

Interactive Inventory Management Simulation for Teaching and Learning: Developing a MATLAB Simulink Gui for Enhanced Educational Outcomes

M. F. Ismail¹, W. E. W. A. Rahaman^{1,*}, A. A. Rashid¹, N. Nasir¹, M. H. M. Rusli¹, I. Siregar²

¹ Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

² Department of Industrial Engineering, Faculty of Engineering, Universitas Sumatera Utara, Sumatera Utara, 20155 Indonesia

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ABSTRACT

This paper presents the development of Inventory Simulator (InventSim), an application to simulate inventory levels based on the economic order quantity (EOQ) model. InventSim could be used to visualize the effect of the main variables in the EOQ model and could also compare two different scenarios simultaneously to ensure that the central concept in inventory control could be understood by the students with less effort. The development of the simulator begins with the determination of the user requirements. The saw-tooth graph is employed to simulate the inventory level using an equation created based on generalized time-series data of the main points of the saw-tooth. MATLAB is the main platform used to compile the algorithm and the user interface. The application could be used on any personal computer with the assistance of MATLAB Runtime and could be installed without an official license hence easier usage and freedom. The application was introduced to current semester Industrial Management classes on a trial basis only and feedback on performance and satisfaction was obtained through a questionnaire. The increase in rating after the trial usage is the initial positive indicator on the promising capability of InventSim in improving students' understanding of EOQ theoretical knowledge.

1. Introduction

Industrial Management is one of the subjects in the mechanical engineering course offered by Universiti Teknologi MARA [1]. Among the topics on the course is inventory management. Inventory management is the system of work of ensuring that a just quantity of stock is available within a business [2]. Inventory management employs several inventory management models, and economic order quantity (EOQ) is one of them. EOQ is a mathematical model that estimates the optimal order quantity for a particular item based on demand, lead time, and ordering costs [3]. The EOQ helps business organizations ensure that they are ordering the right amount of inventory to meet demand while minimizing their inventory-carrying costs [4]. EOQ also be used to explain and predict the effect of related variables such as product demand, product price and holding cost, on other parameters such as the number of orders per year and total inventory cost per year [5].

*** Corresponding author.*

E-mail address: wanemri@uitm.edu.my

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The EOQ model is used to find the ideal order quantity Q that can minimize the inventory cost of a single product with the assumption that no fluctuation occurs in other parameters such as annual demand (D), setup cost (S), holding cost (H) and product cost (P). Eq. (1) shows the relation of the total inventory cost T_c to the other parameters. When the T_c is at the minimum, the ideal order quantity (Q) can be estimated using Eq. (2) which is established based on the derivative of Eq. (1) concerning Q . Once the Q is determined, the other parameters can be easily estimated. N in Eq. (3) is the number of orders per year. In Eq. (4), T is the time (days) between orders while W is the total working days per year. d in Eq. (5) is the inventory's usage or demand (unit per day). ROP in Eq. (6) is the re-order point, indicating the minimum inventory level to initiate the new order, while lead time L is the time required to replenish the inventory from the time of initiating the order.

$$T_c = \frac{DS}{Q} + \frac{QH}{2} + PD \quad (1)$$

$$Q = \sqrt{\frac{2SD}{H}} \quad (2)$$

$$N = \frac{D}{Q} \quad (3)$$

$$T = \frac{W}{N} \quad (4)$$

$$d = \frac{D}{W} \quad (5)$$

$$R_{OP} = L \times d \quad (6)$$

This topic is important to ensure business continuity, especially in the manufacturing industry, which is relevant to mechanical engineering. Therefore, the students must grasp the essence of inventory management through the EOQ model before getting involved in a more complex inventory management model [6]. The teaching and learning activities could be more effective if case studies could be demonstrated and tested rapidly. Currently, the use of presentation slides has a limited ability to compare the dynamic changes of the inventory level over time for different cases. The plotting of the saw-tooth graph [7] using common software such as Microsoft Excel [8] is not straightforward and troublesome as the available equations are not meant to produce time series data for the inventory level [9].

Typical EOQ calculators can be found on the internet [10] which only calculate the order quantity based on EOQ. However, the available EOQ calculators do not consider other parameters such as lead time, making it unideal to be used in certain conditions [11–12]. Hence, besides the use of equations and estimating the EOQ, it is expected that the students understand the concept and can use the information to make decisions on optimum EOQ in answering related course assessments.

