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Comparing the Effects of Automat Use on Assembly Line Performance in the Apparel Industry by Using a Simulation Method

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Abstract
In this article, general information related to efficiency, assembly lines and simulation are primarily reviewed. previous studies on assembly line balancing are theoretically analysed. Thereafter two different assembly lines are designed to produce jean trousers. In one assembly line - manual machines and in another automats are used for seven selected operations. These assembly lines are modelled by the Promodel Simulation Program and the assembly line balancing problem is applied. The aim of the study is to establish which assembly lines have the highest line performance and to research the effects of using automat in assembly lines on production volume and efficiency. The simulation method formerly informs investors about the consequences of their investment in the decision making process for technology investments. The study concludes that automat usage on an assembly line increases the production volume and affects the efficiency of assembly line positively.

Key words: *jean trousers, assembly line balancing, automat, simulation.*

Introduction

The use of the term efficiency dates back to the 18th century. It was generally described as the relation between input and output in 1766 (Quesnay) [1]. In the most common description, efficiency is used as the relationship between output created by a production or service system and input used to produce this output [2]. From the point of view of costumer-oriented production, efficiency can be described as a process which has the highest production level with the highest quality, lasting for the shortest period and with the lowest potential cost by considering costumer and employee satisfaction [3].

The main aim of companies is to make a profit, which depends on efficiency, as efficiency centers its importance on making profit [4].

In present-day conditions, companies need to use their limited sources in the most effective ways to compete in the market and increase their market share while saving them. Among these sources, materials, labour and machines are prominent for production. When the labor source is considered as the duration of making use of labour, shortening the duration of an operation means fewer operators, machines and less labour during the same operations to increase the production volume of the same product. Consequently more products come out in the same duration. For companies, this results in using the limited sources more efficiently and producing faster.

Competitiveness requires constant technological developments. One of the most important factors in attaining a permanent place in a competitive market is to make innovations for both production and products [5]. The use of an automat has an important effect on accelerating the delivery speed and shortening the duration of operations. As is well known, automats are advanced technological machines which can carry out more than one operation and manufacture output products that have a standard quality in one sitting. Automat use not only shortens the duration of operations but also enables to produce outputs which have standard quality [6].

As apparel companies have complicated production systems with a great number of machines and operators, working with assembly lines makes it hard to decide about the investment, especially when the order amount is small. It is difficult to decide whether the system will improve the product quality without analysis of the general position of the production system. Especially it is an enigma to foresee the outcomes of investment decisions. Simulation is one of the most useful methods that can assist in making decisions about the process [6, 7].

Assembly lines are places where parts and components of products are pieced together and treated in different ways. The basic specialty of an assembly line is to transfer work pieces from one station to another [3]. Assembly line balancing or line balancing is to attain needed operations during product formation at assembly stations in a way that the duration of lost times can be reduced. In other words it is described as allocating work pieces to operation systems [8].

Assembly lines are classified according to the number of models and products that are treated, and they are divided into groups according to the way they are produced. Assembly line balancing methods are divided into three groups according to the solution approach: single model, multi-model and mixed-model assembly lines [9 - 11]. Assembly line balancing method based solution approaches are threefold: Heuristic methods, analytical methods and simulation techniques [12].

Simulation, in other words ‘analogy’, is designed to minimise the real size and transfer it onto a computer [6]. Shanon described it as a method of managing experiments to design a computerised system model and to understand system models with this model or to evaluate different strategies which can be used to manage the system [13]. Simulation is an important tool to analyse the current situation and determine what is necessary to be done later on. Simulation also has important advantages to foresee the results of investment decision while a company is determining investments and to be able to make a choice between two current situations. These specialities of simulation make it a method that can be used as a decision making tool without having any risks when it is considered

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that ready to wear sewing lines necessitate capital-incentive.

In this study, two assembly lines which are called manual and automat where jean trousers are sewn are designed and modeled by the simulation method. Then the action of these models are analysed and compared with each other. The aim of the study is to analyse the effects of automat usage on jean trouser assembly lines where manual machines are used on the production volume and efficiency of the assembly lines in order to expand the the decision making process for possible technology investment.

Literature review

Researchers have studied the subject of balancing assembly lines in many different industrial areas. First line balancing researches have been carried out in the automotive sector. Up to today, assembly line balancing studies have been conducted in the textile industry as well as in other industries. When the history of researches on assembly line balancing is considered, it appears that the idea of assembly line balancing was originally suggested by Bryton in his article called "Balancing of Continuous Production Line" in 1954 [14].

The first research published was called "The assembly Line Balancing Problem", conducted by Salveson in 1995 [15]. After this study a great variety of researches were conducted by academics who gave their name to the assembly line balancing method. The names of the researchers that can be given as examples are as follows: Bowman in 1960, Kilbridge & Wester, Helgeson & Birnie, and Tonge in 1961, Hoffman in 1963, Moodie and Young in 1965, Arcus in 1966, Talbotin 1975 and in following years, F.B. & Patterson, J.H., Gehrlein, W. V in 1984 & 1986, Agrawal ve El-Sayed ile Boucher in 1985, Baybars in 1986, and Hoffman in 1990 [16 - 29].

When studies on assembly line balancing in the apparel industry are reviewed, what first comes to mind is the study conducted by Baskak, in which a new method was developed for the assembly line balancing problem [30]. Studies on apparel assembly line balancing were conducted by Eryuruk and her colleagues [31, 32], Guner and her colleagues [33, 34], and Kayar and his colleague [35].

