usable to manage the packaging phases. RFId is employed also to collect data for the algorithms to schedule better the production phases. Further application in manufacturing production system is reported by Day et al. (2011), where tags are attached to production items, while RFID readers are installed at each single machine to bind the production information. In all these contributions the main experienced benefits are: reduction of wasted time, increase of automation in the operations, better traceability in and out of the factory (Ngai et al (2012) and Zelbst et al. (2012)).

- *Supply chain management*: this class represents the major and widespread application of RFId in the industrial sector. RFId is used to give the maximum traceability of goods along the whole supply chain. In particular, one of most important applications takes advantage of the possibility of multiple and simultaneous reading of items. As reported by Chen et al. (2013), multiple parts are stored in a box which is packed on a pallet. If each part is tagged with an RFId, the whole content of the pallet can be read with a single reader before the dispatching phase. RFID can also improve the traceability of products throughout the entire supply chain, and can also make reliable the tracking, shipping, checkout and counting processes, leading to advanced inventory flows and more accurate information (Chow et al., 2006, Gaukler et al. 2005, Sarac et al., 2010). Main benefits of the use of RFId in the whole supply chain are: reduction of the inventory level and of the potential error in the handling operations (Bottani et al., 2008, Tajama et al. 2007), less risks of thefts (De Kok et al., 2007) mitigation of misplacement and labor costs (Lee et al., 2007).

- *Maintenance operations*: RFId technology can be used as a support to preventive and condition based maintenance. An example is the application described by Chen (2009) for the functioning of a steam turbine, where a correct maintenance is needed to guarantee its optimal operating conditions. Since these conditions can quickly change, it needs checking, memorizing and reading relevant data in real time. The tags are easily programmed in-house and are designed to be applied on the turbine. Another application in the maintenance field is given by Adgar et al. (2007), where the information in the RFId tags is stored to manage the CBM activities and "to allow operators identifying tools, machine and spare parts accurately, easily and rapidly". Several applications are shown in different sectors as reported by El Ghazali et al. (2012) where the RFId technology is used to manage maintenance inspections in the oil industry or, as reported by Satoglu et al. (2012), to manage maintenance interventions and spare parts in aerospace industry. Lastly, the RFId could be a support system to manage the activities of resource allocation and resource sharing policies in aerospace maintenance operations (Saygin et al. 2010). The main expected benefits are: increase of maintenance efficiency, decrease of global cost of maintenance, physical applicability on the product (unlike other identification systems, as bar code).
- *Instrumentation and equipment identification*: a potential important area of application, even if a few relevant contributions are yet available in literature, is related to the identification of tools by using RFId tags. It is worth mentioning the contribution by Lampe et al. (2008) in the case of aircraft maintenance: since each operator uses a personal toolbox, there is the need to maintain always a consistency between the single tool and its owner. In this way, the adoption of RFId tags can guarantee the correspondence of each tool to each toolbox and each operator. Another

kind of application is given by Ilie-Zudor et al. (2011) where the RFId tags are used to identify and to track mobile instrumentation at the Bon Secours Hospital chain. In the same way, RFId is employed to monitor telemetry transmitters in hospital environments (Hakim et al. 2006). Main acknowledged benefits are: identification of the right tools, location of tools, monitoring the quality or state of assets and keeping the history of assets.

- *Tool management in tool machinery*: Although the RFId technology has been experimented for more than 20 years, there is still scarce experience as regards its application in tool management. Typical pieces of information that are written on the tag applied to a tool are, among others: tool code, containing technological, material-related and geometric data; position on the rack or in tool room; residual life and state of wear. From the point of view of tool management, through the use of RFId it is possible to automate a series of procedures. Main involved processes are: search and selection of tools, data entry operations, machine set-ups, evaluation of the wear level of a tool, life cycle management (Wang et al. 2009). As reported by XiuLin Sui et al. (2014), it is worth mentioning the importance of having a database where to gather and centralise all the information about tools. If we refer in particular to flexible manufacturing systems (Meseguer et al 2008, Dovere et al. 2015), several subsystems do require update and consistent logistical and technical data related to the tools, including: production planning; presetting maintenance; robotised and/or manual tool assembly; stock control and materials storage. As Naifei Ren et al. (2012) state, a good planning system can heavily reduce the level of tool inventories by exploiting at best the sharing of tools among machines, and, as a result, maximise also tool utilization.

