Simulation-Based Allocation of the Inspection Stations in the Production Line for Production Cost Optimization

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ABSTRACT

Due to increasing competition, companies pursue achieving a maximum production rate with minimal defects in order to saving costs by minimizing the production costs while maintaining high product quality to stay competitive in the markets. The assurance of a high-quality product by inspection of conformity is an important issue. The inspection process plays a crucial role in detecting and eliminating the causes of defects at an early stage, reducing the percentage of defective products and minimizing production costs. In this paper, an allocating algorithm is proposed and a mathematical allocating model is developed to investigate and determine the optimal number and locations of inspection stations along the production line where the proposed model aims to balance the expected cost of defects with the cost of inspection stations to achieve minimum total cost. The proposed model was practically applied to a leather jacket production line. The final results show that two allocation solutions can be adopted. The first is the allocating solution of the proposed model that proposed 23 inspection stations, resulting saving cost 582,839 IQD while, the second solution is derived from the first solution that based on considering only inspection stations that achieve maximum saving cost so,7 inspection stations were allocated, achieving total saving cost of 552,545 IQD.

Keywords-defect percentage; inspection stations; production line; production cost

I. INTRODUCTION

A production line is a series of arranged workstations, where products move from one station to the next. At each station, a portion of the total work is performed, which may result in the generation of defective items. Therefore, faulty parts should be removed to prevent defective items from passing to subsequent processes [1, 2], as this would increase product costs and affect overall competitiveness. Consequently, reducing defective products is an important issue [3, 4]. Sustaining a stable final product quality is a key concern in many manufacturing systems [5, 6]. Today, organizations prioritize both product quality and productivity to remain competitive in the global market. The inspection activities play a vital role in enabling manufacturers to control costs and improve product quality. Therefore, determining the appropriate number and location of inspection stations is crucial for maintaining quality and minimizing production costs. Several techniques are employed to enhance quality in manufacturing systems, including statistical process control, Six Sigma, and inspection [7, 8]. The quality costs are defined as all necessary activities to attain merchantability. The quality is defined as fitness for use, which involves both tangible costs—such as testing, inspections, and losses caused by errors—and intangible costs, including opportunity costs from lost business and a damaged reputation [9, 10]. Inspection can be defined as the measurement and quality assessment of the produced items [11, 12], and as a process that ensures materials and parts conform to the required specifications [13, 14]. The inspection process aims to fulfill several objectives: detecting and eliminating defective raw materials before production, preventing low-quality products from reaching customers to reduce complaints and support reputation, and assisting managers in identifying the weaknesses and causes of defects in the production process [15, 16]. Inspection may be performed automatically or manually at various points along the production line, and even during operation. The product quality is typically assessed at all workstations during the production by quality inspectors, who identify defect-causing failures [17]. The end-of-line testing evaluates product functionality at the final stage, whereas the in-line inspection focuses on identifying and correcting the defects during production [18].

Several considerations must be taken into account when locating inspection stations [13]:

1. Before no return: - the station of inspection can be located after an operation in which the defective product cannot be reworked.
2. It is essential to inspect the incoming purchasing part and raw material to ensure that it is within the required specifications
3. Before a series of operations, where inspection is difficult or impossible to perform or when the rate of flow is extremely high.
4. Before the potential damage.
5. Before the assembly operation and the cove-up operation.
6. The final products.
7. Before the costly operations.
8. After operations that may be expected to produce defective products.
9. After the automated operations.

Two methods are used to inspect the quality and for the item to comply with the required specifications: the first method is 100% inspection, while the second is sampling inspection [3, 7]

Many types of inspection are found [15, 20]: Floor inspection, Centralized inspection, Combined inspection, Functional inspection, First piece inspection, Pilot piece inspection, and Final inspection.

