POLITECNICO DI TORINO

Collegio di Ingegneria Meccanica, Aerospaziale, dell'Autoveicolo e della Produzione

Master of Science degree
Automotive engineering

Master Thesis

Analysis and simulation of models for manufacturing processes

Advisor

prof. Paolo Chiabert

Candidate

Shen Weichen

July 2019

Acknowledgements

Firstly, I would like to express my heartfelt thanks to my thesis advisor Prof. Paolo Chiabert. He is always willing to help me no matter when I get into trouble or have a question in the research. He has a deep range of professional knowledge which makes me understand strange academy quickly with his careful instruction and at the same time, I am totally admired with his perfect personality which influence me a lot in my future life.

Furthermore, I would also like to thank Miss Yang Can for helping me to find relative academic reference materials and modify the format of the thesis. Without her passionate participation and kindness help, the thesis could not have been successfully accomplished.

Finally, I must give the sincere gratitude to my parents who provide selfless support and love to me in my whole master study.

Thank you all.

Abstract

Based on the knowledge of the analytical approach for production queue model, simulation technology, with using Flexsim, has been widely developed and applied in various manufacturing enterprises to achieve lower production costs and improve production efficiency. Flexsim can be modeled in many different ways to illustrate the layout and the working condition of production lines.

In the thesis, researches on production line including methods, optimization and application on Flexsim are briefly introduced. After presenting the concepts of variability, randomness and the production line are discussed in the analytical approach of queue model with application to the queue theory, the modeling tool, Flexsim, which the functions and workable components with the specific operation steps based on simulation software are simply introduced and developed. Furthermore, in the simulation approach for the queue models, four simulation models are established in the Flexsim while introduced the differences, the advantages and the developments of each model. Finally, the models are implemented in a specific method under Flexsim, through analyzing the result data, to find an optimal solution to solve possible problems of manufacturing plants.

Keywords: Flexsim; queue theory; production line; modeling; bottleneck.

Table of Contents

List of Tables

List of Figures

List of Acronyms

CV	Coefficient of variation
SCV	Squared coefficient of variation
LV	Low variability
MV	Moderate variability
HV	High variability
MTTR	Mean time to repair
MTTF	Mean time to failure
CT	Cycle time
TH	Throughput
WIP	Work in process

1. Introduction

With the fierce competition between manufacturing companies and the continuous increasing production costs, companies from all over the world have begun to pay attention to the research of production line problems. At present, all the research on production line problems of processing and manufacturing, the main problems include the following aspects: the balance rate of the production line, the cycle of the production line, the bottleneck process, the production process and the production layout of the production line. The balance of the production line, the efficiency of the production line and the production cost have been seriously affected, which ultimately is made the enterprise at a disadvantage in the competition.

In the face of fierce competition, processing companies all over the world are constantly seeking ways to enhance their own strength in order to improve their market competitiveness. The application of multi-variety small batches, just-in-time production, flexible manufacturing, production system simulation and other methods in processing and manufacturing enterprises have been recognized and popularized. The goal of improving the level of specialization, reducing production costs, improving production efficiency and achieving intelligent factories have gradually become the development goal for various processing and manufacturing enterprises.

However, in the application of various advanced manufacturing technologies, using software to simulate the production system, we can identify possible problems before the whole production line is established or operated, and then propose improvement measures in a targeted manner. It is also possible to find out the bottleneck of the current production line through the establishment and operation of the simulation model and data analysis after the production line is established, to improve the bottleneck, to find out the optimization plan, and to develop a better and more efficient production plan. In the end, standardized production will be achieved.

This method of using computer technology to achieve lower production costs and improve production efficiency has been widely applied and recognized in various manufacturing enterprises. In the production system, due to the dynamic and complex production line, it is impossible to model various production problems of the entire production line by mathematical analysis alone, and the calculation for these problems will become complicated. However, simulation technology can propose corresponding solutions to such problems. Therefore, simulation technology has received more and more attention from people. The theory and methods of simulation technology have also been studied at a deeper level, and the application fields are constantly expanding.

1.1. Research on production line methods

So far, research on production line optimization tools is extensive. In the research on production line problems, optimization tools such as industrial engineering technology, mathematical methods, lean production theory, and simulation technology are mainly used. Through the use of these optimization tools, the production line problems are effectively investigated, the problem improvement points are identified, and the improvement strategies and solutions are specifically proposed to finally optimize the production line, improve production efficiency, lower production costs, and expand enterprise profits.

Yokoyama (2005) produced a wide range of parts in a single machine and performed the final assembly during the assembly phase. The full text mainly analyzes the division of production and the scheduling of semi-finished products. He then solved the Flowshop problem that occurred on the two machines during the part manufacturing process using the branch and bound method.[4]

Anglani (2002) used Arena software to simulate the flexible manufacturing system and analyze the resulting data.[5]

Sun Jianhua (2007) finished a detailed study on the balance of production lines and production operations in a notebook computer company. Then, he proposed corresponding improvement suggestions for the bottlenecks in the production line. Finally, the working hours in the production line were correspondingly reduced and the balance rate of the production line was increased.[6]

Cai Yong (2009) studied from five aspects of processing and handling according to LP theory to find out the cause of the bottleneck station. A targeted improvement method is proposed to adjust the current production line to minimize the waste of the enterprise.[7]

1.2. Research on production line optimization

Since the first production line was invented by Henry Ford in 1913, the analysis of the production line has gradually begun. So far, many scholars have engaged on studying the production line problems, and their research directions are also different.

James P. Womack and Daniel T. Jones (1990) in the book ‘Machine that changed the world’[8], pointed out, in a range of production process optimization methods, job assay is a common and efficient method. Oh. Keytack H. (1997) solved the problem of bottleneck workstation by means of a heuristic optimization algorithm[9]. H. Pierreval (2003) used genetic algorithms to solve the optimization problem of the production line.[10]

Shao Renyu (2014) studied the entire production process with the working part of the production line as the research object. First, a program analysis is performed on the operation process of each process, and then each process is time-measured to obtain its cycle time. Under this premise, the balance and loss rate of the production line were analyzed, and the problems existing on the production line were discussed. Finally, the production line is optimized according to industrial engineering technology.[11]

Zhang Xuelong, et al. (2015) used work research methods to optimize and redesign the production process of GY's core product line. Based on the data obtained from field observations, 5W1H, working time measurement and human-machine operation analysis were used to find out the bottleneck process in the production line and analyze the cause. The methods and measures for solving the bottleneck process and personnel idleness were obtained. Finally, the work content of the workstation was redesigned, and the production line was optimized.[12]

Through reading and analyzing related literatures, it can be seen that scholars have carried out relatively mature theoretical research on the problem of production line optimization from different angles and obtained more research results. In general, these are mainly for the optimization of the production line and the problems of bottleneck process, production process and production line balance.

1.3. Research on production line optimization of Flexsim simulation technology

Flexsim simulation software is an effective tool for next-generation discrete simulation system and it is the world's first simulation software to integrate a compiler and C++ IDE in a graphical environment. The application of Flexsim simulation software is in deep developed, and the entities in the software represent a certain activity and sorting process. Object-oriented technology is used in Flexsim simulation software, and 3D animation display functions has also been developed in the software.[13] Quickly building simulation models and realistic 3D animation displays are important features of Flexsim software. The Flexsim simulation software is used to simulate and model the production line of the enterprise. Through the operation data analysis and research, a feasible solution for the optimization of the production line of the enterprise is formulated. There are many researches on line optimization based on Flexsim simulation technology, which can be basically divided into the following three types:

(1) Research on mixed flow production line based on Flexsim simulation technology

Wang Xuelan (2007) explained the production sequence problem in the mixed flow production line. By using Flexsim simulation software to simulate different production sequences of a mixed-flow production line according to the order requirements, then collected the simulation data and analyzed it to provide a theoretical basis for rational production. [14] Zhang Guohui (2015) used Flexsim simulation software to simulate and model a mixed flow production line in a company, and then based on the report of simulation model data, found the bottleneck station in the mixed flow production line, and then analyzed the cause at the same time. After proposing corresponding improvement measures, finally realized the verification of the optimization scheme.[15] Qiu Yijian (2015) used Flexsim simulation software to establish a simulation model of the mixed flow production line, which optimized the bottleneck problem and production line balance. At the same time, combined with genetic algorithm to minimize the idle and overload time, the production sequence of the mixed flow production line is optimized. At the end, the performance indicators of the mixed flow production line have been improved, and the production cost of the enterprise has been effectively reduced. It proves that the combination of Flexsim software and genetic algorithm is a low-cost but significant analysis method. It provides a theoretical basis for the actual operation of the production line of the enterprise and provides a new method for optimizing and improving the production line.[16]

(2) Research based on Flexsim simulation technology application

William B. Nordgren (2003) believes that an important feature of Flexsim software is that the software is not only fast and easy to model, but also an efficient simulation engine and powerful display capabilities. Simulation with Flexsim software not only improves efficiency, shortens development cycles, saves costs, but also ensures product safety and quality.[17] Yuan Han (2007) found through relevant research that for more complex production lines, if only mathematical methods are used, it is generally impossible to find the production bottlenecks in the production line, so this method is not enough to provide relevant research for the production system under study. Then, the production process in the production line is simulated in the simulation software under study, so as to realize the simulation of the research object, find the bottleneck process existing in the whole production process, and finally improve the bottleneck process to achieve the goal of eliminating bottlenecks. Case studies show that the combination of simulation technology and mathematical methods can effectively improve the operating efficiency of the production line.[13] Cao Yuhua (2009) pointed out that in enterprises with advanced production systems, simulation technology is an effective way for enterprises to carry out scientific production layout and planning. In the paper, the Flexsim software is used to simulate and optimize the production system of a company's refining and bleaching workshop. Finally, the optimization of production system is analyzed to get the verified optimization results of the production system.[18] Feng Xiaoli (2013) took the international logistics process as the research object and analyzed the whole process of using Flexsim software. In order to more truly reflect the operation of international logistics, a third-party 3D-max software is introduced, through modeling, parameter setting and process simulation in Flexsim. The functions of the international logistics process are comprehensively simulated, and the 3D model-guided Flexsim simulation model established by the third-party software is studied to provide reference for the establishment of the Flexsim simulation model for introducing third-party software.[19]

(3) Research based on production line examples

So far, more on Flexsim-based production line examples have been studied. Xu Cheng (2005) took a production line of an automobile manufacturing plant as the research object and carried out detailed analysis and research on the whole process of Flexsim simulation modeling. A detailed summary reflects the importance of Flexsim software in line optimization.[20] Wang Yongqiang (2007) conducted a simulation study on a DAB assembly line of an enterprise by using Flexsim software, established a simulation model of the current assembly line, and analyzed the data report collected in the running mode, so as to propose a targeted relevant improvement measures which were finally modeled with Flexsim to verify the solution. Wang Fuxin (2010) based on the collection of relevant production data of a toy company, established the corresponding Flexsim simulation model, found out the bottleneck process in the production line, and then proposed the improvement of the problem. Then, modeled it with Flexsim to verify the scenario.[21] Tan Guo, et al. (2014) established a motorcycle painting simulation model based on the motorcycle painting production line using Flexsim simulation software and carried out secondary optimization for the process bottleneck in the model, making the motorcycle painting production line achieving balance. Practice has shown that Flexsim-based simulation technology can be widely used in manufacturing enterprises, greatly improving the accuracy and efficiency of modeling.[22]

1.4. Structure of the thesis

In chapter 1, researches on production line including methods, optimization and application on Flexsim are briefly introduced;

In chapter 2, the concepts of variability, randomness and the production line are discussed in the analytical approach of queue model with application to the queue theory;

In chapter 3, modeling tools, which the functions and workable components with its specific operation steps based on Flexsim simulation software are simply introduced;

In chapter 4, in the simulation approach for the queue models, four simulation models are established in the Flexsim while introduced the differences, the advantages and the developments of each model;

In chapter 5, the models are implemented in a specific method under Flexsim, through analyzing the result data, to find an optimal solution to solve possible problems of manufacturing plants.

2. Analytical approach for queue models

2.1. Definition of variability and randomness

In order to define the variability, there are three different ways including non-uniformity of a class of entities, deviation form regularity and predictability of system behavior and deterministic or stochastic. After that, the sources of variability should be discussed, like physical dimensions of the workpiece, process time, repair time for machine failure, set-up time and etc.[23]

So as to know the deterministic or stochastic variability, 3 factors should be determined as well. The first is the worst case, which is full predictable variability due to an inadequate control and the second is the practical worst case that is non predictable variability due to randomness and the last is best case with no variability at all.

In this time, a stochastic variable has the following characteristics in 2 different aspects: distribution and parameters. Especially, in the analytical approach for queue models, variables are important to be measured and defined. Normally, in the distribution, there are plenty of methods, such as exponential, normal, Poisson and etc. For the parameters, mean μ, variance σ^2, skewness, kurtosis, and etc.

