materials that make a difference

Modelling labour allocation over the number of running machines and type of product

Edited version:

Frank Baan
8/23/2012

Optimal relationship between the use of labour, number of running machines and type of product:

Modeling labour allocation over the number of running machines and type of product.

TENCATE

materials that make a difference

Geosynthetics Europe

&

UNIVERSITY OF TWENTE.

Author:	Frank Baan
Student number:	S0170461
Master:	Business Administration
Track:	Financial Management
Supervisors University Twente:	Dr. R.A.M.G. Joosten
	Ir. H. Kroon
Supervisor TenCate Geosynthetics:	I. Lemmens
Date:	June 2012

Table of contents

Word of thanks

I would give my thanks to all the people that helped me during my research and during my whole University career. First of all I will start at the people of TenCate where I have conducted my graduation research. The colleagues of TenCate have helped me from the beginning of my research. My thanks for the development of myself as a person and the gaining of experience about working within a organization. You where all friendly and helpful when I had some questions. I would thank you for the seven months I was able to conduct my research at your organization. In particular I would thank my roommates Paul Hoefnagels, Jeroen Ruiter and Murat Boruza. Every day we spoke each other and I have learned and laughed a lot thanks to you. Also Eric Wessels who helped me with gathering I would give my thank and finally my supervisor Iskander Lemmens who helped me the last seven months to finish my research. Colleagues of TenCate I give you my thanks for all your help and collegiality.

I will also give thanks to my supervisor of the University of Twente, Reinoud Joosten. Thanks for all the help and insights to conduct my research. It was very learning full and interesting to evolve in the way of analyzing an organization. Further thanks go out to whole the University of Twente: The education, the teachers and the friends that I have met there contribute to the person who I have become.

My final thanks go out to the persons who stand close by me all my life. At first I would start with my parents, because without your help and support I would never become so far as I am today. Many thanks for all your support during my whole school career. Further I would thank my two little sisters for all the help in my school career and life. Also my girlfriend I would thank. You helped me a lot to go through my university career and gave me strength to perform at school. In this word of thanks I would also give thanks to God, who gave me my talents to develop and perform. Other extra thanks go out to my friends with whom I could have fun, but also be serious about school and other matters. Thanks for the forming of the person I am today and for all your support.

Summary

Due to confidential information this paper is cut on results and findings. This version of the paper is a short version of the actual paper. In this summary the whole paper is described in short and some conclusions are given which are not confidential.

Introduction:

TenCate Geosynthetics Europe at Nijverdal assigned me to conduct research on declining yield figures at the weaving mill. One of the expected causes is that there is uncertainty regarding the number of weavers to schedule in relation to the given number of machines running and the desired output. For my research I used articles that looked to the allocation of labour at a given number of machines running. Reading these articles I found that the problem that I want to investigate, is known as the 'Machine interference problem' or 'Machine repairmen problem'. The authors Stecke & Aronson (1985) and of Hague & Armstrong (2007) give a summary for this problem and a list of authors that have researched this problem. The machine interference problem is described in short:

Take a simple system with N (number) machines and R (number) operators. A machine operates for a period of time until it stops. Then it needs repair by the operator or repairman. When there are more machines than operators, the chance arises that a machine stops but the operator or operators are all busy. This is called the interference of the machine and causes the machine to be idle, which leads to decreased productivity.

This also applies to the situation at the TenCate weaving mill where a weaver has to operate a given number of machines. These machines will sometimes break down and this results in interference of the machine. Based on the literature and the actual problem at TenCate I came up with the assignment to construct a model where variables like type of machine, type of yarn and type of personnel are input and the outcome is how to plan the workload at the weaving mill. From the problem statement I have come with the following problem statement:

To develop a model to allocate labour over a given number of machines running, taking into account the quality of the yarn.

Research:

The problem statement will be dealt with answering several research questions. Through the conclusions derived from the answers to the research questions I have come up with a model that gives a few outcome possibilities on how to allocate labour over the given number of machines running, taking into account the quality of the yarn. The problem is influenced by three main variables:

- Personnel.
- Machines.
- yarn.

These variables are the key objects of my research. In the research that is conducted I examined these variables on how the output is influenced by each of the variables. By working with the weavers of TenCate alongside of the machines I have experienced the problem myself. For my research and model this was very important to do. By experiencing the problem in reality I was able to adjust the model more to the situation at the weaving mill of TenCate. For engineering of the model I have used the literature on machine interference problems. The literature used describes the aspects of the machine

interference problem and how to build a machine interference model with several parameters. The information used is a mix of empirical articles and information from TenCate. In my research I have use this information to get four parameters that gives the input for the model. These parameters are:

- Breakdown frequency per product per shift.
- Service time per machine type per shift.
- Repair time per machine type per shift.
- Walk time per machine type per shift.

The measuring of data which is done by collecting the individual breakdowns per product per shift and the individual times per machine per shift. Several times I went to the weaving mill to measure the service, repair and walk time of the weavers. These individual measurements I put in a database from where I distracted the averages. The validation of these averages can be tested by using the Poisson or Erlang distribution. These distributions give a probability distribution for the found averages.

Conclusions and recommendations:
With the results of my research I subsequently answered the research questions which is used to build a model for TenCate to allocate the plan the correct number of weavers per shift per route of machines for a given objective. The model uses the input parameters to calculate the output produced per shift by one weaver per hour. Based on the output produced per hour for one weaver the model calculates the outcomes for the following objectives:

- Desired output for the next week.
- Maximum output for the next week.
- Maximum profit for the next week.
- Maximum weaver occupation for the next week.

For each of these objectives an overview is given per machine type per shift from which the management can decide what number of weavers they need to achieve an objective. Unfortunately the model is not perfect and needs some improvements for more accurate results. The model is based on certain assumptions which in reality are not applicable. One omission which has a huge impact is the assumption that when a weaver services the machine he also prevents any upcoming breakdown. This assumption ignores the fact that machines will break down randomly based on their break down rate and that not every breakdown is prevented. Further research is needed to deal with the fact that breakdowns occur randomly. Therefore I give TenCate the recommendation to investigate the model further by a candidate with more expertise in mathematical modeling and optimizationAnother recommendation of a list of recommendations is to split the model between an experienced and an inexperienced weavers. At last I have also do interesting analyses at TenCate where results are coming forward that are of interest in the study on the output yield at the weaving mill.
Enjoy the reading of this paper.