A summary review of these applications and the claimed benefits is reported in Table 1. This summary represents an extended version of the literature review reported in Dovere et al. 2015.

Applications	**Main benefits**	**Sample References**
Production process	Elimination of wasted time. Mitigation of risk. Increase of automation. Better efficiency of the recall actions. More accurate scheduling	Baudin et al (2005) Day et al. (2011) Higgins et al, (2006) Johnson (2002) Ngai et al. (2012) Zelbst et al. (2012) Pacciarelli et al (2012)
Supply chain	Enhancing the whole supply chain efficiency Reduction of labor cost Improvement of the product traceability	Bottani et al. (2008) Chen et al (2013) Chow et al. (2006) De Kok et al (2008) Gaukler et al. (2005) Lee et al. (2005) Tajima et al. (2008) Sarac et al. (2010)
Maintenance operations	Increase of maintenance efficiency. Decrease of global cost of maintenance. Monitoring the quality or state of assets.	Cheng et al, (2008) Chen et al, (2009) Adgar (2007) ElGhazali et al (2013) Satoglu et al. (2012) Saygin et al. (2010)
Instrumentation and equipment identification	Identification of the right tools and right location Monitoring the quality or state of assets. Keeping history of assets.	Hakim et al. (2006) Lampe et al, (2008) Ilie-Zudor et al, (2011)
Tool management in tool machinery	Reduction in tool inventory. Better utilization of tools. Reduction of human errors. Possibility to plan tool requirements.	Kwon (2003) Meseguer (2008) Subrahmanyam (1999) Wang et al (2009) NaifeiRen et al. (2012) XiuLin Sui et al. (2014) Dovere et al. (2015)

Table 1. A review on the areas of application of RFId technology

From this extensive literature analysis, it is evident how the state of the art of RFID applications in industrial sectors can already rely on several cases where this technology is used for the traceability of the items within the production (Baudin 2005, Higgins 2006, Ngay 2012, Pacciarelli 2012) and in the management of supply chain processes (Tajima 2008, Gaukler 2005, Lee 2005).

However, most of the applications are focused on the manufactured product being tagged and monitored during the whole production cycle, while there are only few cases where tools, equipment and machines for production are managed through RFID systems. Another limitation highlighted in literature analysis is that the major number of applications investigates only the achievable qualitative benefits, with the exception of some works developed in research area of the supply chain management. For example, in the case presented by De Kok et al. (2008) the authors show a model to calculate the break even price for the RFId technology comparing the investments with the potential gains to monitor the unexpected shrinkage in the inventory level. Another application is given by Bottani et al. (2008), where an economical assessment of the impact of RFID is presented: a quantitative analysis is carried out, the expected savings are monetized and return of investment (ROI) is calculated. Nevertheless, this case is only implemented for supply chain processes and the calculated savings are mainly considered in terms of manpower cost. If we consider the applications of RFId in the area of equipment identification and tool management, there are not cases where the quantitative benefits are calculated. A list of qualitative benefits is often presented, but there is no implemented model to quantify the economic impacts and the return of investments. Another aspect that in the literature is scarcely covered is how the introduction of RFId technology affects the processes in terms of operations carried out and involved human resources.

This paper could bring a further relevant advancement to the current state of the art for the following reasons:

1. first of all, a specific industrial application is analysed, related to tool management, which commits several manufacturing industries; most of the contributions are focused on issues related to planning and scheduling, neglecting how tool management impacts on the processes themselves; through this paper we would bring forward a model both for the evaluation of the qualitative benefits, based on the kind of production process, as well as for the calculation of the economic savings;
2. the assessment model proposed in this paper would be a relevant model for all the manufacturing processes which adopt machine tools, considering all the variables that could be affected when an RFId system is employed for carrying out tool management.