When the studies on line balancing by the simulation method are analysed, it appears that Cocks and Harlock made a simulation of the sewing department of an apparel company using a program named Fortran 77 [36]. Fozzard and his colleagues made a simulation of the flow line in a clothing company [37]. In his study, Kayar designed two separate assembly lines which had different technology to produce jean trousers by using the Promodal simulation program, and compared the differences between these assembly lines [6]. In the study conducted by Zeilinski and Czacherska, the Lanner Group Witness simulation program was used to optimise a sewing team and minimise the duration of team members' free time. Similarly in a study conducted by Zeilinski, the date taken from a computerised simulation of the production process of a sewing team was analysed [38, 39]. Rajakumar and his colleagues tried to balance an assembly line by using a simulation program written in C++ [40]. In the studies conducted by Kursun, Kaloğlu and their colleagues, between 2006 and 2010, used the simulation method for solving issues about bottlenecks, for production line modeling, determining ideal workflow, assembly line balancing, and for analysis of modular production systems and sewing line balancing [7, 41 - 46]. In the study conducted by Eryuruk dress assembly line was modelled by using a simulation program [47]. Assembly line balancing practices applied by using the simulation method were also conducted by Guner and his colleagues [48, 49].

Experimental

Five pocket jean trousers were used in this study. A model of the trousers and their parts used to create them are shown in ***Figure 1***.

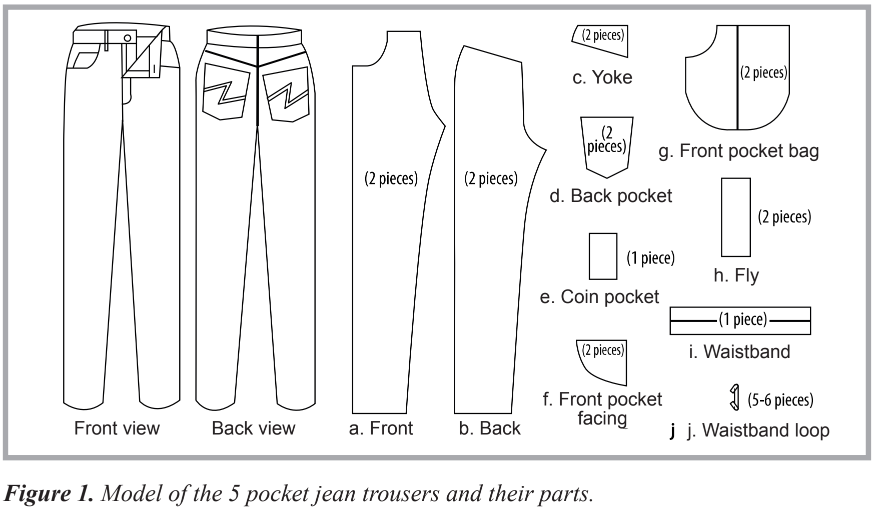

Figure 1. *Model of the 5 pocket jean trousers and their parts.*

The parts of the jean trousers shown above were treated in appropriate machines according to their operation flow chart. In this context, the five pocket jean trousers consisted of 22 - 23 parts. ***Figure 2*** shows the production flow which is necessary for the production of jean trousers. The code "-r" symbolises the codes used in the simulation model.

Work and time study

Before establishing a production line for jean trousers, it is necessary to obtain information about the assembly line that will be used. In consequence of a work and time study, data about the name of the operation, the order of operations, operation times and machines which are used during the operation, the operations that will be assigned to the operators are clear.

A time study provides needed information to design, plan, organise and control the production process. Work measurements should be made by considering the structure of the company and its financial means [2, 50]. The technique most widely used among those for work measurement by companies is the time study, otherwise called the stopwatch technique [4]. All operation times are measured by using a stopwatch to determine the standard time of production of jean trouser sewing. The measurements are made as PM (percentage-minute) and they are turned into minutes (percentage-minute/60) by calculating their arithmetic means.