Allocating inspection stations along the production line is a topic that has received significant attention due to its impact on the total production cost. A mathematical model based on goal programming was developed to reduce the inspection costs by determining the optimal number of inspectors based on skill levels [21]. The results indicated that minimizing inspection costs is possible by optimizing the allocation of inspector skills. An analytical and simulation model was also proposed to examine the effects of the inspection capacity and rate on the production cost, and was applied to a semiconductor production line. The findings showed that a higher capacity increases the optimal rate and reduces the yield loss [22]. A mathematical model was proposed to allocate the inspection stations to manufacturing processes, supported by a heuristic approach for optimization. Enterprise Dynamic software was used for simulation and comparison, and the model was validated in an electromotor manufacturing company [23]. An allocation algorithm was introduced to determine the optimal buffer sizes, as well as the number and position of inspection stations, to meet customer demand for quality-compliant products while minimizing total cost [24]. Another allocation model aimed to determine the optimal configuration of quality control stations that minimize the total production cost, encompassing inspection, processing, station assignment, waiting, rework, and scrap costs. The results showed that this model is adaptable to the demand changes and capable of reducing both the cost and final defect probability [10]. An allocation model based on the particle swarm optimization algorithm was also proposed for assigning inspection stations along a production line by analyzing the total cost and processing time, aiming to identify the configuration that minimizes both [25]. This model was verified on an automobile crankshaft production line.

In this paper, a mathematical allocation model is proposed and developed to investigate and determine the optimal number and locations of inspection stations along the production line. The objective is to reduce the total production cost by balancing the expected cost of defects against the cost of inspection stations. Two feasible solutions are proposed. This study examines the production line to estimate the percentage of defects at each station and calculates the number and cost of defective units. It then evaluates the feasibility of adding inspection stations by estimating their cost, and determines the optimal number and placement by exploring the feasible inspection areas along the line. The proposed model generates both visual and quantitative outputs that confirm the cost-effectiveness of optimized inspection station placement along the production line.

II. THE PROPOSED MATHEMATICAL ALLOCATION MODEL

The product passed through the production line, from raw material to the final product, in serial workstations that differed in their time, importance, cost, and quality. Defective products may be produced in some workstations for various reasons, leading to increased total production costs due to factors such as raw materials, labor, machinery, and inspection tools, particularly when the defective product cannot be reworked (scrapped). The inspection stations should be located between workstations to minimize the number of faulty products. Figure 1 illustrates the production line, where the number of inspection stations depends on the percentage of defects and the type of production line.

In this paper, a mathematical allocation model is proposed and developed, as shown in Figure 2, to investigate and determine the optimal number and location of inspection stations along the production line. It is assumed that the optimal number of inspection stations, which minimizes the total cost, depends on the total percentage of defects at the workstations. Additionally, the location of the inspection stations within the production line depends on the percentage of defects at each workstation and the resulting cost savings, assuming the cost of the inspection station is fixed.

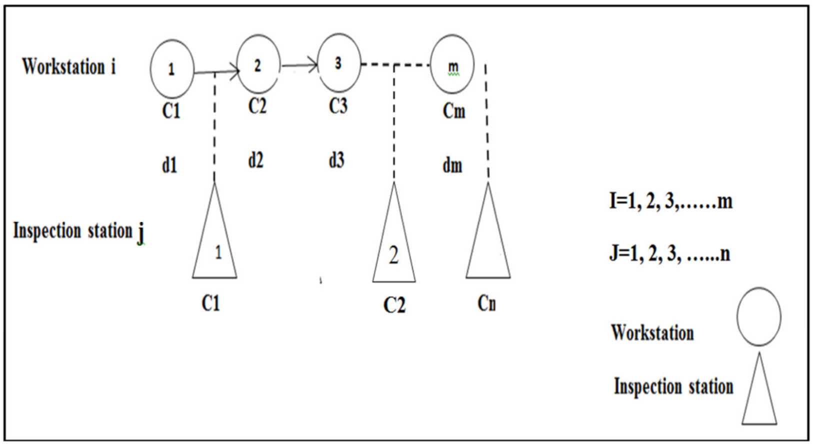

Fig. 1. Positioning the workstation and inspection stations in production line.