3. Implementation of RFID systems in tool management

The implementation of RFId systems for tool management requires a revision of the overall architecture of the machine centers and a specific tool management process. Regarding the first point, besides the application of RFID tags directly on the tool holder cone, it is necessary to provide the installation of proper readers in different positions. As reported in Figure 1, the application of RFId requires the interconnection between the following elements: the machine tools, the tools, the tool room, the presetting station and the supervisor software.

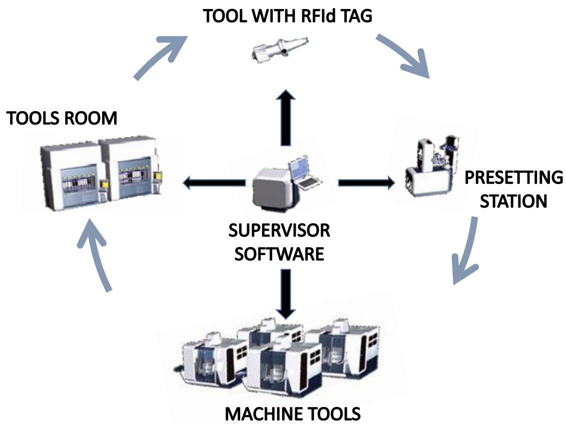

Figure 1. System Architecture for the tool management with RFId

First of all, a reader on the presetting station has to be installed in order to avoid errors from operators. As a matter of fact, when new cutting tools are introduced, the presetting station detects all the geometric data. Traditionally, these data are inserted manually by the operator in the numerical control software of the machine center. Conversely, with the insertion of a RFID tag, the reader on the presetting station is designed to write automatically the geometric data within the tag along with other information related to the tool (e.g., kind of tool, useful life, position in tool catenary, etc.)

Another reader on the machine threshold is required to manage automatically the tools. The operator usually places the tools in a positioning station near the machine; then they are taken by a manipulator which arranges them in front of the reader. Through the reader, all the information in the tag is read and stored directly in the machine software.

It is evident that it is also necessary to provide a software supervisor of the machine which manages all the information scanned by the reader during different operations such as: right positioning tool in the catenary, recall tool for the working operations, planning the remaining useful life, unloading tools at the end of useful life, etc...

In traditional tool management practices all these operations are handled manually by the operator. Hence, a machine downtime is required. Other inefficiencies are related to the increase of risks of mistakes due, as an example, to the incorrect positioning of the tools in the machine, the wrong introduction of geometric data or the incorrect management of the remaining useful life of the cutting edges.

Especially when there is a work center linked by a single tool store, with more machine tools, the supervisor software is also able to handle the machines by allocating the manufacturing process to the machine with a higher availability of tools, thus leading to a minimization of the down time and to an overall increase of production performances.

Regarding the specific tool management process needed, it can be schematically articulated into four main set-up macro phases and, in turn, each phase by more operations (Divere et al. 2015)

- *Preliminary Operations*: the operator searches for the tools needed for the manufacturing process and evaluates whether the work requirements, in terms of durability and weariness, can be fulfilled by the stocked available tools.
- *Presetting*: the operator checks the wear level of tools and its shapes, gets the geometrical features through the presetting machine and finally introduces these data in the NC.
- *Tool load*: this phase is characterized by the set up operations on the working machine and by run tests.
- *End of the manufacturing*: after the working cycle on the machine is performed, the level of tool wear is analysed and, eventually, tools are stored back in the tool room.

For each phase of tool management, there are different activities where possible inefficiencies can arise. A list of the different potential wastes, analysed from literature (Avci et al. 2000) and some case studies in the manufacturing context, against the single phases and activities, is reported in Table 2.