In the part of the stochastic variable, the 'magnitude' is statistically measured by mean μ and the 'variability' is statically measured by variance σ^2 or standard deviation σ. While the classification of the variability of a stochastic variable relies on coefficients without dimension, that is two different parameters coefficient of variation (CV) and squared coefficient of variation (SCV)

$$\text{CV: } c = \frac{\sigma}{\mu} \quad (1)$$

$$\text{SCV: } c^2 = \frac{\sigma^2}{\mu^2} \quad (2)$$

For the sake of comparing the stochastic variables in any systems are classified according to the variability expressed in term of coefficient of variation:

- Low variability: $c < 0.75$ LV
- Moderate variability: $0.75 < c < 1.33$ MV
- High variability: $c \geq 1.33$ HV

The result of variability in the range means different, which LV is from the best case to the practical worst case, MV is the practical worst case and HV is from the practical worst case to the worst case.

When the sources of variability are determined, four critical factors which are natural variability, preemptive outages (out of service and breakdowns), non-preemptive outages (setup and toll change) and reworking are most significant sources of variability in the workstation.

For the natural variability, it is not explicitly related to an identified source, but the natural variability of the process time is generally related to plant workers and it is also related to other sources such as worker ability, material variations, product changes, product quality and etc. Of course, the natural variability of the process time is generally in the type of LV.

$$c_0 = {}^{\sigma_0}/_{t_0} < 0.75 \text{ (LV) (3)}$$

While the preemptive outages are discussed, failures can occur at any time including tool break, consumable stockout, and etc. and interrupt the manufacturing of the job.

- m_f = mean time to failure (MTTF)
- c_f = coefficient of variability of failure times (c_f = 1)
- m_r = mean time to repair (MTTR)
- c_r = coefficient of variability of repair times (c_r)

Failures affect the availability A of the machine:

$$\mathrm{A} = \frac{m_f}{m_f + m_r} \text{ (4)}$$

Mean value of effective process time:

$$t_e = \frac{t_0}{\mathrm{A}} \text{ (5)}$$

Variance of the effective process time:

$$\sigma_e{}^2 = \left(\frac{\sigma_0}{\mathrm{A}}\right)^2 + \frac{(m_r{}^2 + \sigma_r{}^2)(1-\mathrm{A})t_0}{\mathrm{A}m_r} \text{ (6)}$$

, which the first part is natural variability and the second part is variability associated to the repair time.

Squared coefficient of variation of the effective process time:

$$c_e{}^2 = \frac{\sigma_e{}^2}{t_e{}^2} = c_0{}^2 + A(1-A)\frac{m_r}{t_0} + c_r{}^2\mathrm{A}(1-\mathrm{A})\frac{m_r}{t_0} \text{ (7)}$$

, which the first part is natural variability, the second part is variability associated to the repair time and the last part is variability associated to the variability of repair time.

In the non-preemptive outages, they consist of setups or tool changes and allow for the completion of the jobs:

- N_s = mean number of parts manufactured between two setups
- t_s = mean setup time
- c_s = coefficient of variation of setup time

Mean value of the effective process time:

$$t_e = t_0 + \frac{t_s}{N_s} \text{ (8)}$$

Variance of the effective process time:

$$\sigma_e{}^2 = \sigma_0{}^2 + \frac{\sigma_s{}^2}{N_s} + \frac{(N_s-1)}{N_s{}^2}t_s{}^2 \text{ (9)}$$

, which the first part is natural variability, the second part is variability setup time and the last part is interaction of different setups.

Squared coefficient of variation of the effective process time:

$$c_e{}^2 = \frac{\sigma_e{}^2}{t_e{}^2} \text{ (10)}$$

When products need to be reworked for the quality reasons, the following points also need to be considered. Reworking increases the effective process time, it reduces the utilization of the capacity of the workstation, it increases the variability and the congestion in the system.

The probability of a defective part is p, when the control of parts quality detects the non-conformity and asks for a reworking, then the process continues until the non-conformity is removed from the part.

So that mean value of the effective process time:

$$t_e = \frac{t_0}{1-\mathrm{p}} \quad (11)$$

Variance of the effective process time:

$$\sigma_e{}^2 = \frac{\sigma_0{}^2}{1-\mathrm{p}} + \frac{p t_0{}^2}{(1-\mathrm{p})^2} \quad (12)$$

Squared coefficient of variation of the effective process time:

$$c_e{}^2 = \frac{\sigma_e{}^2}{t_e{}^2} = c_0{}^2 + p(1 - c_0{}^2) \quad (13)$$

Effective utilization of the workstation:

$$u = r_a t_e = \frac{r_a t_0}{1-\mathrm{p}} \quad (14)$$

The variability of a single workstation affects another workstation in the production line whose behavior generates the flow variability. The process variability on a single workstation negatively affects performances in increasing CT, increasing WIP and reducing the utilization of workstation capacity, however, the flow variability negatively affects performances in perturbing arrivals on following workstations, affecting CT and WIP and reducing the utilization of capacity in the whole line.

For the utilization, while it is equal to 1, the workstation is always busy, and the inter-departure time depends on the process time. When the utilization is equal to 0, the workstation is always empty, and the inter-departure time depends on the inter-arrival tine.

2.2. Definition of production line

The normal production line that runs under a certain takt time, analyzes the differences between the operation time and the work load between the various processes, adjusts the operation contents of each process, and averages all the processes, so that the operation time and the work load between the processes are completed.

The extent of keeping the production line normal reflects the level of equilibrium in each production line. For an unbalanced production line, it will often generate a lot of unnecessary waste, resulting in a large amount of overstock and lost time in the production, and even cause the production line to stop. The balance of the production line is an important indicator to reflect. The higher the balance rate of the production line, the more efficient of the production line.

CT is the abbreviation of cycle time, which refers to the longest operation time in all the processes of the production line. Since the operation time of each process in the production line is different, the longest operation time determines the operation cycle of the entire production line, that is the takt time of the production line.

2.2.1. Definition of takt time

For the takt time, it can be divided into the following two types:

(1) Takt Time, which refers to the time interval between two identical products after the production line is stable, and the calculation unit is second/piece, the calculation formula is:

Takt time = Effective working hours / Product output during the planning period (15)

The effective working hours under the planning period actually are used to produce the products during one production shift. The planned production period refers to the quantity of qualified products are produced during one shift.

(2) Since the takt time is for the entire production line, each production line is composed of various processes, and the working time of each process is different. Therefore, the extent of the synchronization of the actual production cycle of each production line is measured, and the cycle time is defined as the time required for each unit of product output. The calculation unit is seconds/piece, and the calculation formula is as follows:

Cycle time = Effective process working time / Process product output (16)

Takt time and cycle time are both indicators that reflect the production efficiency of the production line. In order to keep the production line normal, it is necessary to meet the needs of takt time ⩾ cycle time.

2.2.2. Definition of bottleneck

The bottleneck process or workstation refers to a production unit or a certain processing process that influences the production process in the entire production line with the longest working time, resulting in takt time increasingly.

Since it is a line-type production flow, as long as one cycle time is higher than the takt time of the entire production line, the overall production efficiency becomes low, and the working load is unbalanced in some processes, which affects the smooth operation of the production line.

Therefore, when optimizing the production line, you can focus on adjusting the cycle time that causes the bottleneck process.

2.3. Application to queue theory

Nowadays, in the modern plants, 'Queue theory' has been analyzed as 'waiting'. Of course, in a manufacturing queue system including three parts, that is, arrival process, manufacturing/service process and queue. While single job or single batch and arrival time deterministic or stochastic are parts of arrival process, single machine or parallel machines and process time deterministic or stochastic are aspects of manufacturing/service process and FCFS, LCFS, EDD, SPT…and limited or unlimited queue.

As a part of queue system, the detailed parameters and concepts need to be defined as well.

- r_a = Arrival rate (job/time) to the workstation;
- t_a = Mean interarrival time;
- c_a = Coefficient of variation of interarrival time;
- m = Number of parallel machines in the workstation;

- B = Buffer dimension;
- t_e = Mean effective process time;
- c_e = Coefficient of variation of effective process time;
- p_n = Probability of n job in the workstation;
- CT_q = Mean waiting time in the queue of the workstation;
- CT = Mean time spend in the workstation;
- WIP = Mean work in process in the workstation;
- WIP_q = Mean work in process in the queue of the workstation.

In the queue system M/M/1/inf, the work in process in a workstation is the product of the number of jobs n of every admissible state and the probability p_n the system is in such defined state:

$$WIP = \sum_{n=0}^{\infty} np_n = \frac{u}{1-u} \quad (17)$$

The system performances decrease when u and t_e increases, however, they explode when u approaches 1:

$$CT = \frac{WIP}{r_a} = \frac{t_e}{1-u} \quad (18)$$

$$CT_q = CT - t_e = \frac{u}{1-u} t_e \quad (19)$$

$$WIP_q = r_a \frac{u}{1-u} t_e = \frac{u^2}{1-u} \quad (20)$$

Furthermore:

$$TH = r_a \quad (21)$$

$$u = r_a / r_e < 1 \quad (22)$$

3. Modeling tool introduction

3.1. Flexsim introduction

Flexsim is a commercial discrete event system simulation software from Flexsim Software Production with providing simulation modeling services in the United States. Flexsim uses object-oriented technology with 3D graphics and it drives to create bold new advancements. Fast and easy modeling with clear display capabilities are important to the software. The software provides various of functions such as raw data fitting, input modeling, graphical modeling, virtual reality display, model simulation test, optimization results, generation of 3D animations and others. With using the software, you can go into a simulation project with satisfying daily working needs.

With enhancements in ease-of-use, improved performance, increased 3D capabilities, and greater extensibility, Flexsim continues to set the standard in cutting edge discrete event simulation software.[1]

3.2. Flexsim function

3.2.1. Modeling

Flexsim applies for deep development objects that represent a certain activity and sorting process. To take advantage of an object in a template, it's simple to drag the object out of the library and place it into the window. Objects can be created, deleted, and moved nested within each other, which functionalities are from their own or other objects. The parameters of these objects describe the main features of manufacturing process, material handling, rapid business process and efficient modeling.

Object parameters in Flexsim can be represented for any physical existed objects like machines, operators, conveyor belts, forklifts, warehouses, traffic lights, tanks, boxes, pallets, containers, etc. Flexsim allows users to make construction of the model more hierarchical when building a client object.

Each component uses an inherited method to save development time, because the objects in Flexsim are open sourced that those objects can be exchanged between different users, libraries and models and the height of the objects can be customized in order to improve the speed of modeling.

3.2.2. Simulation

There is a simulation engine in Flexsim that runs both the simulation and the model window. The hypothetical plot can be simulated in some kinds of experiments by Flexsim and it can be run automatically and the results in reports and charts can be presented. Each part can be analyzed by predefined or customized behavior indicators. It is also possible to import results into other applications like Microsoft Word and Excel, using ODBC (Open Database

Connection) and DDEC (Dynamic Data Exchange Connection) to import simulation data directly.

3.2.3. Visualization

Flexsim integrates all new virtual reality graphics on a personal computer. There is an option to import files directly into 3DS (3DStudio), VRML, 3D DXF and STL in Flexsim and a built-in virtual reality window that lets users add light, fog, and virtual reality stereo technology. User-defined "Fly-Throughs" can be defined as the state-of-the-art model. AVI files can be quickly generated by AVI recorder and any models can be recorded and copied into a CD to send to anyone's live viewer.

3.3. Modeling basic components

3.3.1. Source and Sink

A source is a component to generate items or to receive items from outer sources and send them to the next component. Figure 3.1 is a source and its properties. The Arrival Style is set into an inter-arrival time, arrival schedule or arrival sequence.

When setting inter-arrival time, statistical distribution would be preferred, because it is much closer to the actual situations.