As these measurements are being done, data on how many measurements are

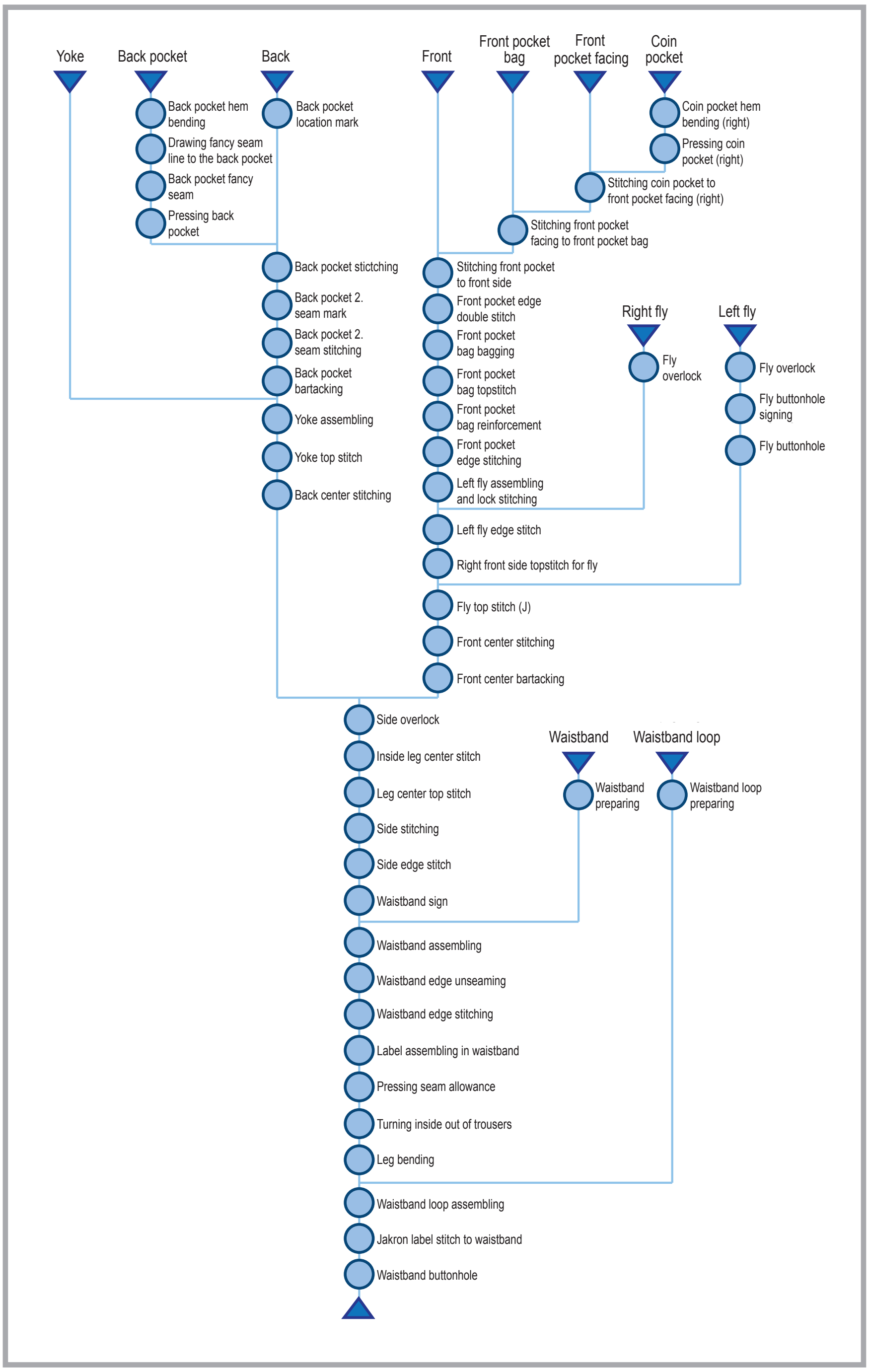

Figure 2. *Operations and flow chart of the operations in five pocket jean trouser production.*

necessary to be made for each operation are provided by means of the formula given below. These measurements are repeated by considering the data which are generated. In this statistical method, several pre-observations (n^1) are conducted firstly. Afterwards the formula given below is solved for a 95, 45 security level and ± 5% error margin [51].

$$n = \left(\frac{40\sqrt{n^1 \sum x^2 - (\sum x)^2}}{\sum x} \right)^2$$

where, n is the actual sample size, n^1 the number of pre-observations, x the time measured, and $\sum x$ is the sum of times measured [52].

Pre-observations are made for each operation (the number of pre-observations is 5). In parallel with these pre-observations, the formula is solved to determine how many times operations are needed to be measured. The maximum rate regarding the measurement numbers for all operations is found to be 15. In parallel with the result taken from pre-observations 15 measurements are performed for every operation. An example of calculating the measurement number of the "side stitching" operation related to the formula is given in ***Table 1***.

$$n = \left(\frac{40\sqrt{5(3095.93) - (124.06)^2}}{124.06} \right)^2$$

$n = 9.24 = 10$

Time studies also necessitate usage of techniques such as performance assessment to attain the operation speed and to link it with the standard operation pace [2]. Performance estimation is a process that really requires being experienced and having vast knowledge [53]. While operation durations are being measured, a performance assessment is made for each operation.

The normal duration, estimated by multiplying the time *measured* by the distilled performance, needs to some additions. Some operations that cannot be repeated in every loop, unpredictable loss of time, and some reasons such as fatigue require increasing the normal duration with deliberately appointed additions. These additions that are attained to increase the normal duration are called tolerance (highly flexible) [50].

During the interview that is conducted with executives of the company in which the jean trousers are produced, it is stated that the tolerance share was calculated as 15% as a result of previous measurements. and is used to estimate the standard time.

Afterwards the standard time is calculated for each operation by using the formula shown below.

$$ST = MT \times R + MT \times R \times t$$

where, ST is the standard time, MT the measured time, R the performance, t the tolerance [6].

Table 1. *Example of problem solving related to the formula for the side stitching operation.*

Number of measurements	Times measured (x)	x^2
1	23.03	530.38
2	23.25	540.56
3	26.46	700.13
4	27.66	765.07
5	23.66	559.79
$n_l = 5$	$\sum x = 124.06$	$\sum x^2 = 3095.93$

Table 2. *Operations, operation times, and machine types used for the trouser sewing.*