A simulator is a computer-based or mechanical system that replicates the behaviour, characteristics, or functions of a real-world environment, system, or process. In the manufacturing industry where the Industrial Management course is strongly related to, simulators and applications are widely utilized. For instance, a study by Faishal *et al.*, [17] simulated proposed layouts of a sponge

slipper manufacturing factory in Indonesia to solve the material handling challenges. Meanwhile, Jamaludin *et al.*, [18] used MATLAB graphical user interface module to integrate the CAD/CAM software data and a milling machine position controller in MATLAB/Simulink platform for analyzing geometrical accuracy and precision.

Using a simulator to assist teaching offers several benefits in various fields, including education, training, and skill development. Hannel *et al.*, [13] suggest that the use of simulators in education can increase learner motivation and interest in the subject matter. Well-designed simulators can facilitate the transfer of learning from the simulated environment to real-world situations [14, 19–25].

Although some study had been reported on EOQ simulators like Anigbogu *et al.*, [19], the application was developed for small scale and medium enterprise. Thus, the objective of this study is to develop an interactive application to simulate inventory levels (InventSim) based on the EOQ model as a teaching and learning tool for operation management courses in undergraduate mechanical engineering programs. The InventSim would allow users to calculate output parameters based on input parameters and visually compare two scenarios simultaneously. The parameters of the input could be adjusted, allowing for rapid calculation, and viewing of results.

2. Methodology

2.1 Establish design specification of InventSim

The following are the design requirements of InventSim.

- i. Input parameters. All the input parameters can be manipulated to simulate various conditions. The input parameters are D , S , H , W and P .
- ii. Output parameters. InventSim is a calculator that calculates all parameters accurately. The output includes Q , T_c , N , T , d , and R_{op} .
- iii. Saw-tooth graph. InventSim can create a saw-tooth graph as a visual aid to demonstrate the impact of specific parameters.
- iv. Visual Comparison. With InventSim, two different scenarios can be simulated at the same time for easy comparison.

2.2 Visualization Tool Development

Figure 1 shows the saw-tooth diagram representing the relationship between the quantity of an item in the inventory or inventory level (unit) (y -axis) and time (day) (x -axis) according to the EOQ. The diagram results from calculations of economic order quantity Q , the number of orders per year (N), and the time between orders (T) obtained. Each triangle of the tooth represents the inventory level movement of an order cycle (C), which needs at least 3 data: A_j , B_j and A_{j+1} , to form the triangle shape. A_j is the initial point of the N^{th} cycle where the inventory level $q = 0$ at time t_j . B_j is the second point of the N^{th} cycle when the inventory level increases to $q = Q$ because the order is fulfilled at the same time (day) t_j as A_j . A_{j+1} is the third point of the N^{th} cycle when the inventory level becomes $q = 0$ due to the daily usage d . A_{j+1} also will be the initial point of the $(N+1)^{\text{th}}$ cycle.

These are assumptions of the EOQ model. The inventory level of the item is 0 on day 1. The ordered item arrived in a single delivery, and the receiving process is completed within day 1. The daily usage of the item was constant, and the inventory level of the item also reduced at a constant rate. The next order would arrive at a constant interval T , with the assumption that there would be

no variation in the lead time. The consecutive order of the item arrives on the day the inventory is reduced to 0, filling back the inventory level to Q .

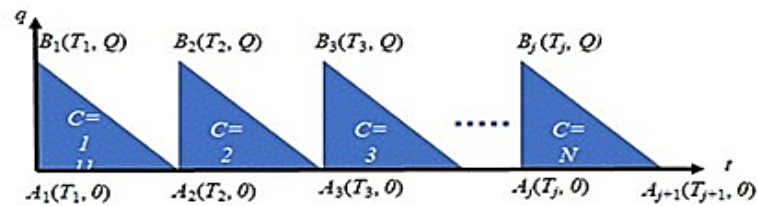


Fig. 1. Saw-tooth diagram for inventory level versus time according to EOQ

The generalized equations of the EOQ saw-tooth diagram were as follows. The integer j was the sequence of the data series from 1 to n as shown in Eq. (7), where n is set to complete the saw-tooth triangle until the last N^{th} order cycle of the year as in Eq. (8). Eq. (9) showed the alternating value of the inventory between 0 and Q for every odd and even number as at points A_j and B_j in Figure 2 while adding the time between order T to the value of t_j for the next order cycle A_{j+1} .