1. Introduction

1.1 Problem explanation

TenCate Geosynthetics Europe in Nijverdal assigned me to conduct a research on declining yield Figures at the weaving mill. The problem is that the costs of output produced have risen, but the revenue of output produced not. They want to investigate this problem by looking at the production processes of Geosynthetics in Nijverdal and how cost can be lowered. The costs are split in fixed and variable costs. Some of the fixed costs are amortization, rent, quality of yarn, staff and office costs, etc. Some variable costs are the working personnel (contract workers or temporary workers), at the plant, the number of running machines, output delay, quality of the product, etc.

The goal of the assignment is to construct a model where variables like type of machine and yarn and type of personnel are inputs with the outcome how to plan the workload in the weaving mill. It is about how to use your personnel that effective that you generate the most output at the lowest cost price possible. My expectation is that this problem contains many variables. It is not only about personnel, but the type of personnel, the quality of the personnel, etc. Other variables are the type of machines, the number of running machines, the type of yarn and the Dtex which is the measurement of the mass of the yarn in grams per 10.000 meters. The focus lies also on the waiting time theory and the number of stops per machine. Al these factors form a complex problem for my research is my expectation. My goal is to form a model that take all these factors into account.

1.2 Causes of the problem

From my impressions, interviews and theoretical background I have come up with some possible causes of the problem that occur at the weaving mill and shall be investigated.

One likely cause is the use of different of qualified labour. Some of the workers are temporary workers, these people have less experience than the own employees of TenCate. Also they have less skill than the regular workers at TenCate and do the more simplistic jobs in the weaving mill. The time for a handling by a regular worker is less than by a temporary worker. Another difference between the two types of workers is that the regular workers prevent more problems at the machine when they walk their round. So by preventing more problems, they have to perform fewer reparations.

Another expected cause is the quality and specifications of the yarn. Most stops occur due to problems with the quality of the yarn. The quality can be so bad that the yarn unwraps at the weaving process. When this happens the machine stops and need to be repaired. Another expected aspect is the specifications of the yarn and especially the Dtex of the yarn. The Dtex is measured as the mass in grams per 10.000 meters. The expectation based on experience and intuition of the plant manager is the lower the Dtex, the easier the yarn runs through the machine. When the Dtex is high, the machine has some problems to correctly weave it.

The plant manager provides another cause for the problem is given which is the difference in set-up and quality switch time per machine type. When a machine is set-up or a quality switch is made the machine is standing still. The longer the time for set-up or quality switch the longer the machine is standing still and less output is produced per week. The problem with set-up and quality switch is that there are not enough personnel for these tasks, this causes that machines have longer idle time. Another explanation is that the personnel do not achieve their expected set-up or quality switch times.

From the financial controller of TenCate another expected cause is named. It is about how fast an employee can do his round, the faster he does the round the shorter the waiting time of the machine when it breakdowns. Also the stop frequency of the machines has an impact on the problem. Every time the machine stops there is no output.

The transfer of TenCate Geosynthetics from Almelo to Nijverdal is also an expected cause. Since March the products of TenCate Geosynthetics have been produced in the weaving mill at Nijverdal. This huge production transfer can have an effect on output produced. Personnel need to settle down in a new factory, the correct place of machine and walk route of the weavers must be found again. The expectation is that this will lead to an inefficient walk route and inefficient placement of machines, which results in longer idle times of the machines.

In the next months I will investigate whether the expected causes are true. Whether there are more causes or that the expected causes are false and some other causes are the reason for the problem. The expected variables for the causes are personnel, machines and yarns. I hope that my research will show these variables and form the input for a model of the efficiency of the weaving mill.

1.3 Research plan

To conduct my research based on the expected causes and variables named in Section 1.2 I will state my research problem and set up the right research questions. After this has been done I will come up with a research plan on how I will try to answer my questions and try to solve my problem. This research plan will contain information about how I will conduct my research, what kind of data I'm planning to use, what planning I will follow and what I'm expecting to deliver at the end of my research.

1.3.1 Problem statement and questions:

After investigating and hearing employees of TenCate, I came up with the follow problem statement:

To develop a model to gain insights in how to allocate labour over the given number of running machines taking the quality of yarn into account.

To solve this problem I have come up with research questions. For the research empirical studies that look to the subject of the expected causes and variables will be used. From TenCate I use qualitative and quantitative data from the weaving factory and interviews will be conducted with key persons about the weaving process. Finally I will look and work by myself at the weaving mill to better understand how the weaving process works.

1. *What is the contribution of the personnel to the output yield?*
   The workers ensure that the machines are running and therefore producing output. They ensure that the machines are set-up and repaired. The skill and work attitude are expected influences how well the machines runs, how fast the machines are set-up and how fast repairs are done. The expectation is that the quality of the personnel has a huge impact on the output yield of the machine.
2. *What is the contribution of machinery to the output yield?*
   The machinery park contains of five different types of machines. I will expect differences in the machines for their set up time, but not great differences when they are running. It is my expectation that the difference in machines have a great contribution to the output yield. The output yield will be lowered because of an old machinery park and a wrong setup of the machines.
3. *What is the contribution of the woven product to the output yield?*
   The woven product is made from yarns. The combination of the two types of yarns is expected to have a huge impact on the output yield of the machines. The quality of the yarns affects how well

the yarn runs through the machines runs and causes the yarn to break. These breakdowns result into the waiting time of the machines.

4. *Which data do I need to form a model for the output yield at the weaving mill?*
   For my model it is my expectation that I will need data for each type of breakdown, type of machine and type of personnel. The expected data needed are the frequency of breakdown per product, service time, set up time, quality switch time, repair time and walk time. The individual times of these different data need to be measured. These measurements need to be put in a database. From this database the averages are found for each type of breakdown, type of machine and type of personnel. The research done by other researchers related to this subject are used to find the correct data to use and to find the right way of calculating the averages.
5. *Which outcomes can come forward from the model?*
   The model desired by TenCate to solve their problem can be based on several outcomes. The expectation is that model can be based on a combination of the number of machines compared with a time to service these machines and number of weavers needed. The outcome can lead to different set up times per machine type, per product per type of personnel. The model can be based on output produced, by revenue made or profit made by a weaver. Also the model can look to the weaver occupation or the machine occupation.
6. *How will the model been build up to the efficient use of personnel at the weaving mill?*
   Efficient can be read on different ways. I need to Figure out what is meant by efficient for TenCate. From a financial point of view it is my opinion that the profit made by a given set of machines for a given number of workers will result in the number that gives the most efficient use of personnel at the weaving mill. By testing the several outcomes that I have found at the previous question, I try to come up with a model for TenCate. This testing is been done by using all the collected data, outcomes and information, to come up with the model as I expect it. This model will not be tested, because the time-span is too short and this is another problem beyond the scope of my research. My focus is to create a model for TenCate that will lead to a more efficient use of personnel at the weaving mill.