Op. No	Operations	Op. No	Automat assembly line (machines)	Op. times, min.	Manual assembly line (machines)	Op. times, min.
r1	Back pocket hem bending	r1	Pocket hem bending automat	0.13	Double needle lock-stitch sewing machine	0.19
r2	Drawing fancy seam line to the back pocket	r3	Back pocket fancy seam automat	0.39	Hand-made	0.30
r3	Back pocket fancy seam				Lock-stitch sewing machine	0.38
r4	Pressing back pocket	r6	Back pocket stitch automat	0.51	Press	0.35
r5	Back pocket location mark				Hand-made	0.40
r6	Back pocket stitching				Lock-stitch sewing machine	0.70
r7	Back pocket 2. seam mark				Hand-made	0.30
r8	Back pocket 2. Seam stitching				Lock-stitch sewing machine	0.60
r9	Back pocket bartacking				Bartack machine	0.30
r10	Yoke assembling	r10	3 thread overlock machine	0.43	3 thread overlock machine	0.43
r11	Yoke top stitch	r11	3 thread chain stitch machine	0.25	3 thread chain stitch machine	0.25
r12	Back center stitching	r12	3 thread chain stitch machine	0.40	3 thread chain stitch machine	0.40
r13	Fly overlock	r13	3 thread overlock machine	0.14	3 thread overlock machine	0.14
r14	Fly buttonhole signing	r14	Hand-made	0.09	Hand-made	0.09
r15	Fly buttonhole	r15	Buttonhole machine	0.27	Buttonhole machine	0.27
r16	Coin pocket hem bending (right)	r16	Pocket hem bending automat	0.05	Double needle lock-stitch sewing machine	0.11
r17	Pressing coin pocket (right)	r17	Press	0.20	Press	0.20
r18	Stitching coin pocket to front pocket facing (right)	r18	Double needle lock-stitch sewing machine	0.09	Double needle lock-stitch sewing machine	0.09
r19	Stitching front pocket facing to front pocket bag	r19	Cover stitch machine	0.20	Cover stitch machine	0.20
r20	Stitching front pocket to front side	r20	Lock-stitch sewing machine	0.43	Lock-stitch sewing machine	0.43
r21	Front pocket edge double stitch	r21	Double needle lock-stitch sewing machine	0.28	Double needle lock-stitch sewing machine	0.28
r22	Front pocket bag bagging	r22	3 thread overlock machine	0.29	3 thread overlock machine	0.29
r23	Front pocket bag top stitching	r23	Lock-stitch sewing machine	0.22	Lock-stitch sewing machine	0.22
r24	Front pocket bag reinforcement	r24	Lock-stitch sewing machine	0.43	Lock-stitch sewing machine	0.43
r25	Front pocket edge stitching	r25	Lock-stitch sewing machine	0.15	Lock-stitch sewing machine	0.15
r26	Left fly assembling and lock stitching	r26	3 thread overlock machine	0.21	3 thread overlock machine	0.21
r27	Left fly edge stitch	r27	Lock-stitch sewing machine	0.26	Lock-stitch sewing machine	0.26
r28	Right front side top stitch for fly	r28	Lock-stitch sewing machine	0.28	Lock-stitch sewing machine	0.28
r29	Fly top stitch (J)	r29	Fly top stitch automat	0.22	Double needle lock-stitch sewing machine	0.45
r30	Front center stitching	r30	Double needle lock-stitch sewing machine	0.51	Double needle lock-stitch sewing machine	0.51
r31	Front center bartacking	r31	Bartack machine	0.14	Bartack machine	0.14
r32	Side overlock	r32	3 thread overlock machine	0.48	3 thread overlock machine	0.48
r33	Inside leg center stitch	r33	3 thread overlock machine	0.46	3 thread overlock machine	0.46
r34	Leg center top stitich	r34	3 thread chain stitch machine	0.33	3 thread chain stitch machine	0.33
r35	Side stitching	r35	5 thread overlock machine	0.39	5 thread overlock machine	0.39
r36	Side edge stitch	r36	Lock-stitch sewing machine	0.40	Lock-stitch sewing machine	0.40
r37	Waistband preparing	r37	Lock-stitch sewing machine	0.09	Lock-stitch sewing machine	0.09
r38	Waistband sign	r39	Waistband assembling automat	0.19	Hand-made	0.30
r39	Waistband assembling				Waistband assembling machine	0.40
r40	Waistband edge unseaming	r40	Hand-made	0.27	Hand-made	0.27
r41	Waistband edge stitching	r41	Lock-stitch sewing machine	0.53	Lock-stitch sewing machine	0.53
r42	Label assembling in waistband	r42	Bartack machine	0.27	Bartack machine	0.27
r43	Pressing seam allowance	r43	Press	0.30	Press	0.30
r44	Turning inside out of trousers	r44	Invers machine	0.09	Invers machine	0.09
r45	Leg bending	r45	Leg sewing machine	0.65	Leg sewing machine	0.65
r46	Waistband loop preparing	r46	Cover stitch machine	0.17	Cover stitch machine	0.17
r47	Waistband loop assembling	r47	Waistband loop assembling automat	0.42	Bartack machine	0.85
r48	Jakron label stitch to waistband	r48	Lock-stitch sewing machine	0.28	Lock-stitch sewing machine	0.28
r49	Waistband buttonhole	r49	Buttonhole machine	0.20	Buttonhole machine	0.20
			Total time	**12.09**	**Total time**	**15.81**

Table 3. Number of machines – operators required for the operations

Automat assembly line				Manual assembly line			
Op. No	Machine type	Operation times, min.	Number of machine – operators required	Op. No	Machine type	Operation times, min.	Number of machine-operators required
r1	Pocket hem bending automat	0.13	0.241	r1	Double needle lock-stitch sewing machine	0.19	0.352
r3	Back pocket fancy seam automat	0.39	0,722	r2	Hand-made	0.30	0.556
				r3	Lock-stitch sewing machine	0.38	0.704
r6	Back pocket stitch automat	0.51	0.944	r4	Press	0.35	0.648
				r5	Hand-made	0.40	0.741
				r6	Lock-stitch sewing machine	0.70	1.296
				r7	Hand-made	0.30	0.556
				r8	Lock-stitch sewing machine	0.60	1.111
				r9	Bartack machine	0.30	0.556
r10	3 thread overlock machine	0.43	0.796	r10	3 thread overlock machine	0.43	0.796
r11	3 thread chain stitch machine	0.25	0.463	r11	3 thread chain stitch machine	0.25	0.463
r12	3 thread chain stitch machine	0.40	0.741	r12	3 thread chain stitch machine	0.40	0.741
r13	3 thread overlock machine	0.14	0.259	r13	3 thread overlock machine	0.14	0.259
r14	Hand-made	0.09	0.167	r14	Hand-made	0.09	0.167
r15	Buttonhole machine	0.27	0.500	r15	Buttonhole machine	0.27	0.500
r16	Pocket hem bending automat	0.05	0.093	r16	Double needle lock-stitch sewing machine	0.11	0.204
r17	Press	0.20	0.370	r17	Press	0.20	0.370
r18	Double needle lock-stitch sewing machine	0.09	0.167	r18	Double needle lock-stitch sewing machine	0.09	0.167
r19	Cover stitch machine	0.20	0.370	r19	Cover stitch machine	0.20	0.370
r20	Lock-stitch sewing machine	0.43	0.796	r20	Lock-stitch sewing machine	0.43	0.796
r21	Double needle lock-stitch sewing machine	0.28	0.519	r21	Double needle lock-stitch sewing machine	0.28	0.519
r22	3 thread overlock machine	0.29	0.537	r22	3 thread overlock machine	0.29	0.537
r23	Lock-stitch sewing machine	0.22	0.407	r23	Lock-stitch sewing machine	0.22	0.407
r24	Lock-stitch sewing machine	0.43	0.796	r24	Lock-stitch sewing machine	0.43	0.796
r25	Lock-stitch sewing machine	0.15	0.278	r25	Lock-stitch sewing machine	0.15	0.278
r26	3 thread overlock machine	0.21	0.389	r26	3 thread overlock machine	0.21	0.389
r27	Lock-stitch sewing machine	0.26	0.481	r27	Lock-stitch sewing machine	0.26	0.481
r28	Lock-stitch sewing machine	0.28	0.519	r28	Lock-stitch sewing machine	0.28	0.519
r29	Fly top stitch automat	0.22	0.407	r29	Double needle lock-stitch sewing machine	0.45	0.833
r30	Double needle lock-stitch sewing machine	0.51	0.944	r30	Double needle lock-stitch sewing machine	0.51	0.944
r31	Bartack machine	0.14	0.259	r31	Bartack machine	0.14	0.259
r32	3 thread overlock machine	0.48	0.889	r32	3 thread overlock machine	0.48	0.889
r33	3 thread overlock machine	0.46	0.852	r33	3 thread overlock machine	0.46	0.852
r34	3 thread chain stitch machine	0.33	0.611	r34	3 thread chain stitch machine	0.33	0.611
r35	5 thread overlock machine	0.39	0.722	r35	5 thread overlock machine	0.39	0.722
r36	Lock-stitch sewing machine	0.40	0.741	r36	Lock-stitch sewing machine	0.40	0.741
r37	Lock-stitch sewing machine	0.09	0.167	r37	Lock-stitch sewing machine	0.09	0.167
r39	Waistband assembling automat	0.19	0.352	r38	Hand-made	0.30	0.556
				r39	Waistband assembling machine	0.40	0.741
r40	Hand-made	0.27	0.500	r40	Hand-made	0.27	0.500
r41	Lock-stitch sewing machine	0.53	0.981	r41	Lock-stitch sewing machine	0.53	0.981
r42	Bartack machine	0.27	0.500	r42	Bartack machine	0.27	0.500
r43	Press	0.30	0.556	r43	Press	0.30	0.556
r44	Invers machine	0.09	0.167	r44	Invers machine	0.09	0.167
r45	Leg sewing machine	0.65	1.204	r45	Leg sewing machine	0.65	1.204
r46	Cover stitch machine	0.17	0.315	r46	Cover stitch machine	0.17	0.315
r47	Waistband loop assembling automat	0.42	0.778	r47	Bartack machine	0.85	1.574
r48	Lock-stitch sewing machine	0.28	0.519	r48	Lock-stitch sewing machine	0.28	0.519
r49	Buttonhole machine	0.20	0.370	r49	Buttonhole machine	0.20	0.370
	Total	**12.09**	**22.389**		**Total**	**15.81**	**29.280**