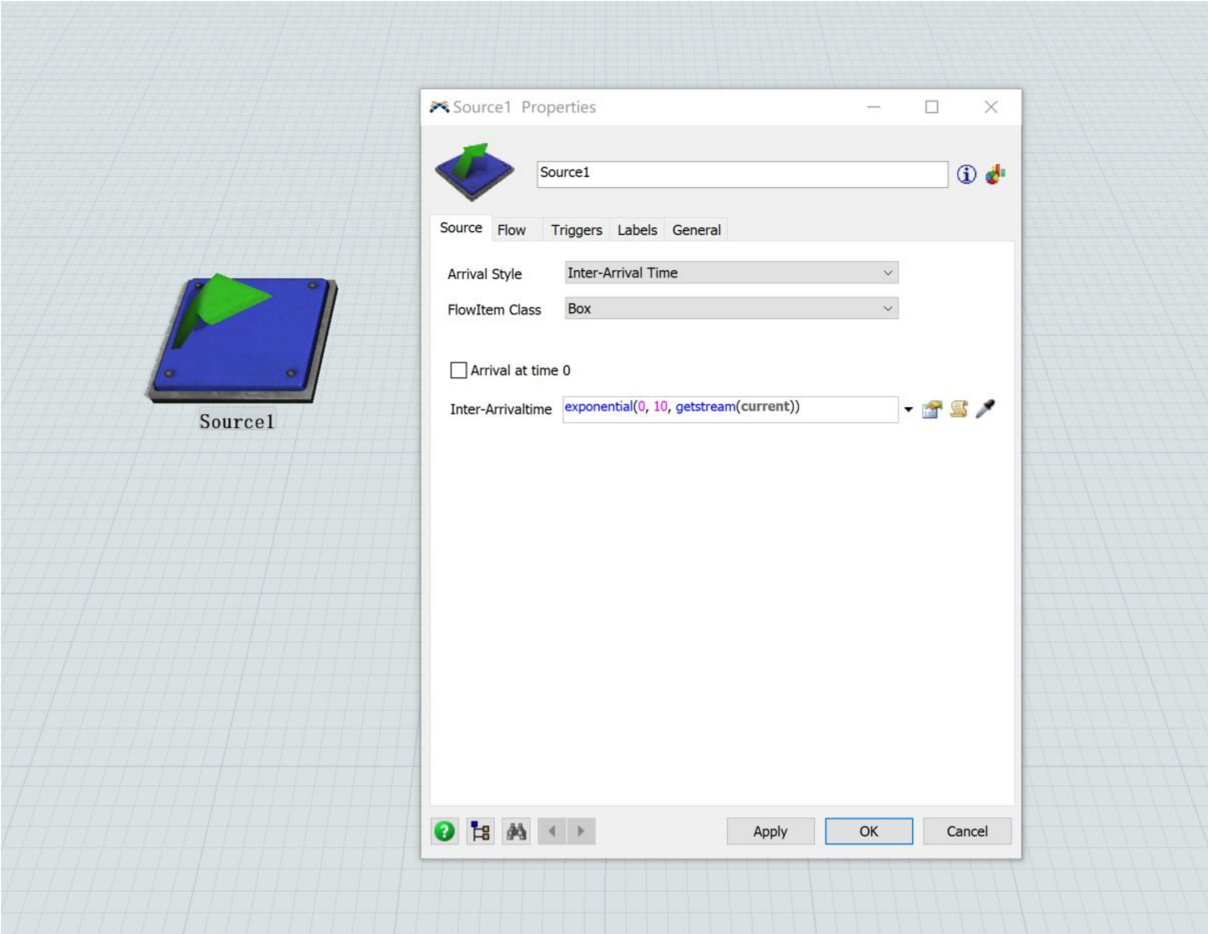

Figure 3.1 Source and properties

A sink is a simplified model that the finished products would be delivered to the outer sources directly which is the last step of the total system and consider about final simulation statistics and results. Figure 3.2 is a sink and its properties. Generally, in this part, there is no need to change any settings or parameters.

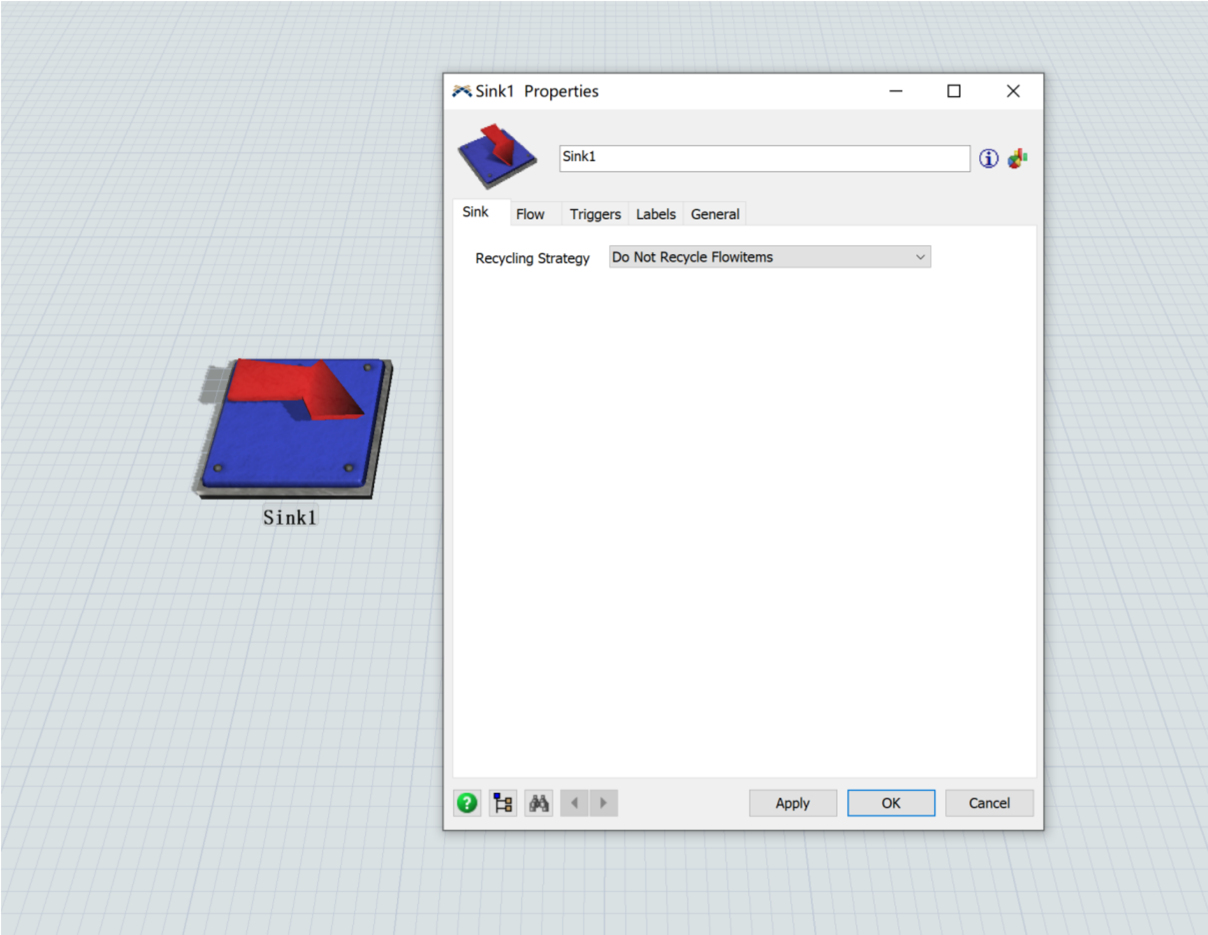

Figure 3.2 Sink and properties

3.3.2. Queue

A queue is a component and an area identically which items or raw products can be stored or waited to be processed or to be transported. The maximum content of items in a queue can be customized by users in the property tab, as well as the transportation logic like choosing 'LIFO' (Last In First Out) or not, as Figure 3.3 shows.

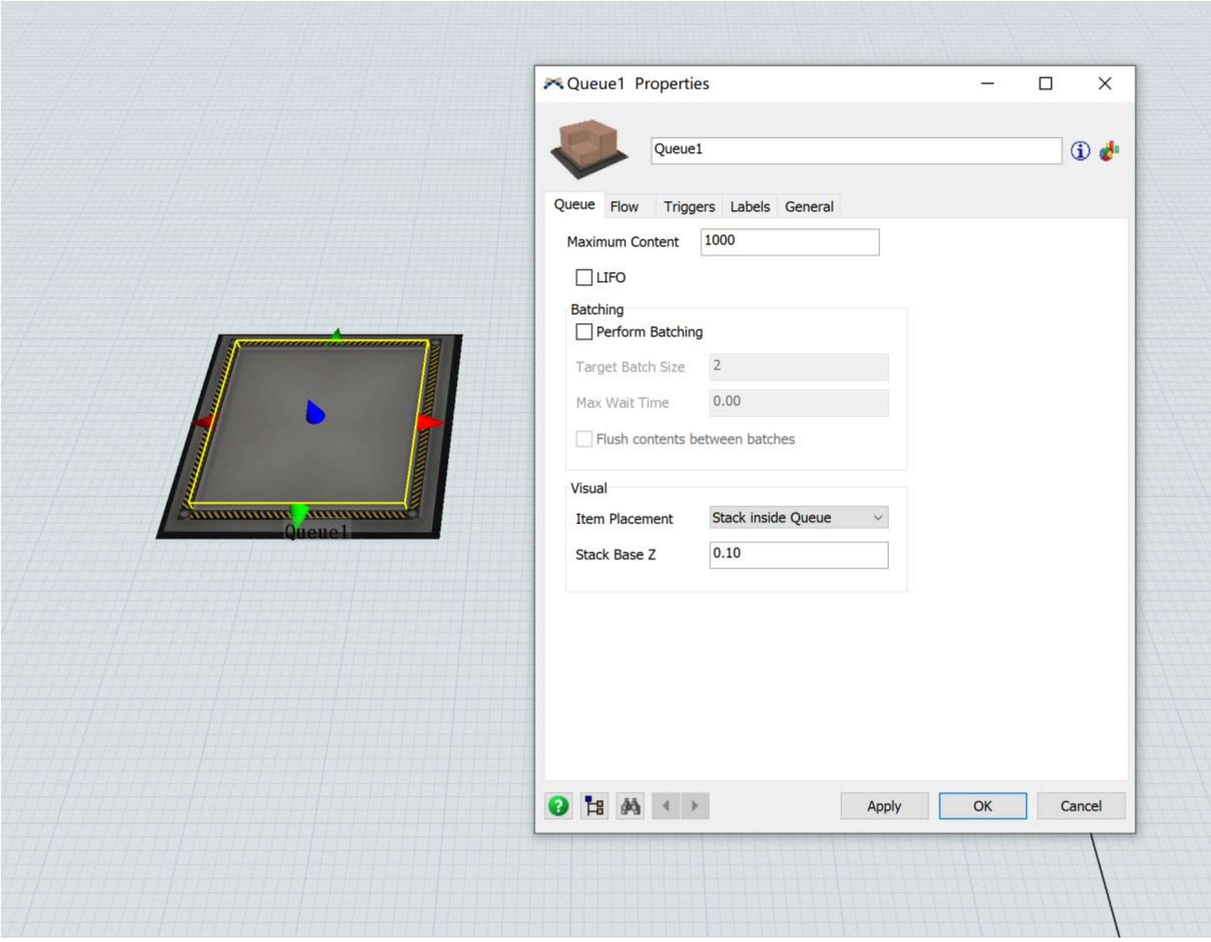

Figure 3.3 Queue and properties

3.3.3. Processor

A processor is a component which is to manufacture raw materials or items into finished products and then transfer to the next component. Figure 3.4 is a processor and properties. The Arrival Style is set into an inter-arrival time, arrival schedule or arrival sequence. According to different working conditions, we have to set various parameters for processors in order to approximate the reality situations such as ‘Setup time’, ‘Process time’, ‘MTTR/MTBF’, ‘Reworking’, etc.

When setting time parameters, ‘Statistical distribution’ would be preferred, because it is much closer to the actual situations. But sometimes, on the basis of different schedules of manufacturing factories, ‘Values by case’ would be preferred as well.

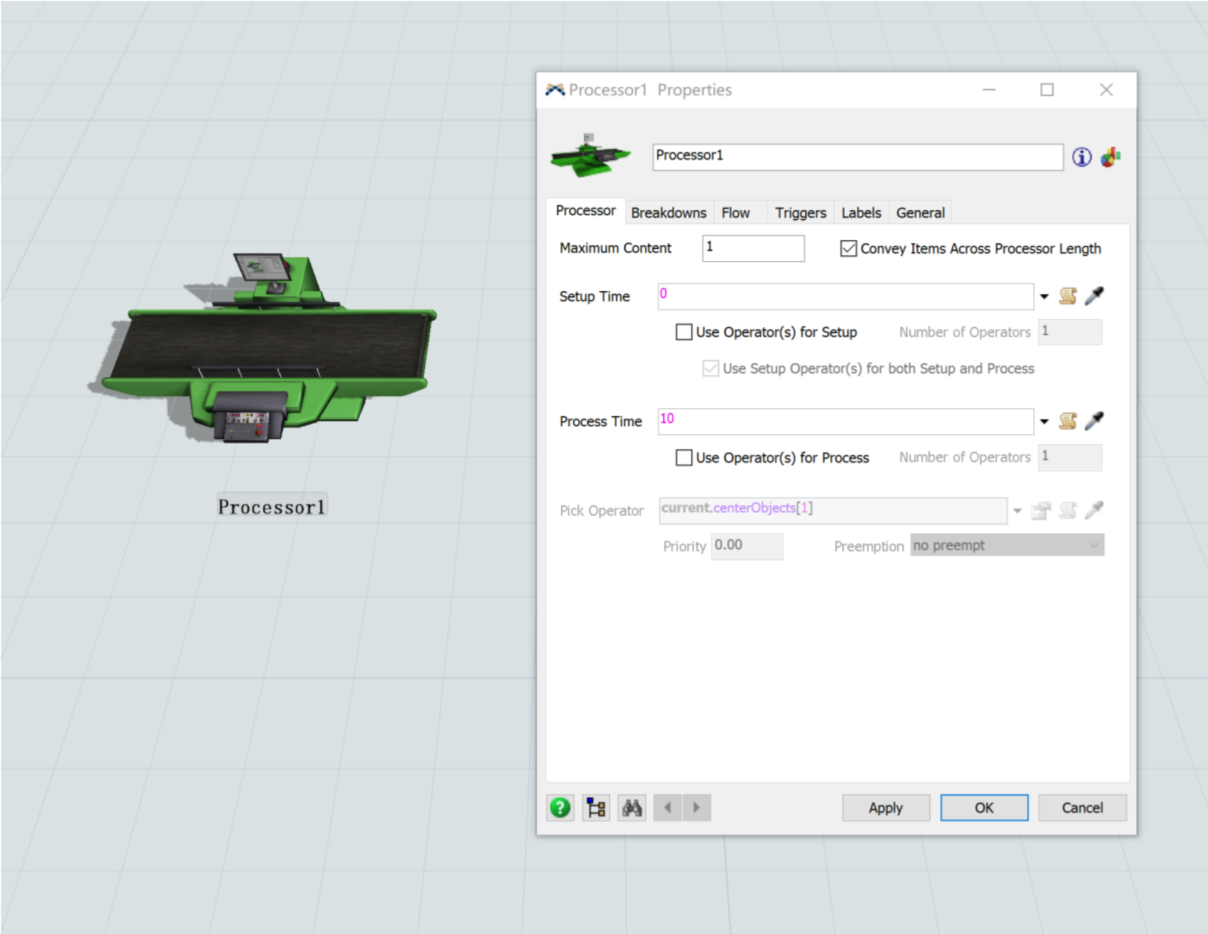

Figure 3.4 Processor and properties

3.4. Modeling basic steps

There are five basic steps of Flexsim simulation modeling:

1. To set the layout: Drag the object from the library to an appropriate location in the simulation view window according to the previous predesigned system.

