A WEB-BASED HOLONIC INVENTORY MANAGEMENT SYSTEM FOR TOOL AND DIE WORKSHOP OPERATIONS

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ABSTRACT

Raw material inventory is a major element of the working capital of many organizations. Hence its proper control is crucial for the profitability of the organization and development of surrounding communities. The sudden unavailability of raw material inventory for production can be a great operational disturbance which results in delivery delays, customer dissatisfaction and loss of market share. The paper presents a Holonic Inventory Management System for managing raw materials utilized by Tool and Die workshops forming an industrial cluster in the Western Cape Province of South Africa. The proposed architecture consists of five autonomous holons which are utilized to analyze the inventory levels, select the optimum inventory model for replenishing stocks and analyze suppliers’ quotes for those raw materials thus establishing the best policy for replenishing stocks from the best suppliers in a distributed manufacturing environment. The holons communicate with each other via eXtensible Mark-up Language (XML). Results of a valid simulation model established the efficacy of the system.

Keywords: Inventory Management, Holons, Distributed Manufacturing, Holarchy

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1 INTRODUCTION

Raw material inventory is an essential part of any production system. Adeyemi and Salami [1] cited that low inventory may lead to stock outs which result in production halts, inability to meet deadlines, customer dissatisfaction and loss of goodwill. On the other hand, high inventory levels block huge capital which is a scarce resource for any organization. Mahapatra [2] alluded to the fact that as much as twenty percent of total investment may be tied up in inventory for most companies.

In the Tool, Die and Mould-making (TDM) industry, due date reliability and product time to market have been identified as key success factors for global competitiveness by Schuh et al. [3] and Choi et al. [4]. Customers demand customized quality products at less cost and fast delivery. Hence there is a need for firms in the TDM industry to increase their flexibility and speed. Unfortunately, the TDM sector in South Africa has been currently facing a lot of challenges in satisfying customer demand on time. This is mainly because of the operational disturbances the sector has experienced which slow down production as identified by Dewa in [5]. Manual fixed review inventory systems are still being employed by most firms in the sector to monitor stock levels of available raw materials for production. This has resulted in frequent stock out of raw materials leading to either lost sales or back orders.

It is against this background that a web-based Holonic Inventory Management System was developed for the South African tooling industry. A case study for firms in the Western Cape Province forming an industrial cluster was used. The paper presents the architecture of this proposed system which consists of five autonomous holons; the Order Holon, Purchasing Holon, Supplier Holon, Inventory Level Holon and Bill of Materials Holon. The system will aid in the proper control of raw material inventory used in the sector thus improving the operational excellence of the order processing function with the objective of minimizing production lead time.

The organisation of the paper is as follows: firstly the different processing strategies and inventory policies used in the TDM sector are discussed, then the proposed Holonic Inventory Management System architecture is presented together with algorithms for each holon and lastly there is a presentation of the system’s simulation results to support system efficacy.

2 LITERATURE REVIEW

2.1 Processing strategies in South African Tool Die and Mould making sector

The Tool, Die and Mould-making (TDM) industry in South Africa is a critical support industry to the broader manufacturing industry bridging the gap between product development and production. According to Geyer and Bruwer [6], about 90% of firms in the South African TDM sector constitute of Small, Medium and Micro Enterprises (SMMEs) with the Automotive and Packaging industries being their biggest clients. Canis [7] highlighted that dies and moulds are used in the mass production of other products while tools are precision devices employed for cutting or shaping metals and other materials. According to Choi et al. [4] the process strategy employed in the making of moulds and dies is usually make-to-order and assemble-to-order with many firms collaborating in the production. Figure 1, which is an adaptation from work by the United States International Trade Commission [8] supports this notion by illustrating the manufacturing steps involved in the production of moulds and dies. Raw materials are only procured after the clients (manufacturers) are in agreement with the Tool and Die makers on the price and the design drawings generated.
The strategy adopted in the production of machine tools is usually on a make-to-stock basis. This is mainly because machine tool buyers normally demand and expect very rapid delivery times. Hence, machine tool builders have historically stocked finished goods inventory of standard tools in the sales channel. This implies the need for raw material inventory used in making tools to be consistently available in stock. However, stocking raw material inventory may negatively impact the firm’s cash flow while also being financially risky as the overall tool demand is uncertain. These factors are driving toolmakers to seek efficient business models that facilitate “Just in Time” delivery for both standard and custom engineered implements. Figure 2 illustrates the process of tool fabrication. Raw materials are stored in stocks so that they are available for the manufacturing of the tools which is done on a batch production basis.

