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Simulating Economic Order Quantity and Reorder Point Policy for a Repairable Items Inventory System

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Abstract**—**Repairable items inventory system is a management tool used to incorporate all information concerning inventory levels and movements for repaired and new items. This paper presents development of an effective simulation model for managing the inventory of repairable items for a production system where production lines send their faulty items to a repair shop considering the stochastic failure behavior and repair times. The developed model imitates the process of handling the on-hand inventory of repaired items and the replenishment of the inventory of new items using Economic Order Quantity and Reorder Point ordering policy in a flexible and risk-free environment. We demonstrate the appropriateness and effectiveness of the proposed simulation model using an illustrative case problem. The developed simulation model can be used as a reliable tool for estimating a healthy on-hand inventory of new and repaired items, backordered items, and downtime due to unavailability of repaired items, and validating and examining Economic Order Quantity and Reorder Point ordering policy, which would further be compared with other ordering strategies as future work.

Keywords**—**Inventory system, repairable items, simulation, maintenance, economic order quantity, reorder point.

I. Introduction

INVENTORY systems of repairable items are more complex than conventional inventory systems. They involve on-hand inventory of both new and repaired items. Those repaired items are faulty ones, which are less expensive to repair than to replace by new ones. Such repairable items are overhauled and stored in an on-hand inventory of repaired items rather than discarded. This inventory system is problematic as it is concerned with the optimal on-hand inventory of the repaired and new items, backordering, and availability. Few solution approaches have been implemented in practice, and no single model has addressed these obscuring issues [1].

Production systems are usually concerned with converting inputs such as raw materials, manpower, and processes into products or services that satisfy customer needs. The primary outputs of the production systems are finished products or services, and the secondary output is degraded or failed items. This secondary output generates demand for maintenance [2].

Maintenance systems play a key role in industries to achieve firms' missions, strategic objectives, and profit targets [3], [4]. Maintenance systems are responsible for maintaining, repairing, and overhauling mechanical items for production departments. Maintenance departments are also responsible for keeping a healthy stock of repaired and new spare parts in the inventory. They must conduct timely procurement of new spare parts and timely repair of repairable items. The timely repair that a production system requires is essential for the continuation of operations and avoidance of lost productions. Maintenance systems need to manage their spare items demand and supply effectively and efficiently as well as managing the on-hand inventory of repaired items.

Additionally, maintenance systems also take care of the maintenance of all faulty repairable items coming from production systems. The repairable items inventory management of a firm can be enhanced by overseeing its inventory level for both new and repaired items, the time required to undergo various processes that are involved in the procurement of new repairable items, and the repair of faulty repairable items.

Firms face problems of managing repairable items inventory levels and having the correct inventory levels of both repaired and new spare parts at a low cost. Firms also face problems in deciding the best ordering policy considering the uncertainty of repairable item failure and repair times.

The primary focus of this paper is to address these problems by proposing and describing the development of a general simulation model for imitating the procedure of generating, processing, and repairing faulty repairable items, requesting and procuring new repairable items using lot-for-lot, or Just In Time, ordering policy, and managing both the on-hand repaired and new repairable items in the inventory and repair shop. When the lot-for-lot policy is adopted, new repairable items are ordered based on the exact quantities of the requested items.

Very few researchers have developed exact simulation models, which can be deployed for use in repairable items inventory management [5]-[9]. Nevertheless, as far as the author is aware, no published research has addressed these problems and proposed an approach that models the inventory of repairable items using an in-depth simulation model.

II. Repairable Items Processing

The maintenance system manages an inventory system of repairable items used in production lines. These production lines require repairable items to execute different work orders for preventive and corrective maintenance. Repairable items for preventive maintenance (PM) are replaced by new repairable items, which are taken from the inventory of new repairable items. It is assumed that PM must be carried out using only new items, whereas corrective maintenance would be carried out using either a repaired or new repairable items. It is also assumed that PM items may be overhauled and

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reused for corrective maintenance. Therefore, some of the replaced repairable items may be repaired and added to the inventory of repaired items depending on particular operational conditions. Moreover, repairable items for corrective maintenance (CM) are replaced by either repaired items which are taken from the inventory of repaired items or new repairable items that are taken from the inventory of new repairable items. Depending on the repairability of items, faulty CM and PM items can either be repaired or discarded if not repairable. The flow chart given in Fig. 1 shows the procedure of processing and managing the inventory of repairable items.