1.3.2 Research plan:

To investigate this problem and to try to answer these questions I need a plan on how I want to come to my information. Several information sources are needed for this such as empirical studies that methodological describes and answer some of my questions. These studies are expected to contain the general information about the subject and are ground for my model that I will form for TenCate. TenCate has a lot of data of how they formed these cost prices and output and this data, articles and other information sources of TenCate are being used. By conducting interviews I will try to get the personal view and knowledge of how the cost and revenue of the output are formed. Information about the problems that occur in the weaving mill and possible solutions from their point of view is a source for the creation of the model. Further on I will work by myself in the weaving mill. By measuring at the weaving mill I will expected to gain quantitative data about the production process. For the model to work I need to gather data of the present situation. I also expect that by working and investigating at the factory I will understand better the problem.

2. Company description

2.1 Royal TenCate

TenCate is a multinational company with a long history that goes back for 300 years, where it is founded in 1704 in Almelo. In the years that followed, TenCate developed into an important player in the advanced textile industry around the globe. In more than 15 countries on several continents they have over 3800 employees. Their slogan is: 'Materials that make a difference'. TenCate develops and manufacture materials which improve the performance, reduce weight, increase safety and lower costs of an end product. This development is established by the use of textile technology in relationship with chemical processes.

2.2 TenCate Geosynthetics

TenCate Geosynthetics is a division of TenCate which focus on designing, producing and marketing geosynthetics products. Their product range consists of non-woven, woven, reinforcement, drainage, erosion control products, specialties and industrial products. TenCate is the world's largest producer for solutions and applications of high-strength geosynthetics that are used for civil engineering projects, the construction industry and the environmental market. They also produce applications for the agriculture, horticulture and leisure sectors. TenCate has production sites in Europe, the United States and Asia. It operates close to the market, which give them logistical and pricing advantages.

As mentioned above, sustainability is a global subject and the market is paying heavy attention to the positive environmental aspects of geosynthetics. By using environmental arguments and reduction of negative environmental effects TenCate geosynthetics receives great emphasis for the promotion, design and specifications of their products. The alternatives considered for TenCate geosynthetics are often concrete, stone and steel. These materials usually have to be transported over long distances, while geosynthetics use locally available materials like sand and sludge.

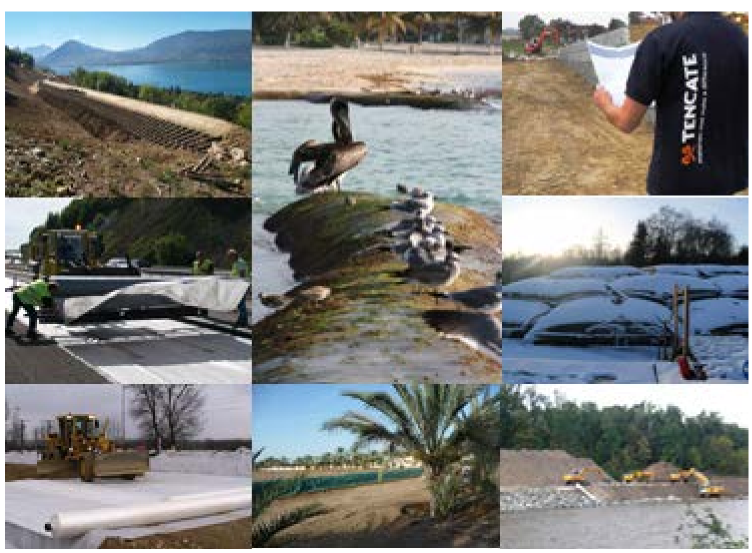

Figure 1. Products of TenCate Geosynthetics.

The exchange of products and system solutions between the various geographic regions is part of the strategy of TenCate geosynthetics. For development of new products in the field of water management is it important that the government develops pilots and provides a testing ground to test their technological skills. The marketing of such complicated system solutions forms constantly a new challenge (Koninklijke TenCate, 2010).

2.3 TenCate Geosynthetics Europe:

TenCate Geosynthetics Europe develops and delivers in Europe, the Middle East and Africa for more than 30 years. They have factories in the Netherlands (Nijverdal), France (Bezons) and Austria (Linz). They have three brands in Europe: TenCate Polyfelt®, TenCate Bidim® and TenCate Miragrid. They deliver turnkey system solutions for the road and railway constructions, retaining structures, hydraulic constructions, embankments, tunnel construction, pipeline construction, landfills and shoreline protection/marine structure construction markets (Koninklijke TenCate NV, 2011).

3. Introduction to the problem

Here I will describe the real problem and name the literature that is relevant to the problem.

In meetings with my supervisors from TenCate and the University, I have decided to focus the problem on the weavers. This is done because the problem would become too complex when we look at the whole weaving mill. There where too many variables that have their influence on the efficiency of the personnel at the weaving mill. In this Section I will describe the introduction to the problem of the weavers at the weaving mill. The weaving process described above in Subsection 3.1.4 forms the input for the problem. The factors described at the weaving process are also the factors for the problem at the weaving mill.

One of the problems is that it is not known how many machines a weaver can handle or reverse when the number of machines is known, how many weavers are needed. The difference between skilled and unskilled workers forms also a problem for the produced output. These facts are not known and causes that the cost of output is not at his most efficient point or at what level of efficiency the weaving mill runs. Several authors Armstrong (2007), Stecke & Aronson (1985), Ching (2001) and Wu & Fu (2005) have written on this subject where the number of machines is assigned to an operator and vice versa. They come up with some objectives that can be desired by multiple divisions of a company. An objective can be the minimization of costs which affects the financial department for which I conduct my research.

The problem is known and now I will try to come up with a model for the weekly planning of weavers where the number of machines for each type, the expected output of the machine and the number of stops per machine can be put in. Stecke & Aronson (1985) has researched several models that look into the interference problem of machines. Their conclusion is "that queuing models will be the most efficient computationally, but also the least detailed. Simulation models allow much detail, but are expensive to develop and run". Khan et al. (1999) have developed a computer simulation model that looks to the evaluation of system performance in respect of capacity utilization, production output for a given input, work in process, time taken in each process, total time taken to finish a product, machine down time, repair time and set up time, busy and idle time of each machine and operator etc. They found that the model easily identify the bottlenecks and problems that interrupts the production of the machines and gives simulations of different situations with different use of machines and labour. Their conclusion is that the model can assist to solve production management problems as well as propose improvements for system performance and manufacturing productivity.

For my model I expect to investigate several variables like the number of machines, the output of a type of a textile depending on the type of machine, the stops per type of textile depending on the type of machine, the output generated by the weaver, the idle time of the machine, the walking time of the weaver and the number of picks per minute of the machine. These variables I will try to find by conducting a quantitative research at the weaving mill. The model based on the input data should give an expected number of operators for a given objective.