$$j = 1:n \in Z \quad (7)$$

$$n = 2N + 1 \quad (8)$$

$$(t_j, q_j) = \{[1 + (j - 1)T, 0], \quad j \in 2Z + 1 \quad [t_{j-1}, Q], \quad j \in 2Z \quad (9)$$

2.3 Algorithm's Flow Chart

As shown in Figure 2, the operation started with reading the input data, D, S, H, P, L and W . Then the EOQ and other output parameters are calculated according to Eqs. (1) to (6). Subsequently, the generation of inventory level data series is initiated according to Eqs. (7) to (9). Lastly, the data series is plotted on a saw-tooth graph to represent the inventory level dynamics over time.

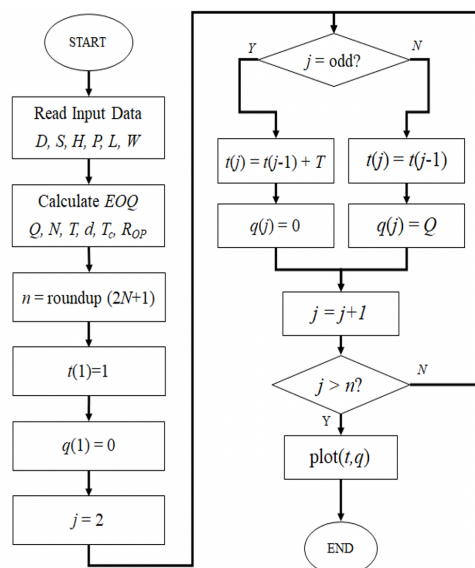


Fig. 2. Flowchart of the algorithm

2.4 User Acceptance Test

The User Acceptance Test (UAT) for InventSim was conducted in the Industrial Management course in the recent semester classes as a trial to evaluate the effectiveness of the apps. The InventSim trial participants' satisfaction and confidence in understanding inventory management topics were obtained via an online questionnaire platform. The questionnaire was partially based on Alqahtani and Mohammad [15]. In [15], the user experience was measured in terms of performance, satisfaction, behaviour, motivation, and usefulness. Nonetheless, this study only measured performance and satisfaction as this is preliminary trial usage only.

Table 1 shows the questionnaire that consisted of 7 questions each on learners' performance and satisfaction and participants must answer the questionnaires before and after the trial. A Likert scale of 1 to 5 was used as a rating system with 1 (strongly disagree), 2 (disagree), 3 (neutral), 4 (agree) and 5 (strongly agree) with the statements.

Table 1

Google form questions

No	Question
1	When I use the InventSim application, my learning skills are enhanced.
2	I am sure that InventSim increased my understanding of inventory usage over time
3	Using the InventSim helped me to achieve my desired grade in the Industrial Management/Industrial Engineering course
4	The application is user-friendly/easy to use
5	I agree that the content of the InventSim application is visibly described to the user.
6	Generally, I am satisfied with the InventSim application
7	I will recommend the app to other people

3. Result and Discussion

The image of the user interface for a typical simulation result is shown in Figure 3.