Fig. 1 shows that the repairable items arriving from the production system are inspected and sorted into PM and CM items based on whether the work order requires the repairable item for PM or CM. For PM, a new item is taken from the inventory of new repairable items to replace the faulty items required for planned maintenance. Concurrently, the faulty repairable item is checked for overhauling; if the faulty item is unoverhaulable then it will be discarded; otherwise, it is repaired and added to the inventory of repaired items.

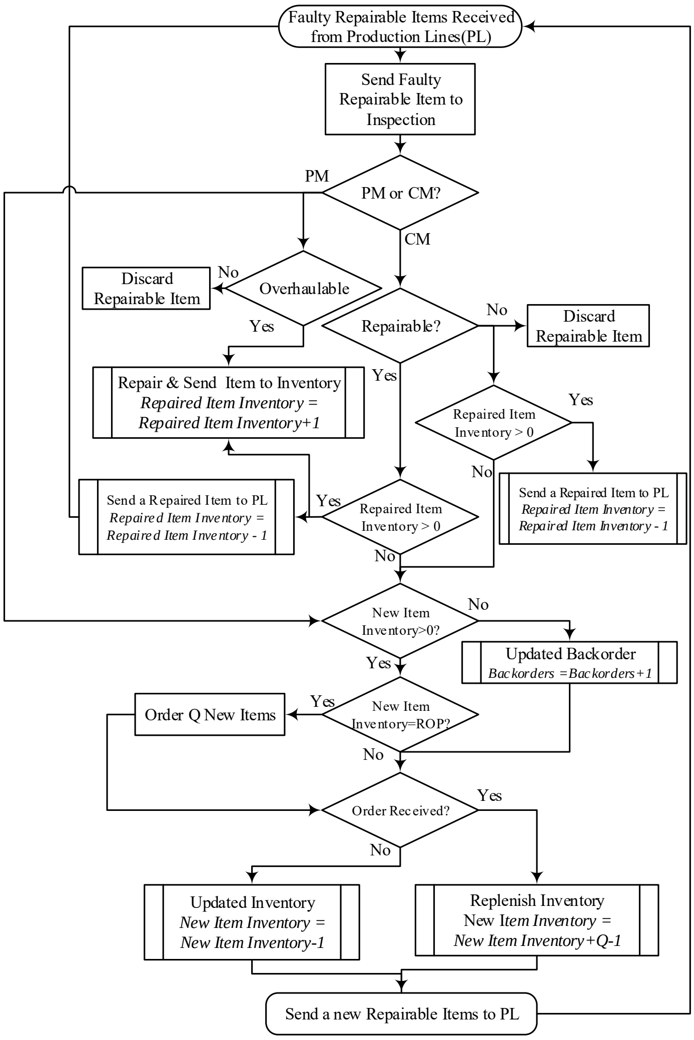

Fig. 1 Flowchart of Processing Repairable Item

As for CM, the faulty repairable item is checked to decide on its reparability. If the faulty item is unrepairable, it would be discarded and then it is either replaced by an item from the repaired item inventory, replaced new repairable item inventory, or backordered. If the on-hand inventory reaches the reorder point (ROP), a requisition for a new replenishment order is processed. The on-hand inventory of repaired and new repairable items are updated each time after sending a repairable item to the production system, and after a replenishment order is received. Moreover, orders are placed based on the with Economic Order Quantity (EOQ) and (Q,R) ordering policy. Upon the arrival of orders, backorders are satisfied and new repairable items are sent to the production lines.