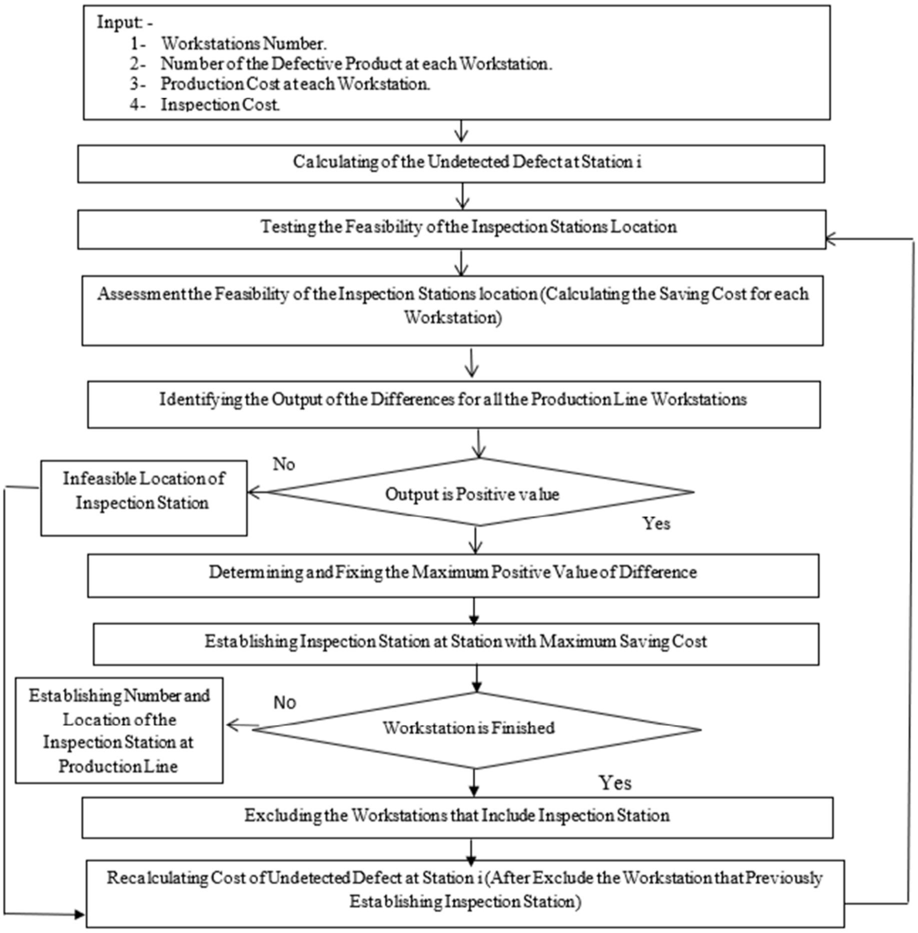

Fig. 2. Structure of the proposed allocation model.

The proposed model is based on two main steps:

- **Stage one:** Determining the number of inspection stations, which are based on the total percentage of defects along the production line.
- **Stage Two:** Determining the location of each inspection station along the production line based on the cost savings.

The mathematical allocation model was developed under the assumption of a known total number of produced units (n) and the cost associated with undetected defective products at each workstation. The solution process involves the following detailed steps:

1. Determine the number of defective products at each workstation.

2. Calculate the total number of defective items, denoted by:

$$N\sum(i=1)^{m} di \quad (1)$$

3. Calculate the cost of an undetected defect at workstation i, using:

$$C_i = (d_i \cdot O_i) + \sum(j = i+1)^{k} O_j \quad (2)$$

where d_i is the number of defective products at station i, O_i is the cost of operation i, and the summation represents the cost of all subsequent operations until the next inspection station.

4. Define the cost of undetected defects across all workstations as:

$$\sum_{i}^{m} d_i \quad (3)$$

5. Assume the inspection station cost is fixed and denoted by C_j
6. Test the feasibility of placing inspection stations between all workstations along the production line. The number of inspection stations is equal to or less than the number of workstations:
7. Constrain the number of inspection stations such that it does not exceed the number of workstations:

$$n \leq m$$

8. Identify feasible inspection locations by calculating the cost savings at each workstation, defined as the difference between the cost of an undetected defect and the inspection station cost: The production cost saved at Station i was calculated using (3), which also saved at Station i equals the cost of undetected product defects at Station i minus the inspection cost.

$$D - C_j \quad (4)$$

9. Select the location with the maximum cost savings (i.e., the highest positive value of the difference). Positioning an inspection station at a station that involves maximum savings.
10. Place an inspection station at that location.
11. Exclude that workstation from further calculations (as it now includes an inspection station).
12. Recalculate the undetected defect cost for the remaining workstations.
13. Repeat steps 3 to 12 until the optimal number and placement of inspection stations have been determined.

