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LEAD TIME REDUCTION: MACHINE INTERFERENCE PROBLEM IMPACT ON LEAD TIME

Master Thesis

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This is to certify that we have read this thesis and we find it fully adequate in scope, quality and content, as a thesis for the degree of Master of Science.

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ABSTRACT

LEAD TIME REDUCTION: MACHINE INTERFERENCE PROBLEM IMPACT ON LEAD TIME

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Customer satisfaction is one of the most important keys for surviving in a high competition markets. Short lead time expectation by customers drives managers of production systems to be eager to continually improve and develop their systems. The following work of thesis considers an appropriate method for lead time reduction in many industrials where one operator operates several machines. Machine interference problem (MIP) has a significant role in those production systems. Therefore, a revised method for allocating the optimum number of similar machines to operators, developed by Hadad and Keren had been used to find the optimum number of machines should be assigned for each operator to improve MIP; Two objective used to get the optimum number of machines per operator maximizing profit and minimizing cost. A quantitative analysis of average service time and run time had been calculated to get the most accurate results before applying them in the revised allocating model. This method used to increase the machine utilization, decrease average cycle time and increase productivity to decrease lead time and increase customer satisfaction.

A real case study illustrates the applicability of the proposed method for lead time reduction. The final finding shows increases of machine utilization, productivity which reduce lead time and increase customer satisfaction.

Key words: Lead time, Productivity, Machine Interference Problem (MIP).

ÖZET

ÜRETIM SÜRESINDE TASARRUF: MAKINA GIRIŞIM PROBLEMININ ÜRETIM SÜRESI ÜZERINDEKI ETKISI

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Müşteri memnuniyeti, yüksek rekabet pazarlarında hayatta kalmak için en önemli anahtarlardan biridir. Müşteriler tarafından kısa teslim süresi beklentisi, sistemlerini sürekli iyileştirme ve geliştirmeye istekli olmak için üretim sistemlerinin yöneticilerini yönlendirir. Aşağıdaki tez çalışması, bir operatörün birkaç makineyi çalıştırdığı birçok endüstride kurşun zamanı azaltımı için uygun bir yöntem olduğunu düşünmektedir. Makine Girişim Problemi (MIP), bu üretim sistemlerinde önemli bir role sahiptir. Bu nedenle, Hadad ve Keren tarafından geliştirilen operatörler için en uygun sayıda benzer makinenin tahsis edilmesine yönelik revize edilmiş bir yöntem, MIP'yi iyileştirmek için her operatör için optimum sayıda makinenin atanması için kullanılmıştır; İki hedef, operatör başına karı maksimize eden ve maliyeti en aza indiren optimum makine sayısını elde etmek için kullanılır. Bu nedenle, Hadad ve Keren tarafından geliştirilen operatörler için en uygun sayıda benzer makinenin tahsis edilmesine yönelik revize edilmiş bir yöntem, MIP'yi iyileştirmek için her operatör için optimum sayıda makinenin atanması için kullanılmıştır; İki hedef, operatör başına karı maksimize eden ve maliyeti en aza indiren optimum makine sayısını elde etmek için kullanılır. Revize edilen tahsisat modeline uygulanmadan önce en doğru sonuçların elde edilmesi için ortalama servis süresinin ve çalışma süresinin niceliksel bir analizi hesaplanmıştır. Bu yöntem, makine kullanımını arttırmak, ortalama döngü süresini ve tedarik süresini kısaltmak ve müşteri memnuniyetini arttırmak için üretkenliği arttırmak amacıyla kullanılmıştır.

Gerçek bir vaka çalışması, önerilen yöntemin kurşun zamanı azaltımı için uygulanabilirliğini göstermektedir. Son bulgular, makine kullanımının, kurşun süresini azaltan ve müşteri memnuniyetini artıran üretkenliği arttırmaktadır.

Anahtar Kelimeler: Telim Süresi, Üretkenlik, Makine Girişim Problemi (MIP).

CONTENTS

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ABBREVIATIONS

AM	: Autonomous Maintenance
ERP	: Enterprise Resources Planning
JIT	: Just In Time
MIP	: Machine Interference Problem
MRP	: Material Resources Planning
OEE	: Overall Equipment Efficiency
PFL	: Printing Fabric Labels Department
SPC	: Statistical Process Control
TL	: Turkish Lira
TOC	: Theory of Constraints

SYMBOLS

Adjusted Cycle Time	: H_N
Average Hourly Profit	: $\bar{\mu}_N$
Average Material Cost per unit	: V
Average Run Time per unit for one machine	: T
Average selling Price per unit	: L
Average service Time per unit for one machine	: t
Hourly Fixed Cost of one machine	: C_{M1}
Hourly Operator Cost	: C
Hourly Variable Cost of one machine	: C_{M2}
Interference Time	: t_{mi}
Interference Rate	: $Pt_{MI}(\rho, N)$
Machine Utilization	: $\mu_{\mathrm{N}}(\rho, \mathrm{N})$
Number of Machines	: N
Number of machines need service	: X
Operator Work Load	: $B_N(\rho, N)$
Optimum number of machines to be assigned to each operator	: N*
Optimum number of operator for all machines	: K*
Probability of idle operator	: P (x = 0)
Service Time to Run Time Ratio	: ρ
Total Cost per unit for N machines	: TCU_N
Total number of machines	: M
Yield per Hour	: Q_N

1. INTRODUCTION

Managers of production systems are eager to maximize profit, reduce cost and achieve customer satisfaction with high market competition and short lead time expectation by customers. One of the key methods to accomplish those aims is to increase productivity. Improve machine interference problem is the key to increase productivity in many industrials where one operator runs several machines.

Finding the optimum number of machines to be assigned to one operator is the key to improve the machine interference problem (MIP). Improving MIP reduce the average cycle time which increase the productivity of the production system. On the other hand, improving MIP reduces lead time, help management to calculate lead time more accurate for customers and achieve customer satisfaction.

A common assumption in many interference models is that all machines are totally identical. However, in reality age, wear, and maintenance quality cause even those machines from the same manufacturer and the same type to be no longer identical. Hence, using of those models is insufficient before doing a time study for each machine to find the appropriate and accurate method to calculate average service time and run time to use in those models.

The point considered in this thesis is determining accurate number of machines to be assigned to one operator using a revised method for allocating the optimum number of similar machines to operators. Hence, decrease the average cycle time, increase productivity, reduce lead time and increase customer satisfaction. This method was applied for the two objectives increase profit and decrease cost. However, in real life firms have product variety, machines efficiency variety and lack of historical data for all the production processes; in this thesis, an average service time and run time calculated according to the available historical data and time study to apply them in the MIP models to get the most accurate results.

Chapter one is dedicated to presentation of the necessity of machine interference rate and problems of allocating the optimum number of machines to operators to increase productivity and lead time reduction.

Chapter two includes literature review of the published articles and previous works about lead time, productivity, machine interference problem MIP. After a general knowledge about lead time and productivity the calculations of overall equipment efficiency OEE methods are presented. Moreover, formulations of revised method for allocating the optimum number of similar machines to operators are given. Lastly, relation between MIP, productivity and lead time is told.

Chapter three is about methodology of thesis. Necessity and reason of proposed method discusses the data collection process and limitations in the collection and the aim of the thesis are included.

Chapter four includes application of proposed method. Firstly, a general knowledge is given about the firm where the proposed method is applied. The firm problem definition and necessity of proposed method is told. Then, application of methodology is exemplified by the real collected data. Lastly, the earnings of the proposed method are presented at the end of this chapter.

Chapter five provides a summary of the results of the study, recommendation and suggestions for future improvements for the firm.

Chapter six provides the conclusions and suggestions for future research.

2. LITERATURE REVIEW

Managers are eager to maximize profits and reduce cost of production to accomplish this target there are many important factors should be consider, monitor and improve (Tirkel and Rabinowitz, 2014). Customer satisfaction and lead time reduction should be improve in maximizing profit strategies (Kristoffersen, 2015). Moreover, increasing productivity one of the most important keys to increase profit and decrease costs (Bebeşelea, 2015). Otherwise, Hadad and Keren (2016) stated that one of the key methods used to accomplish those aims is to find the optimum number of operators needed to run the production lines. This thesis proposes a new vision to improve lead time and customer satisfaction by help managers to determine the optimal number of operators should be assigned to a given number of machines, and the number of machines should be run by each operator which increase the productivity and accomplish the manager’s target of minimizing production costs or maximizing profits.

2.1 LEAD TIME IDENTIFICATION:

There are many researchers studied lead time and all its relevant significant factors. In a make-to-order situation, lead time terms to the delay between the time of the customer’s demand and the time when the demand is completely satisfied while in a make-to-stock situation lead time terms to procurement lead time for obtaining materials from suppliers (Hill and Khosla, 1992). Lead time should be at the minimum level; therefore, analyzing lead time and its perspective are necessary in lead time reduction process (Kristoffersen, 2015).

2.1.1 Lead Time Significant Factors and Variability:

Supply chain management, inventory management, logistics, capital investing, MRP system, production capacity, production control, productivity, procurement, process robustness, process flow, work analysis, machines layout, machines efficiency, worker performance, outsourcing, and complementary products are the most common factors between all lead time reduction studies. Bottani and Rizzi (2008), De Toni and Meneghetti

(2000) defined lead time reduction process as a timing competition. Manufacturing strategy, operational management and production process management has a significant role on lead time reduction factors such as increase productivity, reduce unit cost, improve quality, decrease carrying cost, reduce the safety stock and decrease forecast horizon (Albey and Uzsoy, 2015; Chen and Wang, 2009; Hill and Khosla, 1992). Moreover, logistics, cost, inventory and service level to customer had been defined as significant factors to improve lead time by Cannella et al. (2017). In addition, reduce setup time, raw materials availability, reduce queue time, improving tools equipment and layouts had been defined as significant key factors to improve lead time by (Shirai and Amano, 2017; Hill and Khosla, 1992). Moreover, Shirai and Amano (2017) used the theory of constraints (TOC) which focused on the importance of how to avoid the bottlenecks in production processes. On the other hand, Cannella et al. (2017) defined limiting lead time variability by lean manufacturing, six sigma, improving outsourcing and integration as an effective factor in lead time reduction process.

Just in time (JIT) is one of the most effective key method of lead time reduction by improving the optimum way of production and inventory management (Ouyang et al. 2007; De Treville et al. 2004).

Supply Chain Management and all the internal and external logistics processes should be well managed to control lead time (Bottani and Rizzi, 2008). Moreover, De Treville et al. (2004) observed that the companies should give the first priority to improve supply chain performance which reduces the lead time duration instead of improving the supply chain transfer information system. Managers should start improve supply lead time then improve demand information transfer to reduce transaction uncertainty to get better improvement results (De Treville et al., 2004).

In addition lead time became more critical factor at markets which has a very sensitive price and demand lead time (Zhao et al. 2012; Ray and Jewkes, 2004). Therefore, after the first research appeared by Boyaci and Ray (2003) about the relation between lead time and pricing; Chen et al. (2017) developed a new model to find the optimal lead time and pricing decision and observed that to get a shorter lead time from risk averse suppliers delay penalty cost should be at a certain level which drive suppliers to avoid this penalty cost.

Kristoffersen (2015) studied two partner organizations in the same value chain and observed that without accurate and efficient enterprise resource planning (ERP) system the operators and mangers will not be able to deal with the lack of the lead time and take the right decisions in the right time to improve the lead time and find the appropriate strategy plan. Simultaneously, many researchers studied the relation between the lead time and inventory management and figured out several models to manage this relation (Sarkar and Mahapatra, 2017).

2.1.2 Lead Time Improvement Investment:

How to invest capital is one of the most important and critical managerial decisions. Therefore, many studies discussed the relation between investing capitals in lead time reduction and if it has a significant effect or not (Lin, 2016). After studying the investment strategies of firms in market which has a stochastic dynamic setting by Genc (2017) he observed that there are two main types of firms strategy classification first one has a significant lead time or depend on time to build strategy and the other one without lead time value.

Firms can reduce the safety stock cost, reduce losses in the out of stock, improve their customer satisfaction and go further in the market competition by reducing their lead time (Chen et al., 2017; Lin, 2016; Ouyang et al., 2007). Moreover, Lin (2016) studied the effectiveness of increasing the investment to reduce the variability of the lead time and observed that there are three main factors should be consider which is how to drive the firm to reach the optimal production, integrated inventory and logistic policy with the optimal investment strategy to deal with the realistic and stochastic of lead time. In addition, Hill and Khosla (1992) found that in long term strategies the cost of reducing lead times becomes nothing in compare with the benefit and profits that the firm will get from reducing the lead time.

2.1.3 Lead Time Classification:

There are different types of lead time such as assembly lead time, procurement lead time, production lead time and demand lead time (Chen and Wang, 2009). This thesis focuses on the production lead time. Schmenner (2001) studied “theory of swift, even flow” and observed that firms which emphasize on flow, speed and reducing the variability can improve their productivity better than those emphasize productivity directly which has a significant effect on lead time. According to the previous literature review about lead time and its significant factors it became clear that it is very complicated and very networking; if firms want to improve lead time they have to improve their supply chain management by contrast if they want to improve their supply chain management they have to improve their lead time under the umbrella of supply chain. In addition some studies figured out that lead time is being effected with the management strategy and firms have firstly to improve their management strategy to improve their lead time. By contrast, many researchers argued that firms should firstly improve their production planning and management to improve their lead time. Therefore, it becomes clear that it is like a game of prioritizing and each firm should take the right way and put the suitable prioritizing system to their situation.

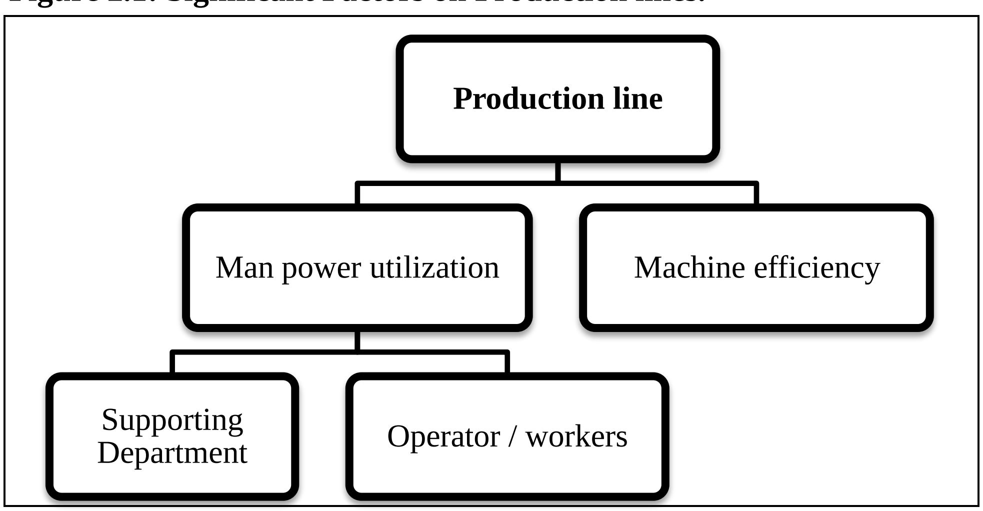
2.2 PRODUCTIVITY:

Evolution of the work load of the system overtime has a significant effect on lead time in firms (Albey and Uzsoy, 2015; Pahl et al., 2007; Missbauer, 2002). Moreover, Azizi (2015) stated that improving production performance such as productivity, equipment, efficiency and process control became the most important key for firms to survive in the competitive market. Therefore many studies focused on this point (Chen and Wang, 2009). Otherwise, continuous improvement in production capability became necessary for firms to survive and to overcome all the uncertainty in the production performance indicators. Therefore Azizi (2015) studied the relation between the overall equipment effectiveness (OEE), statistical process control (SPC) and autonomous maintenance (AM) to evaluate production productivity by continuously improve process control and machine efficiency and observed that to improve quality, production productivity, reduces defects, reduce wastes and customer satisfaction firms should use statistical process control (SPC). On the other, hand to measure the effectiveness of machines, availability, quality and performance rate firms should use overall equipment efficiency (OEE) (Azizi, 2015; Soković et al., 2009). While Wudhikarn (2011) defined the six big losses which affect the machine performance as setup and adjustments, reduced speed, periodic small stops or minor stops, start up rejects and defected and rejected products. Therefore; Azizi (2015) applied statistical process control (SPC) and overall equipment efficiency (OEE) in a tiles manufacturing company and observed that increase productivity had been affected by minimizing the defect rate and maximizing the machine performance.

2.3 Machine Efficiency:

Production managers should accurately interpret all the relevant production data to identify the significant factors at the production line and to immediately take the right decisions to improve productivity, utilization of resources, manpower utilization, machine efficiency and the all over efficiency (Subramaniam et al. 2008). Significant factors on production lines were classified by Subramaniam et al. (2008) into three main levels as shown below in figure 2.1.

Figure 2.1: Significant Factors on Production lines.

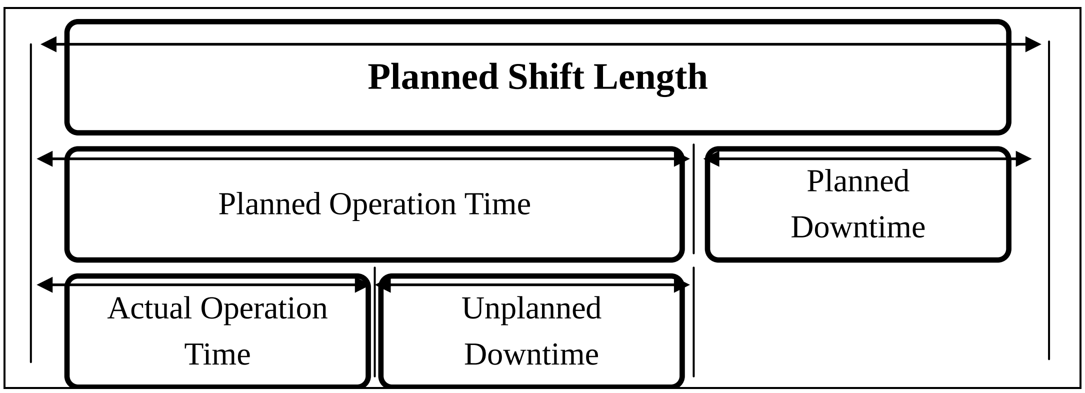


Source: Subramaniam et al. (2008)

2.3.1 Production Breakdown

Planned operation time is classified into two major factors which is actual operation time and unplanned downtime. Hence, identifying planned operation time measurements is the key to help managers to measure machine efficiency and manpower utilization (Subramaniam et al. 2008). Therefore, to improve the production capacity managers are eager to maximize the actual operation time as much as possible and minimize the unplanned downtime to achieve their target (Wudhikarn, R., 2011). Production planning time can be classified as shown in figure (2.2).

Figure 2.2: General breakdown of a production shift



Source: Subramaniam et al. (2008)

2.3.2 Machine Efficiency Measurements

Optimization of machineries in higher rate of production output industry is a common target between all managers to get the maximum usage of machineries in the shortest time possible. Manufacturing productivity losses had been classified into three main factors Availability, Performance and Quality under the Overall Equipment Effectiveness (OEE) umbrella to monitoring and improve the manufacturing efficiency. Measuring those factors used as a gauge to measure efficiency and improve productivity (Wudhikarn, 2011; Subramaniam et al. 2008). Planned downtime such as (meal breaks, scheduled maintenance and planned stops of production) is excluded from the overall time losses such as unplanned failure, breakdowns, material shortage and changeover time to get the actual operation time.

2.3.2.1 Availability

All events which can stop the production process such as material shortage, equipment failures and changeover time are included while calculating the downtime loss to figure out the availability. The changeover time should be included in OEE analysis when it is not be possible to eliminate and became a part of downtime. Actual operation time is the remaining available time. Therefore, availability simply calculated as the ratio of operation time to planned operation time. Availability is calculated according to equation 2.1 (Subramaniam et al. 2008; Sheu, 2006).

$$Availability = \frac{\text{Actual Operation Time}}{\text{Planned Operation Time}} \quad \textbf{(2.1)}$$

2.3.2.2 Performance

Performance is affected by all factors which produce a speed loss in production cycle time which included operator inefficiency, substandard materials and machine. Actual operation time is the remaining available time. Therefore, the ratio of actual operation time to planned operating time calculated the performance. The minimum cycle time that the process could be done within under optimal conditions for a given product is defined as machine ideal cycle time. Hence, performance could be calculated according to equation 2.2 (Subramaniam et al., 2008; Sheu, 2006)

$$\text{Performance} = \frac{\text{Machine Ideal Cycle Time} \times \text{Total pices produced}}{\text{Planned Operation Time}} \quad \textbf{(2.2)}$$

2.3.2.3 Quality

Quality loss is all the quality rejected products or products that require rework. Productive time is the remaining time. The production planning target is to maximize the actual productive time. Quality is the ratio of actual productive time to planned operation time. Quality could be calculated according to equation 2.3 (Subramaniam et al., 2008; Sheu, 2006).

$$\text{Quality} = \frac{\text{Good Pieces Produced}}{\text{Total Pieces Produced}} \quad \textbf{(2.3)}$$

2.3.2.4 Overall Equipment Effectiveness

Overall equipment effectiveness (OEE) is a combination between Availability, performance and quality to become one score to provide a final measure of machine efficiency. The ratio of actual production time to planned production time is called OEE which could be calculated according to equation 2.4 (Subramaniam et al., 2008; Sheu, 2006)

$$OEE = Availability \times Performance \times Quality \tag{2.4}$$

2.4 Operators and Manpower Utilization

Management objectives will not be able to accomplish in industrial production without improving the manpower utilization which classified into two factors first, the direct operators which are the operators on the production line and second, indirect operators which are the operators in the supporting department. Human performance is one of the most important indicators of the planned production time. In case of the operator performance decrease or drop, production output will be directly effect in the same way. By contrast, if the operator performance increase and improve attitude production output will be directly increased. Once the managements faced unmet target it became so important to measure the operators performance to eliminate the wasted time and increase productivity (Subramaniam et al., 2008).

2.4.1 Measuring Manpower Utilization

All the human factors that cause losses at speed base on the cycle time or time study in the production process are consider under manpower utilization measurement. Operator's inefficiency is the major factor on measuring the performance of manpower utilization. Manpower utilization could be calculated according to equation 2.5.

$$\text{Manpower Utilization} = \frac{\text{Actual Production output}}{\text{Target production output}} \tag{2.5}$$

2.5 Machine Interference Problem (MIP)

In some cases and industrials such as textile, food, plastic, electronic, and rubber industries which have a multi machine assignment, it became difficult to calculate machine efficiency because of the machine interference problem (MIP). Machine Interference time is the waiting times for each machine which need service before the operator come to serve it. Machine Interference can be described as a system which consisting of number of machines and operators and each machine operates until it needs attention from the operator (Engin, 2010). At this kind of work stations system the number of machines is always greater than the number of operators. Machine interference problem appeared when one of those machines stop or required serving by an operator (Engin, 2010). In an industrial investigation, the machine interference time may be ten percent of machine time (Chien et al., 2014).

Hadad and Keren (2016) stated that allocating the optimum number of operators to run machines is the key to achieve the manager’s target which is increase the profit and decrease the cost. Several papers studied the machine interference problem from different point of views; Most of these paper are so old but recently the interest of MIP and its related topics has remained high (Ke and Wu, 2012). This multi machine system and machine interference problem should be considered while calculating and measuring the machine efficiency (Engin, 2010).

Hadad and Keren (2016) noted that Stecke and Aronson (1985) in their review about machine and operators models stated that there is a critical MIP decision related to have too few or too many machines to each operator. On the other hand, (Ilani et al., 2014) used in their paper to “reduction approach to the two-campus transport problem” the “partitioning problem with additive objective with an application to optimal inventory groupings for joint replenishment” method which was proposed by Chakravarty et al. (1982) to find the optimum of the partitions by transferring the problem to find the shortest path. Moreover, Yang et al., (2005) in their study about queuing network models with MIP stated that when the system has a bottleneck and if the change of equipment and system is so expensive MIP became more critical and important.

Gupta (1997) considered the MIP with warm standby machines/tools in which the server takes a vacation of random duration and the repair facility becomes empty. They addressed the cases of multiple, single and hybrid multiple/single vacation schemes with exhaustive service. They provided a new transform free, closed form expressions for the probability distribution of the number of machines in the repair facility and the performance measures for MIP with warm standby machines/tools and server vacations. Ke and Wu (2012) studied the MIP between identical machines, repairmen and standby machines in an unreliable machines production system in their paper “Multi-server machine repair model with standbys and synchronous multiple vacation”. Moreover, Ke at el. (2013) used a modeled system as a finite-state Markov chain and obtained its steady state distribution by a recursive matrix approach considers a multi-repairmen problem comprising of number of operating machines with warm standbys machines subject to failures. They searched for the global optimal system parameters using the Quasi-Newton method and probabilistic global search Lausanne method. On the other hand, de Nitto Personè (2009) improved the machine interference model with vacation to deal with the recent problems of the communication area. Their model is extended to include parallelism in the vacation station and underlying Markov process is analyzed.

Kim and Lee (2012) studied the single server parallel machine scheduling problem, considering the setup for loading or unloading the product or handling tools on the machine using mixed integer programming formulations in their paper about “MIP models and hybrid algorithm for minimizing the makespan of parallel machines scheduling problem with a single server”

Chien et al. (2014) develop a methodology to determine the optimal assignment relationships between the test machines and the operators for different product mixes to improve utilization for the optimal system performance by using simulation, response surface methodology, heuristic assignment and genetic algorithms to explore alternative assignment rations to identify well-performed assignment alternatives.

As noted by Hadad and Keren (2016) that several models used the binomial distribution for the MIP were surveyed by Stecke and Aronson (1985). Such as: Bernstein (1941), Weir (1944), Jones (1971), Gillespie and Wysowski (1974), Ackermann (1977) and Stecke and Solberg (1982). All these models assumed that a single operator is assigned to several machines. Moreover, Niebel and Freivalds (2003) gives an example for binomial interference calculations. On the other hand, Hadad et al. (2013) used multinomial distribution in their model of calculation the expected interference time in the queue for each service type. Gurevich et al. (2016) presented binomial and multinomial models for special cases of the MIP. While Hadad and Keren (2016) introduces a new method to determine the optimal number of operators needed to operate machines and calculate the interference rate accurately and simply by expected value calculations, without expressing the probabilities for each situation with machines down when the objective is maximizing the hourly profit/total cost unit.

Hadad and Keren (2016) proposed the first paper that proposes a method for calculation of the adjusted cycle time for the case where one operator runs a number of identical machines. Their study proposed a method for allocating the optimum number of identical machines to operators. Using the ratio between the service time and the run time, along with the number of machines assigned to one operator an interference tables that give the interference rate was included in their study. These tables can help determine the interference rates and the adjusted cycle time in order to compute the total cost per unit (*TCU*) and the hourly profit, the proposed method takes into account two types of cost: first, the hourly fixed cost of one machine. Second, the hourly operating cost of one machine and variable cost which is exists only when the machines are working, this cost is a function of the interference rate. The major differences between the common interference models are the assumptions related to the machine operating time distribution and the service time distribution. This model presented a simple method without any assumptions that relate to machine operating time distribution or service time distribution that enables calculation of the interference rate using binomial distribution. By contrast, according to the common models calculation of the interference rate is complicated and needs the exact distributions of the operating time and the service time.

2.5.1 The revised method for allocating the optimum number of similar machines to operators' calculations:

The value of $Pt_{M1}(\rho, N)$ is the interference rate is determined by ρ and the number of machines *N* as shown in Appendix A.1. The adjusted cycle time (H_N) could be calculating according the following procedure:

a. Calculate the ratio between the service time and the run time using $\rho = t/T$.
b. Calculate the **interference rate** $Pt_{M1}(\rho, N)$ by using the interference tables in Appendix A.1.
c. Calculate the **adjusted cycle time** using equation (2.6) to, as follows:

$$H_N = T + t + t_{M1} = H_1 + t_{M1} = H_1 + Pt_{M1}(\rho, N) \times H_N$$

$$= \frac{H_1}{1 - Pt_{M1}(\rho, N)} = \frac{T(1+\rho)}{1 - Pt_{M1}(\rho, N)} \qquad \textbf{(2.6)}$$

The yield per hour is $Q_N = 60 \times \frac{N}{H_N}$ units **(2.7)**

The **machine utilization** μ_N was calculated according to following Equation (2.8):

The average utilization of machines, μ_N, is the ratio between the run time, T, and the adjusted cycle time, H_N The value of μ is calculated as shown in the following equation:

$$\mu_N(\rho, \mathrm{N}) = \frac{T}{H_N} = \frac{T}{\frac{T(1+\rho)}{1 - Pt_{M1}(\rho, N)}} = \frac{1 - Pt_{M1}(\rho, N)}{1+\rho} \qquad \textbf{(2.8)}$$

As much as the number of machines which is controlled by one operator, *N* increases, the interference rate $Pt_{M1}(\rho, N)$ increases, and the machine utilization, μ_N decreases.

The ratio between the total service time that the operator provides to the machines $N \times t$ and the adjusted cycle time H_N is **the average workload** on the operator B_N. The value of B_N is calculated as follows in equation (2.9):

The probability that the operator is idle is equal to the probability that all the machines are running, that is $P(X = 0)$. Therefore, the operator workload $B_N(\rho, N)$ is the complementary event, specifically, that at least one machine needs service:

$$B_N(\rho, N) = 1 - \left(\frac{1 - Pt_{M1}(\rho, N)}{1 + \rho} \right)^N = \frac{N \times \rho(1 - Pt_{M1}(\rho, N))}{1 + \rho} \qquad \textbf{(2.9)}$$

As the number of machines that are run by one operator, *N* increases, the interference rate, $Pt_{MI}(\rho, N)$ increases, and the operator workload, $B_N(\rho, N)$ also increases.

TCU is the ratio between the total hourly cost (operator cost, machinery operating cost, and material cost) and the hourly yield obtained from *N* machines. The value of **total hourly cost per unit** TCU_N is calculated using equation (2.10) to produce H_N, which is given in units of hours:

$$TCU_N = \frac{N(C_{M1} + \mu_N \times C_{M2}) + C + V \times Q_N}{Q_N}$$

$$TCU_N = \frac{T(1 + \rho)}{(1 - Pt_{M1}(\rho, N))} \left(\frac{C}{N} + CM1 + \frac{(1 - Pt_{M1}(\rho, N))}{(1 + \rho)} \times C_{M2} \right) + V \qquad \textbf{(2.10)}$$

For a given number of *M* machines, one can calculate TCU_N for all the feasible values of $N = 1, \ldots, M$ according to Equation (2.10) (note that for $N = 1$, $Pt_{MI}(\rho, N = 1) = 0$). The value of *N* that minimizes TCU_N will be denoted as *N**. *N** is the optimum number of machines that should be assigned to a single operator in order to minimize the TCU.