III. Proposed Simulation Model

The developed model is for a repairable items inventory system with EOQ and Q,R ordering policy, and backordering allowance. Prior to presenting the details of the proposed model, we introduce the key parameters that are required for modeling the repairable items inventory system in Table I.

TABLE I
MODEL KEY PARAMETERS

Symbol	Description	Type
IAT	Inter-arrival Time	
NOHI	On–hand inventory of new Repairable items at time *t*	Variable
ROHI	On-hand inventory of repaired Repairable items at time t	Variable
ROP	Reorder point	Constant
EOQ	Economic Order Quantity	Constant
BOI	Number of backordered repairable items at time t	Variable
LT	Lead time	Attribute
RT	Repair time	Attribute
MT	Maintenance type	Attribute
OH	No. of Operating Hours	Attribute
MOH	Max Allowable number of Operating Hours	Constant
NR	No. of Repairs	Attribute
MNR	Max Allowable number of Repairs	Constant
IT	Inspection Time	Attribute
RT	Repair Time	Attribute
RIT	Repairable item type	Attribute
OV	Overhaul-ability	Attribute
RE	Repair-ability	Attribute
DT	Downtime/Backordering Time	Variable
AT	Arrive Time	Attribute
TNOW	Current Time	Variable
NOC	Number of Clones	Attribute
NDI	No of Discarded Items	Variable
NBI	No. of Backordered Item	Variable

The proposed simulation model consists of nine submodels: (1) production lines as input source; (2) sorting and processing faulty repairable items; (3) repair shop; (4) discarding unoverhaulable and unrepairable items; (5) processing new repairable item requests; (6) processing backordered requests; (7) inventory of repaired items; (8) ordering EOQ of new repairable items; (9) inventory of new repairable items.

The first submodel is developed to mimic the production lines from which faulty repairable items arrive. Faulty repairable items arrive individually according to some probabilistic process, and are being handled and processed individually one item at a time. When an item failure occurs, the maintenance action is determined for whether a repairable item is required for PM or CM. This submodel represents the model input source that randomly creates CM faulty items based on a given probability distribution; it also generates PM faulty items based on a predetermined maintenance schedule. A set of attributes such as operating hours, number of repairs, max operating hours, max number of repairs, repair time, lead time, arrive time, etc. is assigned to individual PM and CM faulty repairable items using given probability distributions. This submodel also imitates the events of receiving repaired and new repairable items at the production lines and records the unavailability or downtime of individual items. The submodel always maintains one new repairable item on hand for each planned PM work order. The pseudo-code for the first submodel is given in Exhibit I.

EXHIBIT I
PSEUDO-CODE FOR PRODUCTION LINES SUBMODEL

```
CREATE PM faulty repairable items
 IAT=………;
          ASSIGN
          MT=1; OH=………; MOH=………;
          NR=………; MNR=………; RIT=1; OV=0 or 1;
          IT=………; RT=………; LT=………
          END ASSIGN
           GO TO LABEL: Processing PM faulty Items
CREATE CM faulty repairable
 IAT=………;
          ASSIGN
          MT=2; OH=………; MOH=………;
          NR=………; MNR=………; RIT=2; OV=0 or 1;
          IT=………; RT=………; LT=………
          END ASSIGN
          GO TO LABEL: Processing CM faulty Items
```

If the faulty item is replaced for PM, the submodel checks whether the faulty PM item can be overhauled and used for future CM. If the faulty repairable item is overhaul-able, it is sent to repair shop, otherwise to scrap. Concurrently, the submodel requests a new repairable item. Moreover, if the item is required for CM, the submodel checks whether the faulty item can be repaired. If the faulty repairable item is repairable, it is sent to repair shop, otherwise to scrap. Concurrently, the submodel checks the on-hand inventory of repaired items. If the inventory on-hand is enough, an acquisition is issued to the repaired item inventory to send a repaired item to the production line. If the inventory on-hand of repaired items is zero, the submodel requests to process a new repairable item. The pseudo-code for the second submodel is given in Exhibit II.