		PHASES							
		PRELIMINARY OPERATIONS		PRESETTING			TOOL LOAD	END OF MANUFACTURING	
		Search tool	Evaluation inventory requirem	Acquisition of geometrical features	Control tool wear (ante process)	Data Entry	Set up and run tests	Control tool wear(post process)	Storage of tool & Data entry
INEFFICIENCIES	Idle/lDown time	✓	✓	✓	✓	✓	✓	✓	✓
	Loss of tools dimensional data and features		✓	✓	✓	✓	✓	✓	✓
	Decrease of tools life (tool discarded)	✓			✓			✓	
	Increase of errors (Failure piece/machine organ/tool)	✓		✓	✓	✓	✓	✓	
	Increase tool set		✓						✓
	Loss data for the supply planning		✓						

Table 2. Operations vs inefficiencies in tool management (adapted from Dovere et al. 2015)

4. The assessment model

Through the evaluation of well-defined key factors and the identification of measureable performance indicators, an assessment model can be used for comparing the current “AS-IS” situation of a production system with the “TO-BE” scenario which could derive from a pervasive adoption of RFId tags associated to the machining tools.

The model is composed of two main parts: the first part is needed to get all the information about the manufacturing system to find where the RFID can impact on, which are the potential benefits and the quantitative data that characterize the production. The second part allows to calculate the expected economic benefits through the adoption of the OEE (Overall Equipment Effectiveness) indicator and to find the pay back period of the investment done to implement the RFId technology.

According to Dovere et al. (2015), the first step is the definition of the main factors in tool management which could be influenced by the implementation of RFId technology. These factors mainly depend on the technology characterising the specific production system as well as on the typology of products being manufactured. For example, in some situations, the predominant factor could be "increase productivity". This is the typical case when the value of the final product is quite low and for increasing its profitability it is very important to rely on a high production scale. In this case, under the constraint of the available technology, the RFId application could be instrumental for improving the productivity by reducing the occurrence and impact of more sources of time losses. Under other circumstances, when the types of production are very different and more kinds of tools are used, it could be more relevant to search for the reduction of the overall tool inventory costs. This goal is achievable by decreasing the number of tools through tool sharing or through a better understanding of the level of tool wear. Finally, in other production scenarios, the predominant factor could be avoiding any kind of mistakes during the production process. A relevant example is the manufacturing of crankcases, where any error could jeopardise the quality of the item and incur in high recovery costs.

The first part of the assessment system, with factors and related features, is presented in Table3. For each section of this table, information about the production system is collected. The “factors” of each section represent all the information that characterize a manufacturing system that use machine tools for the production. Sections 1 and 2 are functional for a quantitative benefit of RFId. The features in sections 3, 4 and 5 represent the context and the variables where the application of RFId technology can impact on.

SECTIONS	FACTORS	FEATURES
(1) Classification of the production system	Production approach Production volumes	Production volume Number of set up Number of production changes
(2) Software and hardware technology at disposal	Typology of machine tool Software support Level of automation	Number of machine tools Level of automation
(3) Use of human resource in tool management	Tasks assigned to workers	Estimation of times (tool research, presetting, data entry, loading tools)
(4) Information about tools used	Identification of the adopted system.	Number of replicas of the same tool. Total number of tools residing onboard and in tool room. Average price of tools
(5) Information about accidents	Typology of accidents Consequences of accidents	Number of accidents. Not productive times for accidents.

Table 3. Sections of the assessment model (adapted from Dovere et al. 2015)

Going more into detail, section 1 (*Classification of production system*) is devoted to a better understanding of the main production characteristics; this section considers how volumes are produced (i.e. one of a kind, batch or continuous); for each “production kind”, the critical activities and the inefficiencies, where the use of RFId can impact on, are shown in Table 4. This first section is the main part that allows defining qualitatively how the RFId technology can improve the possible inefficiencies in the tool management.