Figure 1: Mould and Die manufacturing process
2.2 The strategic importance of raw material inventory

The effective operation of a production process depends on the proper management of raw materials, from the purchasing through final processing up to packaging. Evans et al. [10] broadly defined inventory as the stock of goods, commodities or other economic resource that are stored or reserved at any given period for future production or for meeting demand. The types of inventory present in industry are raw material, labour, work-in-process, component parts and finished goods. According to Lee [11], inventory control decisions are tactical decisions, because they involve relatively short time horizons and support strategic goals and objectives. The inventory level of any enterprise resource is determined by two key decisions:

1. When to place an order for production/procurement?
2. How much to procure or to order?

Figure 3 illustrates all supporting decisions made in inventory control and the factors contributing to the decision.
Figure 3: Inventory decisions and factors (Lee, [11])

However, Ballou [12] suggested that the total inventory cost is another factor worth considering while taking inventory decisions. He cited that inventory carrying costs typically range from 20% to 40% of most firms’ annual expenditure. Wallin et al. [13] also added that lead-time is another key factor to consider when making inventory decisions.

In any organization, the Purchasing Department is usually responsible for making these decisions when procuring raw materials. Choudhary and Shankar ([14, 15]) described these decisions further as those involving lot-sizing, supplier selection and carrier selection. Lot sizing involves determination of the order size and procurement period. The suppliers’ offers and transportation options are also evaluated and used in making this decision thus rendering it a multi-criteria decision making problem.

The control of raw material inventory pays a lot of dividends in a number of ways. The functions served by inventory control according to Lee [11] are:

1. To keep enough stock so as to meet anticipated customer demand: sufficient levels of stock must always be maintained. This reduces the occurrence of late deliveries, dissatisfied customers, back orders, lost sales and production bottlenecks.

2. To protect against stock outs: delayed deliveries and unexpected demand increase. Delays can be due to weather conditions, supplier stock outs and quality problems.

3. To smooth shop floor requirements: firms that experience seasonal patterns in demand often build up inventories during off-season periods. These are often called off-season inventories.

4. To take advantage of quantity discounts: in most cases, ordering large quantities results in the firm enjoying discounts for the purchase which will aid in boosting up the profit margin.
2.3 Inventory Management policies adopted in the TDM sector

Inventory management policies support the making of inventory decisions in an optimal manner. According to a study conducted by Pillai [16] the identified inventory control models (policies) used in most machine tool manufacturing SMMEs are the Economic Order Quantity model, Thumb rules model, Always Better Control (ABC), Computerized Materials Requirements Planning (MRP) systems and the lot-for-lot (Just-In-Time) model.

The Economic Order Quantity (EOQ) model is a widely used inventory decision model. In the EOQ model, the order quantity, reorder level and reorder date can be established with the overall objective of minimizing total inventory costs (Adeyemi and Salami [1]). The Economic Order Quantity has been defined by Monks [17] and Schroeder [18] as the ordering quantity which minimizes the balance cost between inventory holding costs and re-order costs. Lucey [19] stated the assumptions associated with the EOQ model as:

1. The demand rate for the products is known.
2. The price of products per unit is constant.
3. There is no possibility for stock outs.
4. There is a constant stock holding cost and ordering cost.
5. Stock replenishment is done instantaneously and the whole batch is delivered at once.

The EOQ model is therefore a deterministic model where it is assumed that the demand rate is known. The main benefit of using the EOQ model lies in its simplicity to determine the reorder quantity and period in an optimal manner. Table 1 illustrates the derived expressions used in calculating parameters using this methodology. These parameters are the Inventory holding cost, order cost, stock out cost and the order quantity (for replenishing stocks).

Table 1: EOQ, Economic Production Lot size and Back Order Inventory Model Equations (Evans, [10])

<table>
<thead>
<tr>
<th>Model</th>
<th>Holding Cost</th>
<th>Order Cost</th>
<th>Stock out Cost</th>
<th>Order Quantity, $Q^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOQ Model</td>
<td>$\frac{1}{2} QC_h$</td>
<td>$\frac{D}{Q} C_o$</td>
<td>-</td>
<td>$\sqrt{\frac{2DC_o}{C_h}}$</td>
</tr>
<tr>
<td>Economic Production Lot Size</td>
<td>$\frac{1}{2} \left(1-\frac{D}{P}\right) QC_h$</td>
<td>$\frac{D}{Q} C_o$</td>
<td>-</td>
<td>$\sqrt{\frac{2DC_o}{1-\frac{D}{P}C_h}}$</td>
</tr>
<tr>
<td>Back Order Case</td>
<td>$(Q-S)^2 \frac{C_h}{2Q}$</td>
<td>$\frac{D}{Q} C_o$</td>
<td>$S^2 \frac{C_o}{2Q}$</td>
<td>$\sqrt{\frac{2DC_o}{C_h} \left(\frac{C_h + C_b}{C_b}\right)}$</td>
</tr>
</tbody>
</table>