4 Literature review

In this chapter I discuss the literature that I am planning to use for my research. This literature aids to answer my research questions. The literature is based on empirical studies, working models and formulas.

4.1 Problem explanation by literature

4.1.1 MIP/MRP-problem:

The question of my research lies in the context to use weavers as efficiently as possible. When investigating this subject I have found that it is related to efficient use of production process and especially related to repairs at the production process. I have found numerous articles that all describe the problem of a production process where machines stops regularly and repairmen are needed to get the machine going. Most of the articles refer to a weaving factory as an example of this problem. This problem is referred to as the 'Machine Interference Problem' or the 'Machine Repairmen Problem' and researched by many authors, Haque and Armstrong (2007), Stecke & Aronson (1985), Sztrik & Bunday (1993), Mack et al (1957), Ching (2001), Eben-Chaime (1998), Bunday & El-Badri (1985), Engin (2009), Wu & Fu (2005), Chen & Harlock (1999), Hsieh (1997), Bunday & Khoram (1998), Serafini & Speranza (1992), Chakravarthy & Agarwal (2002) and Das & Wortman (1993). I will explain this problem by a general example. Take a simple system with N (number) of machines and R (number) of operators. A machine operates for a period of time until it stops. Then it needs repair by the operator or repairmen. When there are more machines than operators, the chance arise that a machine stops but the operator or operators are all busy. This is called the interference of the machine and causes the machines to be idle, which leads to decreased productivity.

The authors named above have done research on this subject to create or describe a machine interference model also called an MIP – model. Most models try to minimize the cost of interference, minimize the interference, assign the optimal number of machines to an operator or maximize the production. The focus of my research lies in the field of assigning the optimal number of machines to an operator. According to Stecke & Aronson (1985) this is an important nontrivial decision to be made by companies. A trade-off has to be made between too few or too many machines. Some effects of assigning too many machines to an operator are that he cannot handle all the machines and so machines are longer idle. Also the operator can feel some pressure to do his job right and he tries to handle all the machines and it can lead to a burn-out of the operator. When the operator tries to work faster and faster, his quality goes down, which can result in fewer stops prevent and fewer stops immediately repaired. When speeding up your work, the operator also can pay less attention to his safety which can results in more injuries. All these consequences can follow from too many machines to an operator. From an economic point of view the most important aspect is that productivity is decreased per operator. So the variable cost for the operator per product will be higher. The other side can be that there are too few machines assigned to the operator. This can cause that the operator occupation is about 80%, but is paid for the full 100%. So also on this side you have a higher variable cost per operator for a product. The operator can also be affected mentally. He can have a lack of interest to work for the full 100% per machine and therefore the attention can decrease which can lead that the prevention of stops per machine increases. The operators can be bored and can have more idle-time themselves e.g. longer breaks, more chatting, etc. Also here the economic point of view is the most important aspect and that is that the productivity is decreased per operator.

Stecke & Aronson (1985) state that the time between breakdowns or service time (waiting time of the machine) can be classified in two ways, namely deterministic and probabilistic. With deterministic they mean that the waiting time for the machines is constant and with probabilistic the waiting time is random or undetermined, which is often the case. For my research I need to Figure out what the best way to measure the data is. At TenCate the waiting time per machine is different, so the probabilistic method will be chosen.

4.1.2 Operator and Output-yield:

When the top season at TenCate starts, the weaving mill runs on full capacity. For the costs and my research it is relevant to find out the minimum number of weavers necessary to produce a certain yield of output per machine per machine group. The operator or the weaver has his contribution to the output generated by the machine and so to the output-yield of the machine. It follows that the output of the machines is related to the number of weavers. With the same number of machines, adding more weavers leads to that more machines are being serviced or repaired in an given time period, which lead that the idle times are reduced. This can lead that the output of the machines is increased for the given time period when adding extra weavers. But at a given moment adding more weavers does not increase the output of the machine, because maximum output is reached. Based on this an expected S-curve example in Figure 6 is drawn were the number of weavers are related to the produced output. The goal for my research is to come up with a model were the required output and type of products on the right machine can be filled in and the minimum needed number of weavers is given.

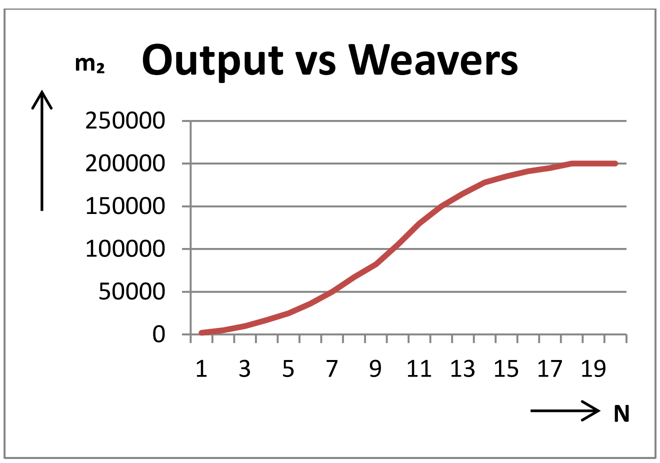

Figure 6. Expected s-curve Output vs Weavers, Where the horizontal axis stands for the number of weavers and the vertical axis for the output in m2.

The outcome of the model that I develop sometimes results in more than one weaver needed per machine. Several advantages and disadvantages occur from the pooling of weavers to the servicing of the machines. At TenCate work is done in three shifts of eight hours per day. It is my expectation that at nights workers are more quickly tired than by day, this can result in less productivity. This is a factor I have to consider in my model, but to measure this factor I need data of three shifts per weaver.

Working in teams instead of individuals comes with some advantages and also disadvantages. Hamilton et al. (2003), describe in their article how working in teams has an impact on the production. An advantage from working in teams is that workers benefit from collaborating with each other. They combine their skills, communicate more, detect flaws faster, learn from each other, have less boring work and can do more machines in an hour. These factors can come from teamwork and have their effect on the output produced by the machines an hour. The total output is increased and the average output per worker can become higher than on individual basis. But there is also a downside of working in teams. Working in teams leads to higher expectations and a greater work pressure. More machines can be assigned to the group which leads to a significant increase of the round time. Another negative factor that can occur is that there's difference in personalities. Dissatisfaction might occur when one worker in a team works harder or has a heavier workload than the others (Stecke & Aronson, 1985 and Hamilton et al., 2003). These factors of expected differences in total output are shown in Figure 7, where three teams have different output, because of these factors. The example is that the combination of worker A and B have a positive effect on the output produced by the team. While the combination between worker A and C have a negative effect on the output and the combination between worker B and C have a normal effect on the output. This example in Figure 7 shows that the output differs per team, because one team cooperates better with each other than the other team.