PRODUCTION KIND	CRITICAL ACTIVITIES	INEFFICIENCIES WHICH RFId IMPACT ON
ONE OF A KIND	Search of the suitable tool	Increased down time (for searching the tool)
	Tools data (geom. dimensional, wear)	Increased down time to take over dimensional data
	Data entry before the manufacturing activities	Increase of probability of breaking a tool or the worked piece during the manufacturing
BATCH	Planning tools use	Difficulty of tool sharing
	Manufacturing scheduling	Increased down time to set up operations
	Set up operations	Increase of probability of breaking a tool or the worked piece during the manufacturing
	Evaluation of tool wear	Increase of probability of breaking a tool and down time
CONTINUOUS	Requirements planning tools	Tool stock out
	Manufacturing monitoring	Increased machine down time.
	Monitoring tool wear	Increase of probability of breaking a tool or the worked piece during the manufacturing activity

Table 4. Critical activities and inefficiencies for section 1 – type of production system (adapted from Dovere et al. 2015)

Section 2 is devoted to the analysis of the technology. In particular, the relevant information is about the number and kind of machine tools (for example: traditional, CNC, FMS, etc.). The other parts regard the system software (i.e. whether there is a supervisor and/or a database), and the level of automation (i.e. whether there is a night shift without the direct presence of an operator on the machine).

Section 3 aims at detecting the tasks that are assigned to workers. The main indicators of this section relate to the amount of time spent by workers for the operations of tools management. In section 4, the model allows to investigate the kind of management and the usage of technologies supporting this phase; more in detail, it is detected if there are some tool identification systems and the indicators are: tool features in terms of price, size, number and duplicates. These elements are useful for making consideration on the possible need to reduce the total number of tools in the company.

Finally, there is a section that allows a free compilation from the auditors. It is particularly related to the acknowledgement of any historical data available in the company. In this section, the model aims at ascertaining any accident which occurred during the production and how frequent they occur. Typical accidents to be analysed are: number of breaking of tools or workpieces or machine organs as a consequence of human errors.

To evaluate quantitatively the benefits when the RFID system is applied in the tool management, an assessment model of the costs and benefits that can be obtained is needed. To calculate the economical savings, the analysis is carried out by the use of the OEE (Overall Equipment Effectiveness) indicator. As reported by Hansen (2001), each percentage improvement of the OEE is equivalent to an increase of productivity level and consequently to an increase of profits. In particular, the OEE is made up of three sub indicators: availability, quality and performance (Muchiri et al., 2008). To evaluate the indicators and relating savings, the machine operators have to fill in a table the value of the following indicators ante and post the application of the RFId:

- Number of failures per month – (N_f)
- Mean time to repair (minutes/failure) – (MTTR)
- Mean time to set up operations (minutes/batch) ($T_{set\ up}$)
- Mean time to preset the tools (minutes/batch) (T_{preset})
- Working days (days/month) – (WD)
- Working hour by day (hour/day) (hWD)
- Theoretical pieces worked by day (pcs/day) – (pcs^{target})
- Effective pieces worked by day (pcs/day) – (pcs_{eff})
- Scraps by day (pcs/day) (pcs_{scraps})

The Availability indicator takes into account down time losses, and is calculated as:

$$A = \frac{T_{up}}{T_{tot}}; (1)$$

Where T_{up} is the time when a machine tool works in good condition and T_{tot}, given by the sum T_{up} and T_{down} (time when machine is not available), is the total disposal time for the production system. The T_{up} is given by:

$$T_{up} = T_{tot} - \left[\left(N_f * MTTR\right) + \left(T_{set\,up} * pcs_{eff} * WD\right) + \left(T_{preset} * pcs_{eff} * WD\right)\right]$$

If the availability indicator increases (A'), the time gained by the machine tool is given by:

$$T_{gained} = T'_{up} - T_{up} = (A' - A) * T_{tot}; (2)$$

This time gained for the machine tools is equivalent to an increase of number of pieces produced according to following formula:

$$\Delta pcs_A = \frac{T_{gained}}{t_c}; (3)$$

Where:

- Δpcs_A: are the pieces made in addition
- t_c is the average cycle time to produce a single piece

The Quality indicator takes into account the number of scraps produced, and is calculated as:

$$Q = \frac{Pcs_{good}}{Pcs_{tot}}; (4)$$

Where Pcs_{good} are the good pieces manufactured by a machine tool and Pcs_{total}, given by the sum of Pcs_{good} and the scraps, are the total number of pieces manufactured by the machine.