The durations obtained as a result of the measurements which are made for each operation by considering the tolerance share, performance assessments made, the arithmetic mean of performance rates in terms of *PM*, which are measured by using a stopwatch, are shown in ***Table 2*** (see page 115). The times of the operations consist of not only the times of the operation on the manual assembly line but also in the automat assembly line.

As is shown in ***Table 2***, jean trouser sewing on the assembly line for a manual machine operation involves 49 operations and the total sewing duration of jean trousers is 15.18 minutes. The assembly line on which automats are used to produce jean trousers involves in 42 operations and the total sewing duration is 12.09 minutes.

As a result of using an automat, both the number of operations and the duration of jean trouser sewing diminishes, making jean trouser sewing 3.72 minutes shorter, which means a 3.72 minute return.

In this study, the assembly line on which automats are used is called an "Automat assembly line" and the other on which automats are not used is called a "Manual assembly line".

Simulation modeling

The Promodel 4.0 simulation program is used to create the simulation model. Each operation which belongs to operators is programmed as shown in ***Figure 2***. This study consists of two steps:

Step 1 - the simulation is modelled based on using one operator and machine for each operation on both manual and automat assembly lines. In organised simulation models, the efficiency of machines, the daily production amount (*PA*), the production time of jean trousers, loss of balance (*LB*) and assembly line efficiency (*LE*) on automat and manual assembly lines are studied. In this step, the manual assembly line is symbolised as "AL_m" and the automat assembly as "AL_a".

Step 2 - the simulation is modelled based on the target daily production amount, 1000 for both the manual and automat assembly lines, and a study on assembly line balancing is conducted. Information about the efficiency of the machines used, the production time of jean trousers, loss of balance (*LB*) and assembly line efficiency (*LE*) is observed. In this step the manual assembly line is symbolised as "ALB_m" and the automat assembly line as "ALB_a".

Table 4. *Operations assigned based on machines for manual and automat assembly lines.*

Machines	AL_a	AL_m
Lock-stitch sewing machine (AL_a = 5.685 = 6 units) (AL_m = 8.796 = 9 units)	r20 - r27	r3 - r23
	r23 - r37 - r48	r6
	r24 - r27	r8
	r25 - r28 - r37	r20 - r23 - r37
	r27 - r36	r24 - r6 - r37
	r41	r25 - r27 - r6
		r28 - r8 - r48
		r36 - r37 - r48
		r41
3 thread overlock machine (AL_a = 3.722 = 4 units) (AL_m = 3.722 = 4 units)	r10 - r13	r10 - r13
	r22 - r26	r22 - r26
	r13 - r32	r13 - r32
	r13 - r33	r13 - r33
Cover stitch machine (AL_a = 0.685 = 1 unit) (AL_m = 0.685 = 1 unit)	r19 - r46	r19 - r46
Double needle lock-stitch sewing machine (AL_a = 1.630 = 2 units) (AL_m = 3.019 = 4 units)	r18 - r21 - r30	r1 - r16
	r30	r18 - r21
		r29
		r30
Bartack machine (AL_a = 0.759 = 1 unit) (AL_m = 2.889 = 3 units)	r31 - r42	r9 - r31 - r42
		r42 - r47
		r47
5 thread overlock machine (AL_a = 0.722 = 1 unit) (AL_m = 0.722 = 1 unit)	r35	r35
3 thread chain stitch machine (AL_a = 1.815 = 2 units) (AL_m = 1.815 = 2 units)	r11 - r12	r11 - r12
	r11 - r34	r11 - r34
Leg sewing machine (AL_a = 1.204 = 2 units) (AL_m = 1.204 = 2 units)	r45	r45
	r45	r45
Invers machine (AL_a = 0.167 = 1 unit) (AL_m = 0.167 = 1 unit)	r44	r44
Buttonhole machine (AL_a = 0.870 = 1 unit) (AL_m = 0.870 = 1 unit)	r15 - r49	r15 - r49
Waistband assembling machine (AL_m = 0.741 = 1 unit)	-	r39
Hand-made (AL_a = 0.667 = 1 unit) (AL_m = 3.074 = 4 units)	r14 - r40	r2 - r14 - r40
		r5 - r14
		r7 - r40
		r38 - r40
Press (AL_a = 0.926 = 1 unit) (AL_m = 1.574 = 2 units)	r17 - r43	r4 - r17
		r43 - r17
Pocket hem bending automat (AL_a = 0.333 = 1 unit)	r1 - r16	-
Back pocket fancy seam automat (AL_a = 0.722 = 1 unit)	r3	-
Back pocket stitch automat (AL_a = 0.944 = 1 unit)	r6	-
Fly top stitch automat (AL_a = 0.407 = 1 unit)	r29	-
Waistband assembling automat (AL_a = 0.352 = 1 unit)	r39	-
Waistband loop assembling automat (AL_a = 0.778 = 1 unit)	r47	-
Total machine - operator	**29**	**35**