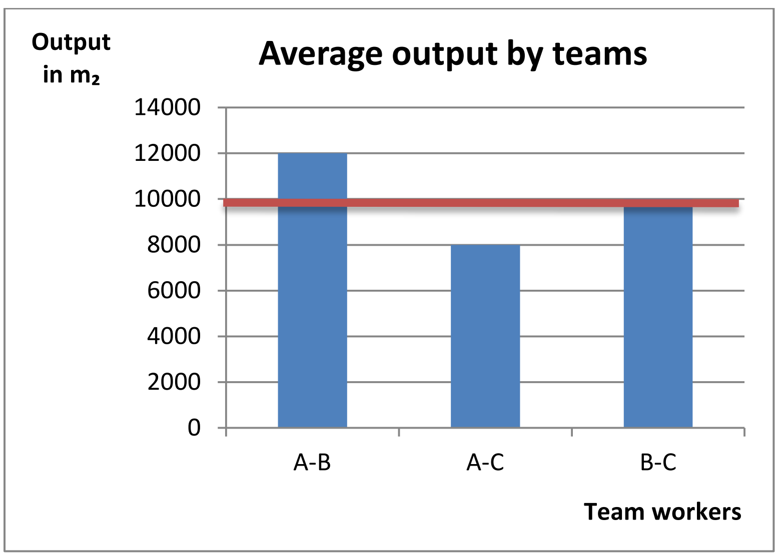

Figure 7. Average output per worker per team.

4.2 Queuing Theory

4.2.1 Queuing models:

Most MIP-models are based on the queuing theory. This theory states that the interference of the machine is waiting or queuing time (Stecke & Aronson, 1985). Stecke & Aronson describe three types of models that are based on this theory. The early models that were developed on this subject ignored the patrolling time or include it with average service (repair) time. The models all assume a Poisson input of the breakdown frequencies which will be described in Subsection 4.2.1, exponential service times and first-come, first-served queue discipline. This is referred as an M/M/R model. From this model many mean performance measures such as machine efficiency, operator utilization, number of idle operators, waiting time and number of waiting machines can be obtained.

Another type of model includes patrolling and other extensions. The route patrolled by the operator depends on the queue discipline of the operator. There are several queue disciplines and each has its effect on the route patrolled by the operator. Several queue disciplines are noticed by Stecke & Aronson (1985) these are named in Table 1. The type of route will not be extend further due to confidential information.

Discipline	**Description**
First-come, first-served	The down machines are serviced in chronological order of their breakdowns.
Random tending	Each down machine has the same probability of being fixed next.
Cyclic patrol	An operator stops to check each machine along the way of a particular path (cycle), even if the machine is not down. A cyclic patrol can be termed: - Closed: The operator walks to each machine along a fixed path, going from the last machine back to the first, to repeat the cycle. - Alternating: The operator walks along a fixed path, and when the last machine is visited, reverses direction to patrol the same machines, but now in reverse order.
Distance priority	The nearest down machine is serviced.
No preemptive priority	An operator services *N* different groups of machines, where the N_i machines in group *i* have a higher priority than any of the N_{i+1} machines in group *i* + 1; the operator chooses randomly within each group.
Preemptive priority	The only difference from the no preemptive priority discipline is that if a machine that has a higher priority than the one being serviced breaks, current service is preempted. Future service on the preempted machine either resumes where it is left off or begins again, depending on the nature of service.
Shortest service time priority	The machine that can be repaired fastest is serviced.

Table 1. Operator queue disciplines by Stecke & Aronson (1985).

A third type of queuing models named by Stecke & Aronson (1985) is the queuing network models that can be used to investigate more realistic interference problems. These models allow much more general assumptions on the breakdown and service distribution, which lead to a more realistic insight on measures as operator utilization and machine efficiency. Several queues are taken in the model. The multiple queues together form a network in which the operator operates.

4.2.2 Little's Law:

The formula Little's Law is first introduced by Little (1961) and has since become well known in the field of queuing systems and researched by many authors Stidham (1974), Keilson & Servi (1988), Glyn & Whitt (1989) and Whitt (1991) . The definition of a queuing system is that running items when arrive at some breakdown rate to a waiting system to be serviced. In other words the items enter a queue before they are serviced. Eventually the item is serviced and after that exits the system. This can be applied at the weaving mill where machines breakdown and enter the system of breakdowns. The broken down machine have to wait until the weaver has reached the machine, this is the waiting time of the machine or the time the machine is in queue. The service time of the machine is the time that the machine is repaired by the weaver. When repair is finished the machine exits the queuing system to enter the system after some time again. Little's law is written as follows:

$$L = \lambda \times W$$

Where;
L = average number of items in the queuing system at time T
λ = average arrival rate of items to the system at a given time interval
W = average time an item waits in the system at a given time interval

This formula is relevant to my research by using the calculations of the number of machines that are in the queuing system. Through measurements it can be calculated that an increase of number of weavers the W decreases and therefore the L is decreased which means more productive machines are running. Little (2011) describes how his formula had impact in the past 50 years. In operations management the formula $L = \lambda W$ is transformed to the following formula stated as:

$$TH = WIP/CT$$

Where,
TH = throughput (items/unit time)
WIP = work in process (items)
CT = cycle time (time units/items)

Here TH = WIP/CT is equivalent to $\lambda = L/W$. This formula can be transformed to the problem at TenCate. Where TH = output per machine per time interval, WIP the number of machines and CT the time it takes to service all the machines by one weaver. When a desired output and the number of machines are given, it is easily to calculate the required cycle time from one weaver. Applied to this, I have to calculate the cycle time of one weaver and from that equation I can calculate how many weavers are needed to achieve the required output.

4.3 Parameters from literature

The research on machine interference models has been conducted by many authors (Bunday & El-Badri (1985) .2, Bunday & El-Badri (1985) .3, Bunday & Khorram (1988), Chakravarthy & Argarwal (2002), Ching (2001), Das & Wortman (1993), Eben-Chaime (1998), Engin (2009), Haque & Armstrong (2007), Hsieh (1997), Mack (1957), Mack et al (1957), Stecke & Aronson (1985), Sztrik & Bunday (1993), TenCate (1990) and Wu & Fu (2005). In the articles of these authors several parameters are used in their models. With these parameters some formulas are formed to calculate the desired outcome like weaver efficiency and number of machines a weaver can operate in a given time interval. Many of the parameters are general in most articles, but calculated differently. Several of these parameters will be used for the model I will come up with.