Variable definitions:
- $D$ = Annual demand for a material (units per year)
- $Q$ = Quantity of material
- $S$ is the backorder supplies
- $C_h$ = Cost of carrying one unit in inventory for one year
- $C_o$ = Average cost of implementing an order of materials
- \( TIC \) = Total annual stocking cost for a material
- \( d \) = Rate at which units are used out of inventory (units per time period)
- \( p \) = Rate at which units are supplied to inventory
- \( C_b \) = Backorder cost

According to Choudhary and Shankar [20], Material Requirement Planning (MRP) involves procurement lot-sizing decisions to be made when demand is both stable as well as lumpy and the approach is spread over a finite time horizon. Computerized MRP systems have been adopted to support this approach. The main benefit of using this model lies in the computational speed computers offer in arriving at the required solution.

Swann [21] described the Thumb Rules model as a simple-minded approach. Decisions made using this approach are based on instinct or gut feelings rather than calculated parameters and guided approaches.

Chukwuemeka and Onwusoronye [22] observed that another important aspect of inventory management is that items held in inventory are not of equal importance in terms of money invested, profit potential, sales or usage volume, or stock out penalties. Therefore, a more reasonable approach would be to allocate control efforts according to the relative importance of various items in inventory as observed by Martin and Stanford [23]. The ABC model employs a prioritization approach where raw materials are split into three categories, A-items, B-items and C-items. Berniker and McNabb [24] indicated that in the ABC classification, inventory items are usually ranked based on certain selected criteria and labeled A (Very important), B (Moderately important) and C (Least important). Hence ABC Analysis provides an important analytical framework for inventory management. However, Prasad [25], Hossein and Ajeet [26] observed that the actual number of categories may vary from organization to organization, depending on the extent to which a firm wants to differentiate its control efforts. When using the Just-In-Time inventory management model (lot for lot), raw materials are ordered based on the current net requirements required for the processing of an order.

### 2.4 SHORTCOMINGS OF EXISTING INVENTORY SYSTEMS

When it comes to inventory management, it pays to be precise. This is especially essential when the transactions involved in procuring raw materials are complex and numerous. Due to the wide range of products it produces, the tool and die industry is characterized by a huge variability of requirements and specifications in each final product. Figure 4 represents the nature of transactions involved in order processing in the tool and die sector. A lot of data and information is exchanged between tool makers and their raw material suppliers or clients (manufacturers). To arrive at an optimal decision, numerous enquiries and computations need to be established making the process time-consuming and cumbersome. This creates a need for highly agile productive structures with respect to the production technology which facilitate process planning, project management, management of raw materials, information flow and optimal decision making.

The main shortcoming of the inventory models outlined in the previous section is that they are deterministic and static in decision making. This makes them incapable of addressing the dynamicity of events involved in the TDM sector’s transactions. Toolmakers are now looking for new approaches and business models for the flexible and rapid design of products to remain competitive. Choi et al. [4] cited that nowadays the manufacturing of moulds and dies has become a collaborative venture with many companies (with different skills and expertise) in the TDM sector teaming up to design and manufacture of different products. Therefore applications enabling the co-operative use of data by firms in geographically distinct locations for supporting simultaneous and collaborative team work are now an emerging requirement. This has resulted in an increasing need for collaborative systems which support the tool and die manufacturing industry. This paper presents one such system for inventory management of raw materials.
2.5 POTENTIAL OF WEB-BASED HOLONIC INVENTORY MANAGEMENT SYSTEMS

A promising way of managing raw materials utilized by firms operating in a distributed manufacturing environment is the use of web based inventory management systems. Karim et al. [27] highlighted that a web-based inventory system facilitates instant tracking, real-time monitoring and update of information concerning raw materials, tools and equipment utilized in manufacturing. Information which is timely and well presented is the key to effective decision making. Pecas and Henriques [28] highlighted that with a web based inventory system in place, there is real-time availability of specific information which flows in the sector’s value chain (suppliers and clients), and remote access to information which supports the collaboration of firms. This approach eventually replaces the traditional manual methods of inventory management thus improving the operational performance of the order processing function in a tool and die workshop.

