

DECISION SCIENCES INSTITUTE

Optimal Location of Repair Stations in a Garments Production Line

Md Shahriar Jahan Hossain
Louisiana State University
Email: msjhossain1@gmail.com

Bhaba R. Sarker
Louisiana State University
Email: bsarker@lsu.edu

ABSTRACT

In a manufacturing system the defective items detected at the inspection station, are generally scrapped or repaired at regular defect-creating workstation or at a dedicated repair station off the line. In this research a sewing line with an inspection station located at the end, is considered to make decisions concerning these issues. A unit cost function is developed for alternative decisions on each type of defect. To minimize the unit production cost, a fractional mixed integer nonlinear programming (MINLP) problem is formulated and solved optimally. The test problem is reflective of some sewing lines of a readymade garments industry.

KEYWORDS: Rework/repair, Defect, Fractional programming, Optimization, Garments production.

INTRODUCTION

Inspection and repair are two important parts of quality control. In industries quality inspections are done in order to identify nonconformities. Defective items are often sent back to the workstation where the defect occurs. This common repair procedure sometimes reduces line efficiency. At the same time if defective items are repaired at a dedicated repair station it adds a fixed cost for that repair station. On the other hand all defective items are not repairable; some defective items are scrapped incurring waste of material and other related costs. Therefore, it is essential to take an optimal decision on defective items whether they should be scrapped, or repaired at regular on-line workstation(s) or at dedicated off-line repair-station(s) in order to ensure minimum cost of production per unit and optimum number of off-line repair-stations to enhance throughput rate.

According to American Apparel and Footwear Association (AAFA, 2012), apparel and textile industries are the world's third largest industry sector after auto industries, and are good examples of imperfect serial production lines. Due to high labor cost most low-cost garments in America, Australia or European countries are imported from the countries like China, India, Bangladesh or Vietnam where human labor is available with comparatively low cost. Garments quality is a vital factor to capture a new market.

Lot of works have been done to improve the productivity, line efficiency of apparel industries and eventually to reduce the cost of production. Islam et al. (2014) presented a case study for obtaining an optimal layout design in an apparel industry by appropriate line balancing. On the other hand, Bahadir (2011) discussed about assembly line balancing by simulation. Several research are found on optimizing quality inspection and repair for reducing cost of quality or

increasing the net profit. Raviv (2013) presented an algorithm for maximizing the expected profit from an unreliable serial production line in which nonconforming items are sent back for repair after going through the inspection stations. None of these study discusses about offline repair facilities for defective items.

Building a suitable framework for taking operational decision on dedicated repair stations still requires extensive research as this involves conflicting objectives. Considering this fact this research focuses in developing a model to minimize the unit cost of production to determine suitable number and location of dedicated off-line repair stations. In order to deal with this objective, following steps are performed in this research:

- (a) To determine production cost per unit as a function of cycle time, proportion of defects, fixed and variable cost, which are eventually dependent on the location of off-line repair stations.
- (b) To find the optimum number and location of off-line repair station(s) that minimizes the production cost per unit.

The outcomes of this research provide an easily executable framework to determine the requirement of repair facilities for dealing with non-conforming items which are identified at the stage of quality inspection in the sewing line.

PROBLEM DESCRIPTION

Assume a garments production line with N sewing stations arranged sequentially to perform a sequence of operations needed to complete a garments product. Each workstation performs different type of operations, completing at least one operation at that station. A product is classified as defective corresponding to the major source (workstation) of defect. An inspection station is located at the end of the line. This inspection station identifies and separates non-conforming items based on the type and origin of the defect(s). Proportion of each type of defective items are estimated from historical experiences. Some workstation may not produce any defects at all and the probability of defect for that workstation is assumed to be zero. If defective items are repaired then number of conforming items increases. Again if the defective items are sent back to the regular on-line sewing station for repair, the regular production may be hampered. The problem thus is to decide whether the defective item should be sent back to original sewing station for repair or there should be a dedicated repair-station so that regular production is not interrupted, or the defective garments should be scrapped. During making this corrective decision, production cost should be kept at a minimum level. The problem described here is a specific situation which can be formulated based on some assumptions:

- (a) A balanced garments production line with no parallel workstation is considered.
- (b) An inspection station is located at the end of the line with negligible inspection error.
- (c) Any particular defective item does not hold multiple types of nonconformity at a time.
- (d) Any kind of defects can be repaired and repaired items assumed to be conforming products.
- (e) Repair cost is constant for a particular defect repaired at a particular workstation.
- (f) Scrapped items are valueless.
- (g) There is no space limitation in the shop floor.