2. To define "flow": According to the logical relationship between objects, to connect the corresponding ports and build the logic flow of the simulation model.

3. To set parameters: Set parameters of each object according to the characteristics of the system.

4. To run the model: Compile the model first, then reset and run the model.

5. To analyze simulation results: Flexsim is a real-time simulation software, during the simulation process, users can detect the current state on each object.

4. Simulation approach for queue models

4.1. Simple model development (M/M/1/inf)

4.1.1. Definition of M/M/1/inf

The main principle of Queue system Kendall notation: A / B / m / b is as the following:

• A: statistical description of interarrival time

- D = deterministic distribution (constant)
- M = exponential distribution (Markovian)
- G = general distribution (normal, uniform, ...)

• B: statistical description of process time

- D = deterministic distribution (constant)
- M = exponential distribution (Markovian)
- G = general distribution (normal, uniform, …)

• m: number of machines in the workstation

• b: max number of jobs allowed in the system[2]

Due to the uncertainty of the arrival-rate, in this thesis, we use the model M/M/1/inf as the first queue model that means both interarrival time and process time are satisfied with exponential distribution in the system, while there is only one working machine with unlimited buffer area.

4.1.2. Detailed parameters of system

This section has a total of 4 workstations, which are produced as a typical assembly line. And the production line is simulated with given operation parameters, the current production cycle of the production line, the working efficiency, idleness and blockage of each station in the production line are observed in order to establish the optimization goal for the current production logistics operation level and to propose an optimization solution.

The principle of modeling simulation is to simplify the constructed model as much as possible without affecting the simulation results. This can focus on the problems solving related to the project in the simulation system, which can reduce errors caused by random factors, workload and keep Flexsim running smoothly.

According to the requirement from the original thoughts, we have the following data as Table 4.1:

Table 4.1 Basic parameters for workstation 1.1

Workstation 1	Symbol	Value
Arrival rate	r_a	4 pz/h
Mean interarrival time	t_a	0.25 h

Coefficient of variation of interarrival time	c_a	1
Number of parallel machines in WS	m	1
Buffer dimension	B	unlimited
Mean effective process time	t_e	12 min
Coefficient of variation of effective process time	c_e	1

Other than these two basic interarrival data and mean process data, it is not enough, we also have to consider about some other actual environment factors such as failure, setup and reworking, etc., while with adding these uncertainties into the system, it is much closer to the realistic working situation. As in this part, it is supposed the relative data as the following Table 4.2:

Table 4.2 Basic parameters for workstation 1.2

Workstation 1	Symbol	Value
Mean time to failure	m_f	4 h
Coefficient of variability of failure times	c_f	1
Mean time to repair	m_r	20 min
Coefficient of variability of repair times	c_r	1
Mean number of parts manufactured between two setups	N_s	10
Mean setup time	t_s	6 min
Coefficient of variation of setup time	c_s	1
Probability of a defective part	p	5%

4.1.3. Construction of entity model

From the software library, four components (source, queue, processor, sink) are dragged into the window. Using 'A' key to connect from source to queue, then from queue to processor and from processor to sink. As the figure 4.1 shown:

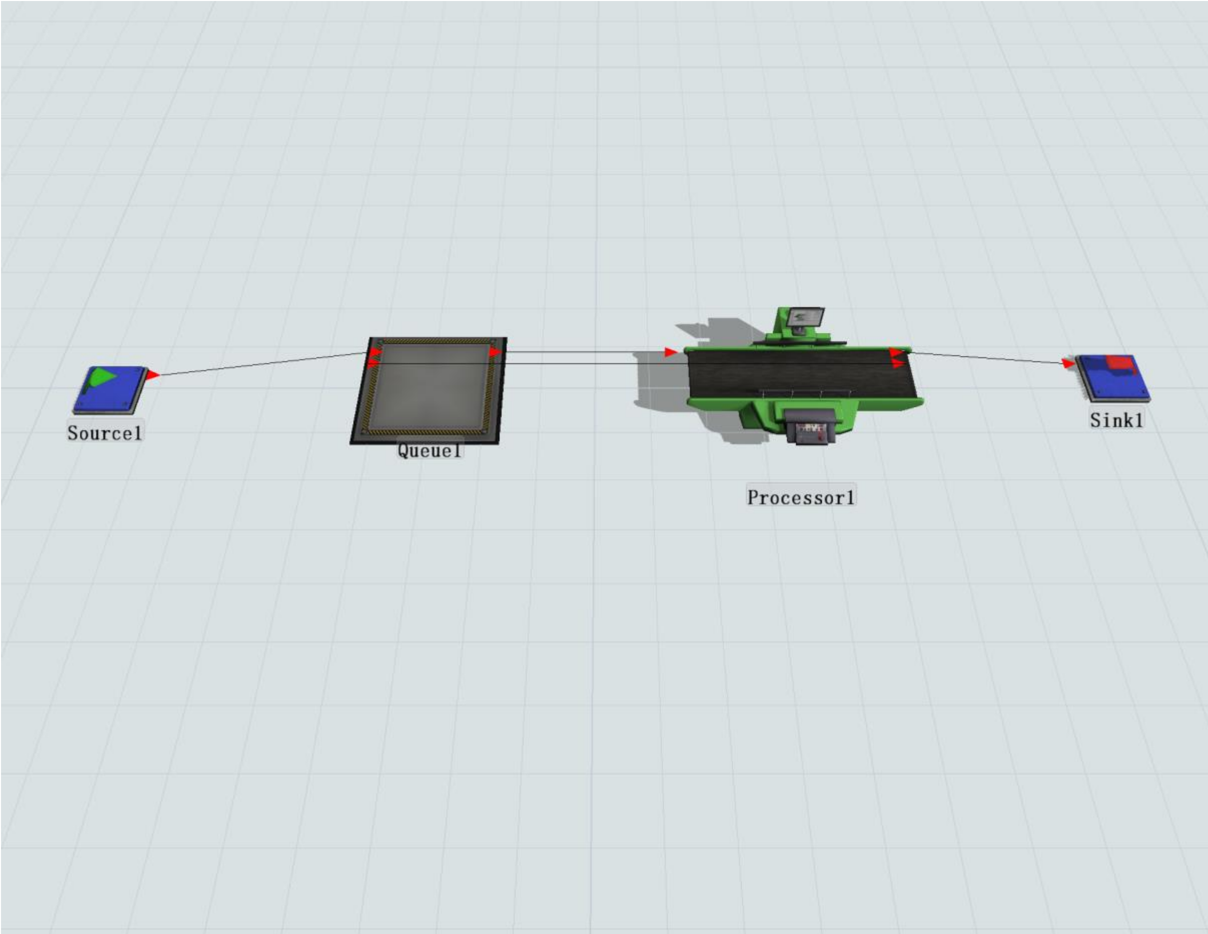

Figure 4.1 Layout of M/M/1/inf system

In order to make the process line in an appropriate working mode, some relevant data from the last section should be set into the corresponding working stations. For the first component 'Source', because the arrival rate is 4 pieces per hour that means 15 minutes per item (The basic time unit is minute in this model), only one parameter needs to be changed in the software is inter-arrival time. Due to the M/M/1 system, the exponential distribution is chosen. At the mean time, because the coefficient of variation of interarrival time equals to 1, the location for the source is zero and the scale is 15 and no any other changes. As the following figure 4.2 shown:

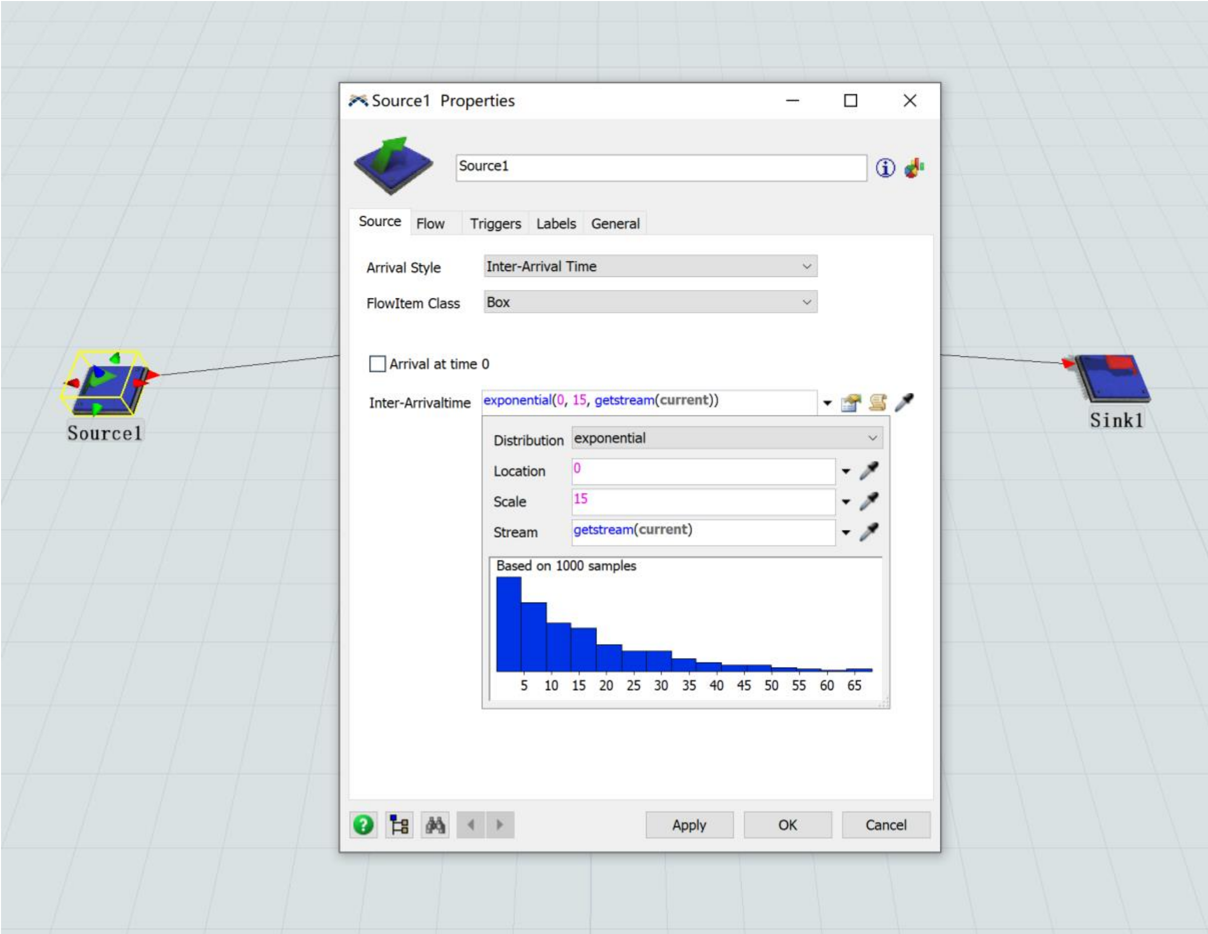

Figure 4.2 Source setting for M/M/1/inf

For the component 'Queue', because it is an unlimited storing area in this part, the parameter of 'Maximum Content' is 1000.