The **average hourly profits** per each machine $\bar{\mu}_N$ when one operator runs N machines were calculated according to equation (2.11).

$$\bar{\mu}_N = \frac{(L - TCU_N)Q_N)}{N} \qquad \textbf{(2.11)}$$

However, in reality age, wear, and maintenance quality cause even those machines of the same type and from the same manufacturer to no longer be identical, a common assumption in many interference models is that all the machines are totally identical. In such cases the proposed method can be used by applying the average service ratio of all the machines. It is clear that a low variance of the service ratio among the machines increases the accuracy of the results. Chien et al. (2014) stated that improving MIP can increase the average cycle time. Therefore, in this thesis service time and run time analysis was used to increase the accuracy of results and to get more accurate service time and run time. “A revised method for allocating the optimum number of similar machines to operators” proposed by Hadad and Keren, (2016) used to allocate the optimum number of operators to run a number of machine, how many machines should be run by one operator. This thesis study the effect of the number of operators to avoid the MIP and increase productivity which is improves the Lead time.

3. METHODOLOGY

Several lead time improvement methods have been developed for decades to meet different needs. Many books have been written and several journals are dedicated to improve lead time for different production systems and patterns. However, reduce lead time by improving machine interference problem (MIP) to increase productivity in many industrials where one operator runs several machines is a new developed method.

Finding the optimum number of machines to be assigned to one operator is the key to improve machine interference problem. Improving MIP reduce the average cycle time which increase the productivity of the production system. On the other hand, improving MIP reduces lead time, help management to calculate lead time more accurate for customers and achieve customer satisfaction.

A revised method for allocating the optimum number of similar machines to operators is the most recent model for MIP and the first method that proposes a method for calculation of the adjusted cycle time where one operator runs a given number of similar machines and a method for allocating the optimum number of similar machines to operators. According to the common models; the calculation of the interference rate is complicated and needs the exact distributions of operating time and service time. This model presents a method that enables calculation of the interference rate via binomial distribution, without any assumptions related to machine running time or service time distributions (Hadad and Keren, 2016).

This method could be done with the objective of maximizing profits, minimizing production costs, increasing productivity or setting a given load on the operators. Moreover, the method enables calculating various performance indexes such as workload, machine utilization and yield per hour. The deviation of this method from the observed hourly yield is 2.08 percent which is smaller than the deviations of all other tested models. This method can be applied even for cases where the machine running time and service time distribution functions are unknown. Furthermore, this method needs as input only a single parameter the service ratio (the ratio between the service time and the run time). Hence, this method is applicable for any distributions of machine operating time and service time.

However, in reality age, maintenance quality, and wear cause even those machines from the same manufacturer and type to be no longer identical, a common assumption in many interference models is that all the machines are totally identical. Hence, using of those models is insufficient before doing a time study for each machine to find the appropriate and accurate method to calculate average service time and run time to use in those models.

However, in real life firms have product variety, machines efficiency variety and lack of historical data for all the production process; in this thesis, a quantitative analysis of average service time and run time used to calculate them according to the available historical data and time study to apply them in the revised allocating model to get the most accurate results.

Firstly, overall equipment effectiveness (OEE) and manpower utilization analysis had been used to analyze the machines efficiency and to figure out the significant factors which effect the production lead time from the six big losses (equipment failure, setup and adjustment, idling and minor stoppages, reduced speed of operation, process defects and reduced yield).

Secondly, the revised method for allocating the optimum number of similar machines to operators had been used to figure out the optimum number of operators needed for both objectives maximizing profit or minimizing cost. When viewed from this aspect, the normal average run time and service time method can be inaccurate according to the machines types and efficiency variability. Therefore, time study analysis had been done for each machine for both run time and service time to get the most accurate average time for them; after getting a regression model –using minitab- for each cutting machine for run time in terms of machine speed and product length using the maximum available speed and the weighted average length for a sample of 1619 different orders and substituted in the regression equations to get the average run time for each cutting machine. Similarly, time study analysis had been done for service time which includes four main factors setup time, packaging time, products roll change time and minor stops time to get average service time for all cutting machines.

Finally, after analyzing the system and find out the optimum number of operators needed per shift; measuring increase of productivity, income and profit had been evaluated and suggest a standard method for production lead time calculation for each order to improve the lead time reduction and increase the customer satisfaction.

4. APPLICATION OF PRODUCTION LEAD TIME IMPROVEMENT

SML is a global business and branding solutions provider with 189 employees located in Beylikdüzü, Istanbul, Turkey. SML incorporating their innovative technologies with their partners -the world's most prominent brands and retailers- to help them work smarter, higher quality and get long-term solutions. SML is presence in over 30 countries and based in Hong Kong.

SML TR was established in 2001 to satify the demands of the customers in a manner of total quality and best service in Turkey, Europe, Middle East and North Africa. SML is second in Turkish and the world's Leadership and has a vision to lead the market by 2025. SML produce millions of tags, labels and tickets for the world's leading retailers and brand owners every day utilizing various technologies such as online ordering E-Platform to help customers manage large amounts of complex data on a daily basis efficiently and accurately.

SML TURKEY Departments and Capacity:

i. Offset: working for two shifts with 18,000,000 – 25,000,000 pcs/month capacity using 60 percent of its capacity.
ii. Woven: working for two shifts with 10,000,000 – 12,000,000 pcs/month capacity using 60 percent of its capacity.
iii. Thermal Printing: working for one shift with 5,000,000 - 7,500,000 pcs/month capacıty using 60 percent of its capacity.
iv. **PFL / Care Label:** working for two shifts with 10,000,000 – 13,000,000 pcs/month capacıty using 55 percent of its capacity.
v. RFID: working for two shifts with 10,000,000 – 13,000,000 pcs/month capacıty using 50 percent of its capacity.

4.1 PROBLEM DEFINITION

Printing Fabric Labels (PFL) department has 6 printing machines and 13 cutting machines. Production process flow is printing, cutting, packaging, quality control and final packaging in sequence.

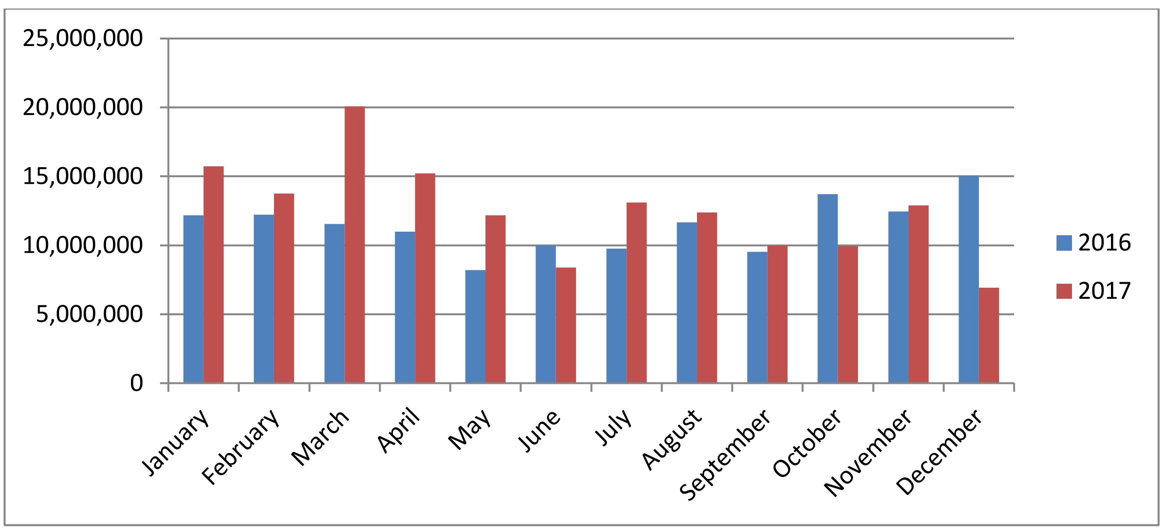
SML's managers are eager to increase productivity to reduce products lead time to increase customer satisfaction which has a significant effect on the customer demand. Monthly sales quantity uncertainty between years 2016-2017 is shown in table 4.1 and figure 4.1. Cutting machines process has a bottle neck in the production process flow. PFL department works in two shifts, six days per week and has three operators assigned for all machines; maximum number of operating machines per shift only six to seven machines.

Overall equipment effectiveness (OEE) for all cutting machines had been discussed in section 4.2 and the Machine Interference Problem (MIP) had been discussed in section 4.3 and proposed an optimal solution for cutting machines to increase productivity and machine utilization by assigning the optimum number of machines to operator.

Table 4.1: 2016-2017 Monthly Sales.

Month	2016	2017	2017-2016
January	12,178,234	15,713,447	3,535,213
February	12,228,891	13,755,441	1,526,550
March	11,551,121	20,067,264	8,516,143
April	10,990,811	15,214,805	4,223,994
May	8,205,743	12,168,049	3,962,306
June	9,990,267	8,390,750	1,599,517
July	9,760,715	13,106,909	3,346,194
August	11,663,963	12,388,799	724,836
September	9,519,228	9,988,293	469,065
October	13,704,933	9,944,288	3,760,645
November	12,443,365	12,886,915	443,550
December	15,059,945	6,924,500	8,135,445
Total	137,297,216	150,549,460	13,252,244
Average	11,441,435	12,545,788	

Figure 4.1: 2016-2017 Monthly Sales.



4.2 OVERALL EQUIPMENT EFFECTIVENESS ANALYSIS AND MAN POWER UTILIZATION

Table 4.2 shows the availability, performance, quality, OEE, and manpower utilization. Collected data will be presented in Appendix A.2. OEE calculated according to equation (2.4); Availability calculated according to equation (2.1); Performance calculated according to equation (2.2); Quality calculated according to equation (2.3) and manpower utilization calculated according to equation (2.5).

Table 4.2: OEE and Manpower Analysis Results

M/c	Availability	Performance	Quality	OEE	Manpower utilization
1	60.00%	35.08%	99.72%	20.99%	35.08%
1	50.00%	47.13%	99.29%	23.40%	47.13%
2	59.26%	54.88%	99.68%	32.42%	54.88%
2	32.76%	32.19%	99.72%	10.51%	32.19%
3	81.33%	68.68%	96.71%	54.02%	68.68%
3	52.35%	36.54%	99.59%	19.05%	36.54%
4	80.77%	76.60%	98.12%	60.70%	76.60%
4	63.07%	63.04%	99.54%	39.58%	63.04%
5	62.16%	60.19%	99.35%	37.17%	60.19%
5	77.78%	70.31%	99.75%	54.55%	70.31%
6	40.48%	56.49%	99.62%	22.78%	56.49%
6	76.92%	72.54%	96.35%	53.76%	72.54%
7	78.86%	78.78%	99.56%	61.85%	78.78%
7	35.29%	24.05%	99.90%	8.48%	24.05%
8	73.33%	69.38%	99.21%	50.48%	69.38%
8	91.18%	83.76%	98.13%	74.94%	83.76%
9	80.19%	77.74%	96.23%	59.99%	77.74%
9	62.00%	57.43%	99.47%	35.41%	57.43%
10	73.68%	67.65%	99.78%	49.74%	67.65%
10	80.00%	72.57%	99.36%	57.69%	72.57%
11	86.67%	80.95%	96.92%	68.00%	80.95%
11	66.97%	62.46%	99.39%	41.58%	62.46%
12	50.00%	59.87%	99.69%	29.84%	59.87%
12	71.43%	68.57%	95.83%	46.94%	68.57%
13	63.64%	51.93%	98.17%	32.44%	51.93%
13	64.10%	56.97%	98.36%	35.92%	56.97%

Figure 4.2: OEE histogram.

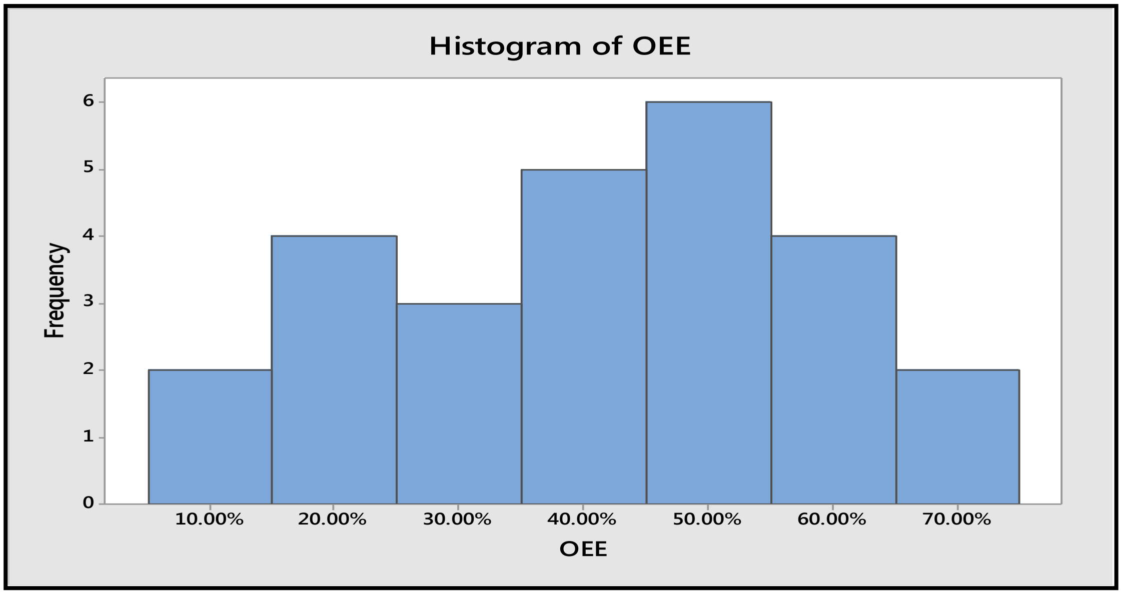


Figure 4.3: Manpower utilization histogram.

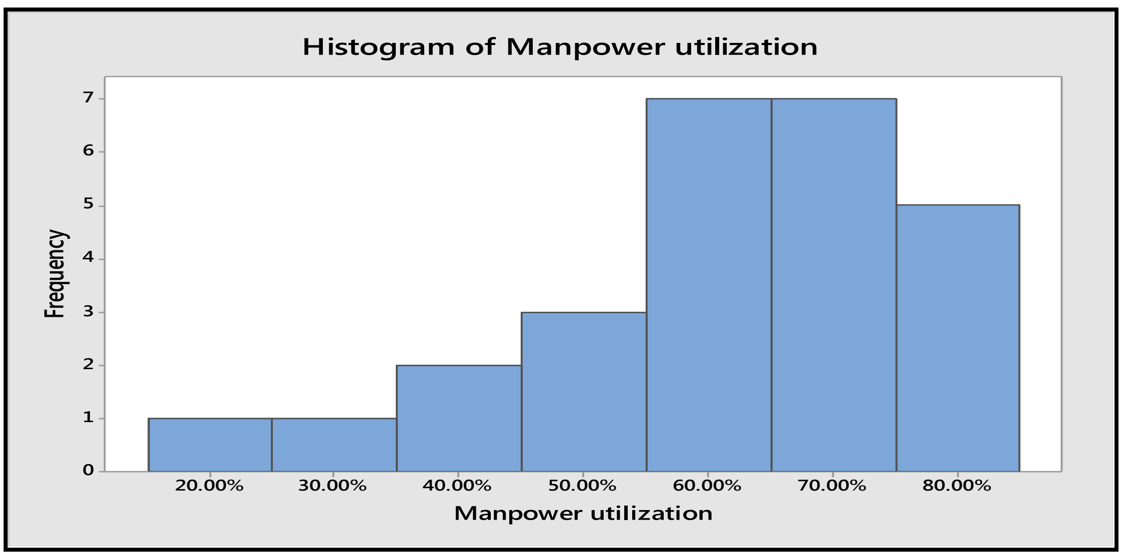


Figure 4.2 shows that twenty out of twenty six observations for OEE calculation for all machines are equal 50 percent or less and all observations are less than 70 percent. Moreover, figure 4.3 shows the uncertainty of manpower utilization calculations. Hence, Machine Interference Problem (MIP) had been discussed in section 4.3 to improve the OEE and manpower utilization to increase productivity and reduce production lead time.

4.3 THE MACHINE INTERFERENCE PROBLEM ANALYSIS

SML has thirteen cutting similar machines, three operators and two shifts. Revised method for allocating the optimum number of similar machines to operators has been applied to get the optimum number of machines to be assigned to each operator and to get the optimum number of operator to reduce interference rate, increase machine utilization and increase productivity. Two objectives have been proposed in this analysis to get the optimum solution; maximizing profit and decreasing costs.

Revised method for allocating the optimum number of similar machines to operators has a limitation – which was discussed clearly in literature review section- which is the assumption that all machines are totally identical. The ratio between run time and service time is necessary to use this method. Hence, a run time and service time analysis has been done as shown in section (4.3.1, 4.3.2) to get an accurate average run time and service time to produce one unit for all cutting machines to avoid method limitation.

4.3.1 Run Time Analysis:

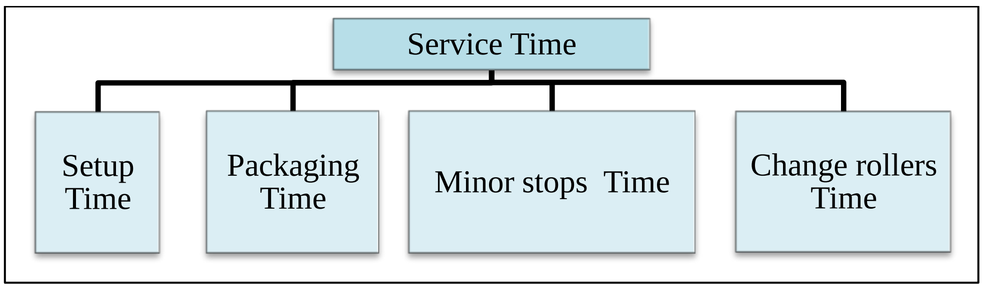
SML has thirteen cutting machines with eleven different models as shown Appendix A.3. This variability required an analysis for each machine separately. Accordingly get an average run time for all machines. Machine speed level and products length are the two variable control machines run time; there are five machines do not have speed level indicator, therefore; an assumption that the maximum available speed was set for each product while taking the observations; hence, machine speed level is neglected in those five machines. Ten random observations for each machine had been taken to get a regression model for each machine in terms of product length and machine speed level for those machines which have machine speed level as will be presented in Appendix A.4. Maximum available speed and average products length had been used to get the average run time for each machine using regression models.

Hence, average products length was necessary; there were no direct available data for the average product length; therefore; 1,619 different printing order -14,633,965 pieces, collected from November 2017 and February 2018 historical data - used to get the average length. All wasted materials were neglected and weighted average method had been used to avoid orders quantity effect on speed as will be presented in Appendix A.5; **weighted average length** is **111.79 mm** and **average run time** is **6.81 min/unit**.

4.3.2 Service Time Analysis:

Similarly, service time analysis was necessary to avoid machines variability. Setup time, packaging time, minor stops time, and change material rollers time are the significant factors of service time as shown in figure 4.4.

Figure 4.4: Service Time factors.



4.3.2.1 Setup time study:

Setup time study was classified into two stages average setup time per item and average quantity per each item to get the average setup time per unit. Each item has different dimensions and some order has same item name which means same machine setup.

Firstly, 44 random observations for setup time were taken between all machines then a histogram with a normal curve drawn for all observations. One observation was an outlier because of a maintenance problem so this observation is neglected. Otherwise; all the other observations has a normality distribution with mean equal 10.46 minutes, median equal 10 minutes and mode equal 10 minutes –all observations data and graphs will be presented in Appendix A.6. Median was preferable to use as the average setup time per item which is 10 minutes.

Secondly, due to the lack of data for cutting machines; 2,009 different orders for daily finished products for printing machines data –November 2017- had been used to calculate the average quantity per each item. Assuming that all daily finished products from printing machines goes directly to cutting machines at same day. Daily data, number of items per day, average daily setup time and average setup time per unit are shown in Appendix A.6 with the histogram with normal curve graph for the average daily setup time to show the normality of data. **Average setup time per unit** was calculated by taking the daily average setup time per unit during the month which is equal **0.45 minutes**.

4.3.2.2 Packaging Time Study:

Packaging time classified into two factor first one is the average time for packing one packet and the second factor is how many packets needed for each unit (equation 4.1).

Firstly, 100 random observations had been used to find the average time needed for packing packet. Median was preferable to use as the average time needed for packet which is 0.5 minutes. All observations data and histogram with normal curve will be presented in Appendix A.7 which shows the normality of data.

Secondly, 2208 different order data with over all 10,758,232 products quantity during November 2017 had been used to get the average needed packets per unit; weighted average method for packing time had been used (equation 4.2)- to increase results accuracy as shown in tables (4.3), (4.4):

Table 4.3: Orders Classification and Quantity Percentage.

Order Quantity pieces	Average packet capacity	Quantity	Quantity %
Order > 2,000	100 pieces	946,191	8.795 %
2,000 < order ≤ 4,000	400 pieces	886,306	8.238 %
4,000 < order ≤ 15,000	1,500 pieces	3,485,656	32.399 %
15,000 < order	4,000 pieces	5,440,079	50.566 %

$$\text{Number of packets per unit} = \frac{\text{pieces per unit}}{\text{average packet capacity}} \qquad \textbf{(4.1)}$$

Table 4.4: Number of Packets needed per unit.

Order Quantity pieces	Average packet capacity	number of packets per unit
Order > 2,000	100 pieces	10
2,000 < order ≤ 4,000	400 pieces	2.5
4,000 < order ≤ 15,000	1500 pieces	0.67
15,000 < order	4000 pieces	0.25

$$\textbf{Wieghted average Packaging Time} = \sum \text{average packging time} \times \text{number of packets per unit } \times \text{quantity wieght} \quad \textbf{(4.2)}$$

$$\begin{aligned} \boldsymbol{Wieghted\ average\ Packaging\ Time} &= (0.5 \times 10 \times 0.08795) + (0.5 \times 2.5 \times 0.08238) \\ &+ (0.5 \times 0.67 \times 0.3239) + (0.5 \times 0.25 \times 0.5056) \\ &= \boldsymbol{0.715 min/unit} \end{aligned}$$

4.3.2.3 Minor Stops Time Study:

Firstly, forty six random observations had been used to experiment the normality of the observations results, then the mean of the observation consider as the average **minor stops time = 0.8811 min/unit.** Observations data and graph will be presented in Appendix A.8.

4.3.2.4 Change Rollers Time Study:

Change material roller time per unit consider two factors; time for change and number of rollers per unit (equation 4.3). Firstly, fifty random observations for change roll had been taken distributed between all machines; normality check has been done using histogram with normal curve as will be presented in Appendix A.9. Median value was preferable to us as the **average time for change** which is **0.5 minutes**. Average changing roller time per unit has been calculated according to (equation 4.4).

$$\text{Number of rollers per unit} = \frac{\text{average production length} \times \text{unit}}{\text{average roll length}} \quad \textbf{(4.3)}$$

$$\text{Number of rollers per unit} = \frac{0.11179 \text{ meter} \times 1000 \text{ picese}}{200 \text{ meter}}$$

$$= 0.5589 \text{ roller/unit}$$

$$\begin{aligned} \text{Average changing roller time per unit} \\ &= \text{average number of rollers per unit} \\ &\times \text{average changing roller time} \end{aligned} \quad (\mathbf{4.4})$$

$$\text{Average changing roller time per unit} = 0.5589 \times 0.5$$

$$= 0.279 \text{ min/unit}$$

Average service time = Setup time + Packaging time + Minor stops time + Changing roll time

Average service time = 0.45 + 0.715 + 0.8811 + 0.279 = **2.325 min/unit**

4.3.3 Revised Method for Allocating The Optimum Number of Similar Machines to Operators Application:

Necessary data for revised method classified into three stages; firstly, run time and service time analysis and time study which had been discussed in section (4.3.1) and (4.3.2) and concluded in table (4.5). Secondly, financial data which has been collected by the SML's financial department according to the monthly financial reports for year 2017 as shown in table (4.6). Final stage will be discussed in section (4.3.3.1) which is the method application.

Table 4.5: Run Time and Service Time Ratio.

Average run time min/unit T =	6.81
Average service time min/unit t =	2.325
Ratio ρ = t/T =	0.34

Table 4.6: Financial Data.

Hourly fixed cost of one machine CM1 =	13.84 TL
Hourly variable cost of one machine CM2 =	31.25 TL
Hourly operator cost C =	250 TL
Average material cost/unit V =	9.62 TL
Average Selling price/unit L =	62.62 TL

4.3.3.1 Optimum Number of Machines to Operator:

Table (4.7) demonstrates the necessary calculations for computation the optimum number of machines run by operator (N*) for both objectives minimizing cost TCU_N and maximizing hourly profit $\bar{\mu}_N$. The values of $Pt_{MI}(\rho, N)$ calculated according to Appendix A.1; H_N calculated according to equation (2.6); the machine utilization μ_N calculated according to equation (2.8); the yield per hour is $Q_N = 60 \times N/H_N$ units equation (2.7); the workloads B_N were calculated according to equation (2.9); TCU_N calculated according to equation (2.10); and the average hourly profits per machine $\bar{\mu}_N$ were calculated according to equation (2.10).

Table 4.7: TCU and Hourly Profit.

N	$Pt_{MI}(\rho, N)$	H_N	Q_N	μ_N	B_N	TCU_N	$\bar{\mu}_N$
1	0	9.135	6.56814	0.74548	0.25452	53.331	61.0122
2	0.04032	9.5188	12.6066	0.71543	0.48851	35.188	172.914
3	0.09338	10.0759	17.8644	0.67587	0.69225	29.48	197.345
4	0.16408	10.9281	21.9618	0.62317	0.85102	27.065	195.211
5	0.25366	12.2397	24.5103	0.55638	0.94978	26.184	178.611
6	0.35056	14.066	25.5937	0.48415	0.99176	26.173	155.467
7	0.43686	16.2215	25.8915	0.41981	1.0033	26.558	133.385
8	0.50616	18.4979	25.9489	0.36815	1.00552	27.062	115.337
9	0.56084	20.8011	25.9602	0.32739	1.00596	27.589	101.047
10	0.60478	23.1137	25.9586	0.29463	1.0059	28.122	89.5509
11	0.64074	25.4273	25.9564	0.26782	1.00581	28.657	80.1422
12	0.67066	27.7373	25.9578	0.24552	1.00587	29.189	72.3167
13	0.69598	30.0474	25.959	0.22664	1.00591	29.721	65.6941

Table 4.7 shows that the optimum number of machines to be assigned to one operator for minimizing cost TCU_N is N* = 6 and for maximizing hourly profit $\bar{\mu}_N$ is N* = 3. Moreover, according to the other constrains work load per worker should not be more that 85 percent so N* for minimizing cost would be equal 4.

Figure (4.5) and (4.6) shows the sensitive change for maximizing profit and minimizing cost by changing the number of machines to be operates per operator. Machine utilization and work load graphs presented in Appendix A.10.

Figure 4.5: Hourly Profit per Machine for one Operator and N Machines

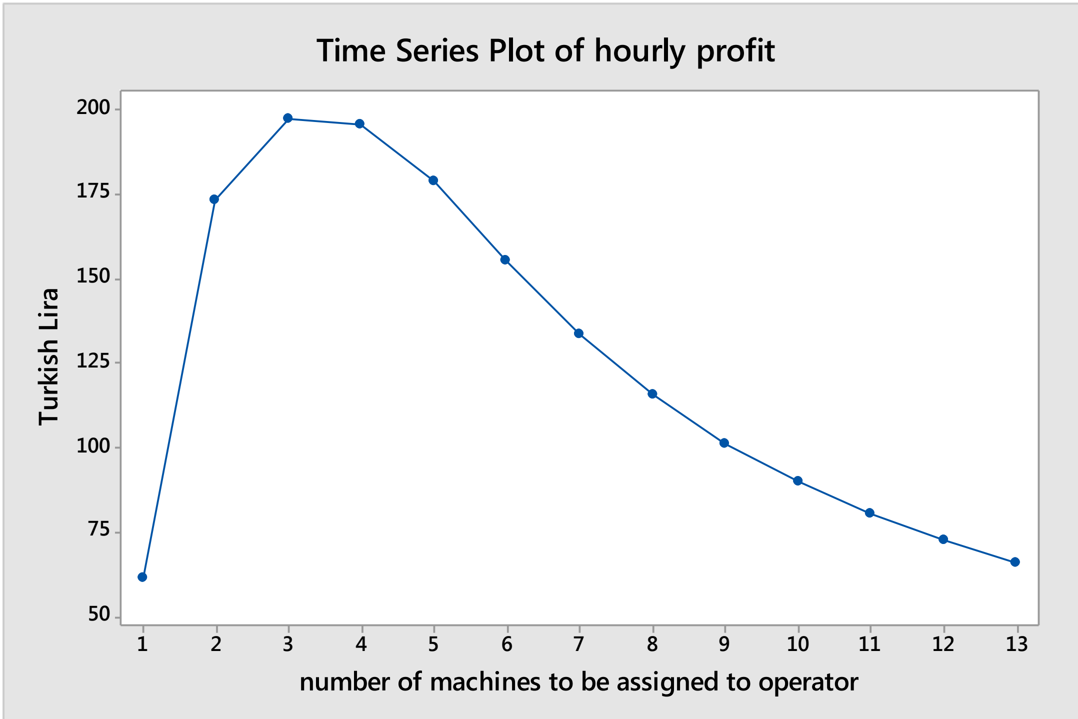
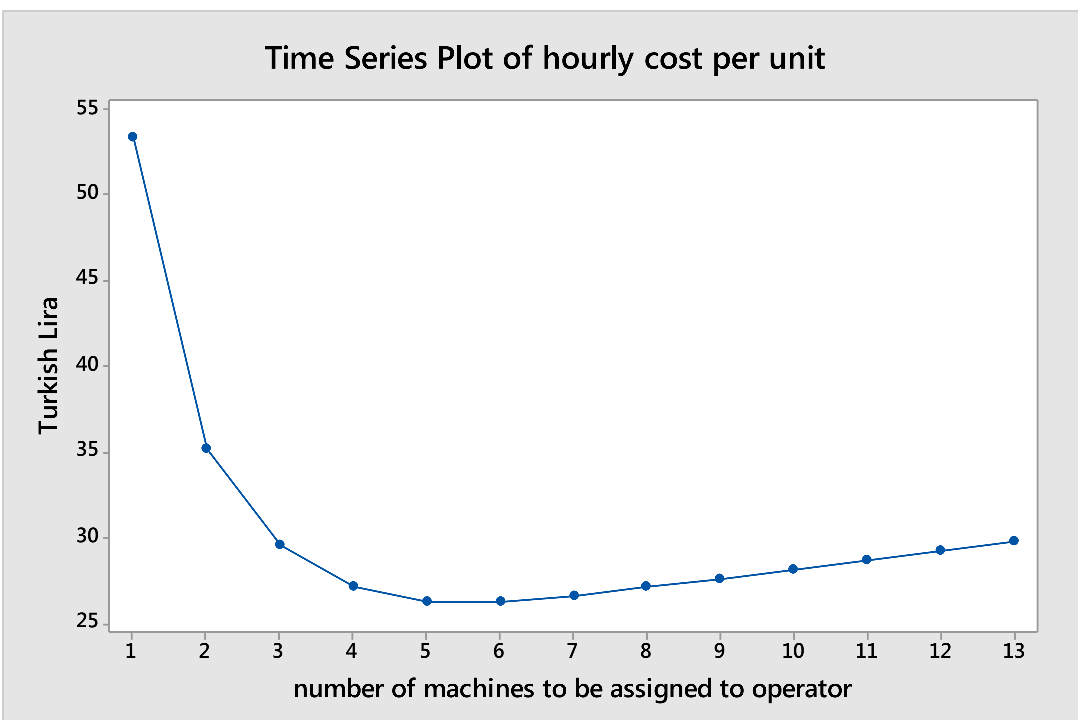


Figure 4.6: TCU for one Operator and N Machines



4.3.3.2 Optimum number of operators:

Distributing the total number of cutting machines inside the department to match with the optimum number of machines to be assigned to one operator (N*) to get the optimum number of operators to run all machines (K*).