MODEL FORMULATION

Before developing the model some notations for system parameters, variables and performance measures are needed to be defined. All notations are defined in the following sub-sections.

System Parameters

C^F = Fixed cost for the sewing line (\$/hour), C_k^F = Fixed cost for regular workstation k (\$/hour), C_k^f = Fixed cost added for a dedicated off-line repair station for operation k (\$/hour), c = Variable cost of sewing a finished item if no item is repaired (\$/unit), c_k^d = Variable cost of repairing at dedicated off-line repair station k (\$/unit), c_k^r = Variable cost of repairing at regular on-line workstation k (\$/unit), N = Total number of workstations, p_k = Proportion of defectives of at workstation k , t_k^P = Processing time of operation at regular workstation k (hours), t_k^R = Repair time of defective item at regular workstation k (hours) and T = Cycle time when no repair work is done (hours).

Intermediate Variables

T_k^R = Total repair time of an item at regular workstation k (hours), T_{eff} = Effective cycle time when repair works are done (hours), and TC = Total cost (\$/hour).

Variables and Performance Measures

u = Unit cost (\$/unit), $x_k = (0,1)$, the number of dedicated off-line repair stations for operation k and $y_k = 0-1$ binary variable indicating decision on scrapping (0) or repair (1) for a defect produced at workstation k .

Now, the production cost per unit of good item has to be reduced, which is the prime objective of this research. Thus the optimization problem can be formulated as fractional mixed-integer nonlinear program as written below.

Problem Z_{MINLP}^f

$$\text{Min } u = \left\{ \left(C^F + \sum_{k=1}^N C_k^f x_k \right) T_{eff} + c + \sum_{k=1}^N c_k^d p_k x_k + \sum_{k=1}^N c_k^r p_k y_k (1-x_k) \right\} / \left(1 - \sum_{k=1}^N p_k + \sum_{k=1}^N p_k y_k \right) \quad (1)$$

Subject to ($\forall k = 1, 2, \dots, N$)

$$x_k - y_k \leq 0 \quad (1a)$$

$$T_{eff} - (t_k^P + p_k t_k^R) y_k (1-x_k) \geq 0 \quad (1b)$$

$$T_{eff} \geq T, x_k \in \{0,1\}, y_k \in \{0,1\} \quad (1c)$$

Problem Z_{MINLP}^f is a fractional mixed-integer nonlinear programming problem (MINLP) for which the solution is not immediate. Since the current problem Z_{MINLP}^f cannot fit to an existing problem, a series of transformations as amenable to the requirement is done here (Li, 1994; Chang, 2001; Hossain & Sarker, 2016) to achieve the solution goal. After several transformation and

letting $w^a = \left[\left(1 - \sum_{k=1}^N p_k \right) + \sum_{k=1}^N p_k y_k \right]^{-1}$, $T_{eff} w^a = w^b$, $x_k w^b = w_k^c$, $x_k w^a = w_k^d$,

$y_k w^a = w_k^e$ and $x_k y_k w^a = w_k^f$ Problem Z_{MINLP}^f is transformed to a mixed-integer linear programming problem (MILP) as

Problem Z_{MILP} :

$$\text{Min } u = c w^a + C^F w^b + \sum_{k=1}^N C_k^f w_k^c + \sum_{k=1}^N c_k^d p_k w_k^d + \sum_{k=1}^N c_k^r p_k w_k^e - \sum_{k=1}^N c_k^r p_k w_k^f \quad (2)$$

$$\text{Subject to } \left(1 - \sum_{k=1}^N p_k \right) w^a + \sum_{k=1}^N p_k w_k^e = 1 \quad (2a)$$

and $\forall k = 1, 2, \dots, N$:

$$x_k - y_k \leq 0 \quad (2b)$$

$$w^b - t_k w_k^e + t_k w_k^f \geq 0 \quad (2c)$$

$$T w^a - w^b \leq 0 \quad (2d)$$

$$w^b + (x_k - 1)M \leq w_k^c \leq w^b + (1 - x_k)M \text{ and } 0 \leq w_k^c \leq M x_k \quad (2e)$$

$$w^a + (x_k - 1)M \leq w_k^d \leq w^a + (1 - x_k)M \text{ and } 0 \leq w_k^d \leq M x_k \quad (2f)$$

$$w^a + (y_k - 1)M \leq w_k^e \leq w^a + (1 - y_k)M \text{ and } 0 \leq w_k^e \leq M y_k \quad (2g)$$

$$w^a + (x_k + y_k - 2)M \leq w_k^f \leq w^a + (2 - x_k - y_k)M, w_k^f \leq M x_k \text{ and } 0 \leq w_k^f \leq M y_k \quad (2h)$$