The repair shop and submodel that is given in Exhibit III imitates the process of repairing or overhauling the faulty items based on the repair time attribute assigned to individual items in the first submodel. Those repaired items are sent to the inventory of repaired items to be added to the on-hand inventory. Moreover, the fourth submodel is used to record the discarded repairable items. Submodel 4 is described in Exhibit IV.

Using (Q,R) ordering policy, the on-hand inventory of new repairable items must be checked against the ROP as faulty CM and PM items are to be replaced with new repairable items.

For processing new item requests for replacing PM or CM items, the third submodel checks the on-hand inventory of new repairable items. If the on-hand inventory reaches the ROP, a new repairable item is sent to the production line, a requisition for a new replenishment order is processed, and the inventory on-hand is decremented one item. If there are one or more new repairable items in the inventory, a new repairable item is sent to the production line. On the other hand, if there is no inventory on hand, the repairable item is backordered. The pseudo-code for the fifth submodel is given in Exhibit V.

EXHIBIT II
PSEUDO-CODE FOR SORTING AND PROCESSING FAULTY REPAIRABLE ITEMS SUBMODEL

```
LABEL: Processing PM faulty Items
  SIGNAL: Signal Value =1
//for sending an item from New Inventory to PL
  DECIDE
   IF OV=1 THEN
   GO TO LABEL: Repair
   ELSE
   GO TO LABEL: Discard
   END IF
 END DECIDE

LABEL: Processing CM faulty Items
 DECIDE
   IF RE=1 THEN
   DECIDE
     IF NQ(ROHI.Queue) > 0 THEN
     SIGNAL Signal Value =1
 ELSE
     CLONE NOC = 1 Send clone to
 LABEL: Request New Item
 END CLONE
     END IF
 END DECIDE
     GO TO LABEL: Repair
   ELSE
     GO TO LABEL: Discard
   END IF
```

EXHIBIT III
PSEUDO-CODE FOR REPAIR SHOP SUBMODEL

```
Label: Repair
 PROCESS Delay Value = RT
   GO TO LABEL: Repaired Items Inventory
```

EXHIBIT IV
PSEUDO-CODE FOR DISCARDING UN-REPAIRABLE ITEMS SUBMODEL

```
LABEL: Discard
 RECORD NDI = NDI + 1
 DISPOSE
```

EXHIBIT V
PSEUDO-CODE FOR PROCESSING NEW ITEM REQUESTS SUBMODEL

```
LABEL: Request New Items
 DECIDE
 IF NOHI=0 THEN
   GO TO LABEL: Backordered Items
  ELSE IF NOHI = ROP
 CLONE NOC = 1 Send clone to
 LABEL: Request New Item
 END CLONE
 GO TO LABEL: Ordering New Items
 ELSE
   GO TO LABEL: Release New Items
```

After checking the on-hand inventory of repaired and new repairable items to replace a faulty item, either the on-hand inventory of repaired or new repairable items is decremented by 1, or the number of reordered items is incremented by 1.

The PM backorders are accumulated in a queue and they will be replaced with a new repairable item after the arrival of a replenishment order. The replenishment EOQ will take a possibly probabilistic, random with some probability distribution, time to arrive and satisfy any PM and CM backordered items and refill the repairable items on-hand inventory.

The CM backorders are accumulated in a different queue and they will be replaced with a repaired or new repairable items whichever become available on-hand first. It is assumed for simplicity that the PM and CM backorders are filled on a first-in-first-served basis. The numbers of backordered items in PM and CM queues are incremented by 1 each time a request for a new repairable item is unsatisfied, and those numbers are to be decremented once on-hand inventory of repaired or new repairable items become available. This submodel also records the backordering time for individual reparable items. The pseudo-code for the sixth submodel is given in Exhibit VI.