K* for maximum profit strategy:

Total Number of machines M = 13 machine
Optimum number of machines to be assigned by one operator N* = 3 machines
Number of operators K* [M/N*] = 13/3 = 4.33 which is not an integer number.
Optimum number of operator has two alternatives either to be four or five operators; to examine the two possibilities alternatives –table 4.8, 9- two steps was followed. Firstly, distribute all machines over the operators equally as much as possible with respect to assign three machines for each operator as much as possible which give the maximum hourly profit. Secondly, examine which alternative will get the maximum hourly profit to be the optimum number of operators K*. Table 4.8 shows the maximum hourly profit.

Table 4.8: Total Hourly Profit First Alternative.

Operator number	Number of machines	Machine Profit per Hour (TL)	Total Profit per Hour (TL)
1	3	197.345	592.035
2	3	197.345	592.035
3	3	197.345	592.035
4	4	195.211	780.844
Total hourly profit			2556.94

Table 4.9: Total Hourly Profit Second Alternative.

Operator number	Number of machines	Machine Profit per Hour (TL)	Total Profit per Hour (TL)
1	3	197.345	592.035
2	3	197.345	592.035
3	3	197.345	592.035
4	2	172.914	345.828
5	2	172.914	345.828
Total hourly profit			2467.76

K* for minimize cost strategy:

Total Number of machine M = 13 machine

Optimum number of machines to be assigned by one operator N* = 4 machines

Number of operators [M/N*] = 13/4 = 3.25 which is not an integer number.

Optimum number of operator has two alternatives either to be three or four operators; to examine the two possibilities alternatives –table 4.10, 11-two steps was followed. Firstly, distribute all machines over the operators equally as much as possible with respect to assign four machines for each operator as much as possible which give the minimum hourly cost. Secondly, examine which alternative will get the minimum hourly cost to be the optimum number of operators K*. Table 4.10 shows the minimum hourly cost.

Table 4.10: Total Hourly Cost First Alternative

Operator number	Number of machines	Machine Cost per Hour (TL)	Total cost per Hour (TL)
1	4	27.065	108.26
2	4	27.065	108.26
3	5	26.184	130.92
		Total hourly cost	347.44

Table 4.11: Total Hourly Cost Second Alternative

Operator number	Number of machines	Machine Cost per Hour (TL)	Total cost per Hour (TL)
1	3	29.48	88.44
2	3	29.48	88.44
3	3	29.48	88.44
4	4	27.065	108.26
		Total hourly cost	373.58

4.4 Improvement of The Proposed Solutions:

Table 4.10 shows the productivity improvement of the proposed solutions according to the calculated adjusted cycle time H_N in table (4.7). Table 4.11 shows the increase rate in compare with the current average monthly production.

Table 4.12: Monthly Production of the Proposed Solutions.

Proposed Method	Number of machines to operator	Adjusted cycle time (min) H_N	Minutes per shift	production per shift	Monthly Production units (one shift six days a week)
Maximum Profit	3	10.0759	415	123.56	2,965.49
	3	10.0759	415	123.56	2,965.49
	3	10.0759	415	123.56	2,965.49
	4	10.9281	415	151.90	3,645.65
		Total production per shift			**12,542.12**
Minimum cost	4	10.9281	415	151.90	3,645.65
	4	10.9281	415	151.90	3,645.65
	5	12.2397	415	169.53	4,068.73
		Total production per shift			**11,360.02**

Table 4.13: Increase rate of the Proposed Solutions

Total Production For two shifts		
Average Current	Maximum Profit optimum Method	Minimum Cost optimum Method
12,545.788	25,084.24	22,720.04
Increase rate	99.94%	81.09%

5. DISCUSSION AND RECOMMENDATION

This thesis proposed a method for lead time reduction after studying the relation with the machine interference problem (MIP) and productivity rate. The revised method for allocating the optimum number of similar machines to operators had been used to get the optimum needed number of operators to operate all machines; service and run time analysis study had been done to avoid the revised method limitation.

Table 5.1 shows the increase rates evaluation for the proposed method for both objectives maximum profit and minimum cost; The table shows the effect of finding the optimum number of operators to avoid MIP on increase productivity, total income, total cost and total profit assuming that market demand is open and all production quantity is sales quantity.

Table 5.1: Proposed Improvement Methods Increase Rates Evaluation

	Current	Maximum Profit optimum Method	Minimum Cost optimum Method
Average Total Production (units)	12,545.79	25,084.24	22,720.04
Increase Rate		99.9%	81.1%
Average Total Income (TL)	785,617.27	1,570,775.11	1,422,728.90
Increase Rate		99.9%	81.1%
Average Total Cost (TL)	328,931	569,286.67	521,323.12
Increase Rate		73.1%	58.5%
Average Total Profit (TL)	456,686.27	1,001,488.43	901,405.78
Increase Rate		119.3%	97.4%

The proposed solution shows possibility to increase profit between 97.4 percent up to 119.3 percent which mean a major change in the firm strategy depend on their objective to get optimum maximum profit or minimum cost, firm’s budget and ability to increase costs by 73.1 percent to get 119.3 percent increase in profit or increase cost by 58.5 percent to get 97.4 percent increase in profit.

This study shows the necessity and sensitivity of assigning the optimum number of machines to operators to avoid MIP and increase productivity. This improvement will not have an effect unless managers change their strategy of reducing the number of operator as much as they can, intimidate that it will increase the profit. On the other hand, this study would help to get an accurate lead time for each order using the adjusted cycle time for each machine to increase customer satisfaction which increase the customer demand.

Future improvement could be include scheduling system to get accurate calculation for each order lead time depend on the assigned machine to produce the order, daily reports for each machine is necessary to evaluate them easily and figure out future necessary improvements, minor stops and packaging time which represent together more than 68 percent of the total service time should be stay under monitoring to find out any possible improvement or innovative ideas to reduce them.

6. CONCLUSION

In this thesis a real case study illustrates the applicability of the proposed method for lead time reduction. Machine interference problem (MIP) analysis had been used to show the critical and significant impact of MIP on lead time reduction by increasing productivity.

Overall equipment effectiveness (OEE) and machine utilization methods had been used to evaluate machines and operators efficiency. On the other hand, service and run time analysis study had been used to avoid the uncertainty between all machines. Then the revised method for allocating the optimum number of similar machines to operators had been used to get the optimum number of operators necessary per shift to get the maximum profit or minimum cost depend on management strategy.

The final results show that by increase the number of operator to the optimum number, the productivity can be increase by the double of the current situation. Hence, reduce production lead time and increase customer satisfaction.

This study able to apply in many industries such as food, plastic, textile, electronic or rubber; where one operator operates several almost identical machines. Future work for lead time reduction may include the innovation process and creativity impact on lead time reduction.

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APPENDICES

Appendix A.1: Interference Rate according to the Revised method for allocating the optimum number of similar machines to operators.

N/ρ	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
2	0.0012	0.0045	0.0096	0.0162	0.0240	0.0328	0.0422	0.0522	0.0625	0.0729
3	0.0025	0.0096	0.0210	0.0362	0.0545	0.0753	0.0979	0.1215	0.1456	0.1696
4	0.0038	0.0154	0.0347	0.0614	0.0944	0.1320	0.1721	0.2126	0.2516	0.2881
5	0.0053	0.0220	0.0516	0.0941	0.1475	0.2067	0.2654	0.3191	0.3659	0.4059
6	0.0068	0.0298	0.0729	0.1377	0.2170	0.2960	0.3642	0.4196	0.4643	0.5007
7	0.0085	0.0390	0.1007	0.1952	0.2983	0.3843	0.4500	0.5004	0.5398	0.5715
8	0.0103	0.0501	0.1376	0.2649	0.3774	0.4588	0.5180	0.5625	0.5972	0.6250
9	0.0123	0.0639	0.1861	0.3366	0.4448	0.5186	0.5714	0.6111	0.6420	0.6667
10	0.0145	0.0814	0.2448	0.4006	0.5001	0.5667	0.6143	0.6500	0.6778	0.7000
11	0.0168	0.1043	0.3057	0.4546	0.5455	0.6061	0.6494	0.6818	0.7071	0.7273
12	0.0195	0.1348	0.3617	0.5000	0.5833	0.6389	0.6786	0.7083	0.7315	0.7500
13	0.0224	0.1742	0.4104	0.5385	0.6154	0.6667	0.7033	0.7308	0.7521	0.7692

N/ρ	0.3	0.34	0.35
1	0	0	0
2	0.0328	0.04032	0.0422
3	0.0753	0.09338	0.0979
4	0.132	0.16408	0.1721
5	0.2067	0.25366	0.2654
6	0.296	0.35056	0.3642
7	0.3843	0.43686	0.45
8	0.4588	0.50616	0.518
9	0.5186	0.56084	0.5714
10	0.5667	0.60478	0.6143
11	0.6061	0.64074	0.6494
12	0.6389	0.67066	0.6786
13	0.6667	0.69598	0.7033

Appendix A.2: Collected Data for OEE and Manpower utilization measurements.

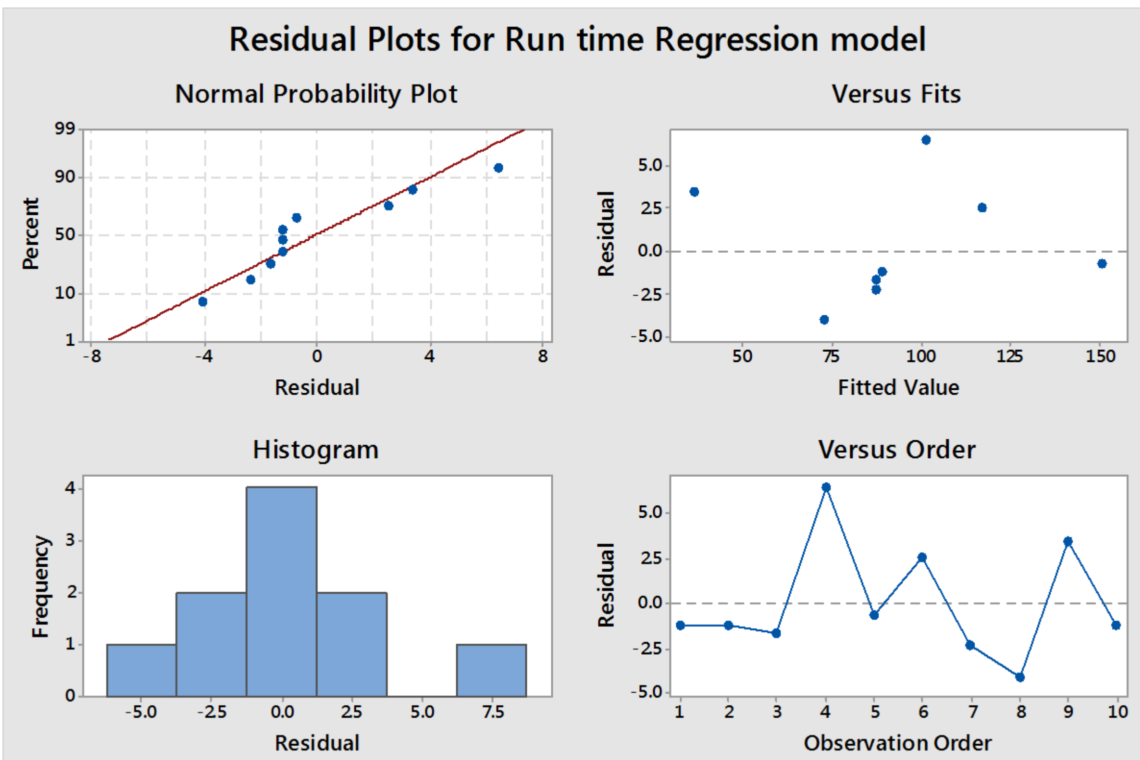
M/c	Start time	End time	Planned breaks (min)	Actual operation Time (min)	Machine Ideal Cycle Time (min)	Total units Produced	Planned Operation Time (min)	Good units Produced
1	7:45	10:00	0	81	6.67	7.1	135	7.08
1	10:00	13:15	45	75	6.67	10.6	150	10.525
2	7:45	10:00	0	80	5.88	12.6	135	12.56
2	9:35	11:46	15	38	5.88	6.35	116	6.332
3	7:45	9:00	0	61	6.06	8.5	75	8.22
3	7:45	10:50	15	89	6.06	10.25	170	10.208
4	12:45	14:55	0	105	7.81	12.75	130	12.51
4	7:45	10:56	15	111	8.47	13.1	176	13.04
5	11:15	11:52	0	23	9.09	2.45	37	2.434
5	12:45	16:00	15	140	6.25	20.25	180	20.2
6	14:38	15:35	15	17	9.09	2.61	42	2.6
6	7:45	10:36	15	120	8.26	13.7	156	13.2
7	13:12	15:15	0	97	7.63	12.7	123	12.644
7	7:45	10:50	15	60	8.3	4.925	170	4.92
8	13:00	13:15	0	11	8.26	1.26	15	1.25
8	7:45	10:50	15	155	8.9	16	170	15.7
9	7:45	9:31	0	85	8.62	9.56	106	9.2
9	9:00	9:50	0	31	10.2	2.815	50	2.8
10	11:00	11:19	0	14	2.85	4.51	19	4.5
10	15:30	16:15	0	36	4.16	7.85	45	7.8
11	14:00	16:45	15	130	9.34	13	150	12.6
11	15:30	17:19	0	73	10.41	6.54	109	6.5
12	15:30	15:40	0	5	3.73	1.605	10	1.6
12	15:30	16:40	0	50	4	12	70	11.5
13	14:00	16:05	15	70	2.38	24	110	23.56
13	15:30	16:48	0	50	3.48	12.77	78	12.56

Appendix A.3: Cutting Machines Models and Method of Cutting Methods.

Machine	Cutting Method	Model	Date
1	Hot and Cold	EN-686	2006-12
2	Hot and Cold	RC-286A	2014-05
3	Hot and Cold	WS-286	2011-12
4	Hot and Cold	RC-486A	2013-05
5	Hot and Cold	RC-328L	2014-07
6	Ultrasonic	SW-300	2006-07
7	Ultrasonic	WS-986	2011-12
8	Ultrasonic	SW-300	2006-05
9	Ultrasonic	SW-886	2006-12
10	Ultrasonic	GF-2080B	2013-03
11	Ultrasonic	RC-928L	2016-04
12	Ultrasonic	RC-828	2016-04
13	Ultrasonic	RC-828	2016-04

Appendix A.4: Run time collected data and Regression models with residual graphs.

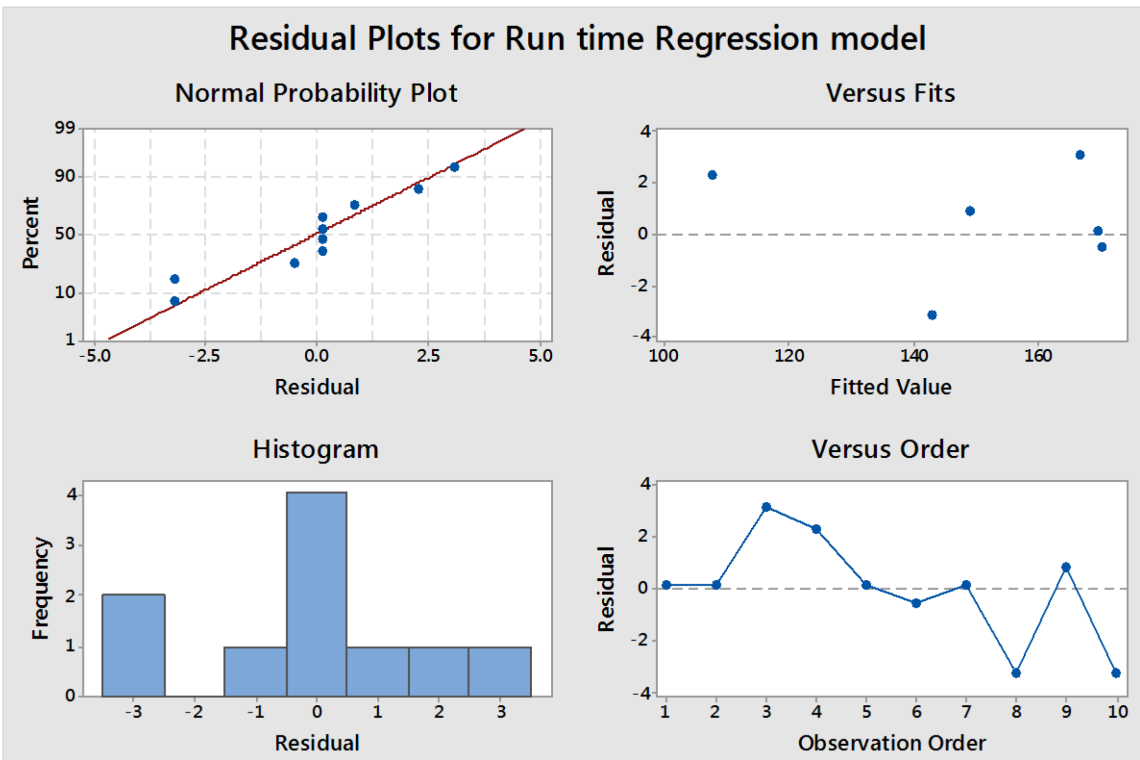
Machine	Speed	Dimensions	Length	Run time
1	3.5	40×58	58	88
1	3.5	40×58	58	88
1	3.5	32×60	60	86
1	4	40×58	58	108
1	6	40×58	58	150
1	6	37×100	100	120
1	5	32×107	107	85
1	5	37×125	125	69
1	4	47×140	140	40
1	3.5	40×58	58	88



Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
3.57853	98.85%	98.52%	97.46%
Regression Model	= 49.11 + 24.59 Speed - 0.7921 Length		

Appendix A.4: Continued.

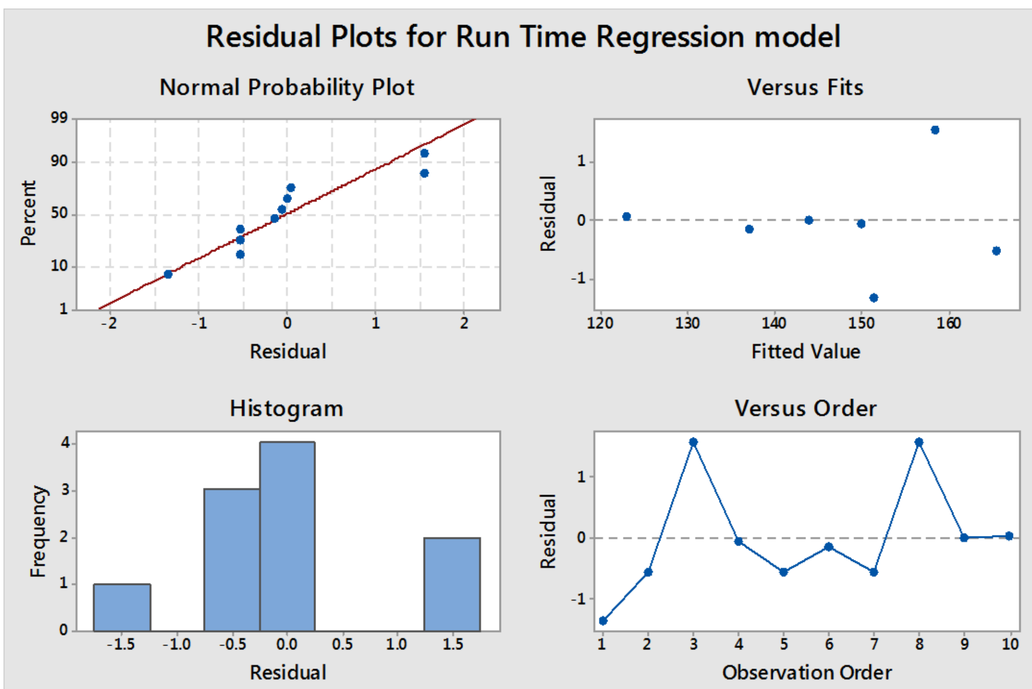
Machine	Speed	Dimensions	Length	Run time
2	10	30×67	67	170
2	10	30×67	67	170
2	10	25×107	107	170
2	7.5	25×107	107	110
2	10	30×67	67	170
2	10	40×58	58	170
2	10	30×67	67	170
2	9	25×107	107	140
2	9.25	25×107	107	150
2	9	25×107	107	140



Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
2.29064	99.04%	98.77%	92.95%
Regression Model	= -61.9 + 23.67 Speed - 0.0741 Length		

Appendix A.4: Continued.

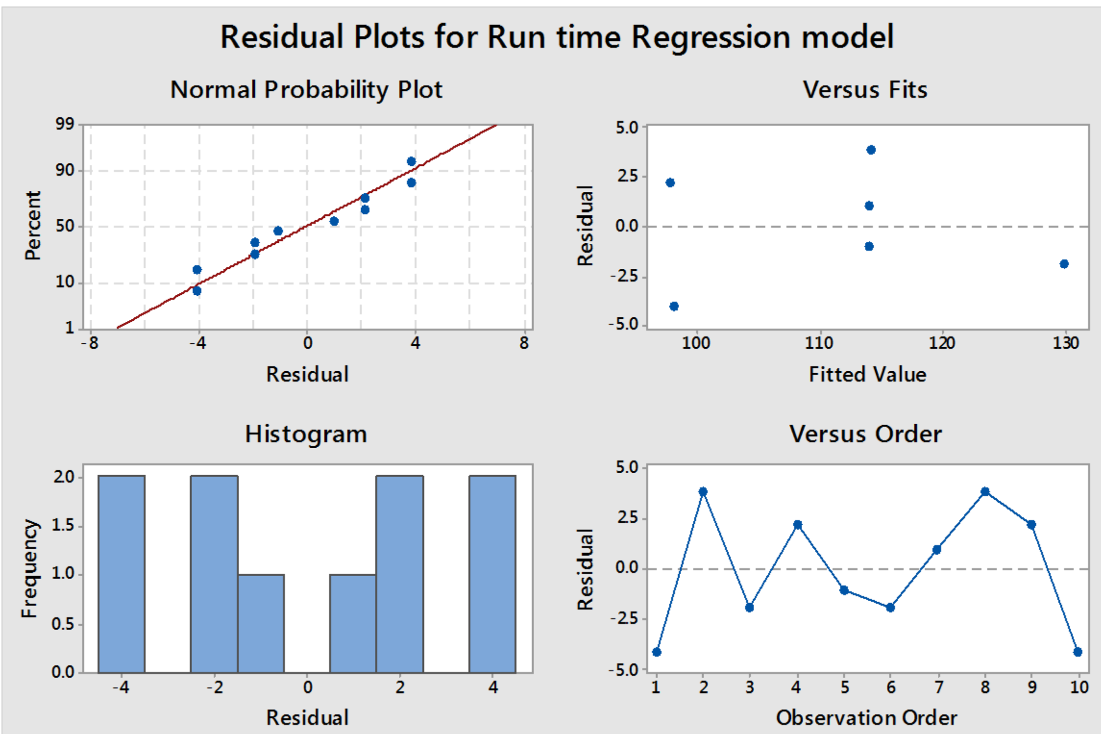
Machine	Speed	Dimensions	Length	Run time
3	6	25×107	107	150
3	7	25×107	107	165
3	6.5	25×107	107	160
3	6	34×100	100	150
3	7	25×107	107	165
3	5	25×107	107	137
3	7	25×107	107	165
3	6.5	25×107	107	160
3	6	34×67	67	144
3	4	25×107	107	123



Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
1.03946	99.57%	99.45%	99.42%
Regression Model	= 46.5 + 14.195 Speed + 0.1839 Length		

Appendix A.4: Continued.

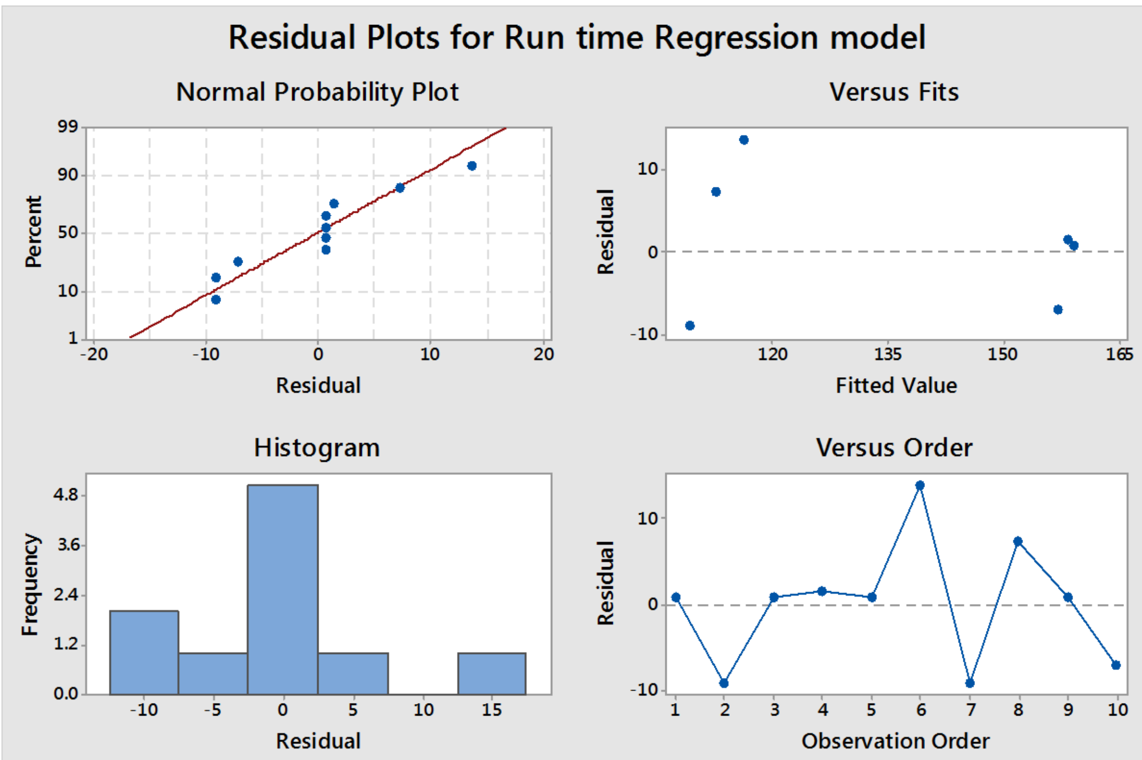
Machine	Speed	Dimensions	Length	Run time
4	6.5	40×120	120	94
4	7	40×124	124	118
4	7.5	40×74	74	128
4	6.5	40×74	74	100
4	7	32×107	107	113
4	7.5	40×74	74	128
4	7	37×100	100	115
4	7	40×124	124	118
4	6.5	40×74	74	100
4	6.5	40×120	120	94



Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
3.41964	94.60%	93.06%	88.75%
Regression Model	= -111.2 + 32.09 Speed + 0.0057 Length		

Appendix A.4: Continued.

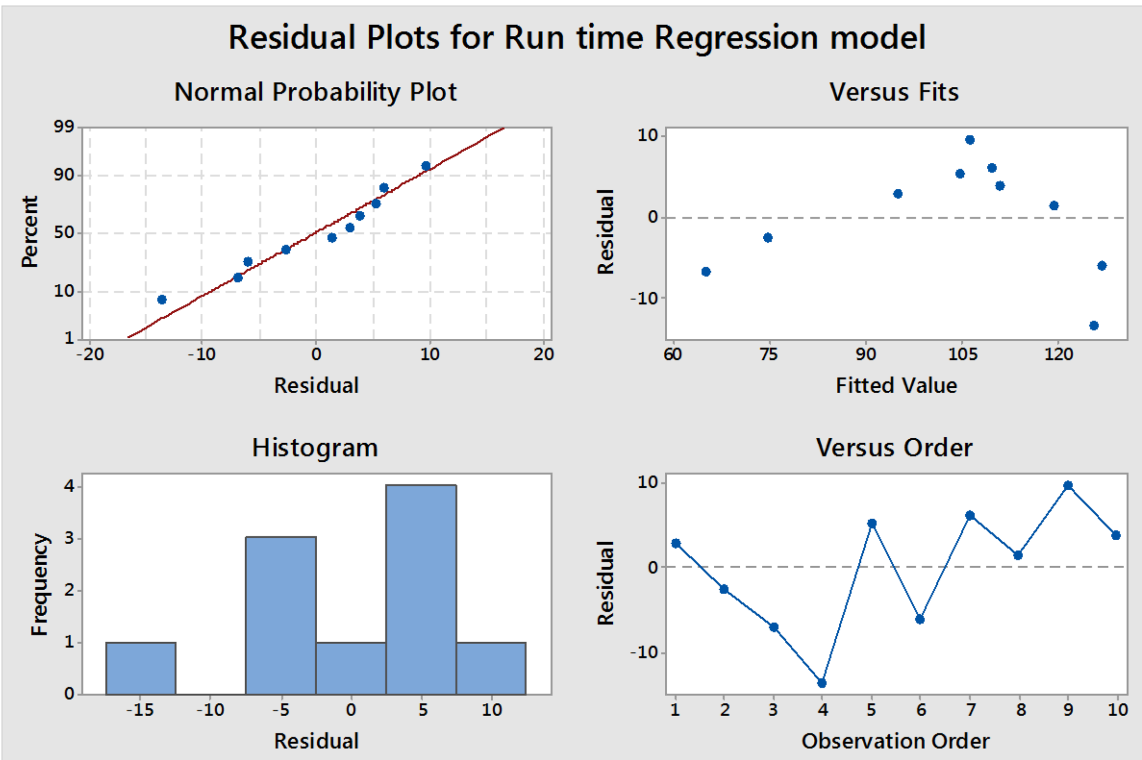
Machine	Speed	Dimensions	Length	Run time
5	160	40×58	58	160
5	100	40×200	200	100
5	160	40×58	58	160
5	160	30×60	60	160
5	160	40×58	58	160
5	130	35×180	180	130
5	100	40×200	200	100
5	120	45×190	190	120
5	160	40×58	58	160
5	150	30×64	64	150



Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
7.63681	91.96%	90.95%	86.32%
Regression Model	= 179.72 - 0.3527 Length		

Appendix A.4: Continued.