Finally, the minimum total production cost is calculated using:

Minimum Total Cost:

$$\sum_{i=1}^{m} C_i + \sum_{j=1}^{n} C_j \quad (5)$$

In the above, m is the number of workstations, i is the current workstation number, C_i is the unit production cost at workstation i, d_i is the percentage of defects at workstation i, j is the inspection number, where j = 1, 2,3,…n, n represents the total inspection stations number, C_j is the unit inspection cost at station j, and IQD is the Iraqi currency.

III. PRACTICAL PART

The proposed mathematical model was applied at the State Company for Textile and Leather Industries, specifically on the production line of leather jackets. The women's Jacket model (416) was selected as a case study to verify the proposed model. The chosen production line produces women's, men's, and boys' leather jackets from natural leather in various sizes and models. The products, manufactured from cowhide, comply with the specifications approved by the Central Agency for Assessment and Quality Control. The monthly production plan is based on market demand, with an average daily production of 60 leather jackets. The leather jacket passes through 49 series operations, as shown in Table I, and is transported between workstations by boxes on a conveyor belt. The production operations include ordinary sewing, tying, folding, bending, gluing leather pieces, visible stitching, and inspection. The inspection time is included within the total production time. A key characteristic of the production line is the high percentage of manual work, which primarily requires simple tools. This explains why the quality of the final product largely depends on the efficiency and experience of the workers, as most defects are caused by human error during the production process. Some defects can be corrected, while others cannot, leading to a defective product. The method of inspection adopted in the production line involves inspecting all products during the production process. The standard time was calculated by averaging five readings for each operation. In contrast, the cost of the operation was estimated based on the company's data and experts, as depicted in Table II. Some defects appear in some parts of the Jacket while passing through the production line workstations, including:

- Defects in the sewing/or joining of the pieces of the jacket.
- Defects in the visible sewing.
- Defects in the folding operations.
- Defects in the final completing operations (installing buttons, opening button holes, etc.)

IV. RESULTS AND DISCUSSION

The proposed allocation model is based on the assumption that an inspection station can be placed between each pair of consecutive workstations along the production line. The cost of inspection was assumed to be fixed and equal to 1000 IQD, because the inspection process in the line is mostly done manually by workers. The production line was simulated based on the proposed allocation model to determine the optimal placement of inspection stations, which achieves maximum cost savings and minimizes production costs. The model's outputs are presented in Figures 3 and 4. The final output from simulating the production line is 23 inspection stations, which achieved maximum production cost savings of 582,839 IQD, as shown in Table III. The locations of these stations along the production line are illustrated in Figure 4.