Considering about large variety of productivities, the time of failures, setup and reworking should be added as well besides the process time. As the source setting, the process time is still satisfied with the exponential distribution with the scale 12 minutes per item and the coefficient of variation of effective process time equals to 1, the location is zero as well. For the setting of the setup time, the exponential distribution is used similarly with 6 minutes per shift between 10 items, and because coefficient of variation of setup time is 1, it is neglected as the figure 4.3 shown:

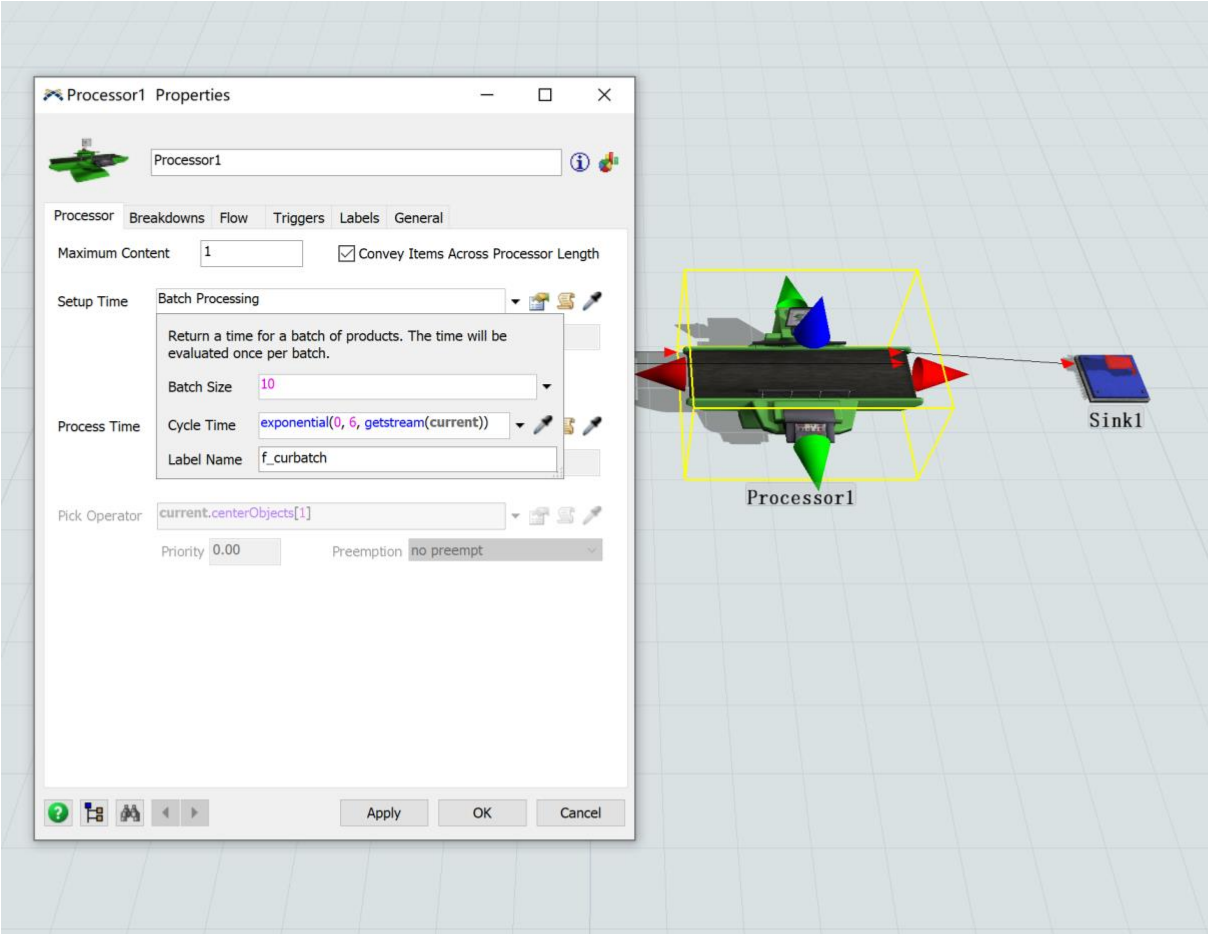

Figure 4.3 Processor setting 1 for M/M/1/inf

While setting the detailed parameters in failure, we have to use MTTR/MTBF function that is to add a list in the software. As known of the mean failure time 4 hours (240 minutes) per failure, after 20 minutes repairing, the production line goes on like the originally. The first failure time is almost the same as the second down time that is average failure time between two failures. In the system, the repair time is actually equal to up time. Coefficient of variability of failure time and coefficient of variability of repair time are both equal to 1 which are neglected in the whole system, as figure 4.4 shown:

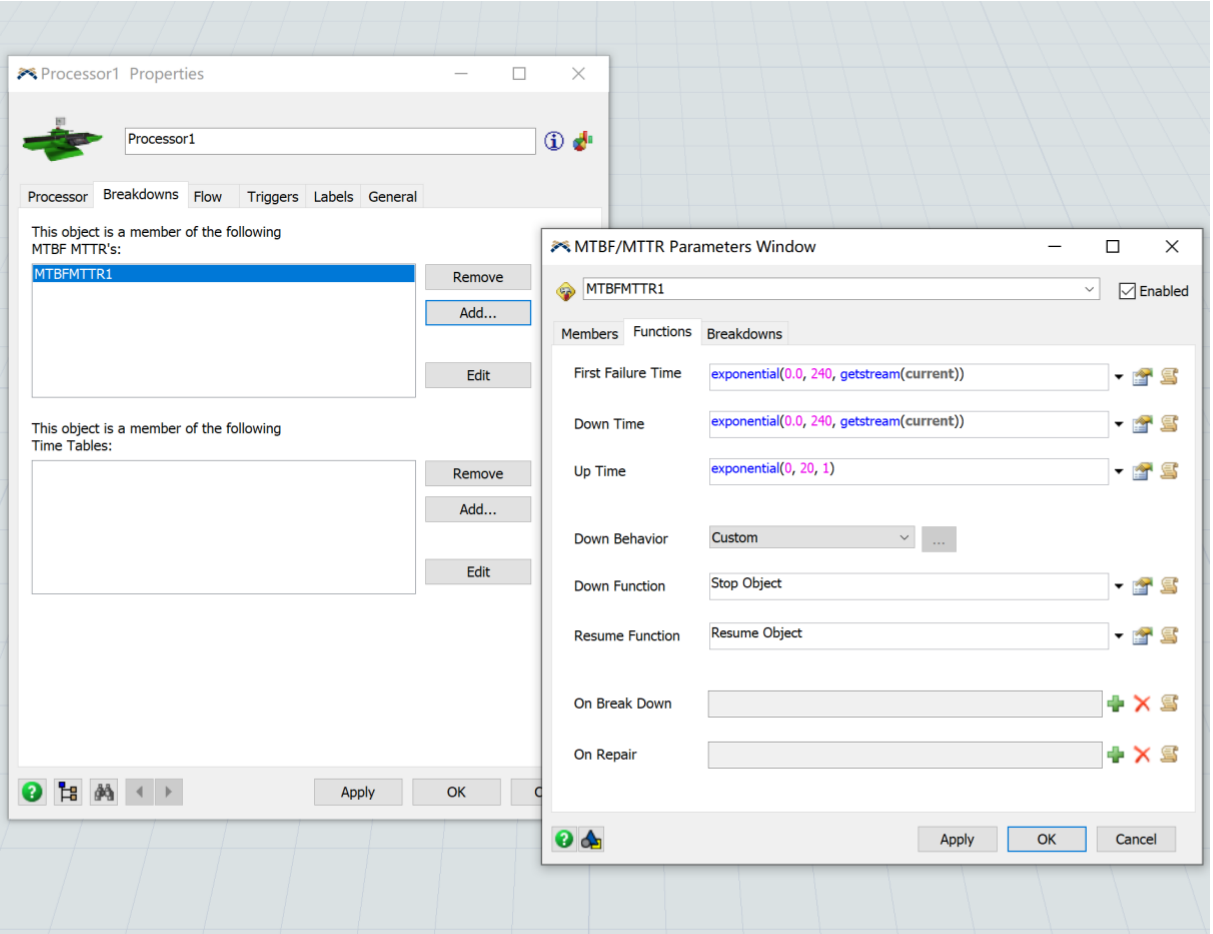

Figure 4.4 Processor setting 2 for M/M/1/inf

Reworking increases the effective process time, it reduces the utilization of the capacity of the workstation, it increases the variability and the congestion in the system. Thus, in this part, we have to reconnect the processor to the queue so that a defective item can be delivered to the processor directly, it can be set in the system in a different way, because it can not be set directly in the software.

With the given data, probability of a defective part, 5% products are for working again in the manufacturing line and the other 95% products are delivered to the sink directly which are out of the system model. As the figure 4.5 shown:

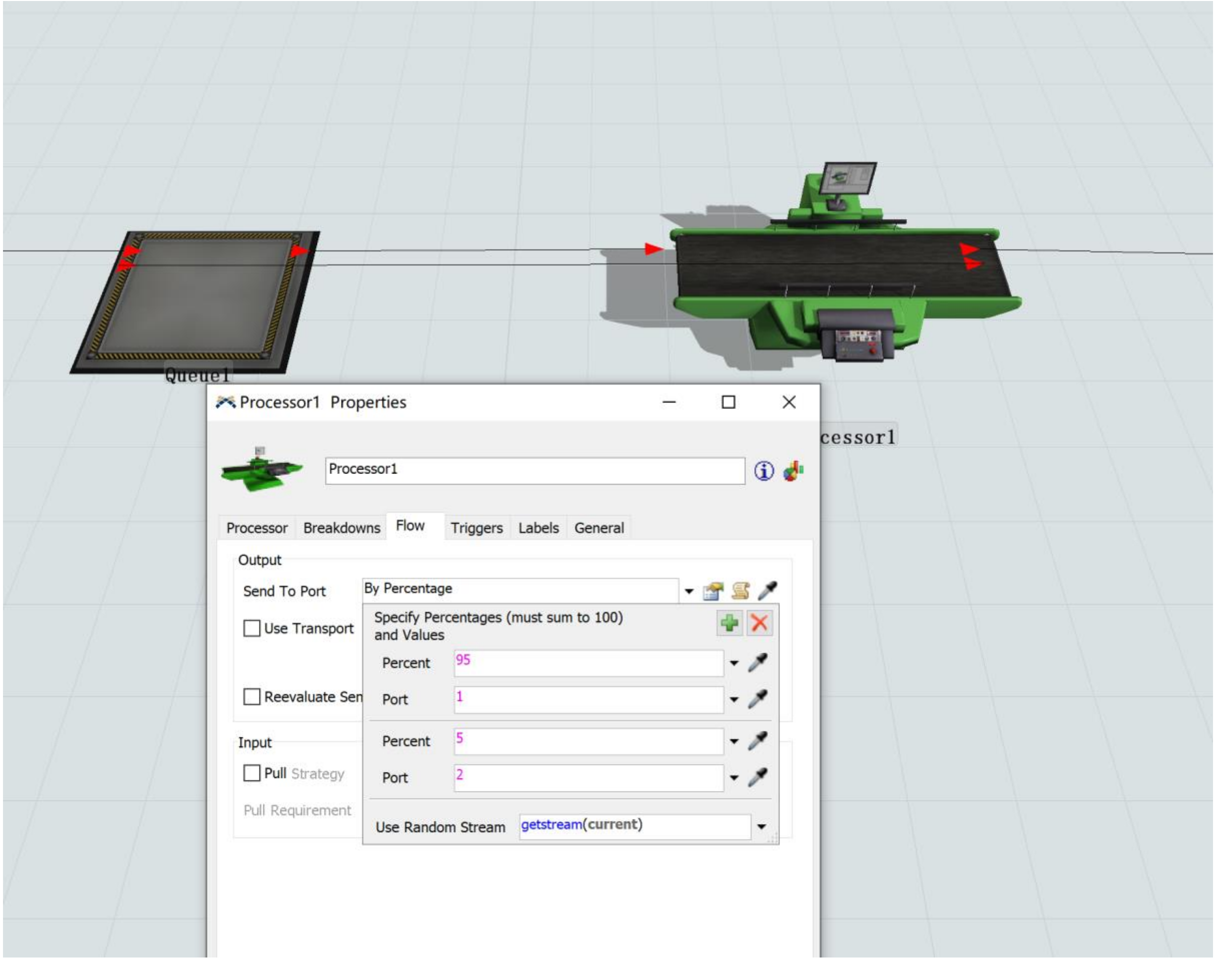

Figure 4.5 Processor setting 3 for M/M/1/inf

4.2. Buffered model development (M/M/1/b)

The most different point between M/M/1/inf system and M/M/1/b system is that buffer area (or storing area to be said) is limited in the later system because of lacking enough area in the realistic situations for a factory. Relatively, in the simulation software Flexsim, for the simplification, the component of 'Maximum Content' in the 'Queue' can be modified in a suitable value for the actual needs.

However, sometimes if the value is set in a low value, the source will be blocked because the arrival rate is much higher than the process rate so that so many raw materials will be stored outside. If the value is too high, the idle rate of the processor is high as well so that the manufacturing cost will be increased indirectly. Thus, setting a suitable value of the buffer area is significant. As the figure 4.6 shown, '20' is set at first.