If the quality indicator increases (Q'), the number of pieces produced in addition are:

$$\Delta pcs_Q = \left(Q' - Q\right) * Pcs_{tot}; (5)$$

Lastly, the performance indicator, that represents the speed at which the machine runs as a percentage of its designed speed, is calculated as:

$$P = \frac{\#pcs}{\#pcs^{target}}; (6)$$

Where #pcs are the effective number of pieces produced in the unit time and $\#pcs^{target}$ are the ideal number of pieces produced in the unit time.

If the performance indicator increases (P'), the number of pieces produced in addition are:

$$\Delta pcs_p = (P' - P) * \#pcs^{target} * T_{up}; (7)$$

The sum of additional pieces manufactured, due to an increase of availability, quality and performance indicators, allows an economical benefit according to the following formula:

$$\Delta\$ = (\Delta pcs_A + \Delta pcs_Q + \Delta pcs_P) * (p - c_v); (8)$$

Where:

- $\Delta\$$ are the global economic benefit
- p is the sale price for each piece
- c_v are the variable costs for each piece

To estimate the amount of costs for the RFId implementation in tool management, the following costs have to be considered: (i) number of readers, (ii) number of tags (one for each tool holder cone), (iii) software development.

Finally, in order to evaluate the viability of the investment, economic savings and the pay back time can be adopted, leveraging on its widespread diffusion in the common practices of companies.

5. The Case Study

The case study refers to two different plants belonging to the same company, which produce dies and equipment for aluminium extrusion. Each die is designed, built and delivered according to the specific customer's specifications. In Figure 2, a sample of the manufactured dies is depicted.

Figure 2. Example of manufactured dies

The production process is made up by four main macro phases:

1. *Cutting and turnery area*: the billets, in tempered iron, are taken from the stock room and cut in circular sectors; after this phase, the circular sectors are turned on a lathe to create the external profile.
2. *Job shop area*: in this phase, by means of numeric control machines (with horizontal axis), the internal profile of the dies is produced.
3. *Heat treatment*: The dies are sent to a different company which carries out a heat treatment;
4. *Finishing Area*: different machine tools (with vertical axis) provide the finishing manufacturing process to complete the dies.

The two production facilities are totally interchangeable in terms of technological capability of the machining centers and product portfolio mix. In both cases, a transfer line is made up by ten CNC machines and production planning is based on a one-of-a-kind approach or on small batches (each die for aluminium extrusion is composed by 2 or 3 different parts). However, while the first plant carries out a traditional tool management process, the second facility adopts RFId technology to manage the manufacturing process on machine tools. In the latter case, the line is equipped with an automatic catenary of tools equipped with a RFId reader (Figure 3).

Figure 3. RFId Reader in tool catenary

In the first plant, each machine is managed on a singular basis: the part program is read by the operator to evaluate which tools are needed for the manufacturing and whether these tools are already present in the rack. After these operations and before the beginning of manufacturing, the operator carries out machine set up and tool presetting. In overall, there are about 3.000 tools, namely approximately 300 for each machine.

If tools are not in the rack, the operator has to assemble the missing ones and place them in rack checking the correspondence between tool position and the kind of tool. Moreover, if the tools are already present but located on different machining centers, it would be necessary to identify their location and provide the correct positioning on a better equipped machine. Another relevant task for the operator is the assessment of the level of tool wear. Finally, since the manufactured pieces are sometimes very similar to each other (they could differ only by a single work of a single tool), the margin of error for selecting the correct tool happens to be very relevant.

In the second plant, for each machine of the production line the operator uploads the part program files, structured according to Figure 4, in order to guarantee more control to the software supervisor in the selection of the tools. At the same time, the software supervisor has more flexibility to allocate the workpieces to the machine that has the most numerous available tools. In the job-shop there are 2500 tools (approximately 250 for each machine) with possibility of redundancy (i.e. two or three items of the same tool).