TABLE I. THE CURRENT SEQUENCE OF THE OPERATIONS OF PRODUCTION LINE

Operation number	Activity classification		Operation description	Processing time (min)	Execution method
	Operation	Inspection			
1	●		Separation of the jacket skin	10.0	Machine + worker
2		▲	Inspection of the pieces	2.48	Worker
3	●		Ironing the sieces	5.0	Machine + worker
4	●		Numbering the jacket pieces	7.18	Worker
5	●		Detail of the lining fabric	5.48	Machine + worker
6	●		Sewing the lining	5.40	Machine + worker
7	●		Cross stitching of back leather pieces	2.35	Machine + worker
8	●		Cross fold for back leather pieces	1.58	Worker
9	●		Longitudinal stitching of back leather pieces	1.32	Machine + worker
10	●		Longitudinal fold of back leather pieces	1.15	Worker
11	●		Back pleat sewing	0.58	Machine + worker
12	●		Joining the sample to the back	0.42	Machine + worker
13	●		Cross stitching of chest skin pieces	0.58	Machine + worker
14	●		Cross fold of chest skin pieces	0.54	Machine + worker
15	●		Longitudinal stitching of chest leather pieces	0.50	Machine + worker
16	●		Longitudinal fold of the breast skin pieces	0.52	Worker
17	●		Planning, preparing, and gluing the pockets	5.50	Worker
18	●		rodrigo's sewing of pockets	2.57	Machine + worker
19	●		Sewing pleats and tying the chest sample	1.48	Machine + worker
20	●		Fold the sample	0.38	Worker
21	●		Cross stitching of the hand leather pieces	2.15	Machine + worker
22	●		Cross-folding of the hand leather pieces	1.48	Worker
23	●		Longitudinal stitching of the hand leather pieces	0.38	Machine + worker
24	●		Longitudinal fold of the hand leather pieces	2.15	Worker
25	●		Tie the chest and back and tie with hand	3.27	Machine + worker
26	●		Fold the hand circumference	2.0	Worker
27	●		Rodrigo's back and chest stitching	4.28	Machine + worker
28	●		Joining the lining leather rulers	0.30	Machine + worker
29	●		Fold the leather lining rulers	1.38	Worker
30	●		Fold the collar lining and leather	1.46	Worker
31	●		Sewing logo of company	2.25	Machine + worker
32	●		Joining the collar and leather rulers to lining	3.46	Machine + worker
33	●		Sewing the leather pieces for the jacket waist	1.20	Machine + worker
34	●		Fold the waist	2.10	Worker
35	●		Rodrigo waist stitching	3.40	Machine + worker
36	●		Preparing the locations of the button hole	4.15	Worker
37	●		Attach the leather collar to the body of the coat	1.20	Machine + worker
38	●		Shoulder fixation	10.0	Worker
39	●		Joining the lining to the Jacket from the waist	3.40	Machine + worker
40	●		Gluing the rulers and lining with the jacket	6.20	Machine + worker
41	●		Rodrigo sewing the jacket	3.58	Machine + worker
42	●		Rodrigo's sewing of the button hole	2.30	Machine + worker
43		▲	Inspection jacket	2.20	Worker
44	●		Cleaning jacket	2.15	Worker
45	●		Opening four button holes	1.10	Worker
46	●		Setting and pressing buttons	1.50	Machine + worker
47	●		Installing buttons	9.0	Worker
48		▲	Inspection jacket	1.58	Worker
49	●		Ironing jacket	2.10	Machine + worker

TABLE II. CALCULATED PRODUCTION COST (IQD)

Operation No.	Labor cost	Machinery cost	Raw material cost	Defect cost	Total operation cost
1	500	166	50.000	7	50.666
2	124	-	15.000	-	15.124
3	250	83	15.000	-	15.333
4	359	-	-	-	359
5	274	90.9	1000	10	1365
6	270	89.6	1000	6	1360
7	117.5	39	40.000	3	40.156
8	79.0	-	40.000	2	40.79
9	66	21.9	40.000	7	40.87
10	575	19	40.000	5	40.575
11	29	9.6	40.000	2	40.38
12	21	6.9	50.000	10	50.28

13	29	9.6	35.000	8	35.38
14	27	8.9	35.000	2	35.36
15	25	8.3	35.000	5	35.33
16	26	-	35.000	3	35.26
17	275	-	40.000	6	40.171
18	128	42.6	40.000	15	50.98
19	74	24.5	50.000	12	50.19
20	19	-	50.000	10	20.143
21	107.5	35.6	20.000	5	20.143
22	74	-	20.000	5	20.74
23	77	25.5	20.000	3	20.102
24	107.5	-	20.000	5	20.107
25	163.5	54.2	140.000	8	140.217
26	100	-	20.000	8	20.100
27	214	71	100.000	10	100.285
28	15	4.9	10.000	15	10.20
29	69	-	10.000	8	10.69
30	73	-	10.000	7	10.73
31	112.5	37.3	140.000	8	140.159
32	173	57.4	21.000	13	21.230
33	60	19.9	10.000	5	10.80
34	105	-	10.000	3	10.105
35	170	56.4	10.000	5	10.226
36	207.5	-	140.000	8	140.207
37	60	19.9	150.000	9	150.80
38	500	-	151.000	6	151.500
39	170	56.4	152.000	16	152.226
40	310	102.9	152.000	6	152.412
41	179	59.4	166.000	8	166.138
42	115	38.1	166.000	3	166.153
43	110	-	-	-	110
44	107.5	-	-	-	107.5
45	55	-	166.000	8	166.5
46	75	24.9	4.000	19	5
47	45	-	170.000	9	170.450
48	79	-	-	-	79
49	105	34.8	170.000	-	170.139