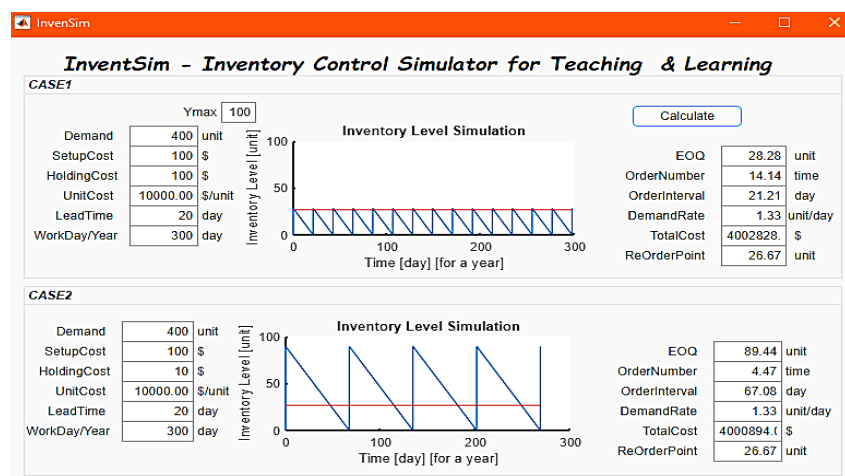


Fig. 3. Example of simulation result

3.1 Non-ideal Conditions

InventSim performed the EOQ calculation based on the given input data without inspecting the applicability of the given condition. Figure 4 (a) shows a typical result of the EOQ in ideal conditions. The changes in the inventory level were shown as the saw-tooth function indicated by the blue line,

while the red line indicates the ROP. In the ideal condition, the ROP level should be below the maximum inventory level. However, as shown in Figure 4 (b) the ROP was higher than the maximum inventory level due to the longer lead time L , which is not the ideal condition, hence the direct application of the EOQ model may not be suitable in this case. On the other hand, this kind of case might be useful for in-class discussion and other activities to increase the understanding of the subject among the students.

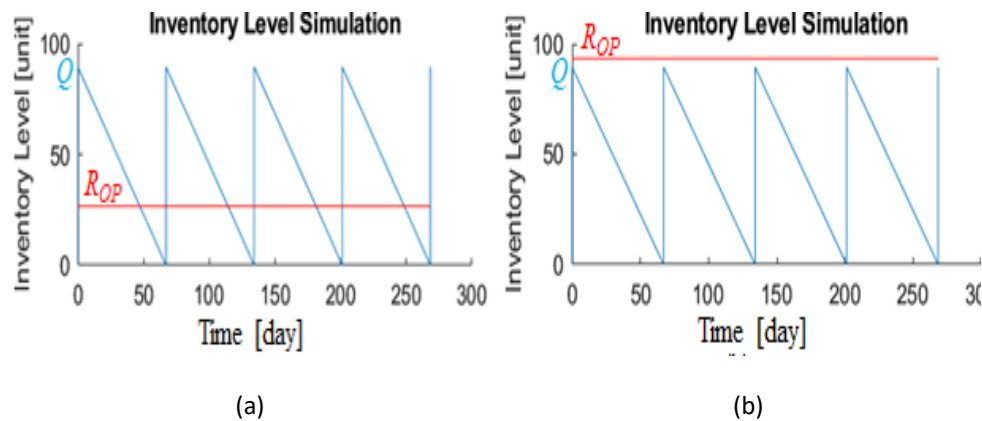


Fig. 4. Example Inventory level simulation on reorder point ROP (a) Ideal ROP and (b) Non-ideal ROP

The y-axis range for both cases in InventSim was set to be equal to the default value of 100. Changing the y-axis value will change the y-axis range of both cases. This is to provide a better comparison standard. The following Figure 5 shows the appearance change on the y-axis of a typical case. The manually adjustable y-axis system is working and fulfilling the purpose of having a standardized comparison. However, it will be in future improvement consideration as it seems more convenient if the process is done automatically.

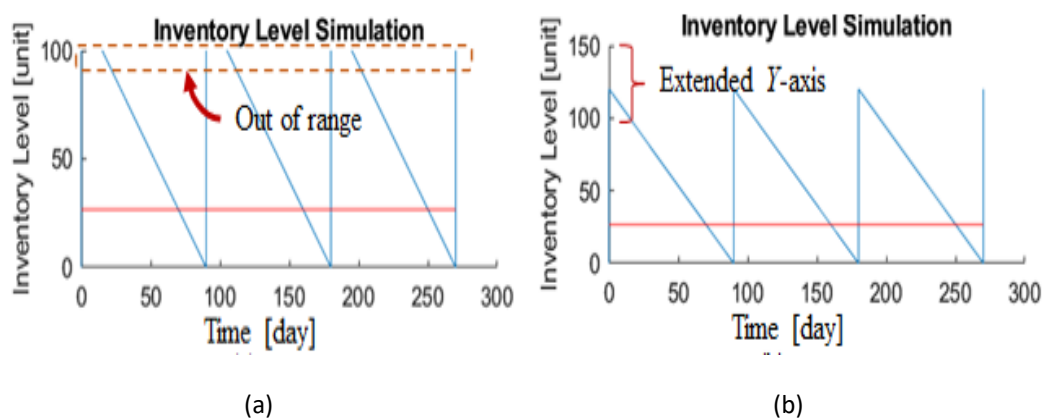


Fig. 5. Inventory level simulation (a) before and (b) after changing the Y-axis range