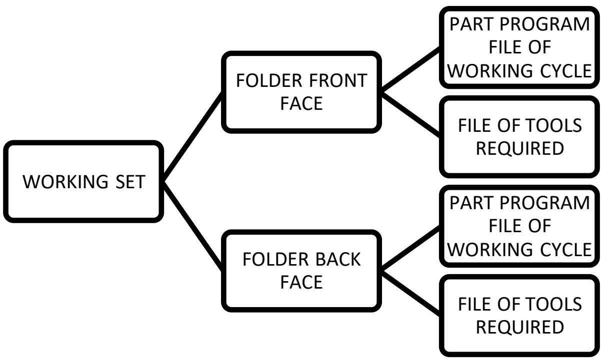

Figure 4. File structure for the working cycle

Using the information taken in Table 3 for these companies and the characteristics of this production system as reported in Table 4, the inefficiencies observed in the first plant, where there is a traditional management of tools without RFId, can be summarized as follows: a) increasing number of tools; b) relevant down times; c) reduced machine availability; d) possibility of error in the association between the tools and the position of the tools within the rack; e) increasing of probability of broken tools during the manufacturing.

In particular, there is a consistent occurrence of production downtimes due to routinary operations management activities (e.g. tool search, set up operations, presetting, tool loading and unloading), due also to data entry operations. These downtimes reduce remarkably the productivity and contribute to the increase of energy expenditure. In addition, the machine auxiliaries consume energy during stand-by times.

In the plant using RFId technology, the information written in the tags and managed automatically by the supervisor software are shown in Table 5.

DATA AVAILABLE IN THE RFId	DESCRIPTION
Identification number	It allows to uniquely identify a tool holder cone and its inserts
Duplicate	It defines the number of the duplicate tool that is in catenary
Position in catenary	It defines the last position that the tool had in catenary before being discharged
Residual life (expressed in minutes)	It represents the useful life of the tool (this information is initially written by the operator during the presetting phase and stored by the supervisor during the loading phase and subsequently updated by the supervisor itself during working cycle)
Threshold value	It is a value set by default which indicates the threshold of useful production life; when this threshold value is achieved, the tool is discharged by the operator who changes the inserts
Radius	Geometric dimensions related to the nominal radius that should have the insert
Speed	It gives the speed that the spindle must have during processing with the selected tool
Maximum size	It is a field which indicates if the tool is "large" or "small"; this information enables the supervisor to select the right position in catenary

Table 5. Data available in the RFId tag

Following the scheme proposed in Table 3 and considering only those parameters which were considered relevant for the analyzed case, a quantitative assessment of the main benefits for each machine has been performed, as reported in Table 6. These values are mean values registered during six months in the two production sites.

Key parameters	With RFId	Without RFId
Number of accidental events *(events/month)*	8	15
Mean Down time for accidental events *(minutes)*	45	60

Mean Down time for machine set up operations and data entry*(minutes)*	1	10
Mean down time for tool management (search tools, presetting, tool loading in catenary...) *(minutes)*	2	6
Units manufactured *(units/day)*	9	8
Scraps*(units/month)*	3	12
Number of tools	2500	3000

Table 6. Significant parameters for the case study

The comparison of these two production systems shows quantitatively the difference between the two cases. In particular, the number of accidents decrease since the geometric data are inserted automatically by the presetting station, and not manually by the operator that could make errors during the data entry phase. For the same reason, the time spent for the set up and data entry operation is reduced. The time for searching tools, for presetting and loading them in catenary decreases because the tools are automatically and univocally identified by the information stored in the tag and read by the reader. The number of units manufactured increases due to a growth of available time of the machine tools. Furthermore, the number of scraps is reduced because the useful life of tools is monitored and the probability of using a worn out tool is very low.