The formula used for calculation is shown below [4].

$$LB = [(nC - \sum C_o)/nC)]\ 100$$

$$LE = (1 - LB)\ 100$$

$$PA = T/C$$

where, *LB* is loss of balance, *LE* is line efficiency, *C* is cycle time, *n* is total num-

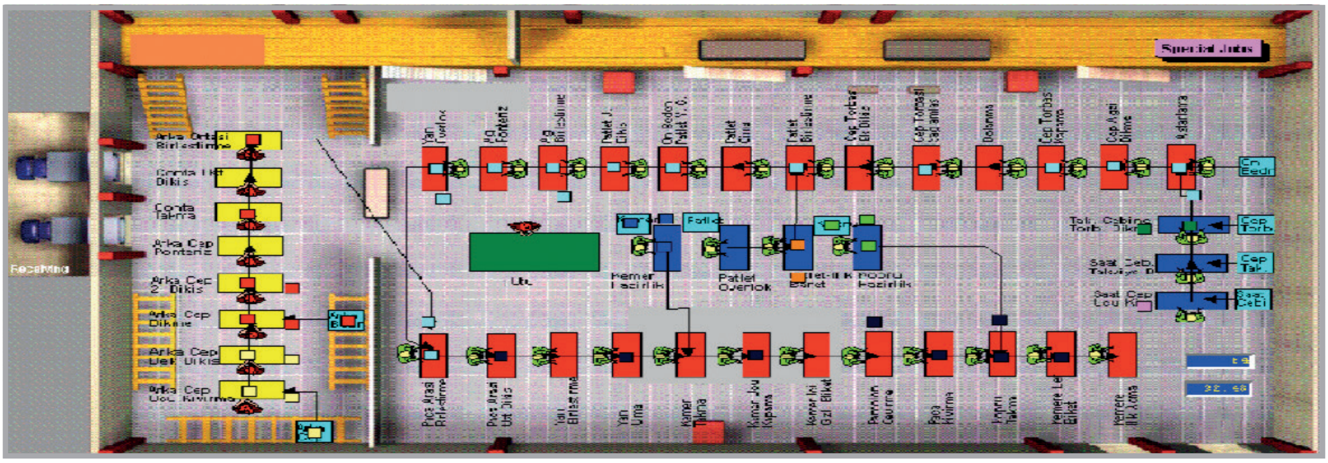

Figure 3. *Computer image of simulation model created.*

ber of work stations, C_0 is average of work station time, *PA* is daily production amount and *T* is daily production time.

To be able to practice step two, it needs to be estimated how many machines and operators will be used to be able to function properly on the assembly lines (***Table 3***).

The formula used for calculation is shown below [4].

$$RMO = (OP \times PA)/T$$

where, *RMO* is number of machines – operators **required**, *OP* is operation time, *PA* is daily production amount, and *T* is daily production time.

For example, the standard time of the operation coded as r10 is 0.19 minute.

The number of machines-operators that is required = (0.43 × 1000)/540 = 0.796

After these calculations, operators are assigned to the operations. The assignment to the manual assembly line (AL_m) and automat assembly line (AL_a) is shown in ***Table 4***.

During the modelling process, some situations that may be experienced in a real production system are taken as they come. Some are assumed that they will not be experienced. Tolerances regarding these assumptions are reflected in the data.

The assumptions accepted in this application are ordered below:

1. The daily production time is accepted as 540 min.
2. It is not taken into consideration that operators have a break because of their individual needs, machine checks and stoppages.
3. It is assumed that there is not power outage nor defective manufacturing, and that every operation proceeds as is required.
4. All operation durations are taken deterministically. In other words, all standard times are taken as same rate.
5. At each machine, only one operator works.
6. It was supposed that operators practice at most three operations on condition that they are done on the same kind of machines.
7. The system of handling the parts of the jean trousers among the machines is made by middle men and their number is accepted as being infinite.
8. The assembly line operates based on a propulsion system. When a follow-up machine confronts a narrow pass, the former machine stops its production and does not deliver parts to the next one.
9. When the simulation model is activated, the first two hours are ignored since this period is accepted as the duration for warming up.

A computer image of the c simulation model created belonging to the manual assembly line is shown in ***Figure 3***.

Results and discussions

This study is conducted in two steps. The results are concluded at the end of these steps.

Step 1 - The production time of jean trousers, the daily production amount, the assembly line efficiency belonging to the manual and automat assembly lines in simulation models which are programmed based on using one machine and one operator for each operation in both assembly lines, and a comparison of machine efficiencies on these assembly lines are shown in ***Figure 4*** and ***Table 5***.