EXHIBIT VI
PSEUDO-CODE FOR BACKORDERING SUBMODEL

```
LABEL: Backordered Items
 ASSIGN
 NBI = NBI + 1
 AT = TNOW
 END ASSIGN
 DECIDE
 IF RIT =1 THEN
 HOLD Backordered PM Item queue:
   IF NOHI > 0 Then
 satisfy PM item requests from queue
 END HOLD
 ELSE
 HOLD Backordered CM Item queue:
   IF NOHI > 0 OR ROHI > 0 Then
 satisfy CM item requests from queue
 END HOLD
 END IF
 END DECIDE
 RECORD DT = TNOW - AT
 DECIDE
 IF NOHI > 0 THEN
 CLONE NOC = 1 Send clone to
 LABEL: Release New Item
 END CLONE
 ELSE
 SIGNAL signal value = 2
 END DECIDE
 DISPOSE close backorder request
```

The submodel of the repaired items inventory that is given in Exhibit V imitates the procedure of receiving repaired items from the repair shop and holding them in a queue until signals or requests are received to send one repaired item at a time to a production line. Those repaired items taken production lines are to be decremented from the inventory of repaired items queue. The pseudo-code for the seventh submodel is given in Exhibit VII.

EXHIBIT VII
PSEUDO-CODE FOR INVENTORY OF REPAIRED ITEMS SUBMODEL

```
LABEL: Repaired Items Inventory
 HOLD Repaired Item queue: wait for signal value = 2
   IF signal value = 2
 Then release one repaired item from queue
 END HOLD
 DISPOSE: Send Repaired Item to PL
```

The eighth submodel processes requests for replenishment orders, which are received when the on-hand inventory of new repairable items reaches the ROP. Each replenishment order is placed with a predetermined EOQ. The time from a new order order is placed until the time that the new repairable items arrive into the inventory is often called the lead time. This submodel mimics the lead time required to receive the new repairable items in the inventory of new repairable items. Once the ordered items are received, the on-hand inventory of new items is incremented by EOQ. Furthermore, the ninth submodel imitates the process of releasing new repairable items to the production system. This submodel also updates the on-hand inventory of new repairable items. The pseudo-code for the eighth and ninth submodels is given in Exhibit VIII and Exhibit IX.

EXHIBIT VIII
PSEUDO-CODE FOR ORDERING NEW REPAIRED ITEMS SUBMODEL

LABEL: Ordering New Repairable Items
PROCESS Place a new order
DELAY Delay value = LT
ASSIGN
NOHI = NOHI + EOQ
END ASSIGN
DISPOSE: Order is received and processed

EXHIBIT IX
PSEUDO-CODE FOR ORDERING NEW REPAIRED ITEMS SUBMODEL

LABEL: Ordering New Repairable Items
PROCESS Place a new order
DELAY Delay value = LT
ASSIGN
NOHI = NOHI + EOQ
END ASSIGN
DISPOSE: Order is received and processed

IV. Illustrative Example

For illustrating the proposed simulation model in Arena software, production lines with one type of faulty repairable items is considered for 30 days, two 8-hour shifts. The lead time (LT) to receive new repairable item is assumed to be seven days. Therefore, the production lines submodel is run for 365 and 5 days, and 10 replications for estimating the annual demand and the demand over 5-day LT as a ROP. The model outputs 5500 as annual demand and 31 as minimum average faulty items respectively. Therefore, ROP is set at 50 and EOQ at 120 repairable items. Moreover, the attributes and input parameters used for this example are given in Table II and entered to submodel 1 as shown in Exhibit X.

TABLE II
Simulation Mode Attributes and Parameters

Attributes and Parameter	Faulty Repairable Item PM	CM
Interarrival Time (*hours*)	8	*Exponential*(3)
Repair Time (*hours*)	*Uniform*(3,6)	*Uniform* (1,4)
No. of operating hours	*Uniform* (1000,2000)	*Uniform* (700,800)
No. of Repairs	*Poisson*(1)	*Poisson*(1)
Max operating hours	2000	1500
Max no. of repairs	6	3

It is assumed that the repair shop operates with one technician two 8-hour shifts a day and the faulty item is considered unrepairable if its operating hours and number of repairs exceed the maximum allowable operating hours and maximum allowable number of repairs.