The opportunity of having information about available tools in the company enables a better planning of the overall manufacturing process (managed by the supervisor software) and the possibility to adopt adequate policies of tool sharing. In the case study, the application of RFId tags on tools has determined a 16% reduction of tools (2500 tools vs 3000 tools).

Finally, it is possible to evaluate quantitatively the savings and the benefits due to the application of RFId technology by comparing the two sister plants. To summarize these savings and benefits, the OEE index has been calculated in terms of availability, performance, quality values in the two companies (Table 7) using the same formulas shown in Section 4. All the indicators are referred to the machine tools of the two production systems. In overall, we can compute an overall increase of 29% in the OEE value.

Indicators	With RFId	Without RFId	Δ
Availability	**97%**	**89%**	**+ 7%**
Performance	**95%**	**84%**	**+ 11%**
Quality	**99%**	**95%**	**+ 4%**
OEE	**91%**	**62%**	**+ 29%**

Table 7. OEE results with and without RFId application

To evaluate quantitatively the economical savings the other available data are:

- Mean time for scheduled production by month (Ttot): 672 hours (the production is in three shifts)
- Mean time to work a single piece on machine tool (tc): 150 minutes
- Ideal target of pieces produced by day (#pcstarget): 9,5 pcs/day
- Profit margin for each piece sold: 300 €/pc

According to formulas (3), (5) and (7), the increase of number of pieces manufactured and the related Δ profit can be computed. The results are shown in the following Table 8:

	Δ	Δpcs/month	Δ profit margin/month
Availability	**+ 7%**	**20**	**6.000 €**
Performance	**+ 11%**	**29**	**8.700 €**
Quality	**+ 4%**	**6**	**1.800 €**
		55	**16.500 €**

Table 8. Comparison between the two companies: total savings where RFId is applied

To evaluate the return of investment, where the RFId is adopted, the following cost items have to be taken in consideration:

- Cost for each tag: 20 euro (*2500 tags)
- Cost of Reader: 2.000 euro (*4 readers)
- Cost of software supervisor: 40.000 euro

Considering all the cost items, the overall investment amounts to 110.000 euro. Conversely, the annual savings deriving from the application of RFId can be estimated to 195.000 euro. As a result, in this specific case the pay back period is less than one year (about 6 month).

6. Conclusions

The paper provides a study on the relevance of tool management in a company, focusing in particular on the inefficiencies that arise due to a lack of good management practices. To overcome these problems, the paper proposes a model for a qualitative and quantitative assessment of the potential benefits deriving from the application of RFId identification tags on machine tools.

The related case study has enabled a direct comparison between two similar companies where the only difference is how the tools are managed. It proves how RFId-based automatic processes can guarantee a higher accuracy than the manual process with significant potential in terms of reduced time throughout all operations in tool management and less occurrence of human errors.

From a managerial perspective, the model allows an evaluation of the benefits of RFId implementation in terms of economic savings. This is quite important, since one of the main issues in the adoption of RFId on an industrial scale, with often a strong dialectics between technology providers and potential industrial users, resides on the lack of an objective and clear evaluation of the pros and cons coming out of its implementation. The paper tries to fill this gap in order to provide a model, which could support practitioners in evaluating and taking robust decisions on the investment in RFId technologies for moveable assets. However, if the qualitative benefits are quite evident, the proposed model has to be adapted to the specific kind of manufacturing production. Indeed, the limit of this model is due to different parameters and variables that change for a production system especially when an economical evaluation is carried out: for example in some contexts the production costs and savings can be more evident if the scraps are reduced, in other contexts if the down time is lessened. In the same way, the cost structure can be different and the pay back of RFId application can change.

Open questions for further research topics are related to the: (i) validation of the model in other case studies to find any more variables that are not included; (ii) to create a benchmark analysis of the possible savings in different application of RFId in tool management; (iii) possible implementation of a benchmark analysis among different companies that have similar production typologies.

For all these reasons, the proposed model can be used as a starting method to estimate the savings but it should be adapted considering the kind of production system and the related specific cost structure.

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