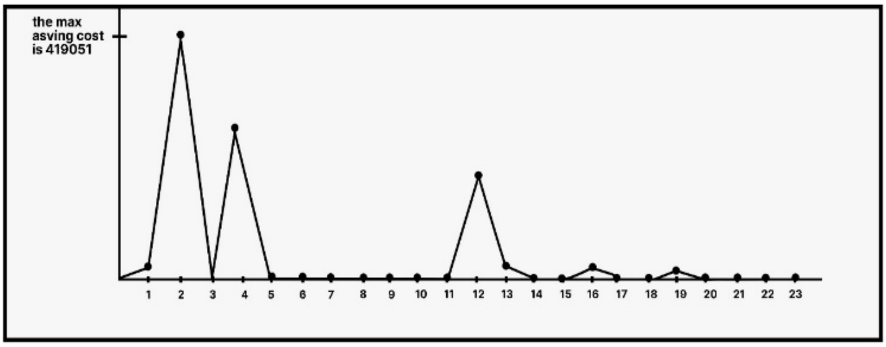

Fig. 3. The saving cost for the proposed allocation.

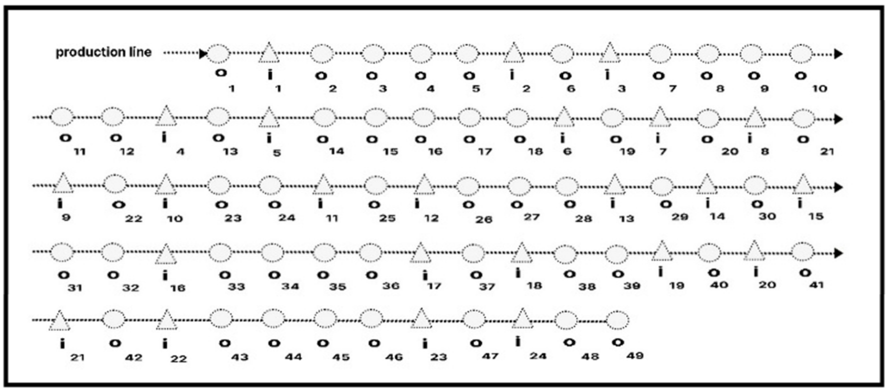

Fig. 4. Allocating the inspection stations along the production line.

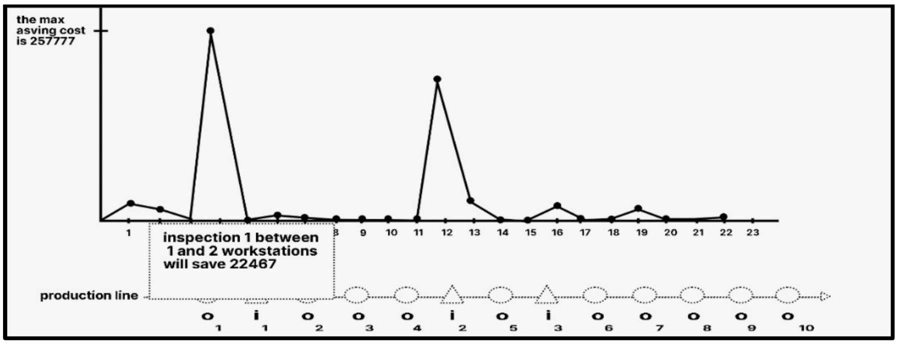

Fig. 5. Saving cost of the 1st allocating inspection station.