EXHIBIT X
ILLUSTRATIVE EXAMPLE PSEUDO-CODE FOR PRODUCTION LINES SUBMODEL

CREATE PM faulty repairable items
IAT=8;
ASSIGN
MT=1; OH=UNIF(1000,2000); MOH=2000;
NR=POIS(2); MNR=6; RIT=1; OV=0 or 1;
IT=EXPO(1); RT=UNIF(3,6);
LT=TRIA(1,3,7)
END ASSIGN
GO TO LABEL: Processing PM faulty Items
CREATE CM faulty repairable
IAT= *EXPO*(3);
ASSIGN
MT = 1; OH = UNIF(1000,2000); MOH=2000;
NR=POIS(2); MNR = 6; RIT=2; RE=0 or 1;
IT=EXPO(1) RT=UNIF(3,6);
LT=TRIA(1,3,7)
END ASSIGN
GO TO LABEL: Processing CM faulty Items

The system used to solve the Arena simulation models for illustrative example is Dell Inspiron 15 3000 Series laptop with Windows 10 and Intel(R) Core(TM) i3 6006U CPU at 2.0 GHz processor, 4GB of RAM. Furthermore, the number of replications in the Arena simulation software is set at 10 replications and 10 days warm-up period just to initialize the on-hand inventory of repaired and new repairable items given that the initial values of NOHI and ROHI are set at 32 and zero.

The summaries of the number of created faulty PM and CM items, number of discarded items, number of EOQ orders, average holding times in inventory, average numbers of repairable items in inventory for both repaired and new items, average backordering/downtimes/unavailability, and average number of backordered repairable items are shown in Table III. Downtime or unavailability of a repairable item is measured from the time a faulty item is requested to the time a repaired or new item becomes available in inventory. These outputs are obtained by running the simulation model for 1, 3, 6, 9, and 12 months.

TABLE III
Summaries of Simulation Model Outputs

Rep. Length (*months*)	No. of Created Faulty Repairable Items		No. Discarded	No. of Orders	Average Holding Time in Inventory (*hours*)		Average No of Items Held in Inventory		Average Backordering Time (*hours*)	Average Backordered items
	PM	CM			New	Repaired	New	Repaired		
1	133	182	26	1	218.5	3.1	87.2	1.11	0.35	0.001
2	335	519	74	2	195.3	3.2	55.3	1.11	1.9	0.004
3	485	845	120	3	190.9	3.1	56.1	1.12	2.6	0.003
6	1003	1734	263	7	201.1	3.2	55.3	1.12	3.1	0.003
9	1589	2534	392	10	206.8	3.2	55.5	1.13	3.9	0.002
12	2182	3422	532	14	210.5	3.24	55.7	1.14	4.9	0.003

V. Conclusions

This paper described the development of a simulation model in Arena software. As long as the simulation methods have become promising methods to investigate and optimize real-world processes, the objective of the proposed model is to investigate the use of the EOQ and ROP (Q,R) strategy for ordering new repairable items to replenish the inventory of repairable items in a flexible and risk-free manner.

A case problem of inventory of repairable items along with its simulation model, results, and managerial insights are presented in this research to exemplify the applicability and suitability of the proposed simulation model. The key outcomes are the valuable model for (Q,R) policy, just as building a simulation model into the complex inventory system of repairable items is instructive regardless of results. The proposed model provided promising managerial insights about (Q,R) ordering policy that would further be compared with other ordering strategies as future work. These managerial insights are vital for achieving organizations' objectives, such as estimating the EOQ and ROP based on probabilistic demand, determining the healthy on-hand inventory of repaired and new items in order to minimize the inventory costs and maximize the service levels.

As a continuation of this research work, the author is currently working on developing simulation models for the inventory of repairable items using (S,s) ordering policy to be used for comparative analysis in centralized and decentralized environments.

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