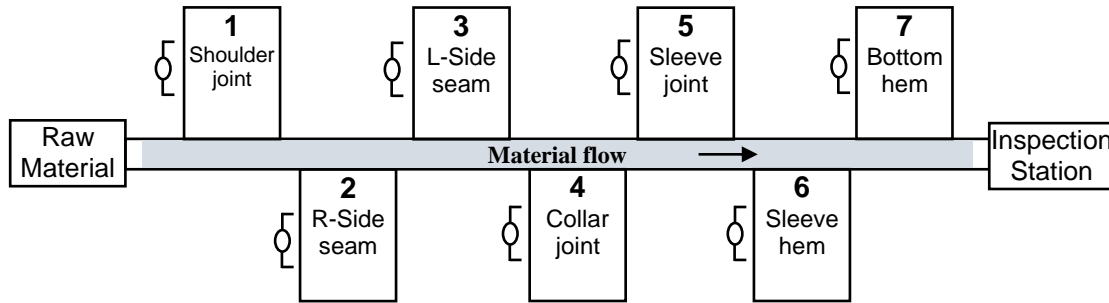
$$1 \leq w^a \leq \left(1 - \sum_{k=1}^N p_k \right)^{-1}, w^b \geq T, x_k \in \{0, 1\}, y_k \in \{0, 1\}, \quad (2i)$$

where M is a very large number. The final version of problem Z_{MILP} has a total of $2+6N$ variables for N number of workstations, among which x_k , y_k are 0-1 binary integers, and w^a , w^b , w_k^c , w_k^d , w_k^e , w_k^f are positive values. Given $T, C^F, c, C_k^f, c_k^d, c_k^r, p_k, t_k^P$ and t_k^R the problem Z_{MILP} can be solved by a mixed-integer branch and bound method.

A CASE STUDY IN GARMENTS INDUSTRY

The apparel industry is of great importance to the economy in terms of trade, employment, investment and revenue all over the world. On experiencing such an endeavor in a readymade garments (RMG) industry, 5 different 7-workstation sewing lines are considered that manufactures a certain design of branded T-shirts. Separate distinct operations are being done in each of the workstations. The operations follow a sequence as shown in Figure 1.

Figure 1: A branded T-shirt sewing line with 7 different workstations



The factory bears a fixed cost of production \$100 per hour for a sewing line that includes capital, labor and fixed utility costs. Variable cost of production that includes material and variable utility costs is listed as \$3.10 for an item no matter whether the item is defective or not. All other necessary variable costs and fixed costs involved with each workstation ($k = 1, 2, \dots, 7$) in the first sewing line are estimated from existing data and listed in Table 1. This problem is formulated as Z_{MLP} in order to solve with branch and bound method. For a 7-workstation problem there are $5+15(7) = 110$ constraints and $2+6(7) = 44$ variables among which 14 variables are 0-1 binary integers. Thus there are $2^{14} = 16,384$ nodes to be explored to find the optimum result, which is a big problem indeed to elaborately demonstrate.