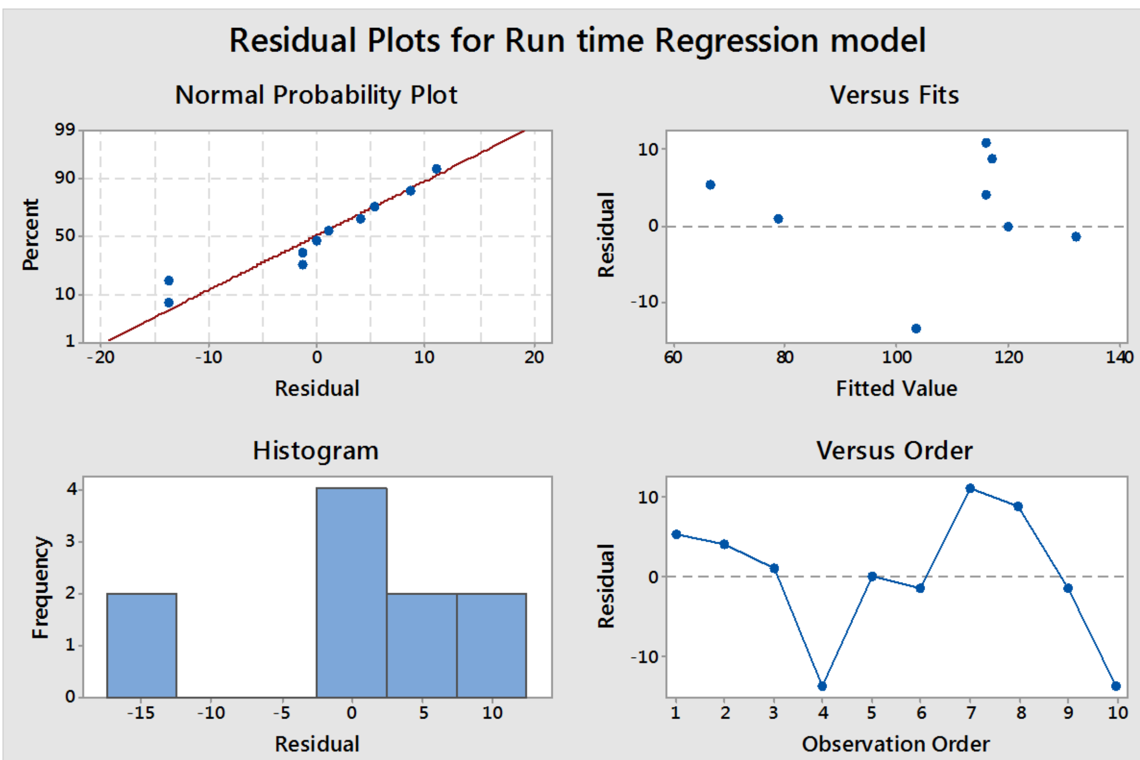
Machine	Speed	Dimensions	Length	Run time
6	6.5	32×160	160	98
6	5.5	33×165	165	72
6	5	35×165	165	58
6	7	35×73	73	112
6	7	32×160	160	110
6	6.5	40×27	27	121
6	6	40×58	58	116
6	6.5	40×58	58	121
6	6	35×73	73	116
6	6.25	35×73	73	115



Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
8.10825	89.20%	86.12%	75.31%
Regression Model	= 8.1 + 19.29 Speed - 0.2402 Length		

Appendix A.4: Continued.

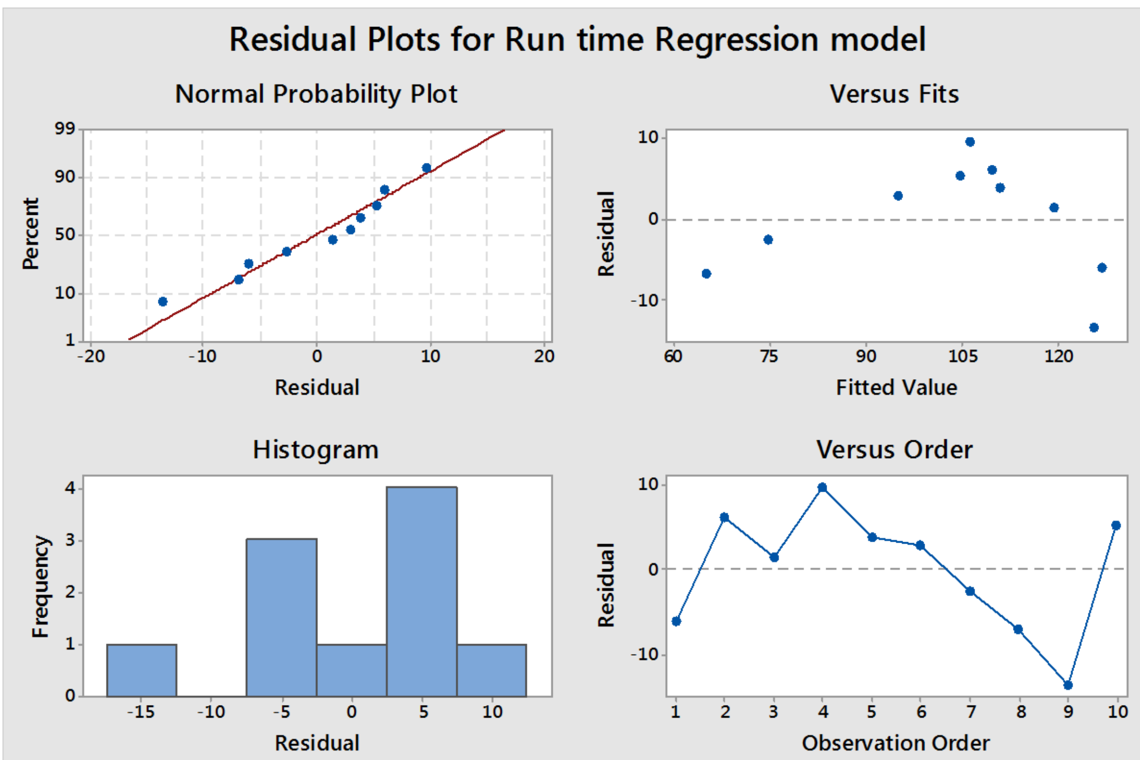
Machine	Speed	Dimensions	Length	Run time
7	5.5	35×120	120	72
7	7.5	35×120	120	120
7	6	35×120	120	80
7	7	35×120	120	90
7	7.5	35×73	73	120
7	8	35×73	73	131
7	7.5	35×120	120	127
7	7.5	35×105	105	126
7	8	35×73	73	131
7	7	35×120	120	90



Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
9.40856	86.97%	83.24%	76.66%
Regression Model	= -58.9 + 24.69 Speed - 0.086 Length		

Appendix A.4: Continued.

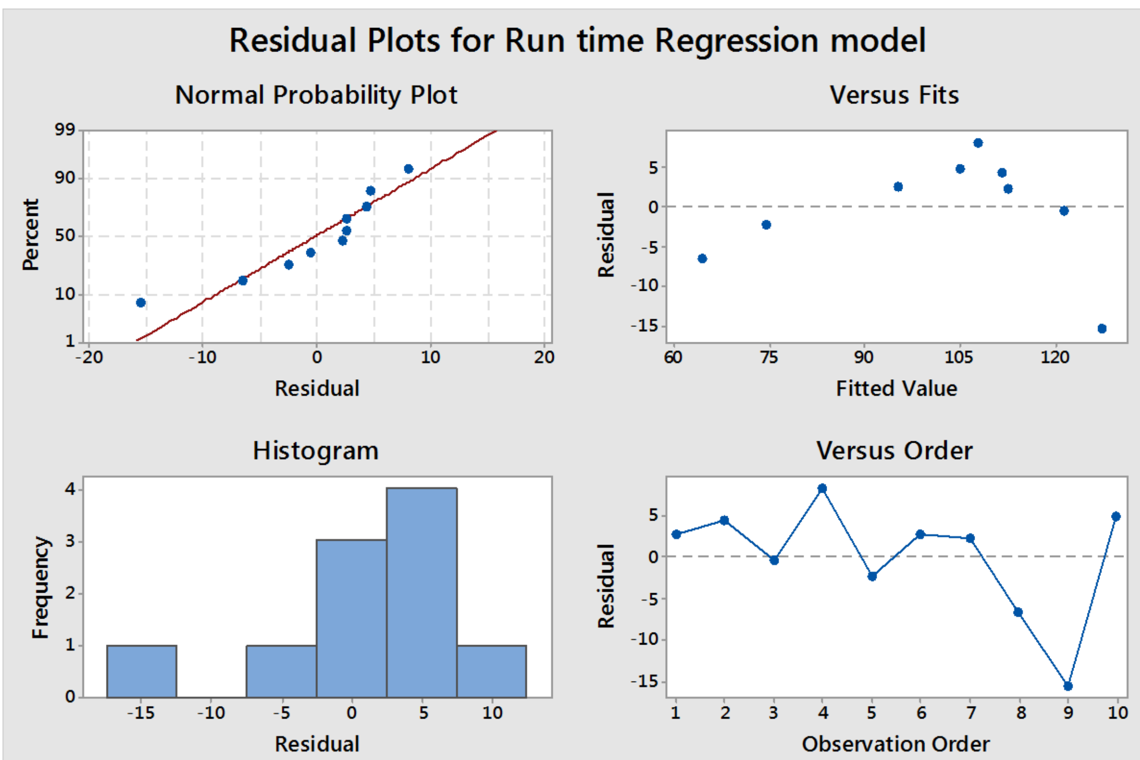
Machine	Speed	Dimensions	Length	Run time
8	6.5	40×27	27	121
8	6	40×58	58	116
8	6.5	40×58	58	121
8	6	35×73	73	116
8	6.25	35×73	73	115
8	6.5	32×160	160	98
8	5.5	33×165	165	72
8	5	35×165	165	58
8	7	35×73	73	112
8	7	32×160	160	110



Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
8.10825	89.20%	86.12%	75.31%
Regression Model	= 8.1 + 19.29 Speed - 0.2402 Length		

Appendix A.4: Continued.

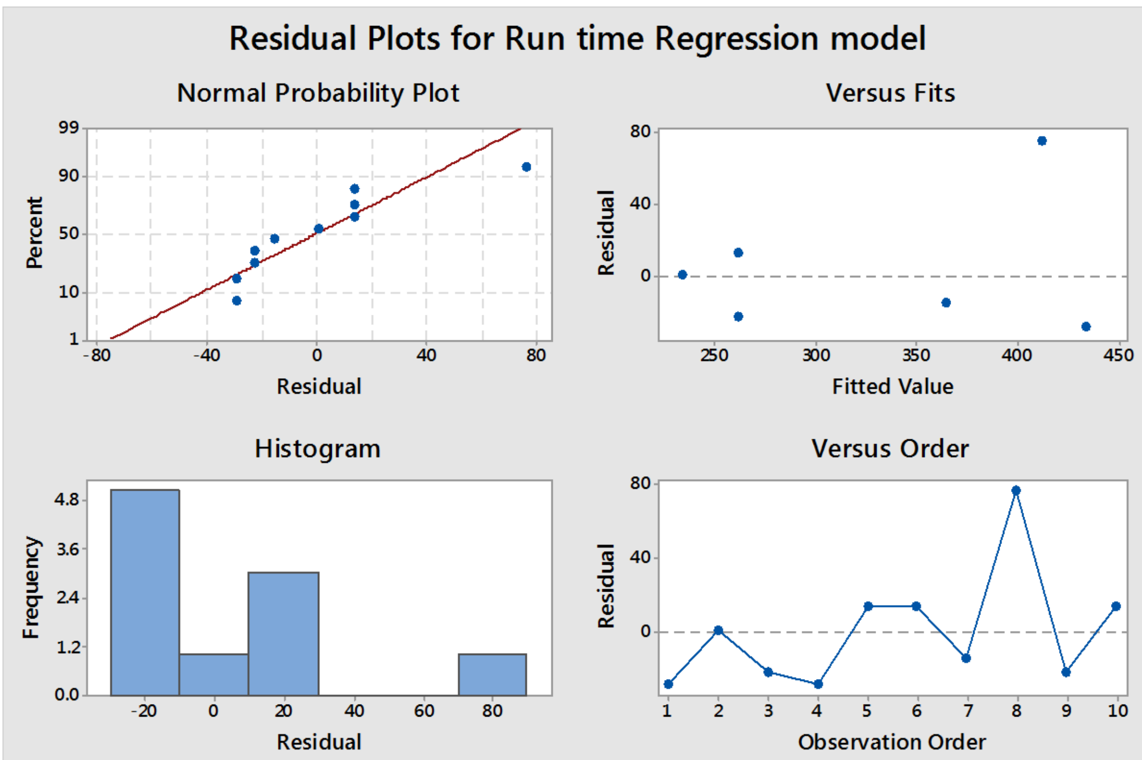
Machine	Speed	Dimensions	Length	Run time
9	6.5	31×160	160	98
9	6	40×58	58	116
9	6.5	40×58	58	121
9	6	35×73	73	116
9	5.5	33×165	165	72
9	6.5	32×160	160	98
9	6.25	35×73	73	115
9	5	35×165	165	58
9	7	35×73	73	112
9	7	32×160	160	110



Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
7.71882	89.45%	86.43%	75.34%
Regression Model	= 8.4 + 19.69 Speed - 0.2563 Length		

Appendix A.4: Continued.

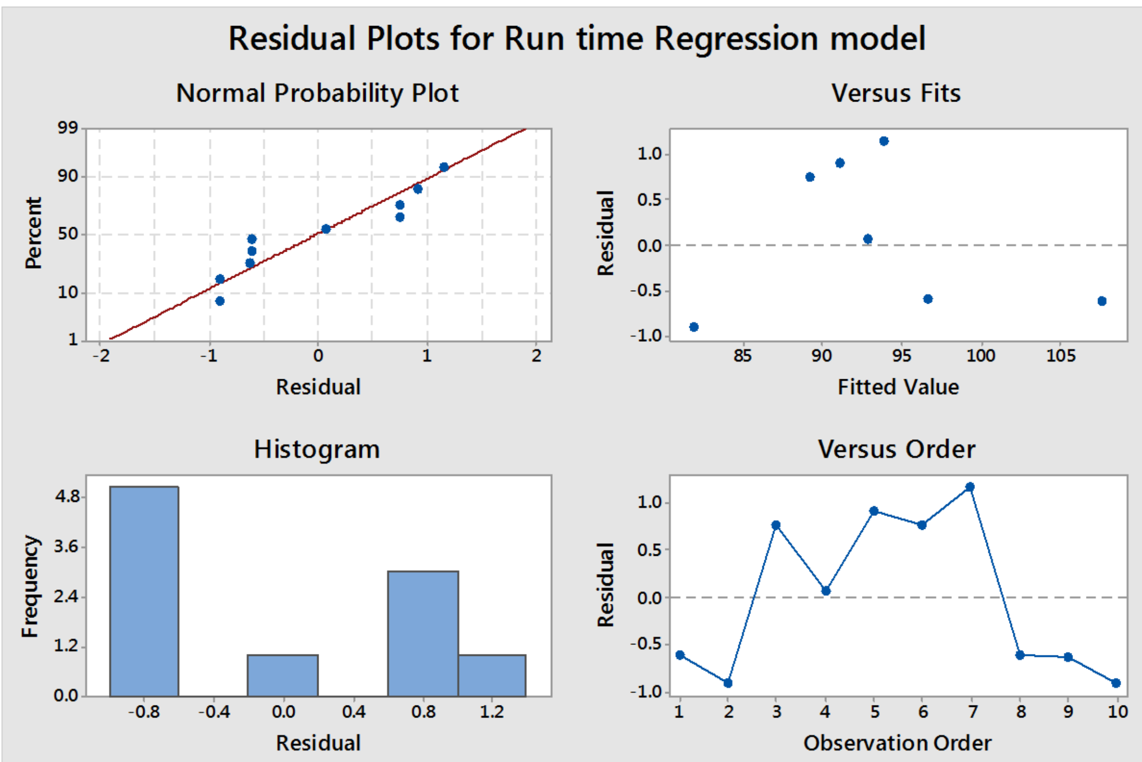
Machine	Speed	Dimensions	Length	Run time
10	405	40×58	58	405
10	235	35×200	200	235
10	240	32×180	180	240
10	405	40×58	58	405
10	276	32×180	180	276
10	276	32×180	180	276
10	350	40×107	107	350
10	489	37×73	73	489
10	240	32×180	180	240
10	276	32×180	180	276



Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
34.0206	86.72%	85.06%	76.72%
Regression Model	= 515.4 - 1.405 Length		

Appendix A.4: Continued.

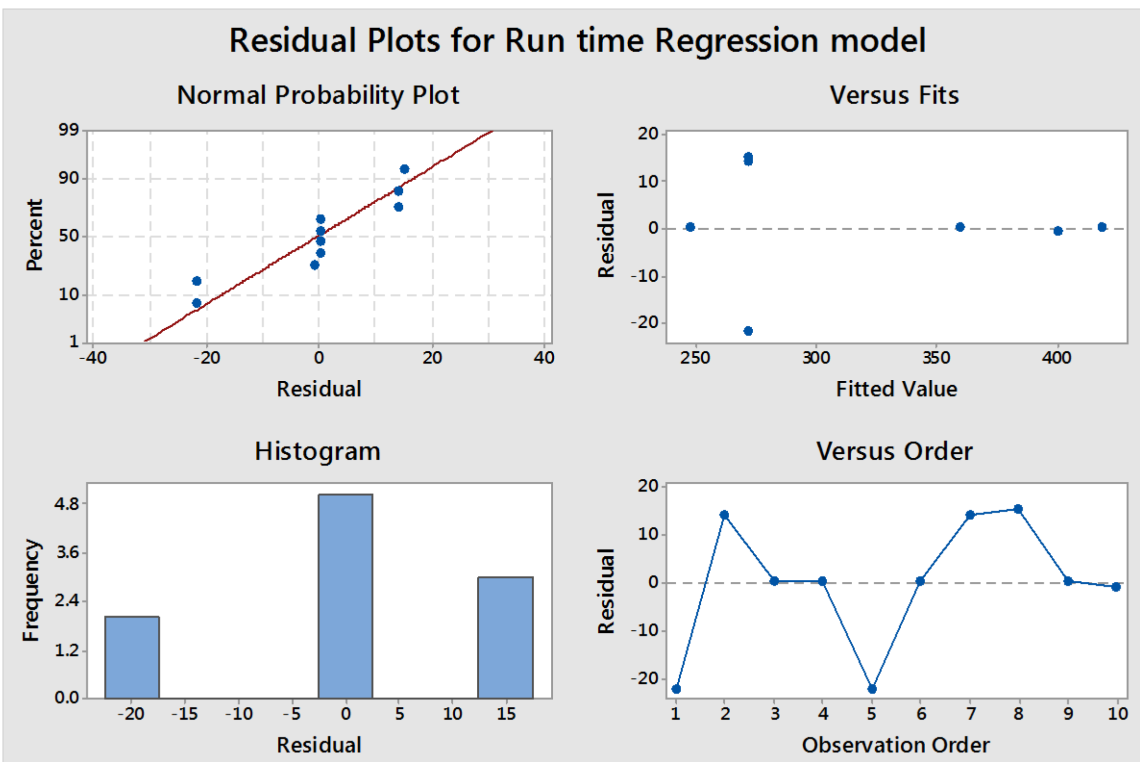
Machine	Speed	Dimensions	Length	Run time
11	96	32×160	160	96
11	81	40×240	240	81
11	90	40×200	200	90
11	93	40×180	180	93
11	92	36×190	190	92
11	90	40×200	200	90
11	95	32×175	175	95
11	96	32×160	160	96
11	107	32×100	100	107
11	81	40×240	240	81



Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
0.868242	98.83%	98.69%	97.94%
Regression Model	= 126.01 - 0.18380 Length		

Appendix A.4: Continued.

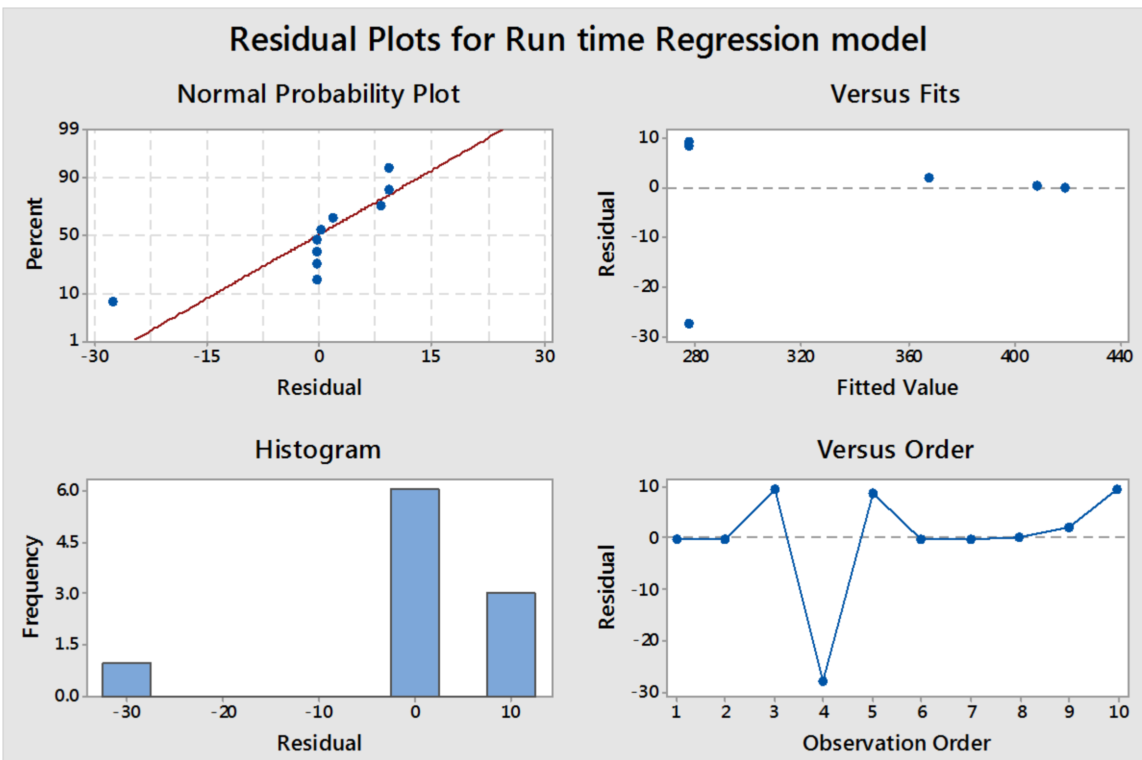
Machine	Speed	Dimensions	Length	Run time
12	250	32×180	180	250
12	286	32×180	180	286
12	419	40×58	58	419
12	248	35×200	200	248
12	250	32×180	180	250
12	419	40×58	58	419
12	286	32×180	180	286
12	287	32×180	180	287
12	360	40×107	107	360
12	400	37×73	73	400



Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
14.0780	96.55%	96.12%	95.19%
Regression Model	= 488.6 - 1.2041 Length		

Appendix A.4: Continued.

Machine	Speed	Dimensions	Length	Run time
13	419	40×58	58	419
13	419	40×58	58	419
13	287	32×180	180	287
13	250	32×180	180	250
13	286	32×180	180	286
13	419	40×58	58	419
13	419	40×58	58	419
13	409	32×67	67	409
13	370	37×102	102	370
13	287	32×180	180	287



Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)
11.2509	97.73%	97.44%	96.04%
Regression Model	= 486.66 - 1.1611 Length		

Appendix A.4: Continued.

Machine	Run time Regression Models	Maximum available speed	Average Length (mm)	Average rate	Run time (min) per unit
1	= 49.11 + 24.59 Speed - 0.7921 Length	6	111.79	108.10	9.25
2	= -61.9 + 23.67 Speed - 0.0741 Length	10	111.79	166.52	6.01
3	= 46.5 + 14.195 Speed + 0.1839 Length	7	111.79	166.42	6.01
4	= -111.2 + 32.09 Speed + 0.0057 Length	7	111.79	114.07	8.77
5	= 179.72 - 0.3527 Length		111.79	140.29	7.13
6	= 8.1 + 19.29 Speed - 0.2402 Length	7	111.79	116.28	8.60
7	= -58.9 + 24.69 Speed - 0.086 Length	8	111.79	129.01	7.75
8	= 8.1 + 19.29 Speed - 0.2402 Length	7	111.79	116.28	8.60
9	= 8.4 + 19.69 Speed - 0.2563 Length	7	111.79	117.58	8.50
10	= 515.4 - 1.405 Length		111.79	358.34	2.79
11	= 126.01 - 0.18380 Length		111.79	105.46	9.48
12	= 488.6 - 1.2041 Length		111.79	353.99	2.82
13	= 486.66 - 1.1611 Length		111.79	356.86	2.80
		Average run time (min) per unit			**6.81**

Appendix A.5: Weighted average length Data and Calculation.

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
33,000	2,000	0	2,000	0.226	60.61	0.14
54,587	5,290	125	5,415	0.373	96.91	0.36
83,927	10,290	120	10,410	0.574	122.61	0.70
64,094	8,194	106	8,300	0.438	127.84	0.56
37,919	9,872	48	9,920	0.259	260.34	0.67
25,650	4,340	0	4,340	0.175	169.20	0.30
64,950	4,620	130	4,750	0.444	71.13	0.32
75,702	7,390	200	7,590	0.517	97.62	0.50
102,356	10,340	60	10,400	0.699	101.02	0.71
31,024	3,469	161	3,630	0.212	111.82	0.24
57,440	7,862	38	7,900	0.393	136.87	0.54
46,460	5,800	0	5,800	0.317	124.84	0.40
13,450	1,690	110	1,800	0.092	125.65	0.12
139,744	10,795	50	10,845	0.955	77.25	0.74
6,800	1,640	60	1,700	0.046	241.18	0.11
41,274	3,491	59	3,550	0.282	84.58	0.24
43,380	9,710	60	9,770	0.296	223.84	0.66
106,155	7,480	0	7,480	0.725	70.46	0.51
41,500	6,710	110	6,820	0.284	161.69	0.46
85,583	5,665	150	5,815	0.585	66.19	0.39
77,054	8,160	80	8,240	0.527	105.90	0.56
31,086	3,504	96	3,600	0.212	112.72	0.24
22,900	5,731	89	5,820	0.156	250.26	0.39
30,900	2,638	140	2,778	0.211	85.37	0.18
4,600	530	20	550	0.031	115.22	0.04
1,815	185	0	185	0.012	101.93	0.01
13,572	965	20	985	0.093	71.10	0.07
845	100	0	100	0.006	118.34	0.01
537	55	15	70	0.004	102.42	0.00
4,044	335	15	350	0.028	82.84	0.02
2,728	250	0	250	0.019	91.64	0.02
289	65	0	65	0.002	224.91	0.00
300	60	0	60	0.002	200.00	0.00
382	75	0	75	0.003	196.34	0.01
747	80	20	100	0.005	107.10	0.01
810	105	0	105	0.006	129.63	0.01
722	75	20	95	0.005	103.88	0.01
4,762	380	20	400	0.033	79.80	0.03
1,780	175	10	185	0.012	98.31	0.01
57,500	2,235	15	2,250	0.393	38.87	0.15

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
4,389	335	15	350	0.030	76.33	0.02
5,250	395	15	410	0.036	75.24	0.03
45,000	8,900	100	9,000	0.308	197.78	0.61
14,696	1,645	5	1,650	0.100	111.94	0.11
16,912	1,990	10	2,000	0.116	117.67	0.14
33,000	3,590	10	3,600	0.226	108.79	0.25
33,000	195	5	200	0.226	5.91	0.01
2,300	315	5	320	0.016	136.96	0.02
4,032	490	10	500	0.028	121.53	0.03
5,800	690	10	700	0.040	118.97	0.05
7,696	850	10	860	0.053	110.45	0.06
360	40	10	50	0.002	111.11	0.00
4,235	486	14	500	0.029	114.76	0.03
10,059	1,188	12	1,200	0.069	118.10	0.08
2,390	280	20	300	0.016	117.15	0.02
2,680	350	0	350	0.018	130.60	0.02
1,103	200	0	200	0.008	181.32	0.01
5,864	650	0	650	0.040	110.85	0.04
700	90	0	90	0.005	128.57	0.01
1,300	160	0	160	0.009	123.08	0.01
480	100	0	100	0.003	208.33	0.01
200	30	0	30	0.001	150.00	0.00
800	100	0	100	0.005	125.00	0.01
800	100	0	100	0.005	125.00	0.01
800	100	0	100	0.005	125.00	0.01
800	100	0	100	0.005	125.00	0.01
1,000	120	0	120	0.007	120.00	0.01
1,100	130	0	130	0.008	118.18	0.01
1,400	150	0	150	0.010	107.14	0.01
800	100	0	100	0.005	125.00	0.01
1,800	200	0	200	0.012	111.11	0.01
6,150	60	0	60	0.042	9.76	0.00
400	40	0	40	0.003	100.00	0.00
6,900	700	0	700	0.047	101.45	0.05
4,650	480	0	480	0.032	103.23	0.03
1,450	150	0	150	0.010	103.45	0.01
1,150	120	0	120	0.008	104.35	0.01
1,150	120	0	120	0.008	104.35	0.01
1,650	180	0	180	0.011	109.09	0.01
1,600	180	0	180	0.011	112.50	0.01
3,700	380	0	380	0.025	102.70	0.03
2,650	280	0	280	0.018	105.66	0.02
2,650	280	0	280	0.018	105.66	0.02
800	100	0	100	0.005	125.00	0.01