In order to use one machine, an operator can be used for each operation in both assembly lines. Maximum operation times are also cycle times on manual and automat assembly lines. Therefore the cycle time is 0.85 minutes for AL_m and 0.65 minutes for AL_a. According to these, the daily production amount is calculated for each assembly line as below.

$$PA = 540/0.85 = 635\ (AL_m)$$

$$PA = 540/0.65 = 830\ (AL_a)$$

In order to calculate the efficiency of the assembly line, 49 machines were used for the manual assembly line and 42 machines for the automat assembly line. According to this information, assembly line efficiency is calculated as below.

$$LB = [[(49 \times 0.85) - (15.81)]/(49 \times 0.85)] \times 100 = 62\%$$

$$LE = (1 - 0.62) \times 100 = 38\%\ (AL_m)$$

$$LB = [[(42 \times 0.65) - (12.09)]/(42 \times 0.65)] \times 100 = 55.7\%$$

$$LE = (1 - 0.557) \times 100 = 44.3\%\ (AL_a)$$

When the data described in ***Table 5*** are analysed, it is clear that automat usage on an assembly line provides an advantage from the point of view of the production time, daily production amount, assembly line efficiency and cycle time.

Figure 4 shows that using of an automat on the assembly line increased the effi-

Table 5. Comparison of manual and automat assembly lines.

Comparison Criteria	AL_m	AL_a
Production time, min.	15.81	12.09
Cycle time, min.	0.85	0.65
Daily production amount (PA)	635	830
The number of operators used	49	42
Assembly line efficiency, %	37.9	44.2

ciency of other machines on it, the reason for which is that the cycle time of the automat assembly line is lower than for the manual assembly line. Decreasing the cycle time increased the operations of all machines. The efficiency of machines and operators who work doing activities in which an automat is not used in both assembly lines needs to be taken into consideration to make a proper comparison in the figure above.

Step 2 - simulation models are programmed by considering the daily production amount (PA) on the manual and automat assembly lines to be 1000 pieces. Data on the production time, assembly line efficiency, and machines which exist on both automat and manual assembly lines are shown in ***Table 6*** and ***Figures 5 - 6***.

According to ***Table 4***, in order to manufacture 1000 jean trousers, 35 (26 + 9) machines/operators for the manual assembly line and 29 (19 + 10) machines/operators for the automat assembly line were used. Cycle times of both assembly lines were 0.54 minutes. According to this information, the cycle time and assembly line efficiency for AL_m and AL_a are calculated as below.

$$PA = T/C \Rightarrow C = T/PA$$

$$C = 540/1000 = 0.54 \text{ minute } (AL_m \text{ and } AL_a)$$

$$LB = [[(35 \times 0.54) - (15.81)]/(35 \times 0.54)] \times 100 = 16.35\%$$

$$LE = (1 - 0.1635) \times 100 = 83.65\% \ (AL_m)$$

$$LB = [[(29 \times 0.54) - (12.09)]/(29 \times 0.54)] \times 100 = 22.8\%$$

$$LE = (1 - 0.228) \times 100 = 77.2\% \ (AL_a)$$

As is understood from ***Table 6***, the results approximate those of step 1. The automat assembly line provides more advantages than the manual assembly line with regard to the production time, and the amount of operators and machines that used during the jean trouser sewing operations. Especially when they are compared according to the number of operators and the machines that are needed for completing the production, it can be seen as a big advantage that an automat assembly line can operate with the same production volume even if 6 operators and 4 machines are not functioning. When the efficiency of the assembly lines are compared, it can be concluded that the efficiency of the manual assembly line is higher. The reason for the lower efficiency of the automat assembly line is that automats are designed to operate in specific operations so they are not able to function while different machines are used.

As can be seen in ***Figures 5*** and ***6***, the low efficiency of machines of automat assembly lines negatively affects its efficiency . Since automats are able to do the operation of more than one assembly line during operations , this problem disappears by means of the speciality of automats previously mentioned.

As is deduced in ***Figure 5***, it can be generally stated that the efficiency of the machines is high. When the machines on which "r1 - r16", "r18 - r21", "r19 - r46", "r44" and "r45" coded operations are done are taken into consideration, it is pointed out that the efficiency of these machines is below 70%. The machine on which coded operations "r1 - r16" and "r18 - r21" are done is a double needle lock-stitch machine, seen in ***Table 4***, and the number of machines required is 3.019. Although 4 machines operate in theory, this operation can be done using 3 machines in practice. Therefore 100% efficiency of the machines can be obtained by using 3 machines. When the "r44" coded operation is reviewed, the machine number required for this operation is 0.617, as can be seen in ***Table 4***. Since different operations cannot be done using this machine, the efficiency results in are low.

Table 6. Comparison of manual and automat assembly line balancing.

Comparison Criteria	ALB_m	ALB_a
Production time, min.	15.81	12.09
Cycle time, min.	0.54	0.54
The number of operators used	35	29
Assembly line efficiency, %	83.65	77.2

As can be interpreted from ***Figure 6***, the efficiency of the machines is generally high. The operations demonstrated with a light colour are done using automats the efficiency of which is low because of not being able to assign a different operation to these automats. As was is mentioned before, since the automats operate for more than one assembly line in operations where many assembly lines are used, its negative effect can be eliminated by means of its specialty mentioned. As with the manual assembly line, the operation which has the lowest efficiency is that coded "r44".

Conclusion

The main purpose of this study was to analyse the effect of automat usage on the production volume and efficiency of assembly lines. The other aim was to compare different assembly lines by using the simulation method in assembly line balancing.

Within the context of the study, broad research was conducted on the duration of the jean trouser sewing process in a company where jean trousers are produced. As a result of detailed analyses

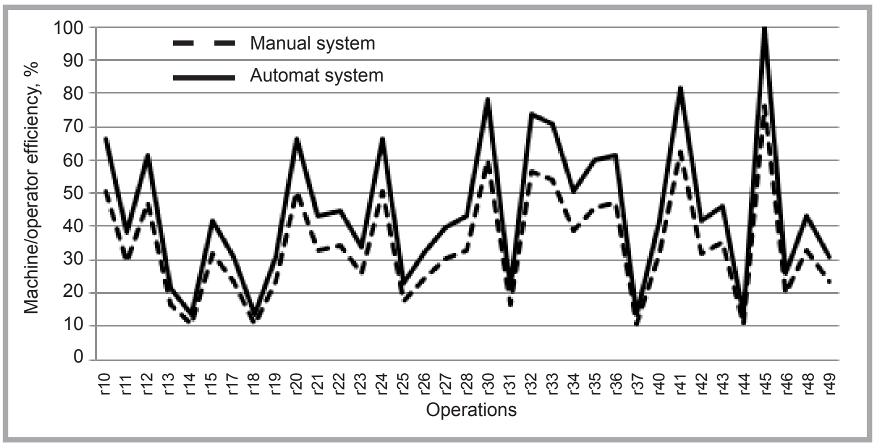

Figure 4. Comparison of machine - operator efficiencies between the manual and automat assembly lines.