3.2 In-class Application

This study found two ways to integrate the simulation tool into the curriculum. The simulation tool can be directly used for classroom demonstration, as computers and audiovisual equipment are commonly available in classrooms nowadays. The instructor is not limited to preset examples, but

many different cases and issues can be explored spontaneously with the active participation of students.

The other area of application is direct assignment. This approach is expected to be more effective after ensuring that the students are introduced to the basic theory and the simulation model in class. The students are directed to perform and observe a series of specific simulations. The students are expected to spend time observing and thinking about the meaning of the simulated results and to write up the interpretation, explanation, and implication of the parameters to the inventory management under the model. Table 2 shows some suggested exercises and the learning outcomes to be incorporated into the curriculum with the use of the simulation tool.

Table 2

Classroom exercises

Exercise	Learning objectives
Gradually increase the holding cost per unit.	Expensive storage reduces the EOQ and increases the number of orders.
Gradually increase the ordering cost and observe the EOQ.	An increment in setup costs reduces the number of orders.
Increase the amount of demand and observe the EOQ and ROP curves.	The elevated number of orders lowers the EOQ compared to the ROP and results in an unideal condition.
Change the unit cost and observe the EOQ graph.	Changes in the unit cost will not affect the EOQ model.
Change the lead time and observe the EOQ.	There are no changes in the EOQ curve as the EOQ model is separated from ROP estimation.
Find the condition where the $ROP > Q$ and discuss the consequences.	The optimal order quantity Q from EOQ should be compared to the ROP for logical implementation.

3.3 User Acceptance Test

24 students' responses before InventSim usage were recorded in the pre-InventSim trial questionnaire while 14 students answered the post-InventSim trial questionnaire. Only 13 respondents' results were used to validate effectiveness as they rated both questionnaires. Figure 6 showed that students rated higher after they used InventSim to calculate the EOQ in all questions. Before the InventSim usage, all of them felt the applications could effectively or ineffectively impact their performance and satisfaction. However, they did agree on all aspects that InventSim could have helped to improve their understanding of EOQ as well as better user satisfaction experience, hence they could agree to recommend the application. This showed that with the use of technology (GUI), knowledge of inventory management can be delivered comprehensively to the student thus motivating students to practice and study [16].

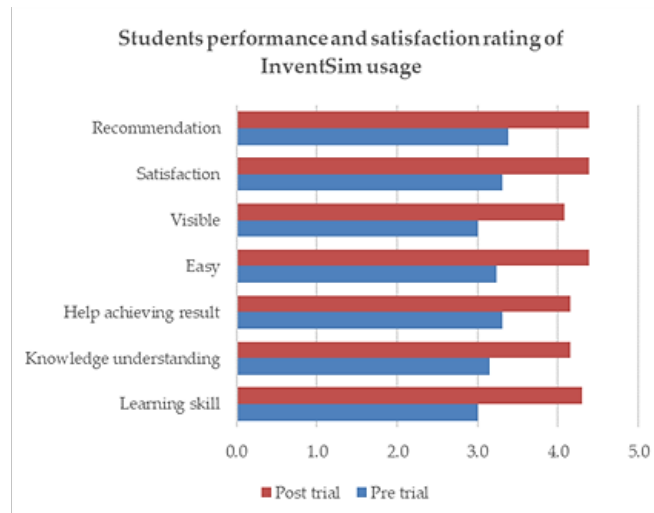


Fig. 6. Students rating pre and post-InventSim trials

4. Conclusions

This paper introduced the development of the simulator for the EOQ model in the inventory management topic of our undergraduate Industrial Management class. The simulator is a good presentation device and can be the basis for assignments for our undergraduate Industrial Management classes. The rapid visualization results due to different parameter changes by InventSim complement the existing teaching methods.

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