Table 1: Fixed and variable costs involved with different operations

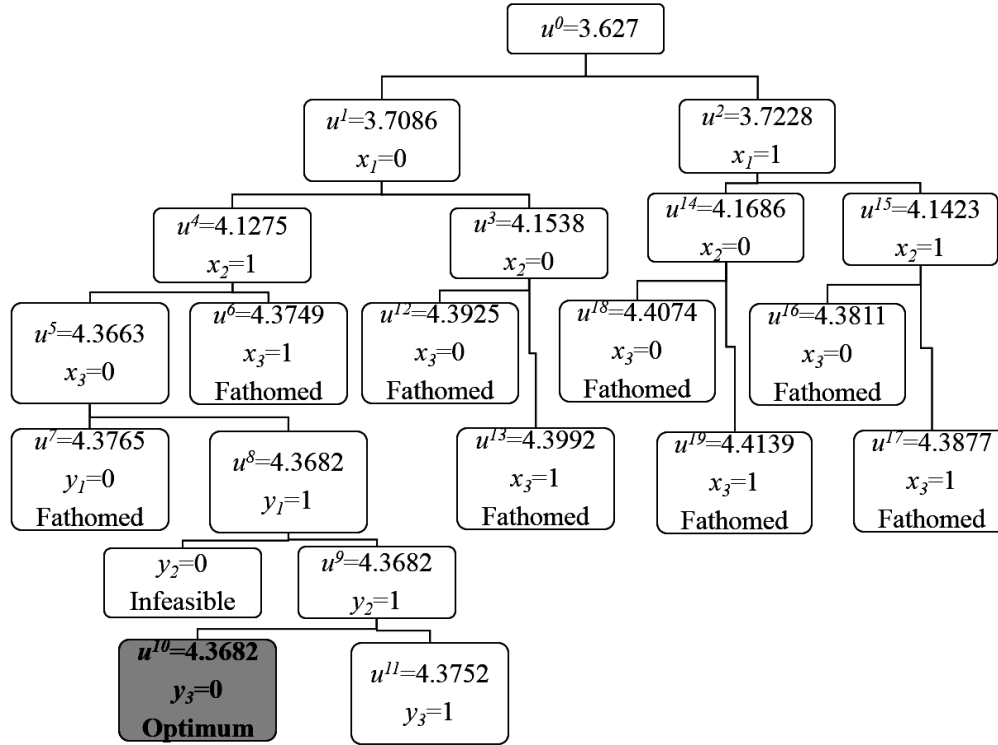
W/S k	Operation name	C_k^f (\$/hr)	c_k^r (\$/unit)	c_k^d (\$/unit)	t_k^p (sec/unit)	t_k^R (sec/unit)	Proportion of defects p_k
1	Shoulder Joint	1.70	2.30	0.44	35	20	0.0040
2	R-Side seam	1.50	3.85	1.19	43	125	0.0164
3	L-Side seam	2.20	5.50	1.21	41	100	0.0062
4	Neck Joint	0.80	2.65	0.16	45	35	0.0005
5	Sleeve Joint	4.00	5.10	1.57	44	75	0.0030
6	Sleeve hem	1.80	1.30	0.25	39	10	0.0063
7	Bottom hem	2.20	3.21	1.16	37	60	0.0042

A Three-Station Garments Sewing Line

In order to explain the solution procedure, a 3-workstation garments sewing line is considered with an inspection station located at the end of workstation-3 for demonstrative purposes. Let $C^F = \$100/\text{hour}$ and $c = \$3.10/\text{unit}$. Also, as given in Table 1, $C_k^f = \{1.70, 1.50, 2.20\}$ dollars/hour, $c_k^r = \{2.30, 3.85, 5.50\}$ dollars/T-shirt, $c_k^d = \{0.44, 1.19, 1.21\}$ dollars/T-shirt, $t_k^p = \{35, 43, 41\}/3600$ hour/T-shirt, $t_k^R = \{20, 125, 100\}/3600$ hour/T-shirt $p_k = \{0.0040, 0.0164, 0.0062\}$, and $T=43/3600$ hour/T-shirt. A branch and bound (B&B) method is applied on this 3-workstation problem and illustrated in Figure 2. A total of 19 nodes were explored. The optimum result is found at node 10 with $(x^*, y^*) = \{(0,1), (1,1), (0,0)\}$ and the minimum unit cost is \$4.37/T-shirt. Here $(x_1, y_1) = (0,1)$ indicates that the defective items produced at first workstation should be

repaired at the regular on-line workstation-1. Similarly, $(x_2, y_2) = (1,1)$ indicates that defective items produced at second workstation should be repaired at separate dedicated off-line repair station. Thus the defective items produced at third workstation have to be scrapped.

Figure 2: B&B results for 3-workstation problem



Identical Sewing Lines with Varying Output Quality

Five different identical sewing lines, each with 7 workstations are manufacturing the same T-shirts, but as machine operators are different for different lines, output quality and throughput varies. Though fixed and variable costs as well as production and repair times are assumed to be the same, defect probabilities are not so. Defect probabilities $p_k, \forall k = 1, 2, \dots, 7$ at corresponding operations at different sewing lines are listed in Table 2. All other data are the same as shown in Table 1 except p_k .

Results have been summarized in Table 2. Here (x,y) in Table 2 indicates the prescribed optimal solutions with number of off-line repair stations, unit production cost and throughput rate for good items in the last three columns, respectively. For sewing lines allowing no offline repair have been analyzed as well. In this case calculations are done by considering very large values for fixed costs of offline repair stations (i.e. $c_k^d \rightarrow \infty, \forall k$) in the existing problem setup such that the possibility of selecting a dedicated repair workstation is automatically neglected. The unit cost of production and corresponding throughput rates for good items are calculated from this problem setup (i.e., no offline repair) and noted in the parenthesis in Table 2 along with other optimum results.