Other scholars and researchers have developed web based applications in different industries to facilitate inventory management. Chan [29] developed an inventory system using web-based technologies for steel nuts inventory, while Siong et al. [30] designed an inventory analysis tool for stock availability optimization for a National Heart Centre in Singapore. Blauth and Ducati [31] presented a web-based system for monitoring, research and management of grape production in Brazil while Karim et al. [27] developed an inventory system for managing tools and equipment in a university library.

However, to facilitate instant decision making in a collaborative manufacturing environment, the paradigm of holonic manufacturing has been chosen in the design. According to Seidel and Mey [32] holons are autonomous, intelligent and cooperative computerized entities capable of transforming, transporting and validating information or physical objects. A group of cooperating holons is called a holarchy and in this paper the inventory management holarchy consists of five autonomous holons which are the Order Holon, Inventory level Holon, Bill of Materials Holon, Supplier Holon and Purchasing Holon. These entities assist in the decision
making process during the inventory control activities of the proposed architecture. Figure 5 illustrates how a web-based inventory management system can significantly improve the transactions involved in the entire supply chain involving customers, manufacturers, tool and die makers and suppliers.

![Diagram of inventory management system](image)

**Figure 5: Potential of Web based Inventory Management Systems**

3 RESEARCH METHODS AND MATERIALS

The study is confined to the Tool and Die industry in the Western Cape Province of South Africa who will be the users of the proposed system. As such, structured questionnaires were used as a means for data collection. The purpose of the questionnaire survey was for establishing the number of firms with inventory management policies and the types of inventory management policies and systems in the tool and die industry in South Africa. The questionnaire was developed in two stages which included a pilot study to test and refine the data collection instrument and a formal study to collect the required information.

In the questionnaire survey, a targeted population size of 150 tool rooms forming an industrial cluster in the Western Cape region of South Africa were selected for investigation. Of these, 102 firms agreed to take part in the study making them the sample size for analysis. A total number of 102 questionnaires were sent out to the organizations participating. A follow up on receipt of the questionnaires was done via telephone calls and emails. Of the 102 questionnaires, 71 were returned; hence the response rate was 70%, which is acceptable. Among the 71 returned for analysis, only 58 were in an acceptable format (13 were spoiled or inadequately filled). The inventory policies cited in section 2.3 of this paper were used as variables of the study. Questions pertaining to the adoption of these policies and frequency of stock outs and backorders were asked. During the system development stage, PHP (Preprocessor Hypertext Processor) was used for the development of the web application and MySQL was employed for the backend database. Lerdorf et al. [33] recommended the use of PHP and MySQL in developing web-based applications due to their capabilities, flexibility and modularity. The Java Agent Development Environment was employed to develop the holons utilized by the application.

4 RESEARCH FINDINGS AND SYSTEM ARCHITECTURE
4.1 Questionnaire Survey results

Table 2 summarizes the findings of the questionnaire survey. 34% of the investigated firms had no inventory practice in place while the remaining 66% adopted some form of inventory practice. 88% of the firms used manual fixed review inventory policies with only 12% having a computerized system in place.

Table 2: Inventory policies adopted in TDM sector

<table>
<thead>
<tr>
<th>Type</th>
<th>Inventory Management policy practice employed</th>
<th>Number of firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No practice</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Thumb rules</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>EOQ (Economic Order Quantity)</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>ABC (Always Better Control)</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>Computerized Inventory Management</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>Just-In-Time (JIT)/ Vendor Managed Inventory (VMI)</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>58</strong></td>
</tr>
</tbody>
</table>

Out of the surveyed 58 firms, all of the companies explicitly stated that inventory management was important for a firm’s successful performance. 90% of firms confirmed the occurrence of back orders and lost sales during production at some points in the previous year.

5 PROPOSED INVENTORY CONTROL SYSTEM HOLARCHY

The goal of the proposed system is to manage and control raw material inventory so as to minimize the number of stock outs which occur during production. A main server contains the Inventory Control Holarchy which integrates the entire supply chain. Figure 6 illustrates the Interaction model of the Inventory Control Holarchy.
5.1 Order Holon

When a client places an order for tools, moulds or dies, an Order Holon (OH) is immediately created. This basic Holon carries information regarding the customer’s specifications on the products they require. Information concerning product dimensional tolerances, sizes and due dates is carried by the Holon. The Order Holon transfers this information to the Bill of Materials Holon (BOMH).