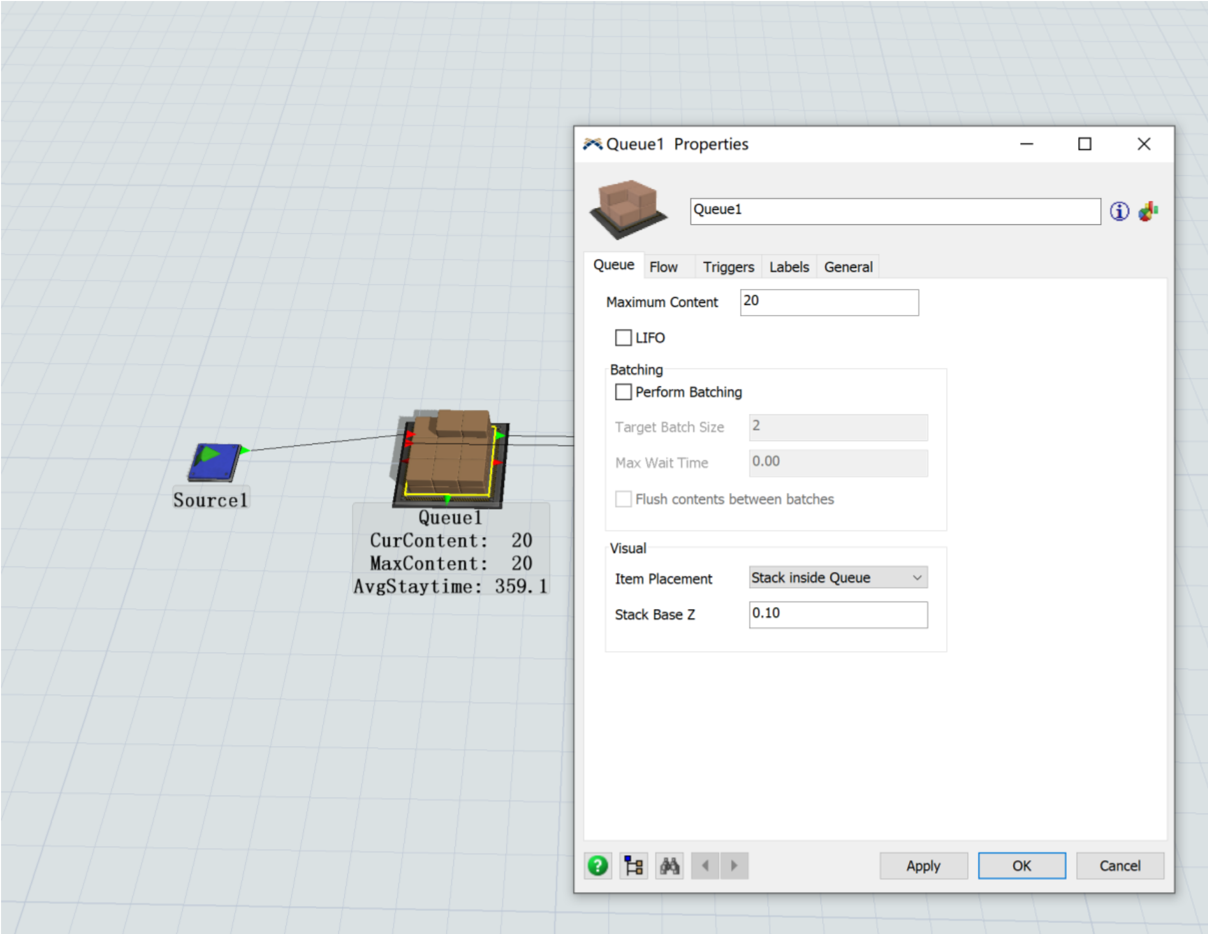

Figure 4.6 Queue setting for M/M/1/b

4.3. Line model development (M/M/2/inf)

In a professional manufacturing workshop, there is not one processing machine at least. Therefore, 2 working processors will be considered in this section.

4.3.1. Line model layout

Originally, in order to simplify the production line, we assume that there are only two different processing workstations in the simulation model so that we can observe the trend of the total system changes through using different variables to find the system bottleneck.

In this section, through using a similar method to build a new system model in the Flexsim software, as the following figure 4.7 shown:

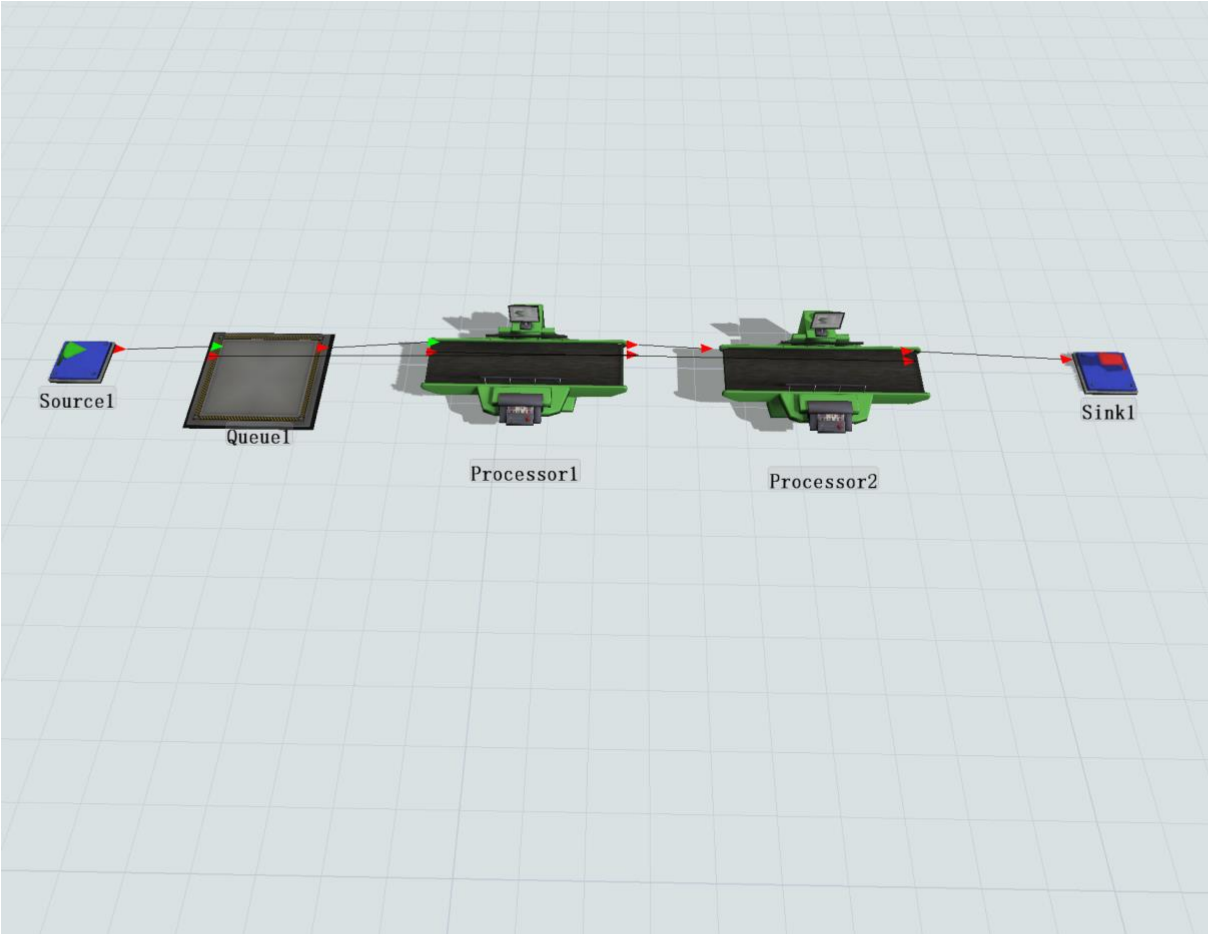

Figure 4.7 Layout of line model

4.3.2. Mathematical parameters setting

For the sake of comparing the difference between two disparate processors in the simulation system, we still use the same parameters setting of the first processor and for the other one, it is established as the following table 4.3 shown:

Table 4.3 Line model parameters

Workstation 2	Symbol	Value
Mean effective process time	t_e	15 min
Coefficient of variation of effective process time	c_e	1
Mean time to failure	m_f	3 h
Coefficient of variability of failure times	c_f	1
Mean time to repair	m_r	20 min
Coefficient of variability of repair times	c_r	1
Mean number of parts manufactured between two setups	N_s	8
Mean setup time	t_s	8 min
Coefficient of variation of setup time	c_s	1

Probability of a defective part	p	5%

From the above table, it is clearly seen that almost every parameter from the workstation 2 is totally different from the first workstation. For the failure, mean effective process time is 15 minutes which is bigger than the workstation 1 with a more frequent failure every 3 hours and it need 20 minutes to be repaired. At the mean time, for the setup time of the system is 8 minutes every 8 items compared with 6 minutes per 10 items of the first workstation. However, the probability of a defective part is the same as the former workstation.

4.3.3. System block and bottleneck

After a long term running (simulation in 10 days), it is found that so many items will be blocked in the line waiting to be operated by the second workstation. As a result, adding a new empty buffer area between these two workstations is an effective method to solve this problem.

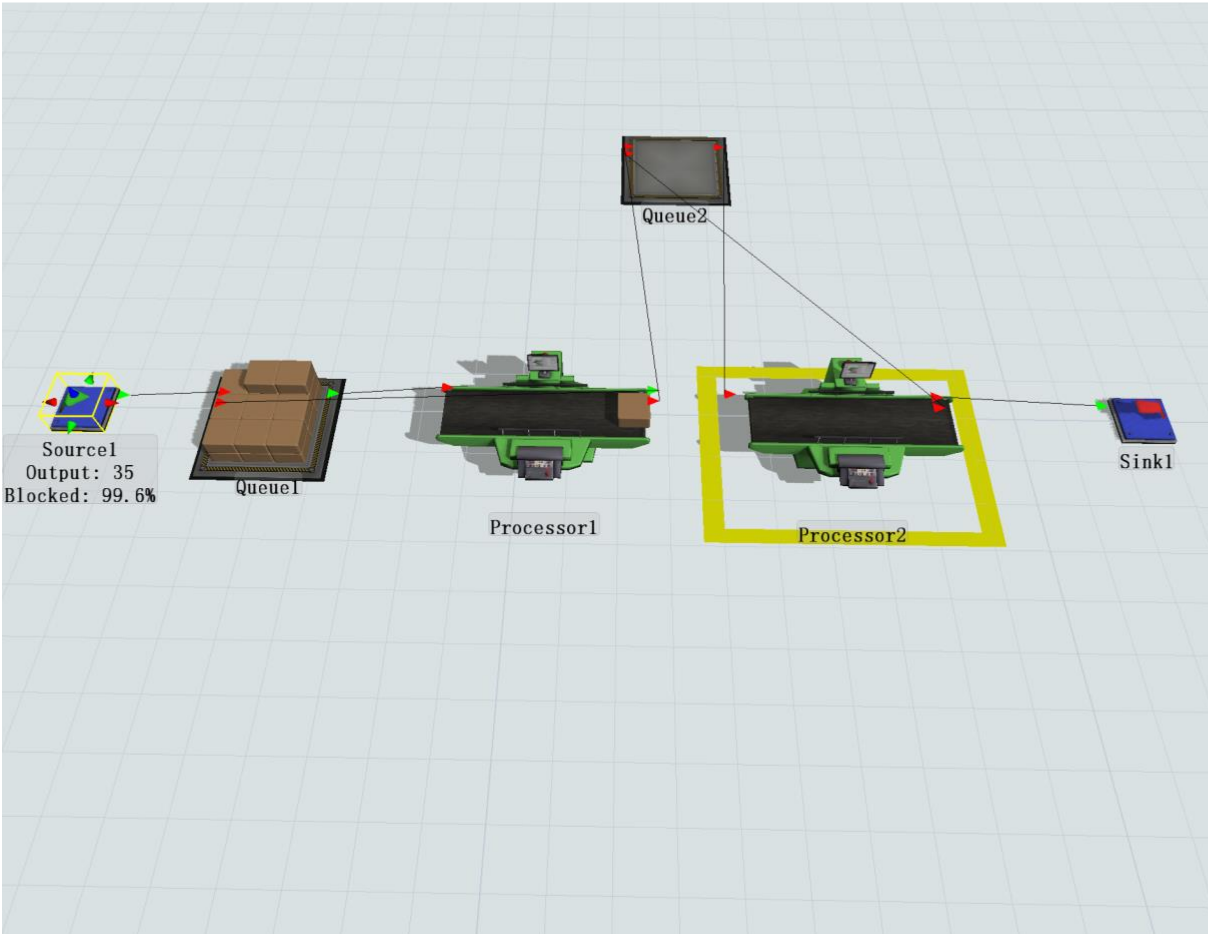

Figure 4.8 Solution to system block

From the figure 4.8, in the statistics panel, we can see that 'source' are blocked seriously. After adding a new buffer area, the complete simulation model becomes more effective so that much more items are waiting in the component 'Queue 2' to be processed into the 'Processor 2' and the idle rate can be decreased with the processing rate increased as well.

4.4. Parallel machines introduction (M/M/m/inf)

The models last paragraphs described are simplified models, with only one machine of each type and just one flow of materials or unfinished items go through. It is clearly seen that a model which is used to take into account the takt time, failure time, setup time, reworking time and more factors for those comprehensive queue systems, because those factors would not be considered normally in the simplified system.