Sewing Line		Proportion of defects p_k and decision (x, y)							Number of dedicated repair station	Min. unit Production cost (\$/unit)	Throughput Rate for good items (units/hour)
		Workstations									
		1	2	3	4	5	6	7			
1	p_k	0.0040	0.0164	0.0062	0.0005	0.0030	0.0063	0.0042	1	4.4620 (4.4880)†	79.9689 (79.9112)‡
	(x, y)	(0,1)	(1,1)	(0,0)	(0,1)	(0,0)	(0,1)	(0,1)			
2	p_k	0.0027	0.0011	0.0003	0.0024	0.0012	0.0007	0.0012	0	4.3805 (4.3805)	79.8509 (79.8509)
	(x, y)	(0,1)	(0,1)	(0,0)	(0,1)	(0,0)	(0,1)	(0,1)			
3	p_k	0.0060	0.0028	0.0112	0.0159	0.0064	0.0129	0.0017	2	4.4791 (4.5342)	83.0450 (79.0228)
	(x, y)	(0,1)	(0,1)	(1,1)	(1,1)	(0,0)	(0,1)	(0,1)			
4	p_k	0.0031	0.0013	0.0056	0.0030	0.0193	0.0030	0.0098	2	4.5135 (4.5209)	83.4057 (79.8138)
	(x, y)	(0,1)	(0,1)	(0,0)	(1,1)	(1,1)	(0,1)	(0,1)			
5	p_k	0.0008	0.0181	0.0063	0.0072	0.0068	0.0024	0.0155	3	4.5110 (4.5605)	92.2509 (79.5360)
	(x, y)	(0,1)	(1,1)	(0,0)	(1,1)	(0,0)	(0,1)	(1,1)			

† Unit production cost if all repairs were done on line. ‡ Throughput rate of good products if all repairs were done on line.

It may be noted that dedicated offline repair workstation provides cost no more than that obtained under no-offline repair policy. This offline repair policy advantageously provide no less throughput rate than that yielded from the online repair system. Though all the system parametric data in Table 1 remains unchanged for this problem except p_k , various optimal results are not the same due to the variation in p_k . For example, there is no dedicated repair station required for sewing lines 2, whereas the number of dedicated off-line repair station required in sewing lines 1, 3, 4 and 5 are 1, 2, 2 and 3 respectively.

CONCLUSION

Deciding, whether the defective items should be repaired on-line at regular workstation(s) or off-line at separate dedicated repair station(s) or should be scrapped instead of repair, is an important concern for making the operational decision in a line production system. This research dealt with locating repair station on or off the production line wherein the inspection is stationed at the end of main line. To describe the implication of the prescribed model a case of T-shirt sewing lines is presented in this article. It is observed that, in general, the optimum unit cost of production is lower and throughput rate for good items is higher for the cases where separate off-line repair station is prescribed. Though the problem investigated pertains to garments industry, this research outcome is beneficial and implementable to many engineering production systems, especially in discrete production systems. Since the garments industry and other engineering industries involve billions of dollars of revenue and sales, a small improvement in those systems will likewise impact the sectors with huge financial benefit to the management and consumers. Considering possibility of detecting nonconformities within the production line, dependent defects and/or the imperfect inspection facilities can be considered for extending the model in future.

References

Aafa (2012). *U.S. Apparel Imports - 2002 – 2011*. American Apparel & Footwear Association, 1601 North Kent Street, Suite 1200, Arlington, VA 22209.

Bahadir, S.K. (2011). Assembly line balancing in garment production by simulation, Chapter 4 in *Assembly Line-Theory and Practice*, edited by Waldemar Grzechca, ISBN: 978-953-307-995-0, published by InTech, Janeza Trdine 9, 51000 Rijeka, Croatia, 67-82.

Chang, C.T. (2001). On the polynomial mixed 0-1 fractional programming problems. *European Journal of Operational Research*, 131 (1), 224-227.

Hossain, M.S.J. & Sarker, B.R. (2016) "Optimal locations of on-line and off-line rework stations in a serial production system," *International Journal of Production Research*, 54(12): pp. 3603-3621.

Islam, M.M., Mohiuddin, H.M., Mehidi, S.H., & Sakib, N. (2014). An optimal layout design in an apparel industry by appropriate line balancing: A case study. *Global Journal of Researches in Engineering*, 14 (5.1), 35-43.

Li, H.L. (1994). A global approach for general 0-1 fractional programming. *European Journal of Operational Research*, 73(3), 590-596.

Raviv, T. (2013). An efficient algorithm for maximizing the expected profit from a serial production line with inspection stations and rework. *OR Spectrum*, 35(3), 609–638.