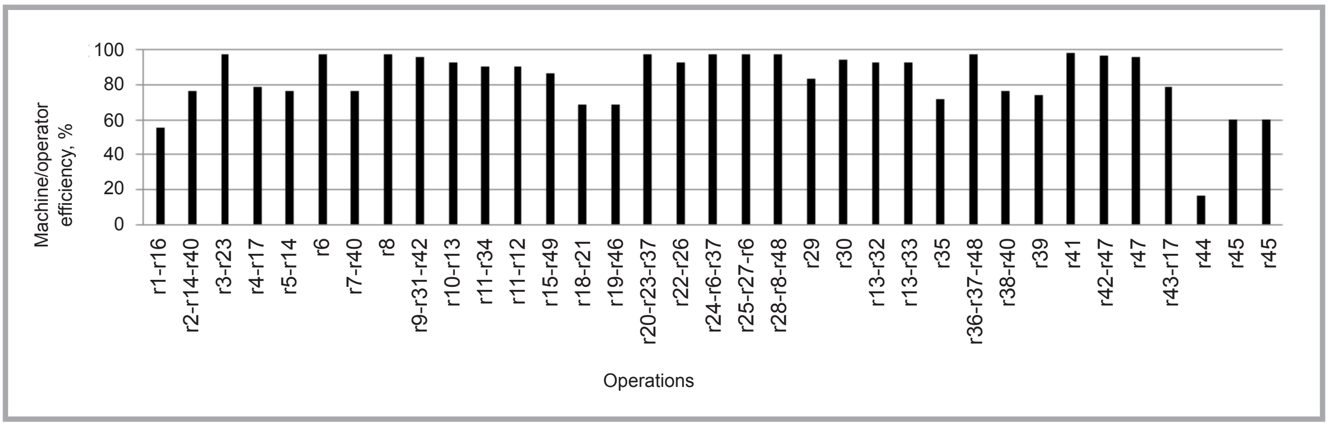

Figure 5. *Manual assembly line machine productivity.*

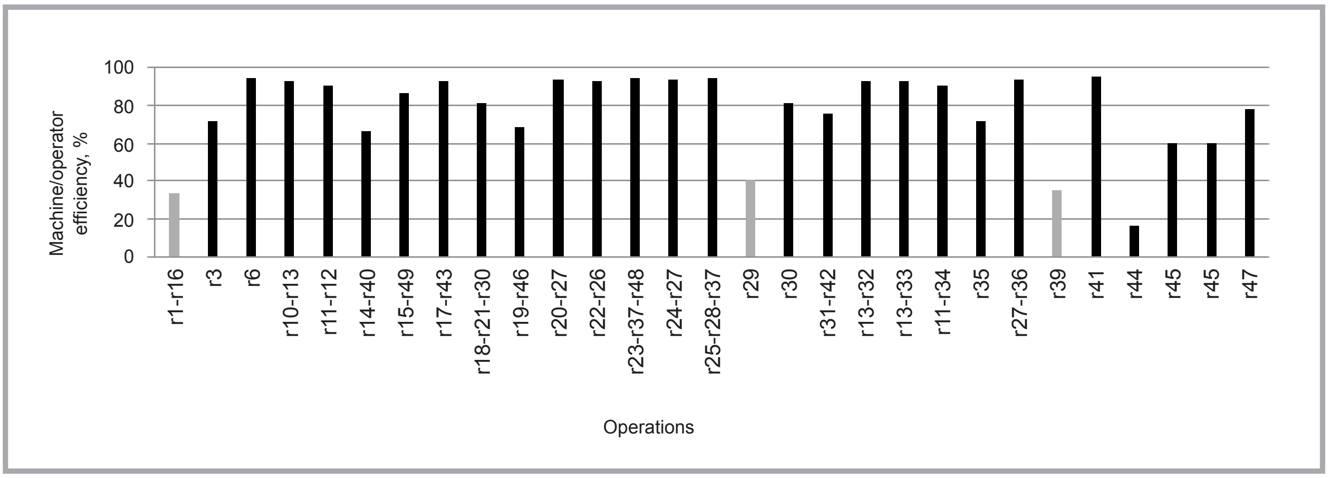

Figure 6. *Automatic assembly line machine productivity.*

carried out by the work and time study technique, the order and duration of operations, and the machines that are used for the operations are identified. Afterwards two main steps are determined and modeled. Data related to research of these models entered into the simulation program are taken and presented in order. The study concludes that automat usage increases the production volume. Especially when efficient use of time is concerned, it is clear that automat usage effects the performance positively since it produces more output than manual assembly lines.

In practice, based on using one operator and machine for each operation, it is also seen that automat usage affects the performance of the assembly line positively. In the practice applied in step two, it is seen that automat usage results in having the same production volume as a manual assembly line by using fewer machine and operators. But when assembly line performance is considered, it must be stated that the performance of an automatic assembly line is lower than a manual assembly line. Therefore using automat in companies which have many assembly lines has the effect of lower performance.

The results taken from the study can be outlined below;

1. Automat usage enables to shorten the operation duration, and accordingly the production duration, as well as increase the current output.
2. By means of automat usage, the operation that requires more than one machine can be done by using a single automat.
3. Automat usage has the advantage of the the work place since it has fewer machines for operations.
4. Automats have positive effects on increasing the performance of operations where it is used and also on the whole system.
5. The parts which are produced on automat assembly lines have the same quality, being even better than from manual machines.

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