In Table 2 the model and parameters set up by Stecke & Aronson (1985) is given. They use several parameters which are filled in the model. These parameters are then used in the formulas to calculate the cycle time (***C***), machine efficiency (***Me***), operator efficiency (***()e***) and the efficiency loss of an operator (***E***). The cycle time is calculated by multiplying the number of machines (***N***) with sum of the service(repair) time (***S***), interference time (***I***), walk time (***W***), ancillary time (***A***) and the maintenance time per machine (***M***). With the cycle time the machine efficiency can be calculated by dividing the production time (***P***), through the cycle time. The operator efficiency is calculated by dividing the sum of the service, walk, ancillary and maintenance time per machine by the cycle time. With the operator efficiency, we can see how much percent of the operator one machine takes. The last formula calculates the efficiency loss because of service and interference times. This time you lose per cycle because of repair and interference time of the machine.

N=	number of machines assigned to an operator
S=	average service (repair) time per machine
μ=	average service rate = 1/S
P=	average production (running) time per machine or average time between breakdowns
λ=	average breakdown rate = 1/P
ρ=	ratio of the (average) service time to the (average) production time = servicing factor = S/P = λ/μ
X=	1/ρ = P/S
I=	average interference time (Im = interference time on a machine; Ir = interference time of an operator or repairperson
W=	average time to walke from machine to machine
A=	average ancillary time per machine = operator time for duties that can be done internally (while the machine is running)
M=	average maintenance time per machine = operator time for external duties (those that must be performed while the machine is stopped)
formulas:	
C=	cycle time = max {P + S + Im +W +M, (S + Ir + W + A + M)N}
Me=	machine efficiency = P/C
()e=	operator efficiency = (S + W + A + M)/C
E=	efficiency loss or amount of production lost because of service and interference times = (S + I)/C

Table 2. Parameters used by Stecke & Aronson (1985).

This model is relevant for my research because the parameters here are also applicable at the weaving mill of TenCate.

Another model is that of Engin (2009), which can be found in Appendix 1.1. In this model several parameters come forward including several formulas to calculate the parameters. The input parameters of the model are used to calculate the output parameters. The model is built in nine steps. The following parameters that Engin uses in his model are of importance for my model. These are given in Table 3. The efficiency is calculated on how long the machine runs for a given time period. For my model I also want to look at the efficiency based on the time a machines runs when operated by one operator for a given time period. The parameters are applicable to the weaving mill of TenCate.

Model B-A. Engin (2009)		
Input parameters		
N=	number of machines assigned to an operator	
TW=	time of operator walking between next two machines	
TM=	time of operator mending for on stoppage	
λ=	frequency of stoppage	
Auxiliary input parameters		
ENDTIME=	program running or ending time	
Output parameters to be calculated		
TOSTTM (m)=	total stopping time for every machine equals to zero at the beginning (TOSTIM = 0)	
OPTIME=	operator working time equals to zero at the beginning (OPTIME = 0)	
GCTOSTM=	(N, m=1)∑ TOSTTM (m)	general total stopping times of all machines
AGTOSTTM=	GTOSTTM / N	average stopping time of one machine
E=	(OPTIME - AGTOSTTM) / OPTIME	average machine efficiency for ENDTIME. (to valid every identical machines)

Table 3. Parameters by Engin (2009).

4.4 Measuring quantitative data

4.4.1 Measuring the quantitative data:

In Section 4.4 two distributions that I recommend to use for the testing of the database that TenCate uses for the input parameters are describe. The measured data is been put in a database and from this database the averages are calculated that forms the input for the model. For TenCate I have come up with two probability distributions that validate the found averages of the database. The first distribution is the Poisson distribution and is described in Subsection 4.4.2. The second distribution is the Erlang distribution and is described in Subsection 4.4.3.

4.4.2 Poisson distribution:

Several authors choose a Poisson-process as input for their MRP model. Stecke & Aronson (1985), Mack et al (1957), Chakravarthy & Agarwal (2002), Engin (2009), Little (1961) and Keilson & Servi (1988). A Poisson process counts the number of events that will happen in a given time interval. A stochastic process is also referred as a random process. This is the opposite from a deterministic process were events are determined when they will happen. A Poisson process has an exponential distribution with parameter λ, where each event occur independent of each other. The Poisson process is used in the queuing theory, where the arrival rate of events is often assumed to be a Poisson process. Further on the process is considered as a continuous-time process, this means that the values of the events have a continuous range of values.

From the Poisson process a Poisson distribution can be made. This distribution is a discrete probability distribution and gives the probability that a certain number of events will happen independently of each other at an given mean rate in a given time interval. The discrete probability distribution has a discrete random variable and is characterized by a probability mass function (PMF). The probability mass function gives the probability that discrete random variable equals to a given value. The probability is always nonnegative and the sum of all probabilities is one. For a Poisson distribution the probability mass function gives the probability that there are x number of event with a given mean number of events (*λ).* The probability mass function for a Poisson distribution is:

$$P(x;\lambda) = \frac{\lambda^{x} e^{-\lambda}}{x!}$$

Here *x* is the number of events that occur and *x!* is the factorial of *x*. The *e* is a constant number and used as the base of natural logarithms. Its value is approximately equal to 2,71828. Here the parameter *λ* is the expected number of events that will occur. The parameter *λ* is the same for the mean and the variance, so the mean (μ) = λ and the variance (σ^2) = λ. The λ can be found by calculating the mean or the variance.

The mean of a discrete random variable is calculated by:

$$\mu_x = \sum p_k x_k$$

And the variance of a discrete random variable is calculated by:

$$\sigma_x^2 = \sum p_k (x_k - \mu_x)^2$$

To check if the data is a Poisson distribution I must calculate if the outcome of $(\mu/\sigma^2) = 1$. Therefore I have set up the following hypothesis:

$$H_0: (\mu/\sigma^2) = 1,\ H_1: (\mu/\sigma^2) \neq 1$$

But an outcome of 1 is almost impossible to achieve. Therefore I choose that the outcome is still accepted with a standard deviation of 5,00. This lead that the hypothesis is accepted when the outcome is > 0,975 or < 1,025. When H_0 is not rejected then the data is Poisson distributed. Then I can use the probability found that a number of events will occur in a given time interval. But when the data is not Poisson distributed the database can be validated with another distribution. The Erlang distribution is described in Subsection 4.4.3 and gives more degrees of freedom for the calculation of the probability distribution.