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
900	110	0	110	0.006	122.22	0.01
800	100	0	100	0.005	125.00	0.01
600	80	0	80	0.004	133.33	0.01
850	100	0	100	0.006	117.65	0.01
1,850	200	0	200	0.013	108.11	0.01
1,650	200	0	200	0.011	121.21	0.01
1,800	145	5	150	0.012	80.56	0.01
800	63	10	73	0.005	78.75	0.00
800	68	5	73	0.005	85.00	0.00
800	70	5	75	0.005	87.50	0.00
1,800	148	5	153	0.012	82.22	0.01
600	52	5	57	0.004	86.67	0.00
700	60	5	65	0.005	85.71	0.00
1,800	155	5	160	0.012	86.11	0.01
2,100	170	10	180	0.014	80.95	0.01
950	80	10	90	0.006	84.21	0.01
500	50	5	55	0.003	100.00	0.00
800	70	5	75	0.005	87.50	0.00
1,000	87	5	92	0.007	87.00	0.01
900	80	5	85	0.006	88.89	0.01
800	70	5	75	0.005	87.50	0.00
850	75	5	80	0.006	88.24	0.01
750	65	5	70	0.005	86.67	0.00
1,000	85	5	90	0.007	85.00	0.01
1,500	130	5	135	0.010	86.67	0.01
3,150	265	5	270	0.022	84.13	0.02
1,550	135	5	140	0.011	87.10	0.01
1,650	145	5	150	0.011	87.88	0.01
800	65	10	75	0.005	81.25	0.00
1,800	150	5	155	0.012	83.33	0.01
200	225	5	230	0.001	1125.00	0.02
800	196	4	200	0.005	245.00	0.01
800	215	5	220	0.005	268.75	0.01
200	56	4	60	0.001	280.00	0.00
12,500	9,995	5	10,000	0.085	799.60	0.68
17,980	1,330	20	1,350	0.123	73.97	0.09
19,991	1,475	25	1,500	0.137	73.78	0.10
7,000	485	15	500	0.048	69.29	0.03
36,500	1,385	15	1,400	0.249	37.95	0.09
39,700	3,235	15	3,250	0.271	81.49	0.22
14,500	1,180	20	1,200	0.099	81.38	0.08
650	80	20	100	0.004	123.08	0.01
850	95	5	100	0.006	111.76	0.01
2,300	290	10	300	0.016	126.09	0.02

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
850	125	5	130	0.006	147.06	0.01
900	95	5	100	0.006	105.56	0.01
80	30	0	30	0.001	375.00	0.00
7,000	1,630	20	1,650	0.048	232.86	0.11
350	60	10	70	0.002	171.43	0.00
4,000	280	20	300	0.027	70.00	0.02
7,500	780	20	800	0.051	104.00	0.05
7,696	860	10	870	0.053	111.75	0.06
7,696	860	10	870	0.053	111.75	0.06
13,720	1,590	10	1,600	0.094	115.89	0.11
4,500	690	10	700	0.031	153.33	0.05
8,500	1,490	10	1,500	0.058	175.29	0.10
1,120	340	10	350	0.008	303.57	0.02
4,310	440	10	450	0.029	102.09	0.03
4,326	540	20	560	0.030	124.83	0.04
300	54	6	60	0.002	180.00	0.00
1,350	188	12	200	0.009	139.26	0.01
5,686	616	24	640	0.039	108.34	0.04
280	90	10	100	0.002	321.43	0.01
16,078	1,962	38	2,000	0.110	122.03	0.13
24,000	1,800	0	1,800	0.164	75.00	0.12
110,000	8,400	0	8,400	0.752	76.36	0.57
200	45	5	50	0.001	225.00	0.00
400	98	2	100	0.003	245.00	0.01
1,000	196	4	200	0.007	196.00	0.01
6,205	1,290	10	1,300	0.042	207.90	0.09
36,000	2,695	5	2,700	0.246	74.86	0.18
1,400	314	6	320	0.010	224.29	0.02
800	198	2	200	0.005	247.50	0.01
850	195	5	200	0.006	229.41	0.01
4,650	940	10	950	0.032	202.15	0.06
1,400	346	4	350	0.010	247.14	0.02
100	27	3	30	0.001	270.00	0.00
100	48	2	50	0.001	480.00	0.00
1,600	395	5	400	0.011	246.88	0.03
900	246	4	250	0.006	273.33	0.02
800	217	3	220	0.005	271.25	0.01
1,650	395	5	400	0.011	239.39	0.03
800	216	4	220	0.005	270.00	0.01
2,100	465	5	470	0.014	221.43	0.03
1,600	397	3	400	0.011	248.13	0.03
3,150	646	4	650	0.022	205.08	0.04
1,650	395	5	400	0.011	239.39	0.03
1,400	327	3	330	0.010	233.57	0.02

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
600	195	5	200	0.004	325.00	0.01
800	196	4	200	0.005	245.00	0.01
1,000	265	5	270	0.007	265.00	0.02
800	196	4	200	0.005	245.00	0.01
8,778	665	15	680	0.060	75.76	0.05
41,208	2,960	40	3,000	0.282	71.83	0.20
23,560	4,960	40	5,000	0.161	210.53	0.34
100	20	0	20	0.001	200.00	0.00
100	20	0	20	0.001	200.00	0.00
200	40	0	40	0.001	200.00	0.00
600	150	0	150	0.004	250.00	0.01
600	150	0	150	0.004	250.00	0.01
300	25	0	25	0.002	83.33	0.00
2,500	500	0	500	0.017	200.00	0.03
700	50	0	50	0.005	71.43	0.00
800	55	0	55	0.005	68.75	0.00
250	20	0	20	0.002	80.00	0.00
250	20	0	20	0.002	80.00	0.00
300	25	0	25	0.002	83.33	0.00
22,000	800	0	800	0.150	36.36	0.05
1,500	2,000	0	2,000	0.010	1333.33	0.14
1,310	390	10	400	0.009	297.71	0.03
14,160	1,640	10	1,650	0.097	115.82	0.11
15,750	1,790	10	1,800	0.108	113.65	0.12
9,704	1,090	10	1,100	0.066	112.32	0.07
9,027	1,040	10	1,050	0.062	115.21	0.07
8,907	990	10	1,000	0.061	111.15	0.07
6,809	790	10	800	0.047	116.02	0.05
9,704	1,090	10	1,100	0.066	112.32	0.07
8,907	1,090	10	1,100	0.061	122.38	0.07
3,467	388	12	400	0.024	111.91	0.03
1,762	250	0	250	0.012	141.88	0.02
305	50	0	50	0.002	163.93	0.00
4,370	600	0	600	0.030	137.30	0.04
42,980	4,800	0	4,800	0.294	111.68	0.33
4,400	580	20	600	0.030	131.82	0.04
360	130	10	140	0.002	361.11	0.01
4,410	780	20	800	0.030	176.87	0.05
2,102	390	10	400	0.014	185.54	0.03
2,763	315	10	325	0.019	114.01	0.02
9,820	745	5	750	0.067	75.87	0.05
1,779	149	1	150	0.012	83.75	0.01
4,194	349	1	350	0.029	83.21	0.02
1,400	12	3	15	0.010	8.57	0.00

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
400	59	1	60	0.003	147.50	0.00
3,700	349	1	350	0.025	94.32	0.02
2,950	299	1	300	0.020	101.36	0.02
2,300	249	1	250	0.016	108.26	0.02
1,000	119	1	120	0.007	119.00	0.01
500	79	1	80	0.003	158.00	0.01
550	79	1	80	0.004	143.64	0.01
1,900	209	1	210	0.013	110.00	0.01
1,800	199	1	200	0.012	110.56	0.01
2,100	209	1	210	0.014	99.52	0.01
850	99	1	100	0.006	116.47	0.01
850	99	1	100	0.006	116.47	0.01
1,300	129	1	130	0.009	99.23	0.01
4,050	399	1	400	0.028	98.52	0.03
4,800	459	1	460	0.033	95.63	0.03
1,250	129	1	130	0.009	103.20	0.01
14,500	1,399	1	1,400	0.099	96.48	0.10
12,800	1,199	1	1,200	0.087	93.67	0.08
4,300	355	5	360	0.029	82.56	0.02
3,400	280	5	285	0.023	82.35	0.02
900	77	5	82	0.006	85.56	0.01
900	77	5	82	0.006	85.56	0.01
1,600	135	5	140	0.011	84.38	0.01
1,100	95	5	100	0.008	86.36	0.01
1,900	160	5	165	0.013	84.21	0.01
800	70	5	75	0.005	87.50	0.00
800	70	5	75	0.005	87.50	0.00
1,000	85	5	90	0.007	85.00	0.01
1,000	85	5	90	0.007	85.00	0.01
2,300	195	5	200	0.016	84.78	0.01
2,300	195	5	200	0.016	84.78	0.01
2,100	175	5	180	0.014	83.33	0.01
2,100	175	5	180	0.014	83.33	0.01
1,100	95	5	100	0.008	86.36	0.01
1,400	120	5	125	0.010	85.71	0.01
2,700	225	5	230	0.018	83.33	0.02
2,900	245	5	250	0.020	84.48	0.02
850	72	5	77	0.006	84.71	0.00
800	70	5	75	0.005	87.50	0.00
700	60	5	65	0.005	85.71	0.00
700	60	5	65	0.005	85.71	0.00
1,300	110	5	115	0.009	84.62	0.01
500	45	5	50	0.003	90.00	0.00
1,050	90	5	95	0.007	85.71	0.01

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
900	78	5	83	0.006	86.67	0.01
1,500	131	5	136	0.010	87.33	0.01
6,600	562	5	567	0.045	85.15	0.04
5,500	465	5	470	0.038	84.55	0.03
1,450	325	5	330	0.010	224.14	0.02
800	227	3	230	0.005	283.75	0.02
100	48	2	50	0.001	480.00	0.00
200	57	3	60	0.001	285.00	0.00
200	48	2	50	0.001	240.00	0.00
2,650	595	5	600	0.018	224.53	0.04
600	195	5	200	0.004	325.00	0.01
800	247	3	250	0.005	308.75	0.02
2,650	571	4	575	0.018	215.47	0.04
2,100	497	3	500	0.014	236.67	0.03
550	198	2	200	0.004	360.00	0.01
500	197	3	200	0.003	394.00	0.01
1,000	296	4	300	0.007	296.00	0.02
950	248	2	250	0.006	261.05	0.02
900	247	3	250	0.006	274.44	0.02
2,500	543	7	550	0.017	217.20	0.04
2,300	497	3	500	0.016	216.09	0.03
700	226	4	230	0.005	322.86	0.02
1,240	125	15	140	0.008	100.81	0.01
6,860	505	15	520	0.047	73.62	0.03
5,790	435	15	450	0.040	75.13	0.03
12,030	875	25	900	0.082	72.73	0.06
1,138	125	5	130	0.008	109.84	0.01
4,922	385	15	400	0.034	78.22	0.03
684	75	0	75	0.005	109.65	0.01
478	50	0	50	0.003	104.60	0.00
742	75	0	75	0.005	101.08	0.01
1,740	180	5	185	0.012	103.45	0.01
460	60	0	60	0.003	130.43	0.00
578	70	0	70	0.004	121.11	0.00
561	70	0	70	0.004	124.78	0.00
235	45	0	45	0.002	191.49	0.00
4,170	330	20	350	0.028	79.14	0.02
2,544	215	15	230	0.017	84.51	0.01
1,400	190	10	200	0.010	135.71	0.01
14,000	1,570	30	1,600	0.096	112.14	0.11
700	90	10	100	0.005	128.57	0.01
2,500	295	5	300	0.017	118.00	0.02
9,000	1,040	10	1,050	0.062	115.56	0.07
11,500	1,380	20	1,400	0.079	120.00	0.09

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
14,000	1,570	30	1,600	0.096	112.14	0.11
1,500	845	30	875	0.010	563.33	0.06
13,700	875	0	875	0.094	63.87	0.06
13,700	875	0	875	0.094	63.87	0.06
3,125	875	0	875	0.021	280.00	0.06
9,027	1,040	10	1,050	0.062	115.21	0.07
6,809	790	10	800	0.047	116.02	0.05
8,907	1,090	10	1,100	0.061	122.38	0.07
9,704	1,090	10	1,100	0.066	112.32	0.07
9,027	1,040	10	1,050	0.062	115.21	0.07
6,809	790	10	800	0.047	116.02	0.05
900	270	10	280	0.006	300.00	0.02
650	160	10	170	0.004	246.15	0.01
19,851	2,190	10	2,200	0.136	110.32	0.15
7,080	778	22	800	0.048	109.89	0.05
336	76	4	80	0.002	226.19	0.01
2,402	288	12	300	0.016	119.90	0.02
1,544	190	10	200	0.011	123.06	0.01
1,326	170	10	180	0.009	128.21	0.01
1,920	236	14	250	0.013	122.92	0.02
4,380	532	18	550	0.030	121.46	0.04
38,120	4,240	50	4,290	0.260	111.23	0.29
1,400	145	5	150	0.010	103.57	0.01
1,500	149	1	150	0.010	99.33	0.01
3,400	319	1	320	0.023	93.82	0.02
2,000	199	1	200	0.014	99.50	0.01
2,000	199	1	200	0.014	99.50	0.01
4,700	449	1	450	0.032	95.53	0.03
3,400	329	1	330	0.023	96.76	0.02
800	99	1	100	0.005	123.75	0.01
4,600	449	1	450	0.031	97.61	0.03
1,650	179	1	180	0.011	108.48	0.01
5,500	529	1	530	0.038	96.18	0.04
3,150	299	1	300	0.022	94.92	0.02
1,900	199	1	200	0.013	104.74	0.01
700	79	1	80	0.005	112.86	0.01
2,400	229	1	230	0.016	95.42	0.02
1,100	119	1	120	0.008	108.18	0.01
1,000	109	1	110	0.007	109.00	0.01
700	79	1	80	0.005	112.86	0.01
1,600	179	1	180	0.011	111.88	0.01
700	79	1	80	0.005	112.86	0.01
700	79	1	80	0.005	112.86	0.01
900	99	1	100	0.006	110.00	0.01

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
2,100	209	1	210	0.014	99.52	0.01
2,500	249	1	250	0.017	99.60	0.02
9,000	655	5	660	0.062	72.78	0.04
116,352	9,230	10	9,240	0.795	79.33	0.63
3,150	250	15	265	0.022	79.37	0.02
5,400	445	5	450	0.037	82.41	0.03
1,900	442	8	450	0.013	232.63	0.03
100	37	3	40	0.001	370.00	0.00
700	196	4	200	0.005	280.00	0.01
700	227	3	230	0.005	324.29	0.02
2,400	496	4	500	0.016	206.67	0.03
1,500	347	3	350	0.010	231.33	0.02
1,100	296	4	300	0.008	269.09	0.02
1,000	295	5	300	0.007	295.00	0.02
2,700	746	4	750	0.018	276.30	0.05
800	227	3	230	0.005	283.75	0.02
2,900	595	5	600	0.020	205.17	0.04
1,650	397	3	400	0.011	240.61	0.03
1,000	196	4	200	0.007	196.00	0.01
1,100	295	5	300	0.008	268.18	0.02
12,800	2,394	6	2,400	0.087	187.03	0.16
14,500	2,643	7	2,650	0.099	182.28	0.18
580	60	10	70	0.004	103.45	0.00
1,413	150	0	150	0.010	106.16	0.01
736	90	0	90	0.005	122.28	0.01
602	90	0	90	0.004	149.50	0.01
904	100	0	100	0.006	110.62	0.01
1,089	130	0	130	0.007	119.38	0.01
900	100	0	100	0.006	111.11	0.01
16,590	1,190	30	1,220	0.113	71.73	0.08
286	55	0	55	0.002	192.31	0.00
169	50	0	50	0.001	295.86	0.00
517	70	0	70	0.004	135.40	0.00
117	45	0	45	0.001	384.62	0.00
455	70	0	70	0.003	153.85	0.00
5,265	400	30	430	0.036	75.97	0.03
3,958	300	20	320	0.027	75.80	0.02
990	110	0	110	0.007	111.11	0.01
1,064	115	0	115	0.007	108.08	0.01
524	55	5	60	0.004	104.96	0.00
678	75	0	75	0.005	110.62	0.01
805	85	0	85	0.006	105.59	0.01
1,215	120	0	120	0.008	98.77	0.01
780	85	0	85	0.005	108.97	0.01

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
1,069	100	0	100	0.007	93.55	0.01
540	55	0	55	0.004	101.85	0.00
13,910	965	35	1,000	0.095	69.37	0.07
5,565	530	20	550	0.038	95.24	0.04
1,483	270	30	300	0.010	182.06	0.02
4,905	355	10	365	0.034	72.38	0.02
6,000	460	5	465	0.041	76.67	0.03
8,000	460	5	465	0.055	57.50	0.03
7,000	460	5	465	0.048	65.71	0.03
600	180	20	200	0.004	300.00	0.01
2,000	390	10	400	0.014	195.00	0.03
12,697	1,780	20	1,800	0.087	140.19	0.12
400	125	15	140	0.003	312.50	0.01
8,000	770	30	800	0.055	96.25	0.05
600	35	0	35	0.004	58.33	0.00
4,000	250	0	250	0.027	62.50	0.02
400	100	0	100	0.003	250.00	0.01
250	50	0	50	0.002	200.00	0.00
200	40	0	40	0.001	200.00	0.00
100	20	0	20	0.001	200.00	0.00
1,000	200	0	200	0.007	200.00	0.01
700	150	0	150	0.005	214.29	0.01
19,851	2,190	10	2,200	0.136	110.32	0.15
144	55	5	60	0.001	381.94	0.00
10,203	1,250	10	1,260	0.070	122.51	0.09
21,486	2,590	10	2,600	0.147	120.54	0.18
15,600	1,790	10	1,800	0.107	114.74	0.12
658	140	20	160	0.004	212.77	0.01
2,200	290	10	300	0.015	131.82	0.02
882	110	10	120	0.006	124.72	0.01
380	60	10	70	0.003	157.89	0.00
662	90	10	100	0.005	135.95	0.01
3,300	390	10	400	0.023	118.18	0.03
1,100	190	10	200	0.008	172.73	0.01
720	60	10	70	0.005	83.33	0.00
335	28	22	50	0.002	83.58	0.00
2,320	292	8	300	0.016	125.86	0.02
850	75	5	80	0.006	88.24	0.01
1,650	140	5	145	0.011	84.85	0.01
1,400	120	5	125	0.010	85.71	0.01
1,050	90	5	95	0.007	85.71	0.01
800	70	5	75	0.005	87.50	0.00
1,300	110	5	115	0.009	84.62	0.01
2,950	245	5	250	0.020	83.05	0.02

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
1,300	110	5	115	0.009	84.62	0.01
1,850	155	5	160	0.013	83.78	0.01
1,550	130	5	135	0.011	83.87	0.01
850	75	5	80	0.006	88.24	0.01
1,850	155	5	160	0.013	83.78	0.01
850	75	5	80	0.006	88.24	0.01
850	75	5	80	0.006	88.24	0.01
1,250	110	5	115	0.009	88.00	0.01
700	60	5	65	0.005	85.71	0.00
850	75	5	80	0.006	88.24	0.01
500	45	5	50	0.003	90.00	0.00
1,150	97	5	102	0.008	84.35	0.01
1,350	120	5	125	0.009	88.89	0.01
2,150	180	5	185	0.015	83.72	0.01
1,600	135	5	140	0.011	84.38	0.01
850	75	5	80	0.006	88.24	0.01
2,800	245	5	250	0.019	87.50	0.02
2,550	215	5	220	0.017	84.31	0.01
2,500	210	5	215	0.017	84.00	0.01
800	70	5	75	0.005	87.50	0.00
850	70	5	75	0.006	82.35	0.00
1,000	87	5	92	0.007	87.00	0.01
1,650	145	5	150	0.011	87.88	0.01
1,800	155	5	160	0.012	86.11	0.01
1,900	165	5	170	0.013	86.84	0.01
700	60	5	65	0.005	85.71	0.00
700	60	5	65	0.005	85.71	0.00
1,200	105	5	110	0.008	87.50	0.01
1,700	145	5	150	0.012	85.29	0.01
1,900	165	5	170	0.013	86.84	0.01
800	70	5	75	0.005	87.50	0.00
800	65	10	75	0.005	81.25	0.00
800	70	5	75	0.005	87.50	0.00
1,300	110	5	115	0.009	84.62	0.01
1,200	105	5	110	0.008	87.50	0.01
4,600	895	5	900	0.031	194.57	0.06
3,400	696	4	700	0.023	204.71	0.05
1,900	444	6	450	0.013	233.68	0.03
1,500	366	4	370	0.010	244.00	0.03
5,500	1,095	5	1,100	0.038	199.09	0.07
900	246	4	250	0.006	273.33	0.02
1,100	295	5	300	0.008	268.18	0.02
2,300	524	6	530	0.016	227.83	0.04
2,100	496	4	500	0.014	236.19	0.03

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
6,600	1,195	5	1,200	0.045	181.06	0.08
1,600	397	3	400	0.011	248.13	0.03
1,600	296	4	300	0.011	185.00	0.02
800	247	3	250	0.005	308.75	0.02
900	248	2	250	0.006	275.56	0.02
6,200	1,490	10	1,500	0.042	240.32	0.10
3,485	280	10	290	0.024	80.34	0.02
3,446	290	0	290	0.024	84.16	0.02
2,245	195	0	195	0.015	86.86	0.01
1,213	120	0	120	0.008	98.93	0.01
613	75	0	75	0.004	122.35	0.01
16,763	1,225	25	1,250	0.115	73.08	0.08
369	55	0	55	0.003	149.05	0.00
845	90	0	90	0.006	106.51	0.01
1,449	130	0	130	0.010	89.72	0.01
559	75	0	75	0.004	134.17	0.01
19,851	1,395	25	1,420	0.136	70.27	0.10
775	75	10	85	0.005	96.77	0.01
503	50	10	60	0.003	99.40	0.00
442	50	5	55	0.003	113.12	0.00
4,277	345	5	350	0.029	80.66	0.02
117	20	5	25	0.001	170.94	0.00
273	40	5	45	0.002	146.52	0.00
159	45	5	50	0.001	283.02	0.00
108,160	6,380	20	6,400	0.739	58.99	0.44
2,000	320	30	350	0.014	160.00	0.02
700	130	20	150	0.005	185.71	0.01
700	130	20	150	0.005	185.71	0.01
40,100	620	30	650	0.274	15.46	0.04
1,150	240	10	250	0.008	208.70	0.02
400	95	5	100	0.003	237.50	0.01
1,200	240	10	250	0.008	200.00	0.02
200	35	5	40	0.001	175.00	0.00
650	90	10	100	0.004	138.46	0.01
3,650	390	10	400	0.025	106.85	0.03
6,000	580	20	600	0.041	96.67	0.04
21,811	2,390	10	2,400	0.149	109.58	0.16
11,502	1,310	10	1,320	0.079	113.89	0.09
22,329	2,540	10	2,550	0.153	113.75	0.17
25,116	2,840	10	2,850	0.172	113.08	0.19
140	8	12	20	0.001	57.14	0.00
34,040	3,974	26	4,000	0.233	116.75	0.27
7,970	990	10	1,000	0.054	124.22	0.07
446	90	10	100	0.003	201.79	0.01

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
337	48	12	60	0.002	142.43	0.00
797	86	14	100	0.005	107.90	0.01
468	50	10	60	0.003	106.84	0.00
690	78	22	100	0.005	113.04	0.01
2,200	260	40	300	0.015	118.18	0.02
22,000	2,385	15	2,400	0.150	108.41	0.16
22,000	2,380	20	2,400	0.150	108.18	0.16
22,000	2,390	10	2,400	0.150	108.64	0.16
800	75	5	80	0.005	93.75	0.01
800	75	5	80	0.005	93.75	0.01
1,600	145	5	150	0.011	90.63	0.01
1,100	100	5	105	0.008	90.91	0.01
800	75	5	80	0.005	93.75	0.01
800	75	5	80	0.005	93.75	0.01
800	75	5	80	0.005	93.75	0.01
800	75	5	80	0.005	93.75	0.01
100	25	5	30	0.001	250.00	0.00
100	28	2	30	0.001	280.00	0.00
100	48	2	50	0.001	480.00	0.00
100	49	1	50	0.001	490.00	0.00
1,400	346	4	350	0.010	247.14	0.02
3,400	695	5	700	0.023	204.41	0.05
1,400	346	4	350	0.010	247.14	0.02
2,100	465	5	470	0.014	221.43	0.03
800	194	6	200	0.005	242.50	0.01
2,000	423	7	430	0.014	211.50	0.03
2,000	446	4	450	0.014	223.00	0.03
4,700	944	6	950	0.032	200.85	0.06
1,300	344	6	350	0.009	264.62	0.02
1,050	295	5	300	0.007	280.95	0.02
5,500	996	4	1,000	0.038	181.09	0.07
800	215	5	220	0.005	268.75	0.01
1,500	344	6	350	0.010	229.33	0.02
1,068	110	0	110	0.007	103.00	0.01
1,653	150	0	150	0.011	90.74	0.01
447	50	0	50	0.003	111.86	0.00
4,380	345	25	370	0.030	78.77	0.02
699	75	0	75	0.005	107.30	0.01
660	60	0	60	0.005	90.91	0.00
10,648	780	20	800	0.073	73.25	0.05
288	40	0	40	0.002	138.89	0.00
477	60	0	60	0.003	125.79	0.00
528	55	0	55	0.004	104.17	0.00
183	40	0	40	0.001	218.58	0.00

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
120	35	0	35	0.001	291.67	0.00
5,124	375	25	400	0.035	73.19	0.03
1,440	135	5	140	0.010	93.75	0.01
2,090	195	5	200	0.014	93.30	0.01
5,084	390	10	400	0.035	76.71	0.03
1,032	100	0	100	0.007	96.90	0.01
636	65	0	65	0.004	102.20	0.00
4,644	370	30	400	0.032	79.67	0.03
672	70	0	70	0.005	104.17	0.00
435	50	0	50	0.003	114.94	0.00
1,068	110	0	110	0.007	103.00	0.01
1,410	125	15	140	0.010	88.65	0.01
148,720	8,770	30	8,800	1.016	58.97	0.60
6,000	580	20	600	0.041	96.67	0.04
1,000	220	30	250	0.007	220.00	0.02
6,200	1,500	0	1,500	0.042	241.94	0.10
10,000	2,475	25	2,500	0.068	247.50	0.17
9,189	990	10	1,000	0.063	107.74	0.07
5,904	790	10	800	0.040	133.81	0.05
2,190	350	10	360	0.015	159.82	0.02
2,820	390	10	400	0.019	138.30	0.03
17,577	1,990	10	2,000	0.120	113.22	0.14
27,252	3,140	10	3,150	0.186	115.22	0.21
6,747	750	10	760	0.046	111.16	0.05
9,072	990	10	1,000	0.062	109.13	0.07
9,072	990	10	1,000	0.062	109.13	0.07
9,072	995	5	1,000	0.062	109.68	0.07
3,055	325	10	335	0.021	106.38	0.02
3,055	330	5	335	0.021	108.02	0.02
3,055	330	5	335	0.021	108.02	0.02
400	45	5	50	0.003	112.50	0.00
400	45	5	50	0.003	112.50	0.00
400	45	5	50	0.003	112.50	0.00
9,189	990	10	1,000	0.063	107.74	0.07
9,800	1,195	5	1,200	0.067	121.94	0.08
11,929	1,382	18	1,400	0.082	115.85	0.09
883	140	10	150	0.006	158.55	0.01
1,100	170	10	180	0.008	154.55	0.01
280	44	6	50	0.002	157.14	0.00
3,210	394	6	400	0.022	122.74	0.03
2,245	372	8	380	0.015	165.70	0.03
3,446	392	8	400	0.024	113.76	0.03
18,129	2,076	24	2,100	0.124	114.51	0.14
3,485	408	12	420	0.024	117.07	0.03

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
9,090	1,084	16	1,100	0.062	119.25	0.07
243	54	6	60	0.002	222.22	0.00
1,200	155	5	160	0.008	129.17	0.01
600	205	5	210	0.004	341.67	0.01
4,523	1,399	1	1,400	0.031	309.31	0.10
1,000	299	1	300	0.007	299.00	0.02
1,073	299	1	300	0.007	278.66	0.02
7,100	1,599	1	1,600	0.049	225.21	0.11
1,350	345	5	350	0.009	255.56	0.02
4,800	944	6	950	0.033	196.67	0.06
1,250	345	5	350	0.009	276.00	0.02
850	217	3	220	0.006	255.29	0.01
850	244	6	250	0.006	287.06	0.02
1,900	447	3	450	0.013	235.26	0.03
3,150	645	5	650	0.022	204.76	0.04
800	197	3	200	0.005	246.25	0.01
1,600	395	5	400	0.011	246.88	0.03
1,800	447	3	450	0.012	248.33	0.03
850	248	2	250	0.006	291.76	0.02
2,500	543	7	550	0.017	217.20	0.04
1,650	395	5	400	0.011	239.39	0.03
850	247	3	250	0.006	290.59	0.02
1,150	295	5	300	0.008	256.52	0.02
850	197	3	200	0.006	231.76	0.01
800	795	5	800	0.005	993.75	0.05
800	246	4	250	0.005	307.50	0.02
1,280	115	10	125	0.009	89.84	0.01
1,126	110	0	110	0.008	97.69	0.01
2,030	185	0	185	0.014	91.13	0.01
684	65	0	65	0.005	95.03	0.00
3,324	240	10	250	0.023	72.20	0.02
730	65	0	65	0.005	89.04	0.00
478	55	0	55	0.003	115.06	0.00
342	50	0	50	0.002	146.20	0.00
465	65	0	65	0.003	139.78	0.00
11,080	785	35	820	0.076	70.85	0.05
516	60	0	60	0.004	116.28	0.00
420	45	0	45	0.003	107.14	0.00
402	45	0	45	0.003	111.94	0.00
342	45	0	45	0.002	131.58	0.00
4,040	305	15	320	0.028	75.50	0.02
650	90	10	100	0.004	138.46	0.01
4,890	390	10	400	0.033	79.75	0.03
4,680	370	15	385	0.032	79.06	0.03

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
4,000	325	15	340	0.027	81.25	0.02
8,219	1,085	15	1,100	0.056	132.01	0.07
1,200	185	15	200	0.008	154.17	0.01
1,600	195	5	200	0.011	121.88	0.01
700	95	5	100	0.005	135.71	0.01
700	95	5	100	0.005	135.71	0.01
2,800	295	5	300	0.019	105.36	0.02
2,300	295	5	300	0.016	128.26	0.02
900	145	5	150	0.006	161.11	0.01
950	145	5	150	0.006	152.63	0.01
700	95	5	100	0.005	135.71	0.01
1,300	195	5	200	0.009	150.00	0.01
700	95	5	100	0.005	135.71	0.01
700	95	5	100	0.005	135.71	0.01
350	95	5	100	0.002	271.43	0.01
2,400	295	5	300	0.016	122.92	0.02
850	125	5	130	0.006	147.06	0.01
800	95	5	100	0.005	118.75	0.01
2,000	265	5	270	0.014	132.50	0.02
900	147	3	150	0.006	163.33	0.01
1,200	165	5	170	0.008	137.50	0.01
1,200	165	5	170	0.008	137.50	0.01
500	95	5	100	0.003	190.00	0.01
700	95	5	100	0.005	135.71	0.01
800	145	5	150	0.005	181.25	0.01
700	95	5	100	0.005	135.71	0.01
700	95	5	100	0.005	135.71	0.01
700	95	5	100	0.005	135.71	0.01
700	95	5	100	0.005	135.71	0.01
40,000	7,900	100	8,000	0.273	197.50	0.54
1,190	190	10	200	0.008	159.66	0.01
3,630	540	10	550	0.025	148.76	0.04
1,370	290	10	300	0.009	211.68	0.02
1,360	290	10	300	0.009	213.24	0.02
1,370	290	10	300	0.009	211.68	0.02
1,360	290	10	300	0.009	213.24	0.02
1,360	290	10	300	0.009	213.24	0.02
8,380	940	10	950	0.057	112.17	0.06
4,389	935	15	950	0.030	213.03	0.06
1,040	240	10	250	0.007	230.77	0.02
606	225	15	240	0.004	371.29	0.02
6,747	790	10	800	0.046	117.09	0.05
4,762	510	10	520	0.033	107.10	0.03
4,190	455	5	460	0.029	108.59	0.03