Nevertheless, it is also apparently seen that the model is not an accurate simulation substitute of the real production line of an actual manufacturing factory, since there are much more machines with different types or different functions in the plant (for instance, conveyors, combiners, separators or more) and more orders are produced from the outer source which indicates larger batches of items in the plant can be processed at the same time with same takt time result.

So as to model and simulate on the Flexsim with a complicated environment, we have introduced parallel machines introduction.

4.4.1. Definition of parallel machines

When an ultimate product is developed, a raw material will be processed by two or more manufacturing process machines (or working processes), such as combination, cutting, etc., simultaneously, then it will become a finished product after these working processes. This is called line production.

However, in order to improve the productivity of the workshop, or for solving the bottleneck of the whole process, there should be two or more production lines in the plant to satisfy customers' needs while these two or more lines can work at the same time. Thus, it is performed as a parallel model which two or more lines will not be affected by each other.

Through a simple comparison from the last section, we can find that almost all the parameters of 'Processor 2' which is a bottleneck of the simulation model are worse than 'Process 1', thus, it is obviously feasible to purchase a new processor for the system. All in all, in the modern manufacturing factory, the plan of parallel processing machines is an effective method to be considered.

4.4.2. Parallel model layout

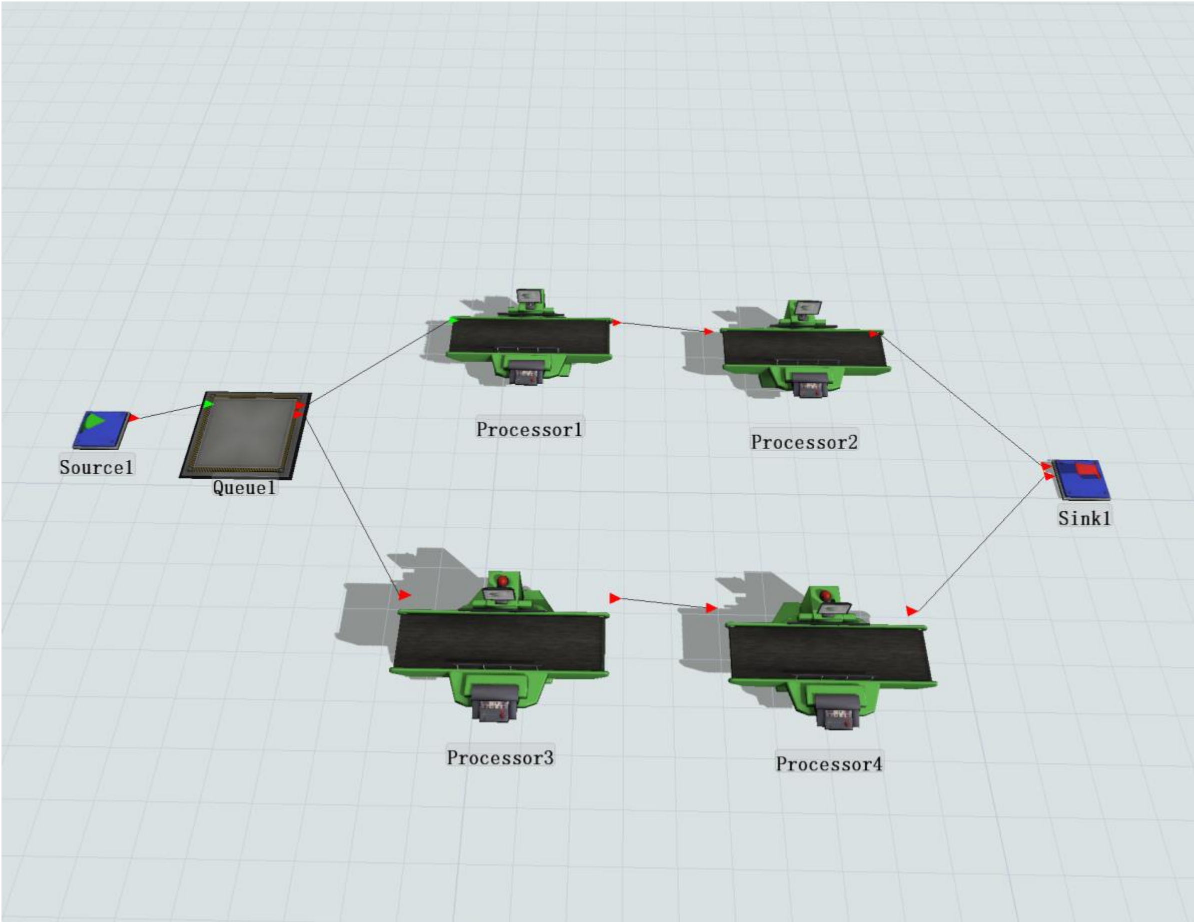

Figure 4.9 Parallel model layout

In Figure 4.9, it is a simplified layout of a parallel model in a classic production line of a factory. The working path of an ultimate product is from the source to the sink. The first path is that a raw material will be received at the 'source 1' after a certain amount of waiting time at the 'Queue 1', it will be sent to the 'Processor 1' for the first working process and then with a second process from the 'Processor 2' and finally it will be delivered to the sink, means to the market. For the second path, it is similar to the first, but a raw material will be sent to the 'processor 3' and 'processor 4' directly instead of sending to 'processor 1' and 'processor 2'.

5. Analysis of queue models

5.1. Difference between simple buffer models

5.1.1. Results of M/M/1/inf system

As described simulation layout and parameters settings in the last paragraphs, the results of the M/M/1/inf system are almost same, since there is enough buffer area for raw materials waiting to enter the processor from the given data.

In the result part, it is assumed that the total duration of working process is 30 days (43200 min) and it will not be blocked due to the high inter-arrival rate and large buffer area and the result of the system is as the following figure 5.1 shown:

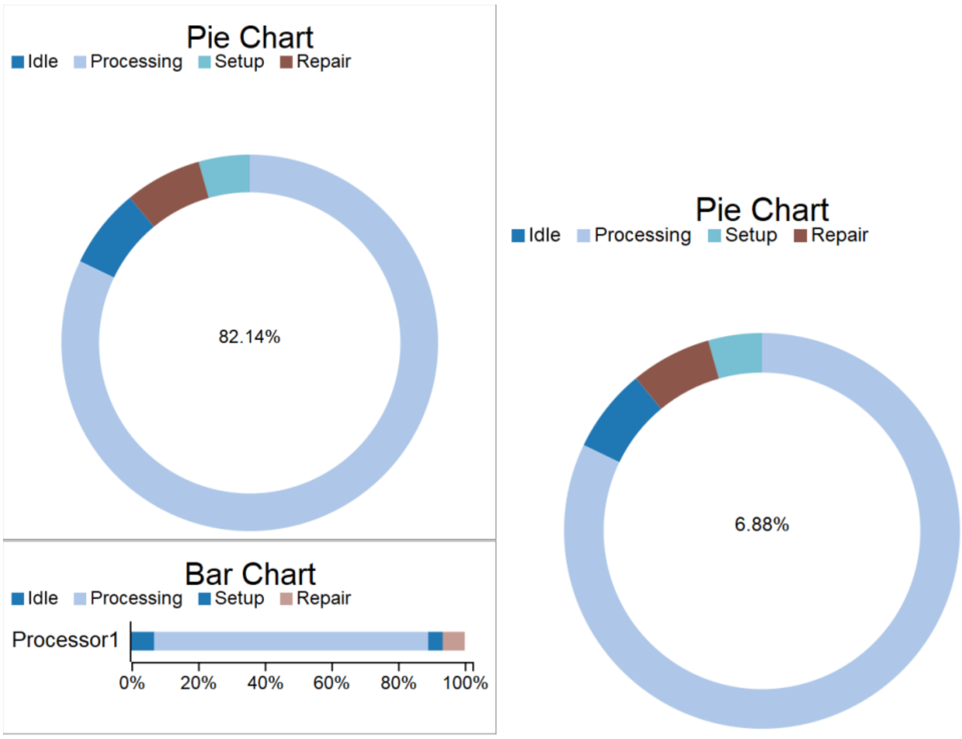

Figure 5.1 Processing and idle rate of M/M/1/inf

After running a period of 30 days (virtually in the software), from the above figure, it is clearly seen that the processing rate is 82.14% while the idle rate is 6.88% in the simulation system which the result is acceptable.

There is no doubt that the setup time and the repair time (failure time instead) cannot be neglected which are 4.54% and 6.46% respectively. With increasing the gross periods, these two factors will be kept in a constant increasing percentage.

5.1.2. Comparison to M/M/1/b model

Due to the limitation of the buffer area, considering about saving cost for the plant, which is in terms of the parameters of 'Maximum Content' is set under 20 that leads to a logistics problem. The simulation system blocking will be appeared that many items need to be waited with much more time and then to be processed.

With taking into account of the factor of blocking, the results should be divided into 4 periods under 12 hours (720 min), 1 day (1440 min), 7days (10080 min) and 30 days (43200 min). The reason of dividing into four periods is that the system is simulated according to an actual working shift and workers change under 12 hours and the plant production plan is developed in a week and a month.

And then it would be better to calculate the maximum content of buffer area that the simulation system will be reached.

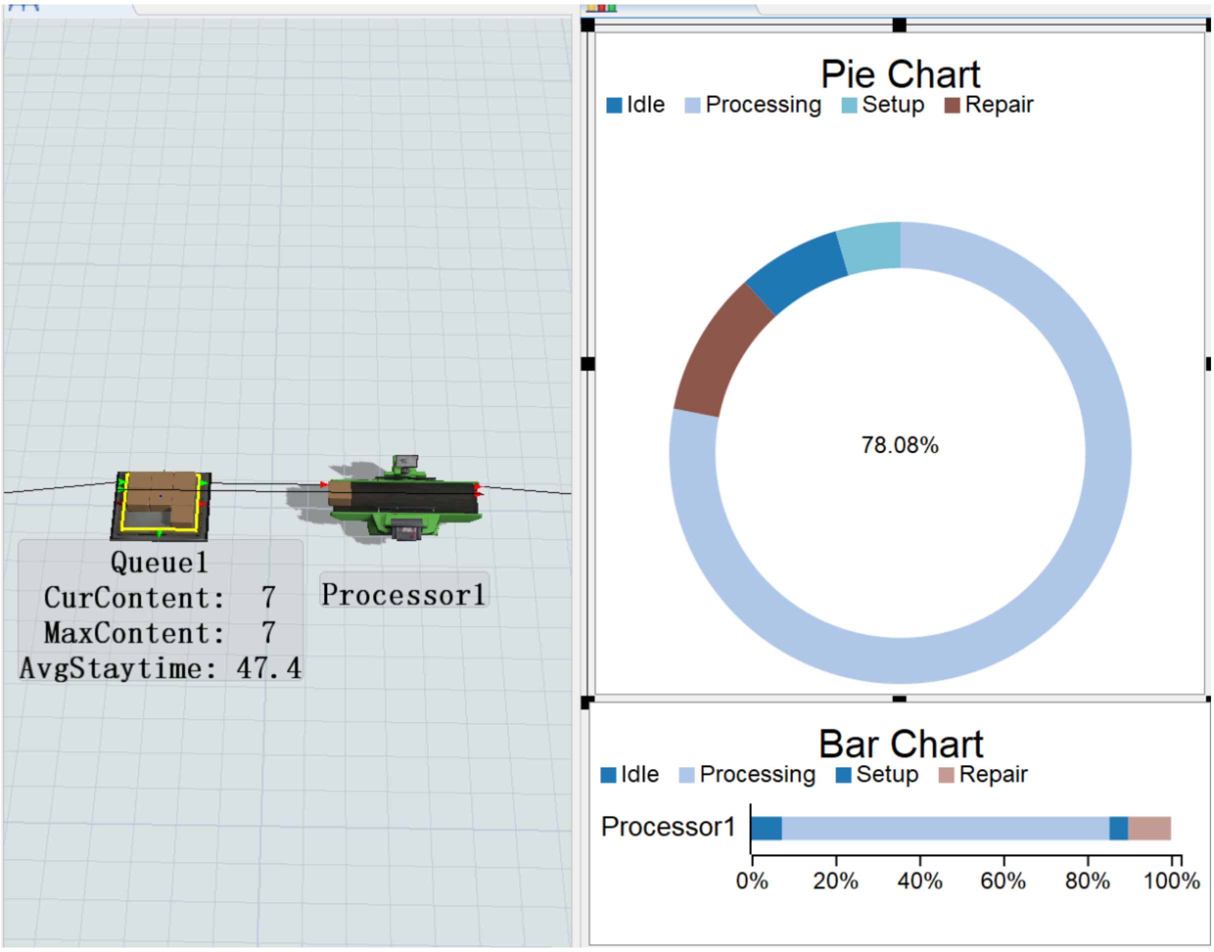

Figure 5.2 Working results 1 for M/M/1/b

When the final time is set under 12 hours, from the figure 5.2, it is distinctly seen that the processing rate is about 78.08% and the idle rate is close to 7.24% while the setup rate is 10.16% and repair rate is about 4.52%.