4.4.3 Erlang distribution:

This distribution has been developed by Agner Krarup Erlang a mathematician from Denmark in the 19th century. He developed the Erlang formula for telephone network analysis. His formula is now widely used in traffic engineering and queuing theory by several authors Bonald (2006) and Ching (2001). In his formula he assumes that events arrive at a Poisson-process. From the Erlang formula an Erlang distribution can be made, where the distribution is a continuous probability distribution. The continuous probability distribution has a probability density function (PDF) where the random variable is continuous. It gives the probability that the expected number of events actually occur in a given time interval. The probabilities of this function are also nonnegative and the sum of all probabilities is one. The probability density function for an Erlang distribution is:

$$P(x; k; \lambda) = \frac{\lambda(\lambda x)^{k-1}}{(k-1)!} e^{-\lambda x}$$

Here *k* is the shape parameter and *k!* is the factorial of *k*. The *e* is a constant number and used as the base of natural logarithms. Here the parameter λ is the rate parameter and x is the number of events that occur. The mean (μ) is *k/λ* and the variance (σ^2) is *k/λ²*. Since $\lambda = \frac{\frac{k}{\lambda}}{\frac{k}{\lambda^2}}$ we may estimate $\lambda = \frac{\mu}{\sigma^2}$.

When the parameter λ has been estimated the shape parameter *k* can be calculated with the following formula: $k = \mu * \lambda$. The use of the shape parameter *k* gives an extra degree of freedom to the Erlang distribution.

5. Results

In this chapter I will answer the research questions based on results found from empirical articles, interviews, studies and data collection. Due to confidential information I will only give some conclusions.

5.1 What is the contribution to the output-yield at the weaving mill of TenCate?

Personnel, machines and yarn contribute to the output-yield at the weaving mill of TenCate. With the results on these three factors I make a model where these three factors are taken in combination. Unfortunately all these assumptions are not valid, because they are not investigated. These are just assumptions from key persons in the weaving production and assumptions made based on my own investigations. Just since a few weeks there has been set up a team to investigate how each yarn quality runs on each machine. They look at several factors of the yarn quality like Dtex and stretch, to how it is rolled up on a beam or creel and also the differences between two machines of the same type are investigated. There are a lot of possible factors for each quality to say something about his running quality. So an actual conclusion on how weavers, machines and yarns affect the output yield cannot be made. For this, further research is needed. Still for the model I can make certain assumptions and use those assumptions to create an outcome on most efficient use of weavers at the weaving mill.

5.2 Which data are needed to create a model for the weaver efficiency and how

The conclusion on the input parameters is that my expectation is very well confirmed. Still the exact use of the times is different than I expected. Because a lack of statistical data and the fact that the model would become too complex, I have not used the repair time for each type of breakdown. In the months investigation the problem my supervisors have come to the conclusions that the expectation was not achievable in the time span of my research, nor it was achievable because a lack of education in model building. For this reason a more general repair time is chosen which is split per machine type.

The interview with the plant manager and the research at the weaving mill showed me that there are big differences in service time per machine type. For this reason I choose to separate the service time per machine type. The setup time is left out of the model, the model focus on the running machines. In the beginning of the investigation I thought of a model where set up time also would be included, but it was very soon confirmed that the model would be to complex and needed far more research than six months. The frequency per type of product is as expected. But I need to state that in my expectation I did not expect differences in type of breakdown.

During the investigation I have found that two types of breakdowns occur at TenCate, a weft and a warp yarn breakdown. These breakdowns have many factors that cause the machine to breakdown. The main cause is the product. In council with supervisors and by self insight I have choose to stick to one general type of breakdown and measure the frequency per product. When starting the research I have found two major items that I have left out of my expectation that affects the input parameters. The two items are the different machine types and the shifts at TenCate. To get an accurate model I split the model per shift and per machine type. The investigation gave me the insight that the parameters are more complex than expected at the beginning and that on some point you need to cut off some variables or you get a un user friendly model.

The way I have calculated the service and repair times per weaver is in line with my expectation. I expected that these times should be measured by hand, because the computer cannot see when a weaver starts to service the machine, when he repair a machine or when he walks to a machine. These times I have measured with a stopwatch by hand. In my expectation I thought this as a normal way of measuring the data, but when measuring the times by the stopwatch I have come to the conclusion that this gives many flaws and therefore is an incorrect way of measuring times. When new research is done I will use precise measured data gathered by a computer. Finally the averages times should be tested in further research. These averages can be tested by using one of the two distributions described in Section 4.4.

References

[1] Bonald, T. (2006). The Erlang model with non-Poisson call arrivals. *SIGMetrics/Performance,* 276-286.
[2] Bunday, B.D. and El-Badri, W.K. (1985). Machine interference a comparison of two patrolling methods. *Int. J. Prod. Res., Vol. 23, No. 4* , 795-805.
[3] Bunday, B.D. and El-Badri, W.K. (1985). Machine interference a comparison of two repair strategies. *Int. J. Prod., Vol. 23, No. 6* , 1115-1120.
[4] Bunday, B.D. and Khorram, E. (1988). A closed form solution for the G/M/r machine interference model. *Int. J. Prod. Res., Vol. 26, No. 11* , 1811-1818.
[5] Chakravarthy, S.R. and Agarwal, A. (2002). Analysis of a machine repair problem with an unreliable server and phase type repairs and services. *Naval research logistics, Vol. 50,* 462-480.
[6] Chen, G. and Harlock, (1999). A computer simulation based scheduler for woven fabric production. *Textile Research Journal, Vol. 69, No. 6* , 431-439.
[7] Ching, W. K. (2001). Machine repairing models for production systems. *Int. J. Production Economics, vol. 70* , 257-266.
[8] Das, T.K, and Wortman, M.A. (1993). Analysis of asymmetric patrolling repairmen systems. *European Journal of Operational Research, Vol. 64*, 45-60.
[9] Eben-Chaime, M. (1998). Spreadsheet calculations for the machine interference queueing model. *Computers Ind. Engng. Vol. 34, No. 2* , 385-390.
[10] Engin, B-A. (2009). Comparative analysis for periodical and random servicing systems considering. *Journal of Manufacturing Systems, Vol. 28* , 89-97.
[11] Glyn, P.W. and Whitt, W. (1989). Indirect estimation via L = λW. *Operations Research, Vol. 37, No. 1*, 82-103.
[12] Haque, L. and Armstrong, M.J. (2007). A survey of the machine interference problem. *European Journal of Operational Research, vol. 179* , 469-482.
[13] Hamilton, B.H., Nickerson, J.A. and Owan, H. (2003). Team incentives and worker heterogeneity: an empirical analysis of the impact of teams on productivity and participation. *Journal of Political Economy, Vol. 111, No. 3,* 465-497.
[14] Hsieh, Y.-C. (1997). Optimal assignment of priorities for the machine interference problems. *Microelectron. Reliab., Vol. 37, No. 4* , 635-640.
[15] Keilson, J. and Servi, L.D. (1988). A distributional form of Little's Law. *Operations Research Letters, Vol. 7, No. 5,* 223-227.
[16] Koninklijke Ten Cate. (2011). *About us, Ten Cate nv.* Opgeroepen op 12 06, 2011, van Website of Ten Cate: http://tencate.com/Pages/451/TenCate/Corporate/en/Home/About-us
[17] Koninklijke ten Cate. (2010). *Jaarverslag 2010 Koninklijke ten Cate.* Almelo: Ten Cate.
[18] Koninklijke ten Cate nv. (2011). *About us, TCGeo Europe.* Opgeroepen op 12 07, 2011, van Ten Cate Geosynthetics Europe: http://tencate.com/286/TenCate/Geosynthetics/eu/en/en-TenCate-Geosynthetics-Europe/en-TenCate-Geosynthetics-Europe-About-us
[19]Little, J.D.C. (1961). A proof for the queuing formula: L=λ W. *Operations Research, Vol. 9, No.3,* 383-387.
[20] Little, J.D.C. (2011). Little's Law as viewed on its 50th Anniversary. *Operations Research, Vol. 59, No. 3*, 536-549.
[21] Mack, C. (1957). The efficiency of N machines uni-directionally patrolled by one operative when walking time is constant and repair times are variable. *Journal of the Royal Statistical Society. Series B (Methodological), Vol. 19, No. 1,* 173-178.
[22] Mack, C., Murphy, T. and Webb, N.L. (1957). The efficiency of N machines Uni-directionally patrolled by one operative when walking time and repair time are constants. *Journal of the Royal Statistical Society, Series B(Methodological), Vol. 19, No. 1* , 166-172.