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
5,390	578	10	588	0.037	107.24	0.04
4,352	480	10	490	0.030	110.29	0.03
1,575	165	10	175	0.011	104.76	0.01
553	60	5	65	0.004	108.50	0.00
553	120	10	130	0.004	217.00	0.01
1,575	165	10	175	0.011	104.76	0.01
5,084	545	5	550	0.035	107.20	0.04
100	8	10	18	0.001	80.00	0.00
90	8	12	20	0.001	88.89	0.00
220	32	18	50	0.002	145.45	0.00
243	34	16	50	0.002	139.92	0.00
6,730	780	20	800	0.046	115.90	0.05
120	10	10	20	0.001	83.33	0.00
150	30	20	50	0.001	200.00	0.00
1,160	134	16	150	0.008	115.52	0.01
245	40	10	50	0.002	163.27	0.00
2,106	280	20	300	0.014	132.95	0.02
1,200	295	5	300	0.008	245.83	0.02
2,200	594	6	600	0.015	270.00	0.04
500	149	1	150	0.003	298.00	0.01
1,970	497	3	500	0.013	252.28	0.03
4,995	1,294	6	1,300	0.034	259.06	0.09
4,969	397	3	400	0.034	79.90	0.03
20	17	3	20	0.000	850.00	0.00
20	23	2	25	0.000	1150.00	0.00
6,150	1,190	10	1,200	0.042	193.50	0.08
1,800	445	5	450	0.012	247.22	0.03
1,850	446	4	450	0.013	241.08	0.03
6,900	1,295	5	1,300	0.047	187.68	0.09
1,200	326	4	330	0.008	271.67	0.02
1,200	196	4	200	0.008	163.33	0.01
1,800	445	5	450	0.012	247.22	0.03
5,400	1,093	7	1,100	0.037	202.41	0.07
3,700	744	6	750	0.025	201.08	0.05
1,800	445	5	450	0.012	247.22	0.03
1,260	110	10	120	0.009	87.30	0.01
1,260	110	10	120	0.009	87.30	0.01
1,490	140	10	150	0.010	93.96	0.01
388	50	5	55	0.003	128.87	0.00
430	60	5	65	0.003	139.53	0.00
1,758	175	0	175	0.012	99.54	0.01
484	55	0	55	0.003	113.64	0.00
691	70	0	70	0.005	101.30	0.00
737	70	0	70	0.005	94.98	0.00

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
3,089	250	25	275	0.021	80.93	0.02
1,124	110	0	110	0.008	97.86	0.01
492	60	0	60	0.003	121.95	0.00
660	75	0	75	0.005	113.64	0.01
429	50	0	50	0.003	116.55	0.00
552	65	0	65	0.004	117.75	0.00
570	65	0	65	0.004	114.04	0.00
7,183	535	35	570	0.049	74.48	0.04
900	100	0	100	0.006	111.11	0.01
516	65	0	65	0.004	125.97	0.00
248	40	0	40	0.002	161.29	0.00
386	45	0	45	0.003	116.58	0.00
563	55	0	55	0.004	97.69	0.00
263	35	0	35	0.002	133.08	0.00
620	75	5	80	0.004	120.97	0.01
196	30	0	30	0.001	153.06	0.00
4,402	360	10	370	0.030	81.78	0.02
196	35	0	35	0.001	178.57	0.00
858	80	0	80	0.006	93.24	0.01
207	35	0	35	0.001	169.08	0.00
6,747	505	15	520	0.046	74.85	0.03
18,000	595	5	600	0.123	33.06	0.04
50,000	3,970	30	4,000	0.342	79.40	0.27
5,700	638	12	650	0.039	111.93	0.04
600	95	5	100	0.004	158.33	0.01
700	125	5	130	0.005	178.57	0.01
2,100	245	5	250	0.014	116.67	0.02
1,100	145	5	150	0.008	131.82	0.01
2,400	295	5	300	0.016	122.92	0.02
10,000	1,970	30	2,000	0.068	197.00	0.13
900	140	20	160	0.006	155.56	0.01
900	155	5	160	0.006	172.22	0.01
900	155	5	160	0.006	172.22	0.01
300	45	5	50	0.002	150.00	0.00
300	45	5	50	0.002	150.00	0.00
300	45	5	50	0.002	150.00	0.00
6,300	445	5	450	0.043	70.63	0.03
13,800	945	5	950	0.094	68.48	0.06
16,050	1,095	5	1,100	0.110	68.22	0.07
6,825	445	5	450	0.047	65.20	0.03
100	5	5	10	0.001	50.00	0.00
900	45	5	50	0.006	50.00	0.00
5,390	610	10	620	0.037	113.17	0.04
4,352	490	10	500	0.030	112.59	0.03

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
4,762	540	10	550	0.033	113.40	0.04
34,050	3,890	10	3,900	0.233	114.24	0.27
24,000	2,690	10	2,700	0.164	112.08	0.18
14,268	1,640	10	1,650	0.097	114.94	0.11
7,898	940	10	950	0.054	119.02	0.06
463	75	5	80	0.003	161.99	0.01
184	36	4	40	0.001	195.65	0.00
2,155	294	6	300	0.015	136.43	0.02
3,083	394	6	400	0.021	127.80	0.03
5,404	586	14	600	0.037	108.44	0.04
3,282	393	7	400	0.022	119.74	0.03
3,150	550	30	580	0.022	174.60	0.04
2,800	530	20	550	0.019	189.29	0.04
1,550	305	20	325	0.011	196.77	0.02
1,300	240	20	260	0.009	184.62	0.02
780	85	0	85	0.005	108.97	0.01
1,956	170	0	170	0.013	86.91	0.01
1,270	110	0	110	0.009	86.61	0.01
528	55	0	55	0.004	104.17	0.00
816	75	0	75	0.006	91.91	0.01
3,734	305	25	330	0.026	81.68	0.02
11,415	815	25	840	0.078	71.40	0.06
3,990	315	15	330	0.027	78.95	0.02
600	185	15	200	0.004	308.33	0.01
45,000	2,085	15	2,100	0.308	46.33	0.14
370	85	15	100	0.003	229.73	0.01
11	8	2	10	0.000	727.27	0.00
2,800	345	5	350	0.019	123.21	0.02
900	145	5	150	0.006	161.11	0.01
600	115	5	120	0.004	191.67	0.01
900	145	5	150	0.006	161.11	0.01
1,800	225	5	230	0.012	125.00	0.02
600	115	5	120	0.004	191.67	0.01
1,300	195	5	200	0.009	150.00	0.01
700	115	5	120	0.005	164.29	0.01
900	145	5	150	0.006	161.11	0.01
700	115	5	120	0.005	164.29	0.01
2,200	295	5	300	0.015	134.09	0.02
2,100	295	5	300	0.014	140.48	0.02
1,000	158	2	160	0.007	158.00	0.01
1,100	158	2	160	0.008	143.64	0.01
1,400	198	2	200	0.010	141.43	0.01
600	98	2	100	0.004	163.33	0.01
2,200	297	3	300	0.015	135.00	0.02

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
3,100	395	5	400	0.021	127.42	0.03
950	147	3	150	0.006	154.74	0.01
1,600	197	3	200	0.011	123.13	0.01
2,800	347	3	350	0.019	123.93	0.02
7,400	847	3	850	0.051	114.46	0.06
900	147	3	150	0.006	163.33	0.01
3,000	230	20	250	0.021	76.67	0.02
4,600	340	10	350	0.031	73.91	0.02
6,075	490	10	500	0.042	80.66	0.03
3,150	240	10	250	0.022	76.19	0.02
3,850	440	10	450	0.026	114.29	0.03
100	0	20	20	0.001	0.00	0.00
4,420	580	20	600	0.030	131.22	0.04
1,000	230	20	250	0.007	230.00	0.02
2,400	380	20	400	0.016	158.33	0.03
1,500	280	20	300	0.010	186.67	0.02
4,612	630	20	650	0.032	136.60	0.04
15,000	1,080	20	1,100	0.103	72.00	0.07
4,200	240	10	250	0.029	57.14	0.02
41,895	4,670	10	4,680	0.286	111.47	0.32
3,949	470	10	480	0.027	119.02	0.03
18,930	2,140	10	2,150	0.129	113.05	0.15
21,042	2,290	10	2,300	0.144	108.83	0.16
2,150	260	10	270	0.015	120.93	0.02
3,098	360	10	370	0.021	116.20	0.02
926	140	10	150	0.006	151.19	0.01
4,212	538	12	550	0.029	127.73	0.04
2,852	344	6	350	0.019	120.62	0.02
3,126	394	6	400	0.021	126.04	0.03
3,330	444	6	450	0.023	133.33	0.03
4,061	494	6	500	0.028	121.64	0.03
882	104	6	110	0.006	117.91	0.01
910	112	8	120	0.006	123.08	0.01
222	90	10	100	0.002	405.41	0.01
1,275	195	5	200	0.009	152.94	0.01
2,568	295	5	300	0.018	114.88	0.02
2,355	294	6	300	0.016	124.84	0.02
2,632	344	6	350	0.018	130.70	0.02
2,472	344	6	350	0.017	139.16	0.02
224	44	6	50	0.002	196.43	0.00
1,488	195	5	200	0.010	131.05	0.01
100	24	1	25	0.001	240.00	0.00
2,750	345	5	350	0.019	125.45	0.02
7,151	695	5	700	0.049	97.19	0.05

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
7,900	599	1	600	0.054	75.82	0.04
1,080	95	5	100	0.007	87.96	0.01
662	85	5	90	0.005	128.40	0.01
800	85	5	90	0.005	106.25	0.01
2,532	195	5	200	0.017	77.01	0.01
3,600	530	20	550	0.025	147.22	0.04
1,150	230	20	250	0.008	200.00	0.02
10,000	1,690	20	1,710	0.068	169.00	0.12
1,650	315	15	330	0.011	190.91	0.02
4,940	390	10	400	0.034	78.95	0.03
4,000	295	5	300	0.027	73.75	0.02
1,700	160	5	165	0.012	94.12	0.01
1,000	95	5	100	0.007	95.00	0.01
2,700	250	5	255	0.018	92.59	0.02
1,400	130	5	135	0.010	92.86	0.01
700	70	5	75	0.005	100.00	0.00
1,800	170	5	175	0.012	94.44	0.01
2,600	245	5	250	0.018	94.23	0.02
800	75	5	80	0.005	93.75	0.01
100	10	5	15	0.001	100.00	0.00
200	20	5	25	0.001	100.00	0.00
900	85	5	90	0.006	94.44	0.01
1,100	105	5	110	0.008	95.45	0.01
10,000	935	5	940	0.068	93.50	0.06
900	85	5	90	0.006	94.44	0.01
2,600	245	5	250	0.018	94.23	0.02
7,500	695	5	700	0.051	92.67	0.05
800	85	5	90	0.005	106.25	0.01
600	55	5	60	0.004	91.67	0.00
15,000	1,380	20	1,400	0.103	92.00	0.09
4,620	285	15	300	0.032	61.69	0.02
2,400	190	10	200	0.016	79.17	0.01
1,400	45	5	50	0.010	32.14	0.00
4,050	258	2	260	0.028	63.70	0.02
100	10	10	20	0.001	100.00	0.00
700	50	20	70	0.005	71.43	0.00
700	65	5	70	0.005	92.86	0.00
1,300	115	5	120	0.009	88.46	0.01
1,000	95	5	100	0.007	95.00	0.01
800	75	5	80	0.005	93.75	0.01
1,100	105	5	110	0.008	95.45	0.01
2,400	195	5	200	0.016	81.25	0.01
4,200	337	5	342	0.029	80.24	0.02
4,200	332	10	342	0.029	79.05	0.02

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
4,500	390	10	400	0.031	86.67	0.03
4,500	390	10	400	0.031	86.67	0.03
15,000	1,390	10	1,400	0.103	92.67	0.09
2,400	440	10	450	0.016	183.33	0.03
800	140	10	150	0.005	175.00	0.01
2,800	200	0	200	0.019	71.43	0.01
320	20	0	20	0.002	62.50	0.00
1,000	70	0	70	0.007	70.00	0.00
700	50	0	50	0.005	71.43	0.00
320	20	0	20	0.002	62.50	0.00
1,000	70	0	70	0.007	70.00	0.00
700	50	0	50	0.005	71.43	0.00
320	20	0	20	0.002	62.50	0.00
1,000	70	0	70	0.007	70.00	0.00
700	50	0	50	0.005	71.43	0.00
320	20	0	20	0.002	62.50	0.00
1,000	70	0	70	0.007	70.00	0.00
800	60	0	60	0.005	75.00	0.00
1,200	90	0	90	0.008	75.00	0.01
2,100	140	0	140	0.014	66.67	0.01
960	70	0	70	0.007	72.92	0.00
2,970	200	0	200	0.020	67.34	0.01
10,000	1,085	15	1,100	0.068	108.50	0.07
3,277	390	10	400	0.022	119.01	0.03
5,084	590	10	600	0.035	116.05	0.04
870	95	5	100	0.006	109.20	0.01
250	46	4	50	0.002	184.00	0.00
222	97	3	100	0.002	436.94	0.01
57,671	6,276	24	6,300	0.394	108.82	0.43
370	100	0	100	0.003	270.27	0.01
2,300	450	0	450	0.016	195.65	0.03
2,700	550	0	550	0.018	203.70	0.04
11	10	0	10	0.000	909.09	0.00
2,600	530	0	530	0.018	203.85	0.04
1,600	360	0	360	0.011	225.00	0.02
900	250	0	250	0.006	277.78	0.02
900	250	0	250	0.006	277.78	0.02
1,800	400	0	400	0.012	222.22	0.03
900	250	0	250	0.006	277.78	0.02
1,200	300	0	300	0.008	250.00	0.02
3,150	295	5	300	0.022	93.65	0.02
5,700	1,194	6	1,200	0.039	209.47	0.08
700	226	4	230	0.005	322.86	0.02
1,850	448	2	450	0.013	242.16	0.03

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
1,650	397	3	400	0.011	240.61	0.03
1,150	346	4	350	0.008	300.87	0.02
850	247	3	250	0.006	290.59	0.02
1,400	345	5	350	0.010	246.43	0.02
1,850	447	3	450	0.013	241.62	0.03
900	148	2	150	0.006	164.44	0.01
850	245	5	250	0.006	288.24	0.02
700	226	4	230	0.005	322.86	0.02
1,250	344	6	350	0.009	275.20	0.02
4,050	846	4	850	0.028	208.89	0.06
2,300	495	5	500	0.016	215.22	0.03
700	194	6	200	0.005	277.14	0.01
1,300	347	3	350	0.009	266.92	0.02
1,000	295	5	300	0.007	295.00	0.02
1,300	346	4	350	0.009	266.15	0.02
900	83	2	85	0.006	92.22	0.01
9,900	735	15	750	0.068	74.24	0.05
7,500	540	10	550	0.051	72.00	0.04
88,000	3,980	20	4,000	0.601	45.23	0.27
8,440	680	20	700	0.058	80.57	0.05
304	90	10	100	0.002	296.05	0.01
330	95	5	100	0.002	287.88	0.01
2,360	245	5	250	0.016	103.81	0.02
600	95	5	100	0.004	158.33	0.01
460	95	5	100	0.003	206.52	0.01
3,023	295	5	300	0.021	97.59	0.02
4,781	445	5	450	0.033	93.08	0.03
5,141	495	5	500	0.035	96.28	0.03
2,450	275	5	280	0.017	112.24	0.02
6,609	595	5	600	0.045	90.03	0.04
3,370	300	5	305	0.023	89.02	0.02
2,200	180	20	200	0.015	81.82	0.01
8,000	580	20	600	0.055	72.50	0.04
120	15	5	20	0.001	125.00	0.00
1,671	240	10	250	0.011	143.63	0.02
100	15	5	20	0.001	150.00	0.00
307	45	5	50	0.002	146.58	0.00
100	15	5	20	0.001	150.00	0.00
100	35	5	40	0.001	350.00	0.00
100	35	5	40	0.001	350.00	0.00
100	35	5	40	0.001	350.00	0.00
100	35	5	40	0.001	350.00	0.00
100	35	5	40	0.001	350.00	0.00
1,642	20	10	30	0.011	12.18	0.00

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
2,287	110	20	130	0.016	48.10	0.01
100	15	5	20	0.001	150.00	0.00
370	35	5	40	0.003	94.59	0.00
4,600	480	20	500	0.031	104.35	0.03
1,406	90	10	100	0.010	64.01	0.01
800	55	20	75	0.005	68.75	0.00
900	75	10	85	0.006	83.33	0.01
1,200	125	5	130	0.008	104.17	0.01
16,100	1,355	10	1,365	0.110	84.16	0.09
3,300	275	10	285	0.023	83.33	0.02
3,100	260	5	265	0.021	83.87	0.02
4,100	345	5	350	0.028	84.15	0.02
4,200	350	10	360	0.029	83.33	0.02
5,200	445	5	450	0.036	85.58	0.03
4,100	345	5	350	0.028	84.15	0.02
800	80	5	85	0.005	100.00	0.01
3,000	255	5	260	0.021	85.00	0.02
2,970	90	10	100	0.020	30.30	0.01
2,100	50	10	60	0.014	23.81	0.00
960	40	10	50	0.007	41.67	0.00
1,200	30	10	40	0.008	25.00	0.00
3,098	390	10	400	0.021	125.89	0.03
2,150	290	10	300	0.015	134.88	0.02
13,328	1,490	10	1,500	0.091	111.79	0.10
5,088	690	10	700	0.035	135.61	0.05
7,350	890	10	900	0.050	121.09	0.06
2,820	350	10	360	0.019	124.11	0.02
9,870	1,190	10	1,200	0.067	120.57	0.08
3,240	390	10	400	0.022	120.37	0.03
27,936	3,090	10	3,100	0.191	110.61	0.21
6,036	690	10	700	0.041	114.31	0.05
4,244	490	10	500	0.029	115.46	0.03
57,671	6,272	28	6,300	0.394	108.75	0.43
400	50	0	50	0.003	125.00	0.00
4,020	450	0	450	0.027	111.94	0.03
6,263	700	0	700	0.043	111.77	0.05
2,600	525	5	530	0.018	201.92	0.04
700	225	5	230	0.005	321.43	0.02
700	225	5	230	0.005	321.43	0.02
800	245	5	250	0.005	306.25	0.02
1,400	345	5	350	0.010	246.43	0.02
1,300	325	5	330	0.009	250.00	0.02
700	245	5	250	0.005	350.00	0.02
850	296	4	300	0.006	348.24	0.02

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
700	255	5	260	0.005	364.29	0.02
850	246	4	250	0.006	289.41	0.02
1,550	394	6	400	0.011	254.19	0.03
850	246	4	250	0.006	289.41	0.02
1,050	297	3	300	0.007	282.86	0.02
2,100	496	4	500	0.014	236.19	0.03
800	247	3	250	0.005	308.75	0.02
900	248	2	250	0.006	275.56	0.02
1,100	157	3	160	0.008	142.73	0.01
800	248	2	250	0.005	310.00	0.02
100	295	5	300	0.001	2950.00	0.02
800	246	4	250	0.005	307.50	0.02
1,100	298	2	300	0.008	270.91	0.02
200	247	3	250	0.001	1235.00	0.02
800	246	4	250	0.005	307.50	0.02
2,950	647	3	650	0.020	219.32	0.04
900	298	2	300	0.006	331.11	0.02
15,660	1,225	25	1,250	0.107	78.22	0.08
33,845	2,675	25	2,700	0.231	79.04	0.18
1,876	300	0	300	0.013	159.91	0.02
6,662	600	0	600	0.046	90.06	0.04
14,080	1,100	0	1,100	0.096	78.13	0.08
9,593	850	0	850	0.066	88.61	0.06
3,290	350	0	350	0.022	106.38	0.02
3,400	27	0	27	0.023	7.94	0.00
370	40	10	50	0.003	108.11	0.00
3,750	290	10	300	0.026	77.33	0.02
1,080	5	5	10	0.007	4.63	0.00
100	5	5	10	0.001	50.00	0.00
100	0	10	10	0.001	0.00	0.00
100	5	5	10	0.001	50.00	0.00
100	5	5	10	0.001	50.00	0.00
300	55	5	60	0.002	183.33	0.00
100	15	5	20	0.001	150.00	0.00
172	35	5	40	0.001	203.49	0.00
100	15	5	20	0.001	150.00	0.00
100	15	5	20	0.001	150.00	0.00
100	15	5	20	0.001	150.00	0.00
300	55	5	60	0.002	183.33	0.00
500	90	10	100	0.003	180.00	0.01
500	90	10	100	0.003	180.00	0.01
3,900	530	20	550	0.027	135.90	0.04
370	40	10	50	0.003	108.11	0.00
100	10	5	15	0.001	100.00	0.00

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
400	40	10	50	0.003	100.00	0.00
100	10	5	15	0.001	100.00	0.00
100	5	10	15	0.001	50.00	0.00
100	5	10	15	0.001	50.00	0.00
400	50	10	60	0.003	125.00	0.00
830	80	10	90	0.006	96.39	0.01
100	5	10	15	0.001	50.00	0.00
100	5	10	15	0.001	50.00	0.00
200	20	10	30	0.001	100.00	0.00
200	25	5	30	0.001	125.00	0.00
3,000	260	10	270	0.021	86.67	0.02
5,200	440	10	450	0.036	84.62	0.03
800	70	10	80	0.005	87.50	0.00
800	70	10	80	0.005	87.50	0.00
800	70	10	80	0.005	87.50	0.00
5,000	155	10	165	0.034	31.00	0.01
4,000	130	10	140	0.027	32.50	0.01
44,000	1,195	5	1,200	0.301	27.16	0.08
8,488	990	10	1,000	0.058	116.64	0.07
12,072	1,340	10	1,350	0.082	111.00	0.09
13,968	1,540	10	1,550	0.095	110.25	0.11
1,620	190	10	200	0.011	117.28	0.01
20,172	2,390	10	2,400	0.138	118.48	0.16
20,172	2,395	5	2,400	0.138	118.73	0.16
7,400	895	5	900	0.051	120.95	0.06
3,879	455	5	460	0.027	117.30	0.03
6,583	750	0	750	0.045	113.93	0.05
7,400	890	10	900	0.051	120.27	0.06
21,692	4,772	28	4,800	0.148	219.99	0.33
19,990	4,162	38	4,200	0.137	208.20	0.28
700	225	5	230	0.005	321.43	0.02
1,800	448	2	450	0.012	248.89	0.03
1,300	344	6	350	0.009	264.62	0.02
500	197	3	200	0.003	394.00	0.01
850	244	6	250	0.006	287.06	0.02
1,800	448	2	450	0.012	248.89	0.03
500	197	3	200	0.003	394.00	0.01
800	218	2	220	0.005	272.50	0.01
1,100	295	5	300	0.008	268.18	0.02
900	267	3	270	0.006	296.67	0.02
2,550	546	4	550	0.017	214.12	0.04
850	247	3	250	0.006	290.59	0.02
2,950	625	5	630	0.020	211.86	0.04
700	226	4	230	0.005	322.86	0.02

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
2,000	444	6	450	0.014	222.00	0.03
1,100	296	4	300	0.008	269.09	0.02
1,900	444	6	450	0.013	233.68	0.03
2,800	593	7	600	0.019	211.79	0.04
2,200	495	5	500	0.015	225.00	0.03
2,100	494	6	500	0.014	235.24	0.03
800	263	7	270	0.005	328.75	0.02
1,700	130	10	140	0.012	76.47	0.01
400	195	5	200	0.003	487.50	0.01
15,360	945	5	950	0.105	61.52	0.06
646	60	5	65	0.004	92.88	0.00
7,767	625	5	630	0.053	80.47	0.04
4,466	365	5	370	0.031	81.73	0.02
15,231	1,245	5	1,250	0.104	81.74	0.09
28,776	2,245	5	2,250	0.197	78.02	0.15
2,000	165	5	170	0.014	82.50	0.01
1,620	235	15	250	0.011	145.06	0.02
874	140	10	150	0.006	160.18	0.01
901	145	5	150	0.006	160.93	0.01
1,402	195	5	200	0.010	139.09	0.01
4,753	445	5	450	0.032	93.63	0.03
23,236	1,695	5	1,700	0.159	72.95	0.12
2,080	245	5	250	0.014	117.79	0.02
24,086	1,790	10	1,800	0.165	74.32	0.12
1,662	135	5	140	0.011	81.23	0.01
11,000	1,230	5	1,235	0.075	111.82	0.08
1,869	280	20	300	0.013	149.81	0.02
1,500	230	20	250	0.010	153.33	0.02
400	90	10	100	0.003	225.00	0.01
1,602	280	20	300	0.011	174.78	0.02
3,045	480	20	500	0.021	157.64	0.03
800	140	10	150	0.005	175.00	0.01
800	140	10	150	0.005	175.00	0.01
1,330	240	10	250	0.009	180.45	0.02
3,879	910	10	920	0.027	234.60	0.06
6,583	1,490	10	1,500	0.045	226.34	0.10
52,800	5,840	10	5,850	0.361	110.61	0.40
16,236	1,840	10	1,850	0.111	113.33	0.13
15,736	1,790	10	1,800	0.108	113.75	0.12
10,536	1,190	10	1,200	0.072	112.95	0.08
3,136	390	10	400	0.021	124.36	0.03
2,132	290	10	300	0.015	136.02	0.02
1,600	162	18	180	0.011	101.25	0.01
600	66	4	70	0.004	110.00	0.00

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
440	47	3	50	0.003	106.82	0.00
330	37	3	40	0.002	112.12	0.00
320	37	3	40	0.002	115.63	0.00
270	40	10	50	0.002	148.15	0.00
270	90	10	100	0.002	333.33	0.01
3,975	435	15	450	0.027	109.43	0.03
2,875	338	12	350	0.020	117.57	0.02
1,100	140	10	150	0.008	127.27	0.01
1,400	170	10	180	0.010	121.43	0.01
1,100	138	12	150	0.008	125.45	0.01
5,452	580	20	600	0.037	106.38	0.04
5,620	630	20	650	0.038	112.10	0.04
14,096	1,572	28	1,600	0.096	111.52	0.11
168	25	15	40	0.001	148.81	0.00
772	85	15	100	0.005	110.10	0.01
960	115	15	130	0.007	119.79	0.01
800	260	0	260	0.005	325.00	0.02
1,300	350	0	350	0.009	269.23	0.02
500	200	0	200	0.003	400.00	0.01
1,300	350	0	350	0.009	269.23	0.02
2,800	600	0	600	0.019	214.29	0.04
1,600	400	0	400	0.011	250.00	0.03
950	250	0	250	0.006	263.16	0.02
1,400	350	0	350	0.010	250.00	0.02
700	200	0	200	0.005	285.71	0.01
350	100	0	100	0.002	285.71	0.01
7,400	1,400	0	1,400	0.051	189.19	0.10
1,200	350	0	350	0.008	291.67	0.02
900	250	0	250	0.006	277.78	0.02
700	220	0	220	0.005	314.29	0.02
700	230	0	230	0.005	328.57	0.02
1,200	350	0	350	0.008	291.67	0.02
1,700	450	0	450	0.012	264.71	0.03
800	250	0	250	0.005	312.50	0.02
1,100	300	0	300	0.008	272.73	0.02
1,200	300	0	300	0.008	250.00	0.02
2,100	300	0	300	0.014	142.86	0.02
2,000	165	5	170	0.014	82.50	0.01
15,231	1,245	5	1,250	0.104	81.74	0.09
5,000	395	5	400	0.034	79.00	0.03
99,000	4,495	5	4,500	0.677	45.40	0.31
6,292	585	15	600	0.043	92.98	0.04
6,948	590	10	600	0.047	84.92	0.04
4,404	390	10	400	0.030	88.56	0.03

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
1,066	175	5	180	0.007	164.17	0.01
1,568	195	5	200	0.011	124.36	0.01
3,766	345	5	350	0.026	91.61	0.02
2,520	295	5	300	0.017	117.06	0.02
800	190	10	200	0.005	237.50	0.01
4,647	280	20	300	0.032	60.25	0.02
100	0	10	10	0.001	0.00	0.00
3,045	280	20	300	0.021	91.95	0.02
1,602	40	10	50	0.011	24.97	0.00
450	25	5	30	0.003	55.56	0.00
1,700	145	5	150	0.012	85.29	0.01
938	45	5	50	0.006	47.97	0.00
3,364	170	10	180	0.023	50.54	0.01
1,191	45	5	50	0.008	37.78	0.00
535	45	5	50	0.004	84.11	0.00
300	45	5	50	0.002	150.00	0.00
1,053	185	15	200	0.007	175.69	0.01
1,310	235	15	250	0.009	179.39	0.02
2,500	285	15	300	0.017	114.00	0.02
950	240	10	250	0.006	252.63	0.02
1,285	290	10	300	0.009	225.68	0.02
745	190	10	200	0.005	255.03	0.01
935	240	10	250	0.006	256.68	0.02
745	190	10	200	0.005	255.03	0.01
2,395	590	10	600	0.016	246.35	0.04
5,200	390	10	400	0.036	75.00	0.03
9,202	590	10	600	0.063	64.12	0.04
5,000	290	10	300	0.034	58.00	0.02
12,000	395	5	400	0.082	32.92	0.03
24,000	800	0	800	0.164	33.33	0.05
17,300	1,890	10	1,900	0.118	109.25	0.13
4,228	482	18	500	0.029	114.00	0.03
10,515	1,190	10	1,200	0.072	113.17	0.08
12,940	1,384	16	1,400	0.088	106.96	0.09
6,297	690	10	700	0.043	109.58	0.05
50	5	5	10	0.000	100.00	0.00
25	0	5	5	0.000	0.00	0.00
25	0	5	5	0.000	0.00	0.00
25	0	5	5	0.000	0.00	0.00
25	0	5	5	0.000	0.00	0.00
25	0	5	5	0.000	0.00	0.00
25	0	5	5	0.000	0.00	0.00
25	0	5	5	0.000	0.00	0.00
25	0	5	5	0.000	0.00	0.00