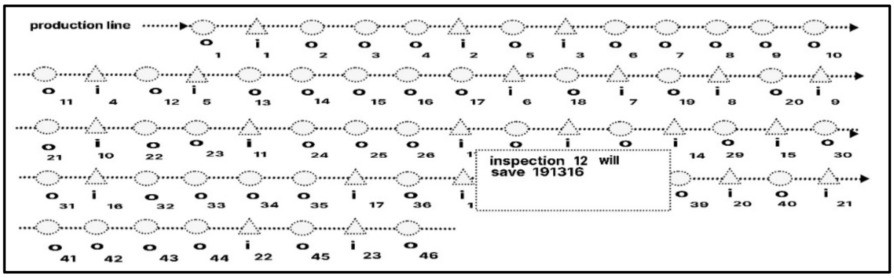

Fig. 6. The saving cost of the 12th allocating inspection station

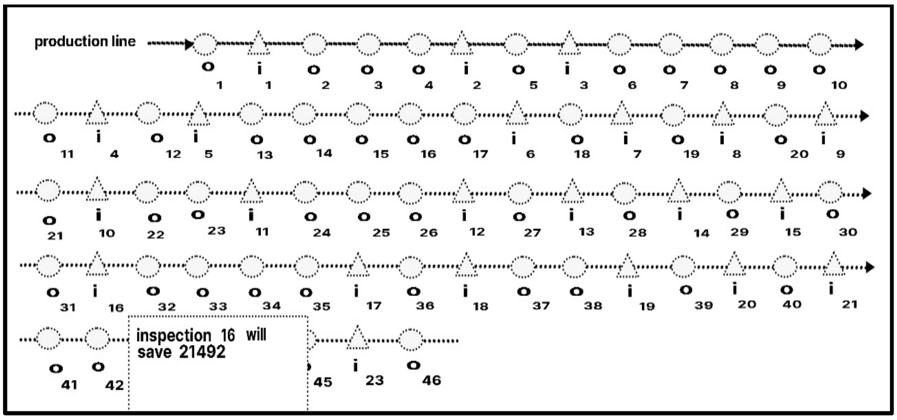

Fig. 7. The saving cost of the 16th allocating inspection station.

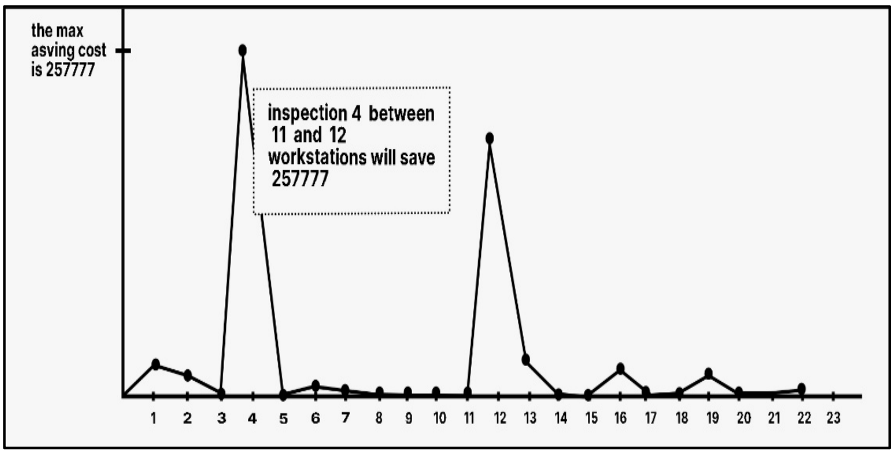

Fig. 8. The saving cost of the 4th allocating inspection station.