[23] Rotab Khan, M.R., Harlock, S. H. and Leaf, G.A.V. (1999). Computer simulation of production systems for woven fabric manufacture. *Computers & Industrial Engineering, Vol. 37* , 745-756.
[24] Serafini, P. and Speranza, M.G. (1992). Production scheduling problems in a textile industry. *European Journal of Operational Research, Vol. 58* , 173-190.
[25] Stecke, K.E. and Aronson, J.E. (1985). Review of operator/machine interference models. *Int. J. Prod. Res., Vol. 23, No. 1* , 129-151.
[26] Stidham, S. (1974). A last word on $L = \lambda W$. *Operations Research, Vol. 22, No. 2,* 417-421.
[27] Sztrik, J. and Bunday, B.D. (1993). Machine interference problem with a random environment. *European Journal of Operational Research 65* , 259-269.
[28] Tucci, M. and Rinaldi, R. (1999). From theory to application: Tabu search in textile production scheduling. *Production Planning & Control, Vol. 10, No. 4* , 365-374.
[29] Whitt, W. (1991). A review of $L = \lambda W$. *Queueing Systems, Vol. 9*, 235-268.
[30] Wu, M.C. and Fu, K.C. (2005). An operator staffing and assignment model for foundry fabs. *International Journal of Advanced Manufacture Technologies, Vo. 26,* 1429-1435.

Appendix

1.1 Model B-A. Engin

Model A.B. Engin (2009)		
Model		
Step 1: Determine the input and output parameters		
Input parameters		
N=	number of machines assigned to an operator	
TW=	time of operator walking between next two machines	
TM=	time of operator mending for on stoppage	
λ=	frequency of stoppage	
auxiliary input parameters		
ENDTIME=	program running or ending time	
Output parameters to be calculated		
E=	average efficiency of machines for ENDTIME	
AGTOSTTM=	average stoppage time of one machine for ENDTIME	
NUSTM=	total number of machine stoppages mended by operator for ENDTIME	
NUSTM/N=	number of machines stoppages mended by operator for one machine	
Step 2:		Determine the operator's random walking time matrix RTWMATRIX (m,j)
RTWMATRIX=	TW	for given N machines considering the operator and stopped machine position
		together as shown.
Step 3.		
STATE (m) = 1	all machines are accepted as stopping	
STATE (m) = 2	all machines are accepted as running	
Step 4.		define a variable for running times of every machine named RUNTIME (m) (m = 1 to N)
RUNTIME (m) =	=-(1/λ) * ln(r) (m = 1 to N)	to calculate running times of every machine constitue Random Number of Exponential distribution
	(0 < RUNTIME (m) < 1)	use for this aim a Random Number "r" (0 < r < 1)

Step 5.		
TOSTTM (m)=	total stopping time for every machine	
	equals to zero at the beginning (TOSTIM = 0)	
Step 6.		
NUSTMN=	number of stoppage mended by operator	
	equal to zero at the beginning (NUSTMN = 0)	
OPTIME=	operator working time	
	equals to zero at the beginning (OPTIME = 0)	
Step 7.	Start operation time. Operator is coming to m = 1st machine with walking time TW	
(A) =	STATE (1) = 1, first machine is stopping	
(A1) =	TM = mending time is repair time	
(A2) =	recalculate the running time of the 1st machine	
(A3) =	TOSTTM= TOSTTM + TW + TM, for every stopped machine between 1st and Nth	
(A4) =	OPTIME= OPTIME + TW + TM	
(A5) =	NUSTM= NUSTM + one number mended stoppages	determine the walking from the machines stopped to the machine which the operator is in front of it.
(A6) =	DISTANCE (m,j) = RTWMATRIX (m,j)	
(A7) =	RUNTIME (m) = RUNTIME - TW - TM, for all running machines	
(A8) =	when (A7) approached to zero enough, then accept these machines have just stopped and STATE (m) = 1	
(A9) =	repeat (A6)	to determine the machine to which the operator will move
(A10) =	MINTW = minium DISTANCE (m,j)	
(A11) =	When no machine is stopped move from mth machine to (m+1)th machine	
(B) =	STATE (1) = 2, first machine is running	
(B1) =	TOSTTM= TOSTTM + TW, for every stopped machine between 1st and Nth	
(B2) =	repeat (A9)	
(B3) =	OPTIME= OPTIME + TW	
(B4) =	RUNTIME (m) = RUNTIME - TW, for all running machines	
(B5) =	when (B4) approached to zero enough, then accept these machines have just stopped and STATE (m) = 1	
(B6) =	repeat step (A9), (A10) and (A11).	

Step 8.	Continue these processes until OPTIM = ENDTIM	
Step 9.		
GCTOSTM=	(N, m=1)∑ TOSTTM (m)	general total stopping times of all machines
AGTOSTTM=	GTOSTTM / N	average stopping time of one machine
E=	(OPTIME - AGTOSTTM) / OPTIME	average machine efficiency for ENDTIME. (to valid every identical machines)