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
25	0	5	5	0.000	0.00	0.00
25	0	5	5	0.000	0.00	0.00
50	5	5	10	0.000	100.00	0.00
25	0	5	5	0.000	0.00	0.00
25	0	5	5	0.000	0.00	0.00
3,505	432	18	450	0.024	123.25	0.03
9,130	1,072	28	1,100	0.062	117.42	0.07
1,100	275	5	280	0.008	250.00	0.02
600	195	5	200	0.004	325.00	0.01
1,600	345	5	350	0.011	215.63	0.02
3,100	595	5	600	0.021	191.94	0.04
2,400	495	5	500	0.016	206.25	0.03
2,800	545	5	550	0.019	194.64	0.04
900	245	5	250	0.006	272.22	0.02
1,900	395	5	400	0.013	207.89	0.03
700	225	5	230	0.005	321.43	0.02
600	195	5	200	0.004	325.00	0.01
2,200	494	6	500	0.015	224.55	0.03
900	247	3	250	0.006	274.44	0.02
600	195	5	200	0.004	325.00	0.01
800	226	4	230	0.005	282.50	0.02
950	294	6	300	0.006	309.47	0.02
800	247	3	250	0.005	308.75	0.02
800	245	5	250	0.005	306.25	0.02
1,300	346	4	350	0.009	266.15	0.02
900	248	2	250	0.006	275.56	0.02
700	195	5	200	0.005	278.57	0.01
600	196	4	200	0.004	326.67	0.01
700	217	3	220	0.005	310.00	0.01
800	244	6	250	0.005	305.00	0.02
16,100	2,993	7	3,000	0.110	185.90	0.20
7,752	685	15	700	0.053	88.36	0.05
5,994	48	7	55	0.041	8.01	0.00
13,597	1,093	7	1,100	0.093	80.39	0.07
1,360	195	5	200	0.009	143.38	0.01
1,270	195	5	200	0.009	153.54	0.01
1,400	195	5	200	0.010	139.29	0.01
1,130	195	5	200	0.008	172.57	0.01
1,650	190	10	200	0.011	115.15	0.01
8,908	1,230	20	1,250	0.061	138.08	0.08
1,060	145	5	150	0.007	136.79	0.01
552	95	5	100	0.004	172.10	0.01
8,896	440	10	450	0.061	49.46	0.03
500	40	10	50	0.003	80.00	0.00

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
34,600	3,840	10	3,850	0.236	110.98	0.26
24,000	2,690	10	2,700	0.164	112.08	0.18
14,700	1,690	10	1,700	0.100	114.97	0.12
943	144	6	150	0.006	152.70	0.01
877	115	5	120	0.006	131.13	0.01
1,320	145	5	150	0.009	109.85	0.01
1,012	145	5	150	0.007	143.28	0.01
765	95	5	100	0.005	124.18	0.01
4,985	594	6	600	0.034	119.16	0.04
9,130	1,094	6	1,100	0.062	119.82	0.07
4,741	594	6	600	0.032	125.29	0.04
1,890	318	2	320	0.013	168.25	0.02
800	144	6	150	0.005	180.00	0.01
400	146	4	150	0.003	365.00	0.01
25,303	1,499	1	1,500	0.173	59.24	0.10
4,488	549	1	550	0.031	122.33	0.04
4,506	559	1	560	0.031	124.06	0.04
5,286	649	1	650	0.036	122.78	0.04
633	79	1	80	0.004	124.80	0.01
800	200	0	200	0.005	250.00	0.01
700	200	0	200	0.005	285.71	0.01
900	250	0	250	0.006	277.78	0.02
600	150	0	150	0.004	250.00	0.01
5,200	950	0	950	0.036	182.69	0.06
5,200	950	0	950	0.036	182.69	0.06
4,200	780	0	780	0.029	185.71	0.05
1,200	300	0	300	0.008	250.00	0.02
800	200	0	200	0.005	250.00	0.01
1,500	350	0	350	0.010	233.33	0.02
1,900	444	6	450	0.013	233.68	0.03
100	295	5	300	0.001	2950.00	0.02
800	194	6	200	0.005	242.50	0.01
1,100	295	5	300	0.008	268.18	0.02
1,100	296	4	300	0.008	269.09	0.02
700	227	3	230	0.005	324.29	0.02
700	195	5	200	0.005	278.57	0.01
700	217	3	220	0.005	310.00	0.01
2,400	525	5	530	0.016	218.75	0.04
3,100	647	3	650	0.021	208.71	0.04
1,500	348	2	350	0.010	232.00	0.02
900	247	3	250	0.006	274.44	0.02
1,200	298	2	300	0.008	248.33	0.02
1,000	294	6	300	0.007	294.00	0.02
1,700	395	5	400	0.012	232.35	0.03

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
2,500	544	6	550	0.017	217.60	0.04
2,900	625	5	630	0.020	215.52	0.04
1,200	346	4	350	0.008	288.33	0.02
1,100	295	5	300	0.008	268.18	0.02
2,000	476	4	480	0.014	238.00	0.03
1,300	344	6	350	0.009	264.62	0.02
800	227	3	230	0.005	283.75	0.02
1,100	294	6	300	0.008	267.27	0.02
1,100	295	5	300	0.008	268.18	0.02
5,268	420	10	430	0.036	79.73	0.03
12,750	920	10	930	0.087	72.16	0.06
1,270	140	10	150	0.009	110.24	0.01
2,074	160	10	170	0.014	77.15	0.01
5,850	160	10	170	0.040	27.35	0.01
8,445	620	10	630	0.058	73.42	0.04
1,270	120	10	130	0.009	94.49	0.01
1,270	120	10	130	0.009	94.49	0.01
3,900	320	10	330	0.027	82.05	0.02
2,610	220	10	230	0.018	84.29	0.02
7,450	560	10	570	0.051	75.17	0.04
24,175	1,740	10	1,750	0.165	71.98	0.12
2,032	90	10	100	0.014	44.29	0.01
530	35	5	40	0.004	66.04	0.00
530	25	5	30	0.004	47.17	0.00
8,000	780	20	800	0.055	97.50	0.05
1,060	135	15	150	0.007	127.36	0.01
500	130	20	150	0.003	260.00	0.01
530	90	10	100	0.004	169.81	0.01
1,060	140	10	150	0.007	132.08	0.01
570	90	10	100	0.004	157.89	0.01
1,613	290	10	300	0.011	179.79	0.02
1,060	40	10	50	0.007	37.74	0.00
530	40	10	50	0.004	75.47	0.00
12,900	640	10	650	0.088	49.61	0.04
1,060	140	10	150	0.007	132.08	0.01
7,350	890	10	900	0.050	121.09	0.06
17,400	1,990	10	2,000	0.119	114.37	0.14
10,178	1,090	10	1,100	0.070	107.09	0.07
4,674	540	10	550	0.032	115.53	0.04
5,328	590	10	600	0.036	110.74	0.04
14,151	1,545	5	1,550	0.097	109.18	0.11
34,233	3,895	5	3,900	0.234	113.78	0.27
16,010	1,790	10	1,800	0.109	111.81	0.12
14,570	1,690	10	1,700	0.100	115.99	0.12

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
8,005	890	10	900	0.055	111.18	0.06
7,285	840	10	850	0.050	115.31	0.06
6,276	2,180	10	2,190	0.043	347.36	0.15
1,900	205	10	215	0.013	107.89	0.01
16,100	1,840	10	1,850	0.110	114.29	0.13
16,100	790	10	800	0.110	49.07	0.05
55,550	2,420	80	2,500	0.380	43.56	0.17
18,900	1,285	15	1,300	0.129	67.99	0.09
500	30	10	40	0.003	60.00	0.00
50,000	1,485	15	1,500	0.342	29.70	0.10
55,000	1,685	15	1,700	0.376	30.64	0.12
150,000	4,970	30	5,000	1.025	33.13	0.34
1,000	140	10	150	0.007	140.00	0.01
2,700	345	5	350	0.018	127.78	0.02
1,300	195	5	200	0.009	150.00	0.01
900	145	5	150	0.006	161.11	0.01
800	145	5	150	0.005	181.25	0.01
1,100	145	5	150	0.008	131.82	0.01
4,100	775	5	780	0.028	189.02	0.05
3,000	595	5	600	0.021	198.33	0.04
3,000	595	5	600	0.021	198.33	0.04
3,300	665	5	670	0.023	201.52	0.05
1,000	129	1	130	0.007	129.00	0.01
2,900	299	1	300	0.020	103.10	0.02
2,600	259	1	260	0.018	99.62	0.02
10,500	999	1	1,000	0.072	95.14	0.07
9,300	899	1	900	0.064	96.67	0.06
6,400	599	1	600	0.044	93.59	0.04
5,600	559	1	560	0.038	99.82	0.04
2,700	594	6	600	0.018	220.00	0.04
1,400	325	5	330	0.010	232.14	0.02
1,800	448	2	450	0.012	248.89	0.03
1,800	445	5	450	0.012	247.22	0.03
900	297	3	300	0.006	330.00	0.02
1,700	395	5	400	0.012	232.35	0.03
1,400	346	4	350	0.010	247.14	0.02
1,000	295	5	300	0.007	295.00	0.02
1,100	297	3	300	0.008	270.00	0.02
2,600	545	5	550	0.018	209.62	0.04
2,900	594	6	600	0.020	204.83	0.04
1,000	296	4	300	0.007	296.00	0.02
1,000	295	5	300	0.007	295.00	0.02
800	196	4	200	0.005	245.00	0.01
700	225	5	230	0.005	321.43	0.02

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
900	257	3	260	0.006	285.56	0.02
1,000	295	5	300	0.007	295.00	0.02
1,000	296	4	300	0.007	296.00	0.02
1,300	325	5	330	0.009	250.00	0.02
1,200	294	6	300	0.008	245.00	0.02
8,756	1,095	0	1,095	0.060	125.06	0.07
24,650	2,400	0	2,400	0.168	97.36	0.16
30,856	2,480	0	2,480	0.211	80.37	0.17
55,310	6,540	0	6,540	0.378	118.24	0.45
3,248	510	0	510	0.022	157.02	0.03
15,147	2,265	0	2,265	0.104	149.53	0.15
26,092	6,500	0	6,500	0.178	249.12	0.44
500	150	0	150	0.003	300.00	0.01
25,099	2,760	0	2,760	0.172	109.96	0.19
10,000	700	0	700	0.068	70.00	0.05
44,276	4,425	0	4,425	0.303	99.94	0.30
33,274	4,010	0	4,010	0.227	120.51	0.27
16,049	2,430	0	2,430	0.110	151.41	0.17
115,290	7,800	0	7,800	0.788	67.66	0.53
82,600	9,400	0	9,400	0.564	113.80	0.64
6,223	1,270	0	1,270	0.043	204.08	0.09
21,000	1,950	0	1,950	0.144	92.86	0.13
31,935	2,880	0	2,880	0.218	90.18	0.20
65,908	7,700	0	7,700	0.450	116.83	0.53
45,155	9,010	0	9,010	0.309	199.53	0.62
25,311	3,365	0	3,365	0.173	132.95	0.23
87,648	10,200	0	10,200	0.599	116.37	0.70
61,740	3,980	0	3,980	0.422	64.46	0.27
32,500	2,950	0	2,950	0.222	90.77	0.20
38,010	3,640	0	3,640	0.260	95.76	0.25
47,066	5,150	0	5,150	0.322	109.42	0.35
39,437	8,197	0	8,197	0.269	207.85	0.56
22,930	5,415	0	5,415	0.157	236.15	0.37
37,000	7,055	0	7,055	0.253	190.68	0.48
31,230	5,080	0	5,080	0.213	162.66	0.35
5,899	1,300	0	1,300	0.040	220.38	0.09
81,150	9,870	0	9,870	0.555	121.63	0.67
45,801	2,980	0	2,980	0.313	65.06	0.20
39,550	5,350	0	5,350	0.270	135.27	0.37
35,230	7,340	0	7,340	0.241	208.35	0.50
30,490	6,220	0	6,220	0.208	204.00	0.43
40,000	9,100	0	9,100	0.273	227.50	0.62
52,710	6,730	0	6,730	0.360	127.68	0.46
31,500	4,100	0	4,100	0.215	130.16	0.28

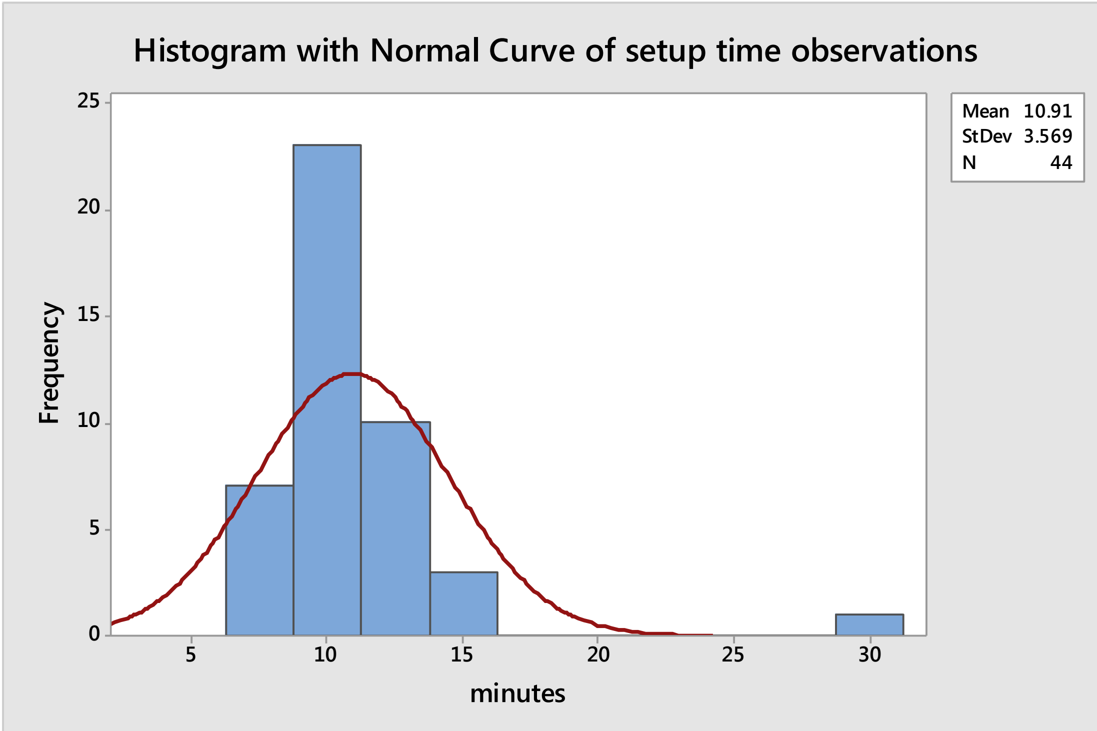
Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
91,550	5,485	0	5,485	0.626	59.91	0.37
47,950	5,825	0	5,825	0.328	121.48	0.40
34,600	4,060	0	4,060	0.236	117.34	0.28
21,689	4,160	0	4,160	0.148	191.80	0.28
17,118	3,340	0	3,340	0.117	195.12	0.23
29,600	5,650	0	5,650	0.202	190.88	0.39
64,730	7,590	0	7,590	0.442	117.26	0.52
54,500	6,100	0	6,100	0.372	111.93	0.42
44,950	3,850	0	3,850	0.307	85.65	0.26
61,860	6,965	0	6,965	0.423	112.59	0.48
63,700	7,200	0	7,200	0.435	113.03	0.49
14,678	3,160	0	3,160	0.100	215.29	0.22
40,000	7,000	0	7,000	0.273	175.00	0.48
11,050	1,970	0	1,970	0.076	178.28	0.13
39,852	3,050	0	3,050	0.272	76.53	0.21
45,500	5,300	0	5,300	0.311	116.48	0.36
73,831	7,750	0	7,750	0.505	104.97	0.53
44,759	5,440	0	5,440	0.306	121.54	0.37
27,564	3,220	0	3,220	0.188	116.82	0.22
38,578	4,765	0	4,765	0.264	123.52	0.33
53,430	6,250	0	6,250	0.365	116.98	0.43
26,940	4,980	0	4,980	0.184	184.86	0.34
10,286	1,700	0	1,700	0.070	165.27	0.12
80,000	9,000	0	9,000	0.547	112.50	0.62
19,619	2,450	0	2,450	0.134	124.88	0.17
62,450	4,530	0	4,530	0.427	72.54	0.31
70,850	7,620	0	7,620	0.484	107.55	0.52
22,023	2,900	0	2,900	0.150	131.68	0.20
17,270	3,010	0	3,010	0.118	174.29	0.21
40,960	6,960	0	6,960	0.280	169.92	0.48
41,814	4,950	0	4,950	0.286	118.38	0.34
120,600	5,000	0	5,000	0.824	41.46	0.34
34,169	3,415	0	3,415	0.233	99.94	0.23
81,860	7,980	0	7,980	0.559	97.48	0.55
41,275	4,970	0	4,970	0.282	120.41	0.34
32,019	4,150	0	4,150	0.219	129.61	0.28
24,400	5,350	0	5,350	0.167	219.26	0.37
50,650	6,410	0	6,410	0.346	126.55	0.44
4,993	655	0	655	0.034	131.18	0.04
24,500	5,050	0	5,050	0.167	206.12	0.35
41,547	4,550	0	4,550	0.284	109.51	0.31
66,840	7,940	0	7,940	0.457	118.79	0.54
26,856	3,635	0	3,635	0.184	135.35	0.25
28,695	3,610	0	3,610	0.196	125.81	0.25

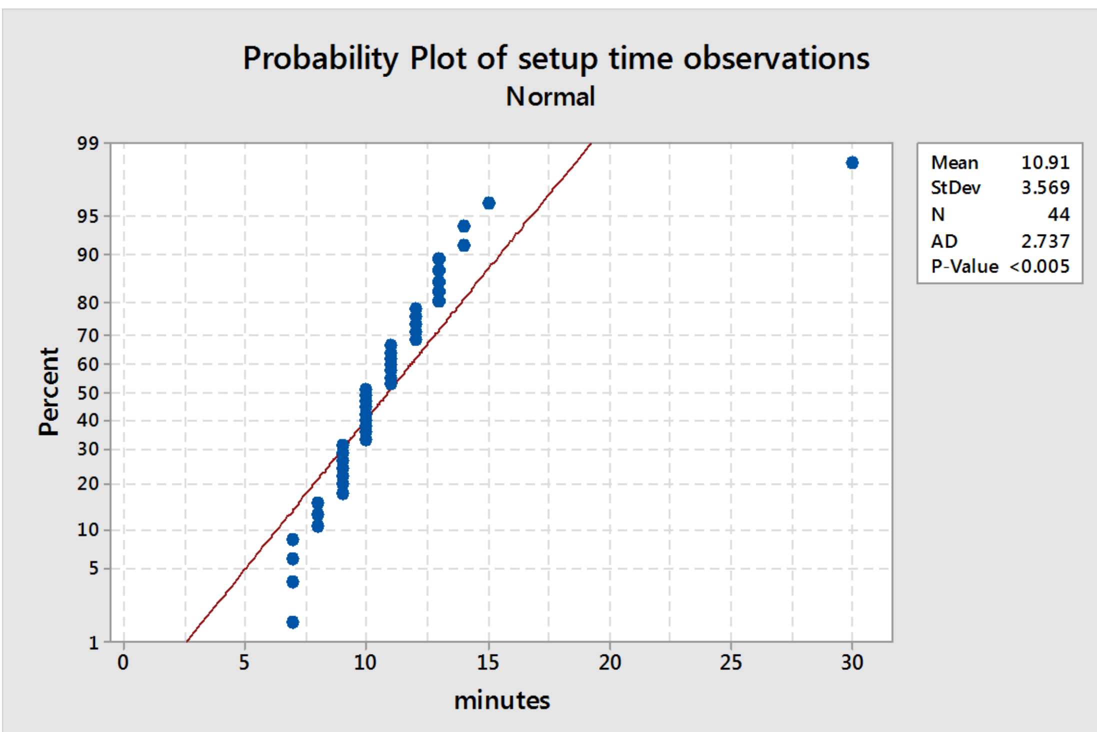
Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
18,010	1,755	0	1,755	0.123	97.45	0.12
8,240	1,510	0	1,510	0.056	183.25	0.10
24,372	4,070	0	4,070	0.167	166.99	0.28
8,475	860	0	860	0.058	101.47	0.06
40,795	4,830	0	4,830	0.279	118.40	0.33
41,515	5,010	0	5,010	0.284	120.68	0.34
31,733	3,960	0	3,960	0.217	124.79	0.27
17,800	4,050	0	4,050	0.122	227.53	0.28
25,068	4,470	0	4,470	0.171	178.31	0.31
38,834	4,710	0	4,710	0.265	121.29	0.32
25,450	2,575	0	2,575	0.174	101.18	0.18
86,855	10,600	0	10,600	0.594	122.04	0.72
13,095	1,610	0	1,610	0.089	122.95	0.11
28,600	5,020	0	5,020	0.195	175.52	0.34
22,185	2,050	0	2,050	0.152	92.40	0.14
23,300	3,180	0	3,180	0.159	136.48	0.22
34,641	3,445	0	3,445	0.237	99.45	0.24
19,100	1,710	0	1,710	0.131	89.53	0.12
30,229	3,535	0	3,535	0.207	116.94	0.24
8,293	1,675	0	1,675	0.057	201.98	0.11
37,500	6,515	0	6,515	0.256	173.73	0.45
25,918	3,800	0	3,800	0.177	146.62	0.26
23,061	2,015	0	2,015	0.158	87.38	0.14
18,850	2,420	0	2,420	0.129	128.38	0.17
54,411	4,335	0	4,335	0.372	79.67	0.30
43,756	8,320	0	8,320	0.299	190.15	0.57
66,855	7,780	0	7,780	0.457	116.37	0.53
14,907	2,460	0	2,460	0.102	165.02	0.17
62,355	6,655	0	6,655	0.426	106.73	0.45
29,217	3,315	0	3,315	0.200	113.46	0.23
85,000	9,500	0	9,500	0.581	111.76	0.65
48,889	4,505	0	4,505	0.334	92.15	0.31
61,460	7,310	0	7,310	0.420	118.94	0.50
77,880	8,850	0	8,850	0.532	113.64	0.60
96,750	7,740	0	7,740	0.661	80.00	0.53
47,535	4,710	0	4,710	0.325	99.08	0.32
58,370	6,355	0	6,355	0.399	108.87	0.43
10,137	1,680	0	1,680	0.069	165.73	0.11
83,500	10,150	0	10,150	0.571	121.56	0.69
53,926	4,618	0	4,618	0.368	85.64	0.32
91,436	7,260	0	7,260	0.625	79.40	0.50
47,644	4,665	0	4,665	0.326	97.91	0.32
26,415	3,605	0	3,605	0.181	136.48	0.25
22,427	4,150	0	4,150	0.153	185.04	0.28

Order quantity	Used meters	Waste meters	Total meters	Quantity %	Product Length	weighted average Length
17,450	2,380	0	2,380	0.119	136.39	0.16
20,192	2,160	0	2,160	0.138	106.97	0.15
46,400	5,430	0	5,430	0.317	117.03	0.37
56,081	6,145	0	6,145	0.383	109.57	0.42
58,273	5,180	0	5,180	0.398	88.89	0.35
27,170	5,600	0	5,600	0.186	206.11	0.38
19,368	3,045	0	3,045	0.132	157.22	0.21
30,802	7,000	0	7,000	0.210	227.26	0.48
56,455	6,450	0	6,450	0.386	114.25	0.44
16,467	1,700	0	1,700	0.113	103.24	0.12
29,000	2,400	0	2,400	0.198	82.76	0.16
136,250	10,400	0	10,400	0.931	76.33	0.71
13,836	3,220	0	3,220	0.095	232.73	0.22
26,500	6,500	0	6,500	0.181	245.28	0.44
16,190	3,050	0	3,050	0.111	188.39	0.21
26,762	2,790	0	2,790	0.183	104.25	0.19
11,600	2,250	0	2,250	0.079	193.97	0.15
136,250	10,400	0	10,400	0.931	76.33	0.71
5,072	890	0	890	0.035	175.47	0.06
71,130	5,750	0	5,750	0.486	80.84	0.39
95,130	7,240	0	7,240	0.650	76.11	0.49
82,913	8,200	0	8,200	0.567	98.90	0.56
9,960	2,560	0	2,560	0.068	257.03	0.17
30,885	2,512	0	2,512	0.211	81.33	0.17
45,400	4,250	0	4,250	0.310	93.61	0.29
93,044	6,000	0	6,000	0.636	64.49	0.41
36,672	2,780	0	2,780	0.251	75.81	0.19
7,500	1,450	0	1,450	0.051	193.33	0.10
92,105	7,020	0	7,020	0.629	76.22	0.48
11,600	2,600	0	2,600	0.079	224.14	0.18
21,840	4,100	0	4,100	0.149	187.73	0.28
24,576	2,830	0	2,830	0.168	115.15	0.19
96,000	11,300	0	11,300	0.656	117.71	0.77
51,230	5,100	0	5,100	0.350	99.55	0.35
71,037	8,400	0	8,400	0.485	118.25	0.57
111,850	8,366	0	8,366	0.764	74.80	0.57
62,125	4,880	0	4,880	0.425	78.55	0.33
22,678	5,600	0	5,600	0.155	246.94	0.38
35,470	6,200	0	6,200	0.242	174.80	0.42

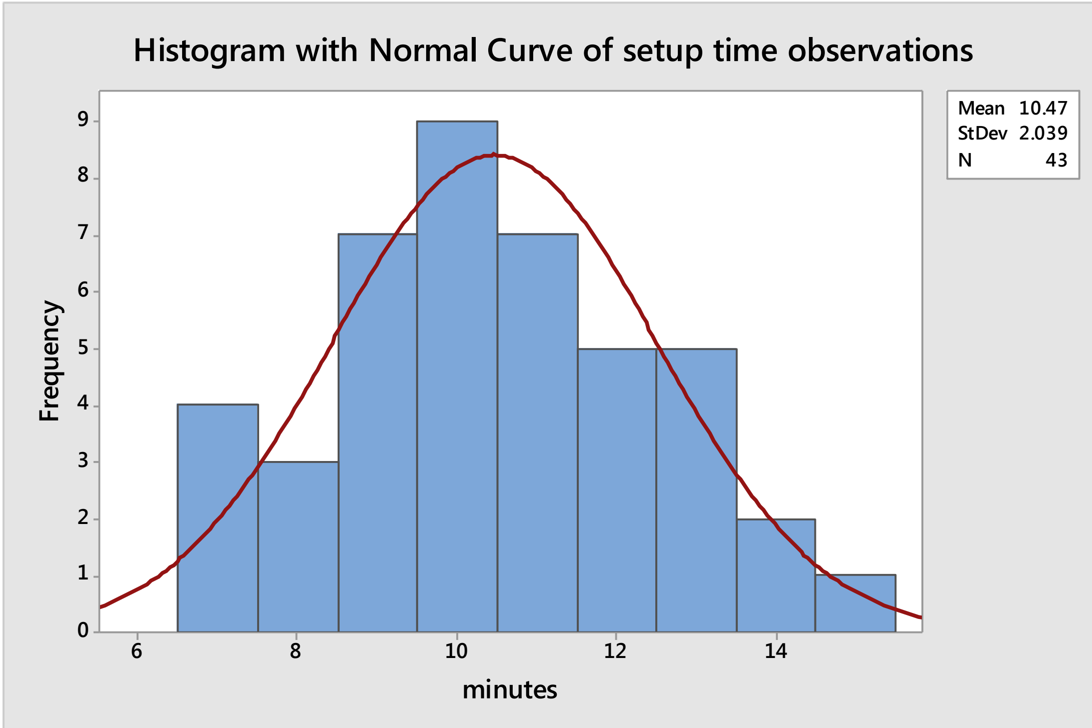
Appendix A.6: Setup time collected data and calculations with normality curves.