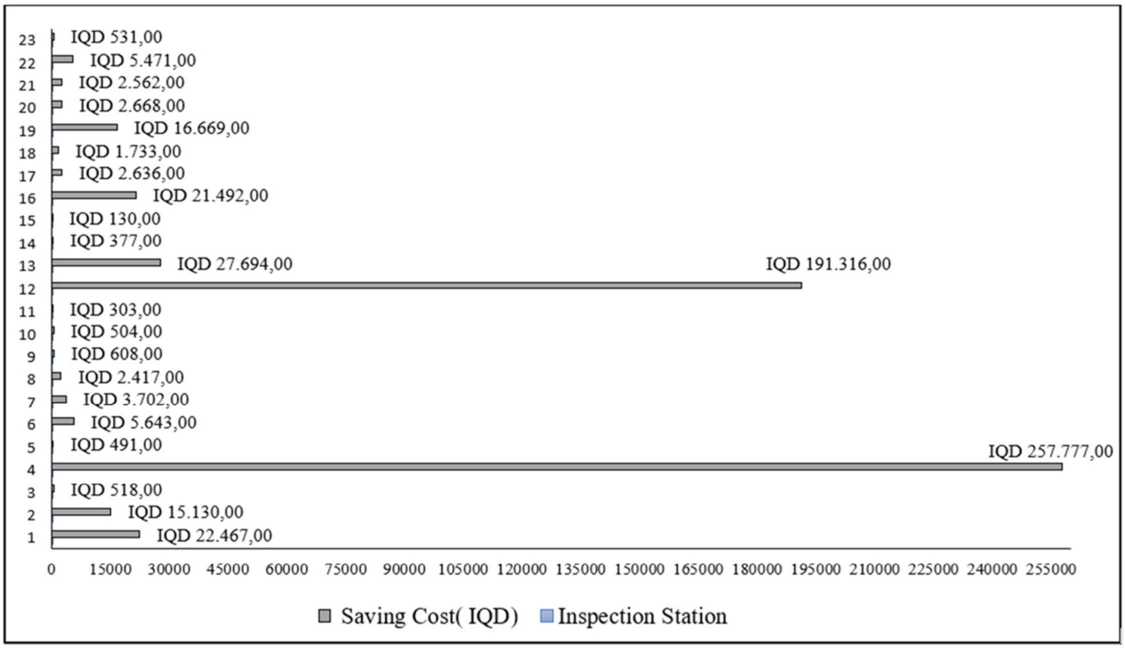

Fig. 9. Saving cost of allocating 23 inspection stations.

TABLE III. THE SAVING COST, NUMBER, AND LOCATION OF THE INSPECTION STATIONS

Inspection station	Location of the inspection stations between workstation	Saving cost (IQD)
1	1-2	22467
2	4-5	15130
3	5-6	518
4	11-12	257777
5	12-13	491
6	17-18	5643
7	18-19	3702
8	19-20	2417
9	20-21	608
10	21-22	504
11	23-24	303
12	26-27	191316
13	27-28	27694
14	28-29	377
15	29-30	130
16	31-32	21492
17	35-36	2636
18	36-37	1733
19	38-39	16669
20	39-40	2668
21	40-41	2562
22	44-45	5471
23	45-46	531
The Total Saving Cost = 582839 IQD		

The proposed allocation model can also be presented individually in two ways: a figure and a graph, showing the saving cost of each proposed inspection station, as explained in Figures 5-8.

There is a significant difference in production cost savings by allocating inspection stations based on the proposed model, as shown in Figure 9. The number of inspection stations can be reduced from 23 to 7 by selecting the most feasible ones, which are those that achieve the highest savings in production costs, as shown in Table IV. A production cost saving of 552,545 IQD was achieved. The difference in total savings between the two proposed solutions is relatively small (30,294 IQD), indicating that the choice between them may be determined by managerial preferences and strategic priorities. In another application, the best solution is the one that achieves the highest saving cost.

TABLE IV. THE SAVING COST FOR LOCATING 7 INSPECTION STATIONS

Inspection stations	Location of the inspection station between workstations	Saving cost (IQD)
1	1-2	22467
2	4-5	15130
3	11-12	257777
4	26-27	191316
5	27-28	27694
6	31-32	21492
7	38-39	16669
Total Saving Cost = 552545 IQD		

V. CONCLUSIONS

Organizations focus on both the product quality and productivity to remain competitive in the global market. Defective products may be produced at specific workstations for various reasons, leading to increased total production costs. So, allocating the inspection stations is an important issue for controlling the quality and reducing the production costs. In this paper, a mathematical allocation model is proposed and developed using Visual Basic to analyze the production line for determining the optimal number and position of inspection stations that minimize production costs. The practical part of the proposed algorithm was verified on a leather jacket production line, resulting in two feasible allocation solutions.

The first solution involves placing 23 inspection stations, resulting in a cost savings of 582,839 IQD. The second solution, derived from the first, reduces the number of inspection stations to 7 and yields a cost saving of 552,545 IQD. The final decision on the allocation of inspection stations depends on the company's management priorities and strategies. A limitation of the proposed model is the need to calculate the production cost, as shown in Table II, which consumes time and requires accurate data.

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