5.2 Bill of Materials Holon

Using the data received from the Order Holon, this staff Holon computes the bill of materials required to fulfil the incoming order. It computes these material requirements together with the buffer stock required in case of emergencies. This information can be used by other Holons in the system for further decision making.

5.3 Supplier Holons

These holons represent the different possible suppliers of raw materials in the production chain. Suppliers of raw materials used by tool and die makers can log on to the system and provide...
information regarding their catalogue of products together with their corresponding prices. Additional information on raw material availability, delivery lead time and discount offers can also be added by the different suppliers as a way of increasing their chances to be the chosen raw material providers.

5.4 Inventory Level Holon

The Inventory Level Holon is a staff Holon which carries out the task that a warehouse supervisor conducts in monitoring stock levels of the available raw materials. Once the reorder level (as prescribed by a selected inventory policy) is reached, the Inventory Level Holon communicates with the Purchasing Holon to place an order for raw material replenishment from the best selected supplier. This Holon also receives signals and messages from the Bill of Materials Holon regarding materials required to process an order. This will be an initial probe to check for the availability of the required materials.

5.5 Purchasing Holon

The Purchasing Holon conducts the duties which a Purchasing department in a firm would do. The function of this Holon consists of making three critical decisions in the procurement of raw materials required. These decisions are the lot-sizing decision, supplier selection and transporter selection. Using information received from the Inventory Level Holon, the Purchasing Holon communicates with different Supplier Holons to establish the suppliers with the required materials. Different Suppliers bid for the order by providing their quotes of the required materials together with lead time and delivery information. The Holon then selects an optimal inventory policy with the objective of minimizing the inventory and shortage costs while simultaneously selecting the best supplier for the replenishment. A purchase order is created and transferred to the selected Supplier Holon to finalise the transaction. The raw material is delivered before a stock out occurs. The holons mimic intelligent functions done in an organization. Based on the operations shown in Figures 1 and 2, a Value Stream Map for processes in Tool and Die manufacturing was developed and is illustrated in Figure 7.

![Figure 7: Tool and Die Operations Value Stream Map](image)

The production of moulds and dies follows a pull system as illustrated in the Value Stream Map. To achieve the holarchy goal of minimizing total inventory costs and number of lost sales, the individual holons have to make decisions based on set criteria. The functional flow diagram representing the decisions made by the individual holons during order processing is shown in Figure 8. The holons communicate with each other by exchanging XML files containing data useful for making the optimal choices and execute tasks based on those decisions.
6 CASE STUDY SIMULATION RESULTS

Based on the Value Stream map in Figure 7, a valid simulation model for Tool and Die operations was developed to compare results generated by the old (fixed review) inventory system in comparison to the use of the proposed web based holonic inventory management system. The model was designed for steel rod raw materials used in the production of machine shafts. Experiments were run for a replication length of 120 days and the key performance measures were the total inventory costs and the number of backordered sales. Rockwell Arena software (Research version) was used in the model logic development and numerical experiments for the two scenarios. The developed model logic is illustrated in Figure 9. It consists of a three sub-models for raw material demand, inventory replenishment decision making and model data sections. Results shown in Figures 10 and 11 reveal that the number of lost sales(backorders) and total inventory holding costs are significantly reduced by 19% while the number of lost sales were significantly reduced from 143 to 47 (67%) by adopting the proposed Holonic Inventory management system. The inventory holarchy was developed using JADE and linked to the model logic via TCP/IP protocols.
Figure 9: Model Logic for Raw Material Inventory system

Figure 10: Performance Measures for Fixed review Inventory Management

Figure 11: Performance Measures for Holonic Inventory Management
7 CONCLUSION AND RECOMMENDATIONS

In today’s dynamic environment, inventory control is not just an advantage but also a necessity. Proper raw material inventory control promotes firm profitability and sustainability in a cutthroat business environment. The paper presents a new approach for managing raw materials utilized by firms in the Tool and Die industry operating in a distributed manufacturing framework. The proposed system will help eliminate some of the operational disturbances the sector has experienced in the past. Further work can be done in the extension of the system to other manufacturing functions like Order Processing, Materials Requirement Planning and Capacity utilization.

8 DECLARATION

This paper was done in partial fulfilment of a Ph.D. study in Industrial Engineering on the Development of a Holonic Control System for the Tool, Die and Mould-making Industry in South Africa conducted by Mncedisi Trinity Dewa.

9 REFERENCES