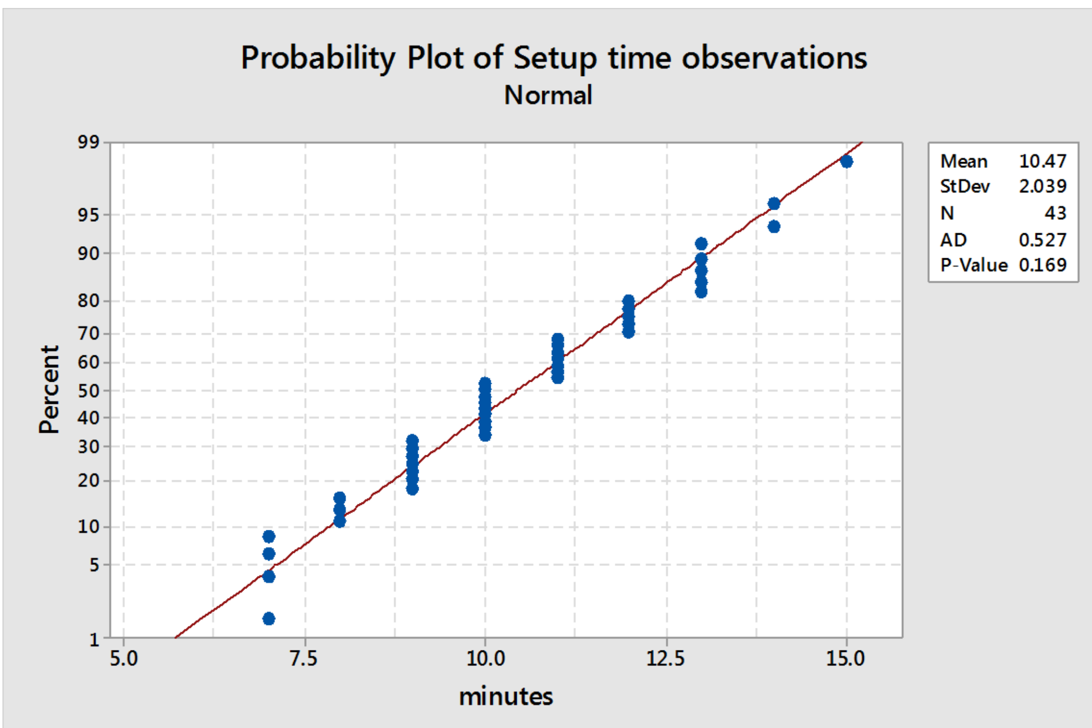
Observation	Machine	Minutes/order	Observation	Machine	Minutes/order
1	1	30	23	7	10
2	1	11	24	7	9
3	1	15	25	7	10
4	1	8	26	8	9
5	2	7	27	8	7
6	2	9	28	8	11
7	2	10	29	9	13
8	3	8	30	9	14
9	3	9	31	10	12
10	3	10	32	10	11
11	4	12	33	11	11
12	4	11	34	11	13
13	4	13	35	11	14
14	5	12	36	12	12
15	5	10	37	12	11
16	5	9	38	12	13
17	6	8	39	12	7
18	6	10	40	12	9
19	6	9	41	13	10
20	6	10	42	13	12
21	7	11	43	13	7
22	7	10	44	13	13





Variable	Mean	Variance	Median	Mode	StDev
Daily setup time/unit	10.909	12.736	10	10	3.569





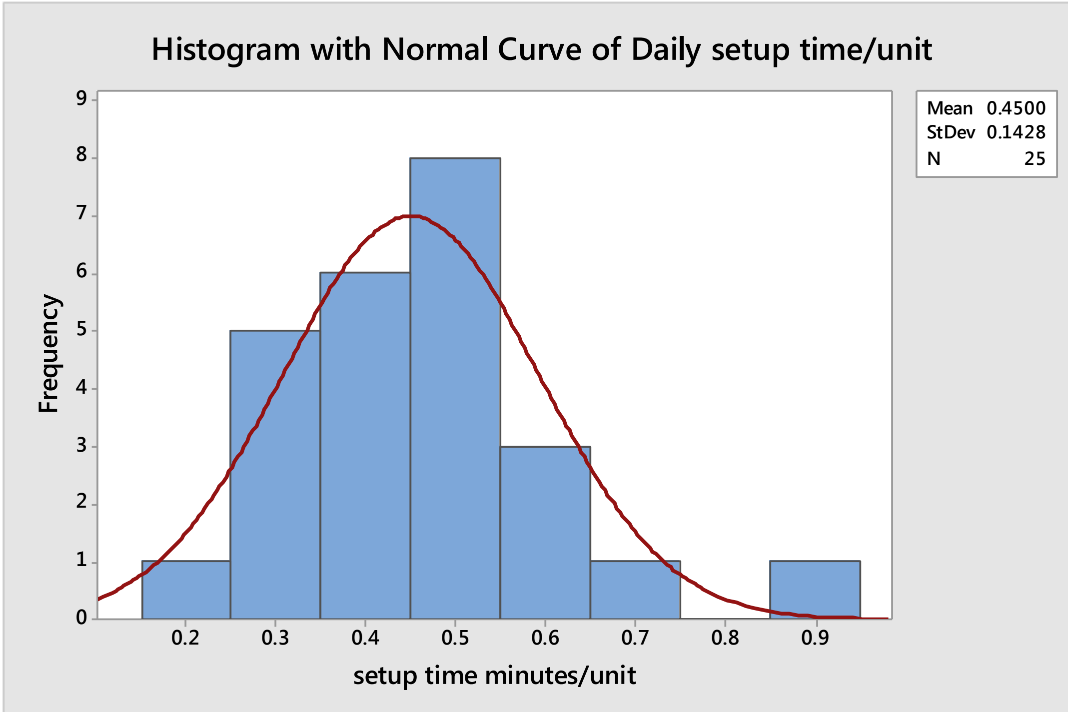
Variable	Mean	Variance	Median	Mode	StDev
Daily setup time/unit	10.465	4.159	10	10	2.039

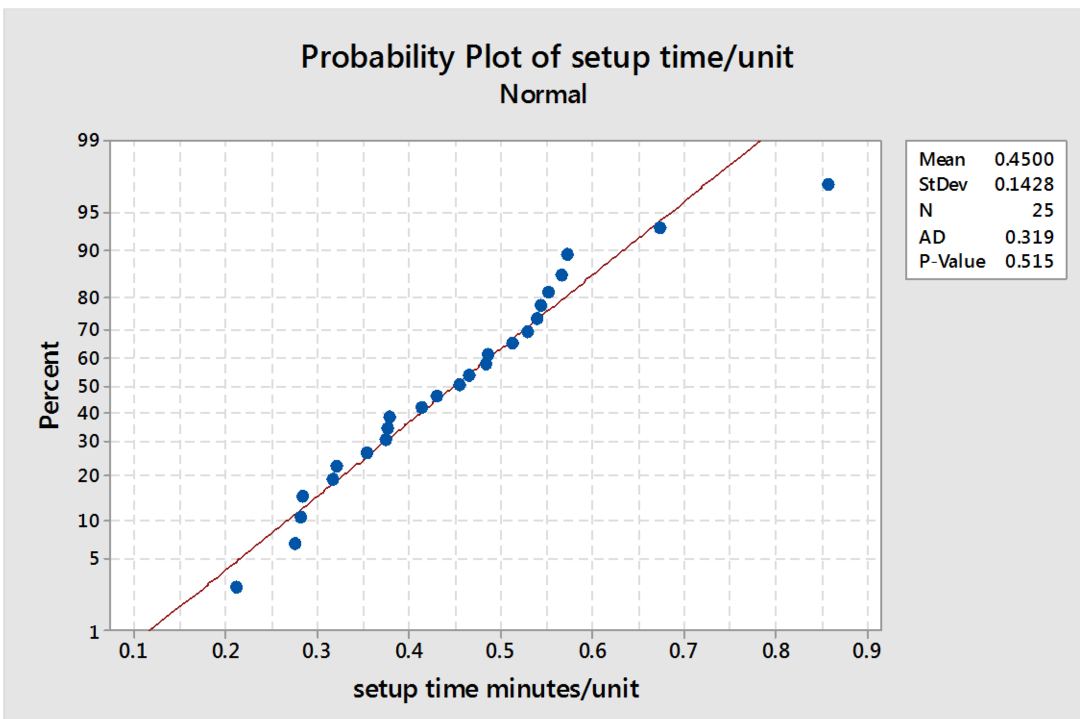
Date	Items	Unit	Setup minutes/unit
2-Nov	21	555.668	0.378
3-Nov	16	386.340	0.414
4-Nov	2	35.340	0.566
6-Nov	15	329.700	0.455
7-Nov	19	690.700	0.275
8-Nov	20	429.331	0.466
9-Nov	19	441.741	0.430
10-Nov	18	477.450	0.377
11-Nov	11	128.483	0.856
13-Nov	17	529.626	0.321
14-Nov	21	408.884	0.514
15-Nov	14	498.014	0.281
16-Nov	11	311.458	0.353
17-Nov	20	362.255	0.552
18-Nov	4	82.442	0.485
20-Nov	12	422.705	0.284
21-Nov	17	314.520	0.541
22-Nov	13	347.887	0.374
23-Nov	17	296.837	0.573
24-Nov	18	331.257	0.543
25-Nov	3	94.936	0.316
27-Nov	22	454.528	0.484
28-Nov	14	208.008	0.673
29-Nov	17	321.338	0.529
30-Nov	9	426.645	0.211

$$\text{Setup time per unit} = \frac{\text{Number of items} \times \text{Average setup time per item}}{\text{Total Quantity}}$$

Average setup time per item = 10 minutes

Average setup time = 0.45 minutes/unit

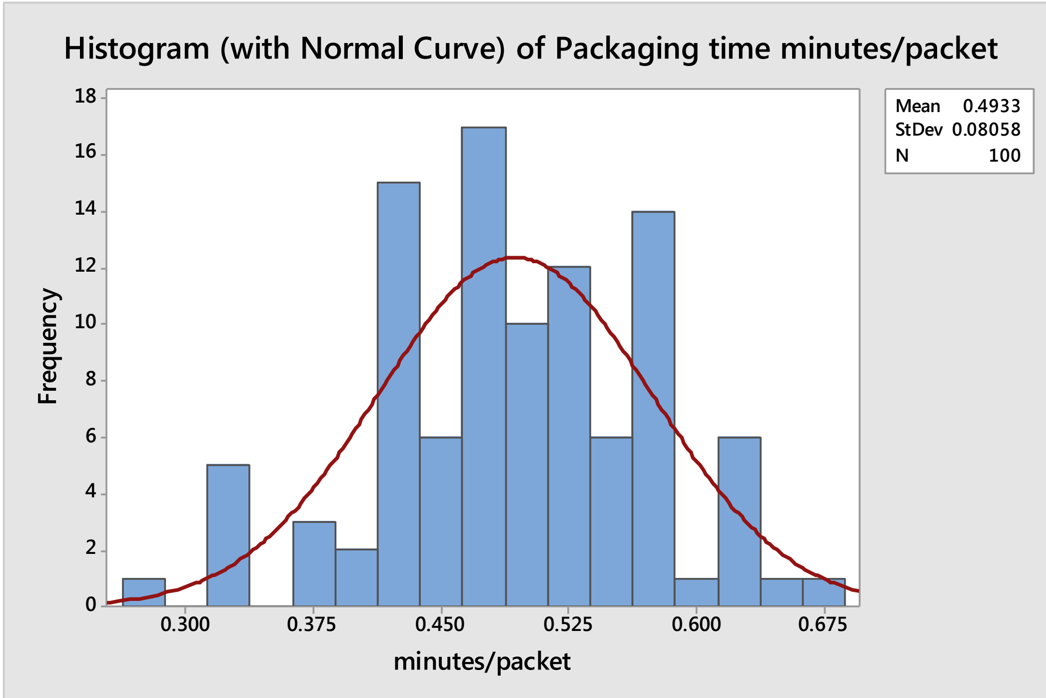


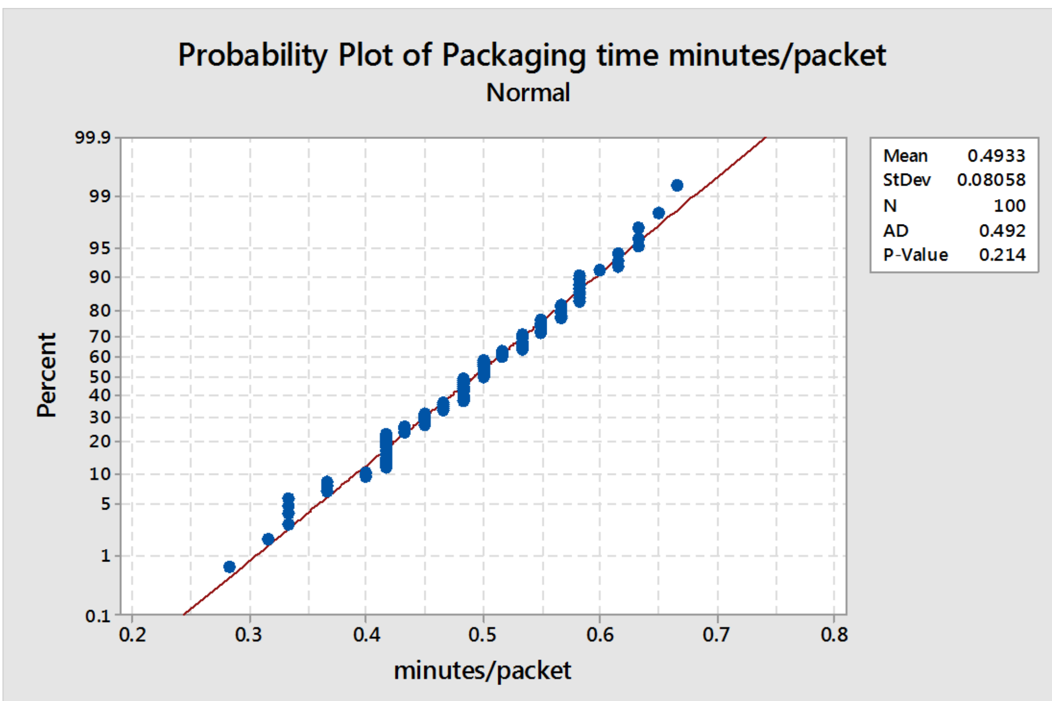


Variable	Mean	Variance	Median	StDev
Daily setup time/unit	0.45	0.0204	0.455	0.1428

Appendix A.7: Packaging time collected data and calculations with normality curves.

observation	m/c	sec/ packet	min/ packet	observation	m/c	sec/ packet	min/ packet
1	1	20	0.33	51	2	29	0.48
2	1	22	0.37	52	2	28	0.47
3	1	29	0.48	53	3	33	0.55
4	1	28	0.47	54	2	34	0.57
5	2	25	0.42	55	2	40	0.67
6	2	20	0.33	56	3	37	0.62
7	2	32	0.53	57	3	35	0.58
8	2	32	0.53	58	4	25	0.42
9	3	20	0.33	59	2	27	0.45
10	3	22	0.37	60	4	33	0.55
11	3	33	0.55	61	5	34	0.57
12	3	34	0.57	62	5	33	0.55
13	4	34	0.57	63	5	33	0.55
14	4	25	0.42	64	4	32	0.53
15	4	27	0.45	65	4	35	0.58
16	4	26	0.43	66	4	25	0.42
17	6	30	0.50	67	4	35	0.58
18	6	32	0.53	68	12	24	0.40
19	5	35	0.58	69	12	25	0.42
20	6	17	0.28	70	13	29	0.48
21	6	19	0.32	71	13	31	0.52
22	5	34	0.57	72	13	30	0.50
23	5	33	0.55	73	11	32	0.53
24	5	20	0.33	74	11	35	0.58
25	7	25	0.42	75	10	25	0.42
26	8	25	0.42	76	11	37	0.62
27	7	26	0.43	77	11	35	0.58
28	7	27	0.45	78	12	38	0.63
29	8	30	0.50	79	12	36	0.60
30	9	35	0.58	80	2	37	0.62
31	9	39	0.65	81	2	32	0.53
32	9	38	0.63	82	3	24	0.40
33	9	34	0.57	83	3	38	0.63
34	10	30	0.50	84	4	29	0.48
35	10	29	0.48	85	4	29	0.48
36	10	28	0.47	86	4	29	0.48
37	10	29	0.48	87	5	30	0.50
38	11	29	0.48	88	5	31	0.52
39	11	29	0.48	89	5	30	0.50
40	12	28	0.47	90	6	31	0.52
41	13	25	0.42	91	6	31	0.52
42	11	25	0.42	92	6	32	0.53
43	11	30	0.50	93	7	22	0.37
44	12	32	0.53	94	7	27	0.45
45	13	35	0.58	95	7	28	0.47
46	10	25	0.42	96	8	30	0.50
47	10	30	0.50	97	8	29	0.48
48	9	25	0.42	98	8	26	0.43
49	1	27	0.45	99	8	27	0.45
50	1	30	0.50	100	6	29	0.48

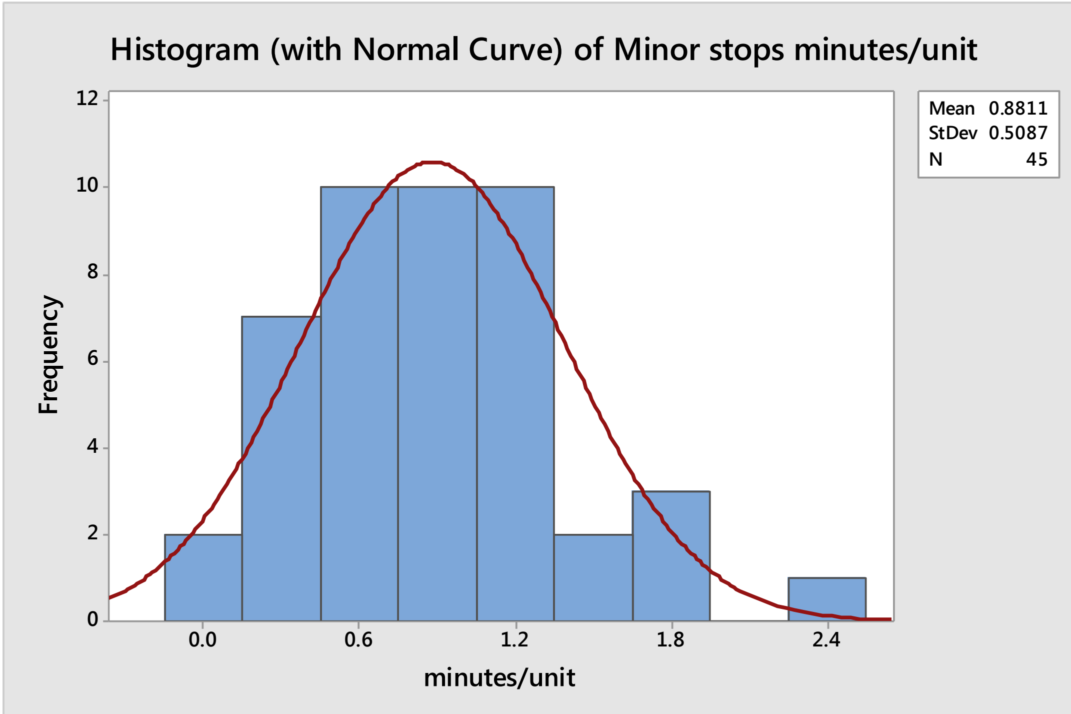


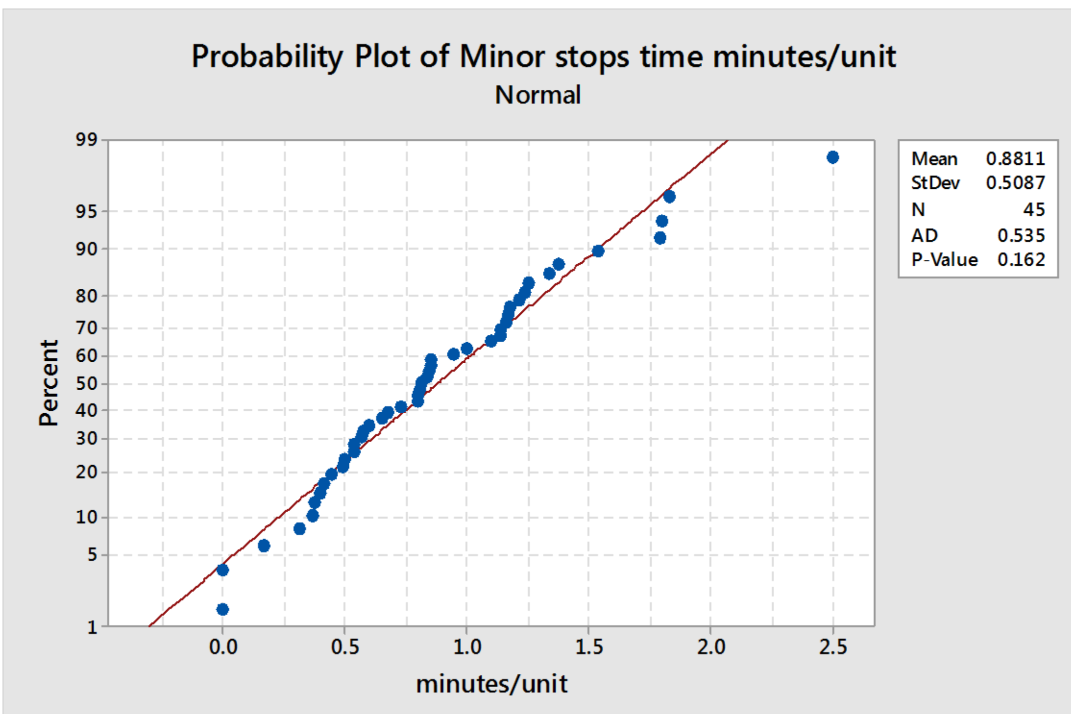


Variable	Mean	Variance	Median	StDev
minutes/packet	0.4933	0.00649	0.5	0.08058

Appendix A.8: Minor stops time collected data and calculation with normality curves.

observation	m/c	min/ order	order quantity	min/ unit	observation	m/c	min/ order	order quantity	min/ unit
1	7	9	4,920	1.83	24	3	15	12,347	1.21
2	7	4	12,764	0.31	25	4	15	22,200	0.68
3	8	1	1,250	0.80	26	5	2	2,347	0.85
4	1	28	8,008	3.50	27	11	8	15,000	0.53
5	4	6	12,225	0.49	28	12	3	7,200	0.42
6	2	3	2,998	1.00	29	13	20	23,600	0.85
7	4	9	5,000	1.80	30	13	2	4,000	0.50
8	12	9	15,020	0.60	31	1	3	1,200	2.50
9	13	9	20,330	0.44	32	9	28	33,450	0.84
10	12	0	800	0.00	33	10	8	6,790	1.18
11	12	0	800	0.00	34	9	5	4,560	1.10
12	11	1	2,500	0.40	35	10	3	2,390	1.26
13	11	9	12,300	0.73	36	10	14	12,340	1.13
14	3	4	2,998	1.33	37	11	4	7,000	0.57
15	2	1	2,714	0.37	38	9	4	3,434	1.16
16	2	0.5	620	0.81	39	10	2	2,349	0.85
17	6	19	23,849	0.80	40	2	4	2,234	1.79
18	13	3	8,000	0.38	41	2	0.5	2,999	0.17
19	12	1	1,742	0.57	42	4	13	15,930	0.82
20	7	15	12,903	1.16	43	5	3	2,640	1.14
21	2	0.5	935	0.53	44	6	2.5	2,640	0.95
22	2	4	3,230	1.24	45	7	7	5,100	1.37
23	2	8	12,250	0.65	46	8	2	1,300	1.54

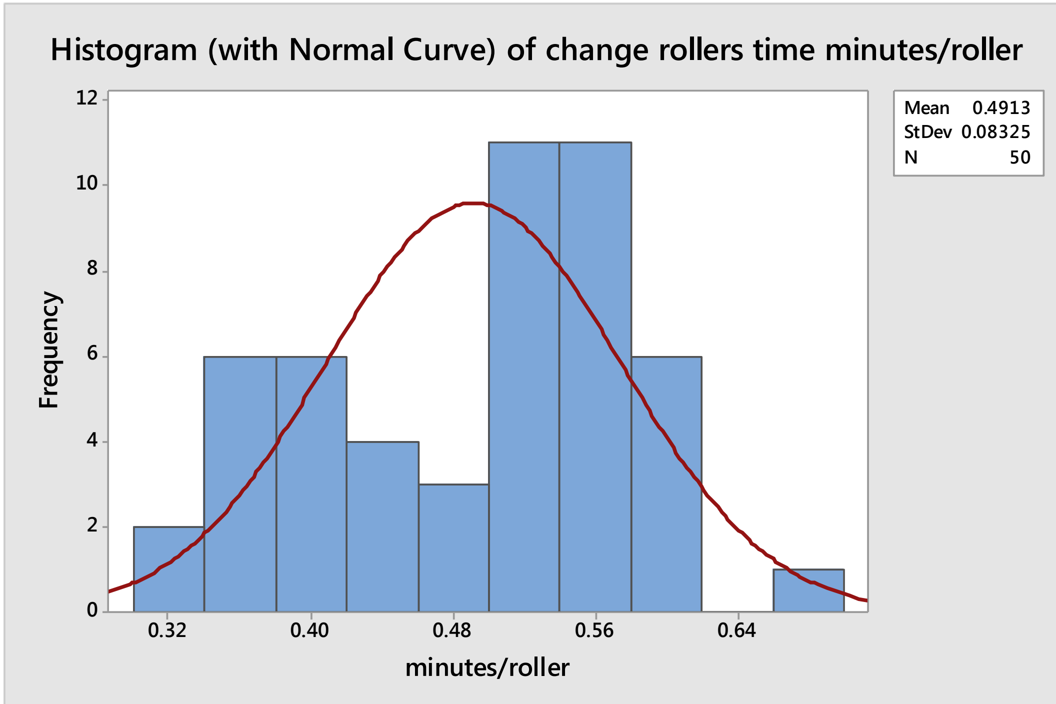


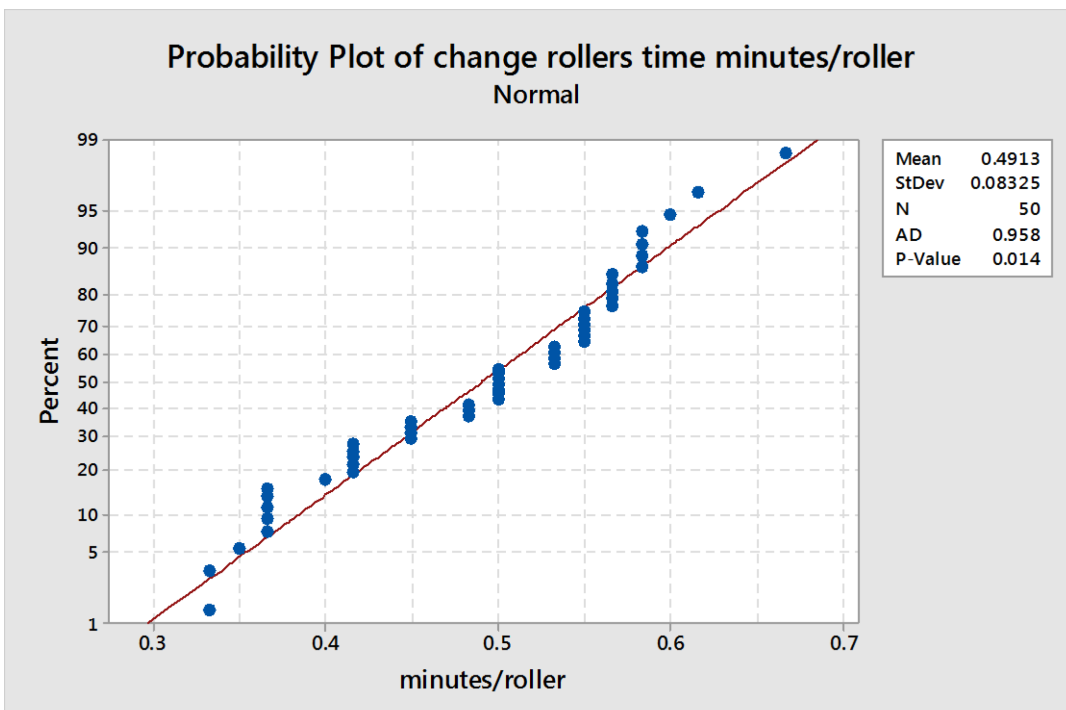


Variable	Mean	Variance	Median	StDev
minutes/unit	0.8811	0.2588	0.8161	0.5087

Appendix A.9: Change rollers time collected data and calculations with normality curves.

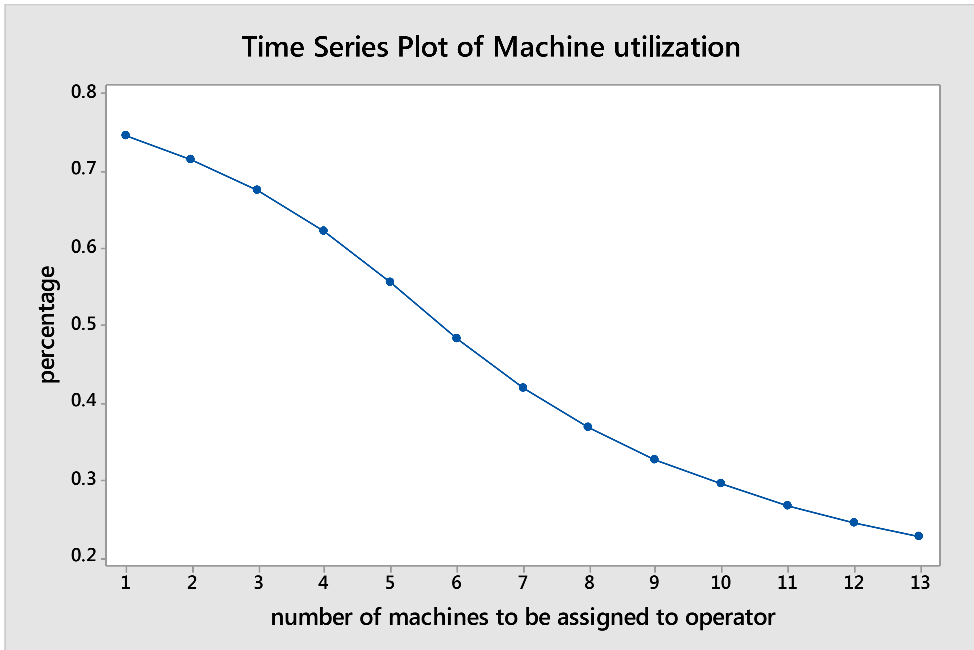
observation	m/c	sec/ roller	min/ roller	observation	m/c	sec/ roller	min/ roller
1	1	20	0.33	26	7	33	0.55
2	1	25	0.42	27	7	29	0.48
3	2	25	0.42	28	7	35	0.58
4	2	27	0.45	29	8	29	0.48
5	2	30	0.50	30	8	35	0.58
6	2	22	0.37	31	8	30	0.50
7	2	32	0.53	32	8	25	0.42
8	2	21	0.35	33	9	29	0.48
9	3	20	0.33	34	9	27	0.45
10	3	27	0.45	35	9	22	0.37
11	3	33	0.55	36	10	34	0.57
12	3	34	0.57	37	10	33	0.55
13	3	22	0.37	38	10	22	0.37
14	4	32	0.53	39	11	33	0.55
15	4	32	0.53	40	11	34	0.57
16	4	30	0.50	41	11	40	0.67
17	4	30	0.50	42	11	37	0.62
18	5	32	0.53	43	12	35	0.58
19	5	35	0.58	44	12	25	0.42
20	5	22	0.37	45	12	27	0.45
21	6	24	0.40	46	12	33	0.55
22	6	34	0.57	47	13	34	0.57
23	6	36	0.60	48	13	33	0.55
24	6	30	0.50	49	13	25	0.42
25	7	30	0.50	50	13	30	0.50

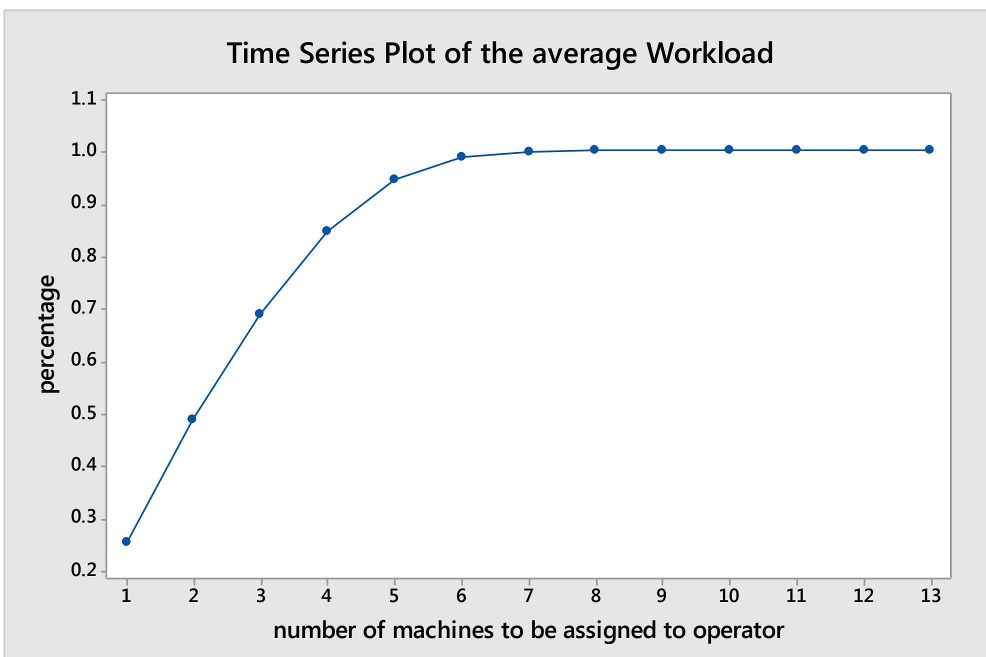




Variable	Mean	Variance	Median	StDev
minutes/unit	0.4913	0.0069	0.5	0.0832

Appendix A.10: Machine utilization and work load Time Series plots.





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