While the maximum content appears in the time point 720 minutes which reaches 7 while the average stay time is about 47.4 minutes.

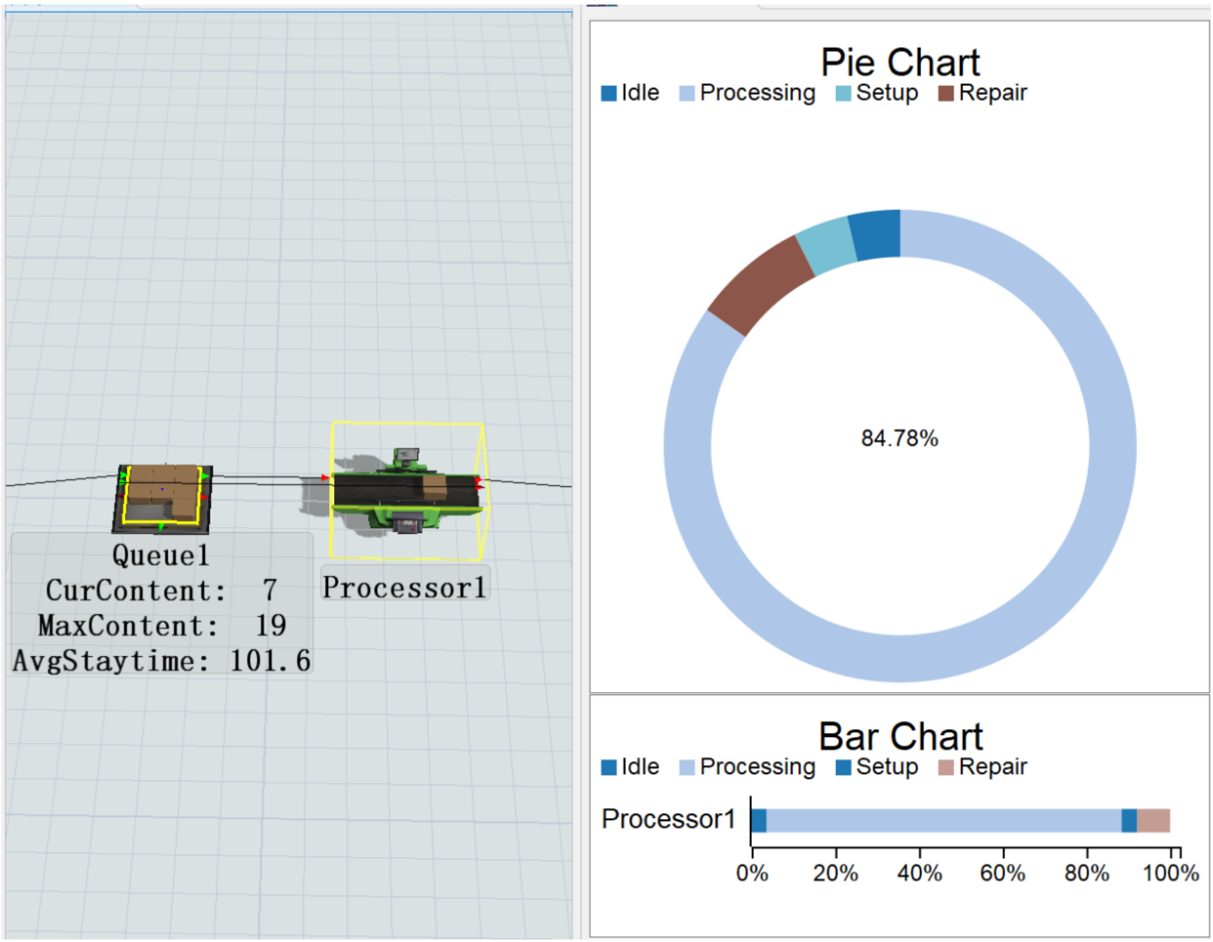

Figure 5.3 Working results 2 for M/M/1/b

After running 12 hours, the final run time is reach 1440 minutes, from the figure 5.3, it is clearly seen that the processing rate is about 84.78% and the idle rate is close to 3.62% while the setup rate is 3.75% and repair rate is about 7.85%. While the processing rate is keep increasing trend with the same as the repair rate. However, the setup rate and idle rate are both decreasing slowly.

Through a simple comparison of these two working shifts (half day and one day), due to the limited buffer area, the maximum content is even reach 19 which is close to the setting number 20 while the average stay time is about twice of the first working shift.

However, in these two working shifts, the maximum content of buffer area is not full, the system blocking phenomenon is not appeared.

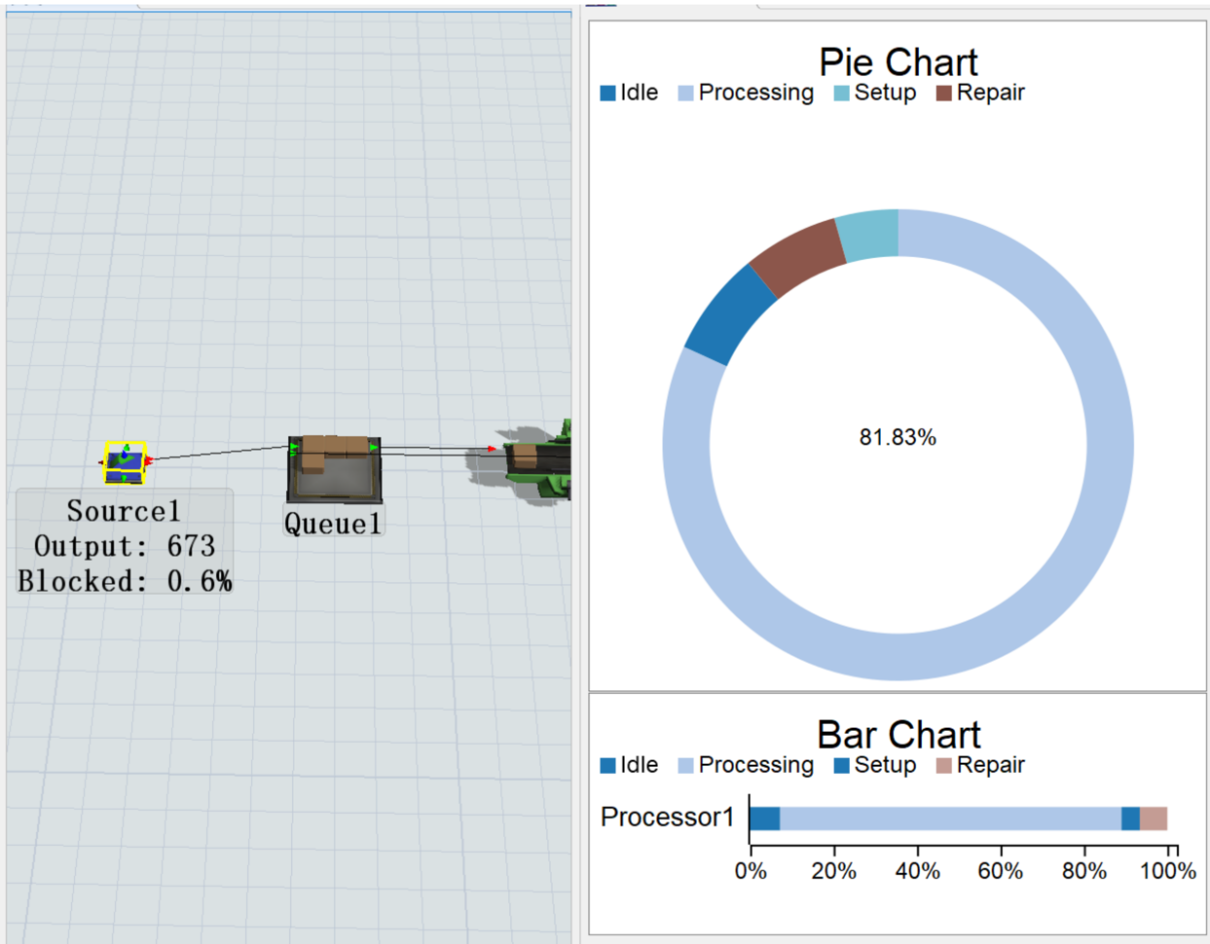

Figure 5.4 Working results 3 for M/M/1/b

As a regular working production plane, the final run time is set in 7 days (10080 minutes), from the figure 5.4, it is clearly seen that the processing rate is about 81.83% and the idle rate is close to 7.19% while the setup rate is 4.38% and repair rate is about 6.6%.

By a simple observation, due to the limited buffer area, the maximum content is reached 20 while the average stay time is 94.6 minutes. Due to a long working shift period, the maximum content of buffer area is filled with items, the system blocking phenomenon is appeared where the blocked rate is about 0.6%.

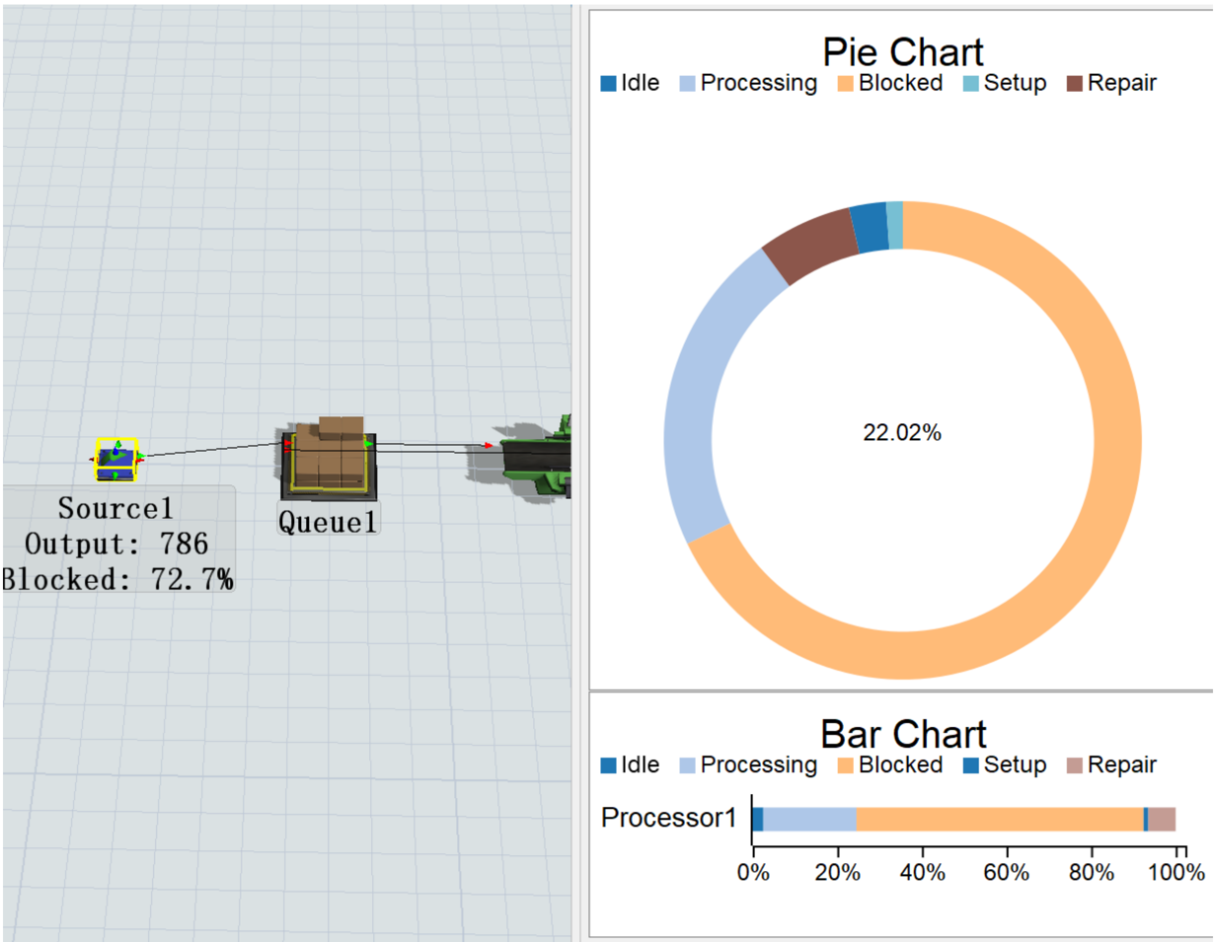

Figure 5.5 Working results 4 for M/M/1/b

From the figure 5.5, the final working time is reach in 30 days (43200 minutes), it is clearly seen that the processing rate is only about 22.02% and the idle rate is close to 2.51% while the setup rate is 1.12% and repair rate is about 6.46%. The largest factor of the system is the blocked rate which reaches 67.88% in the processor side while it is reached at 72.7% in the source side.

By a simple observation, due to the limited buffer area, the maximum content is reached 20 while the average stay time is 93.2 minutes.

5.1.3. Expansion of buffer area

In order to solve the above-mentioned problems with increasing production efficiency and decreasing idle rates, one of solutions is to enlarge the buffer area. Originally, we have set the maximum content of the 'Queue' is 20, with considering about the manufacturing cost and the economic benefit comprehensively, we decide to set the number as 40 instead.

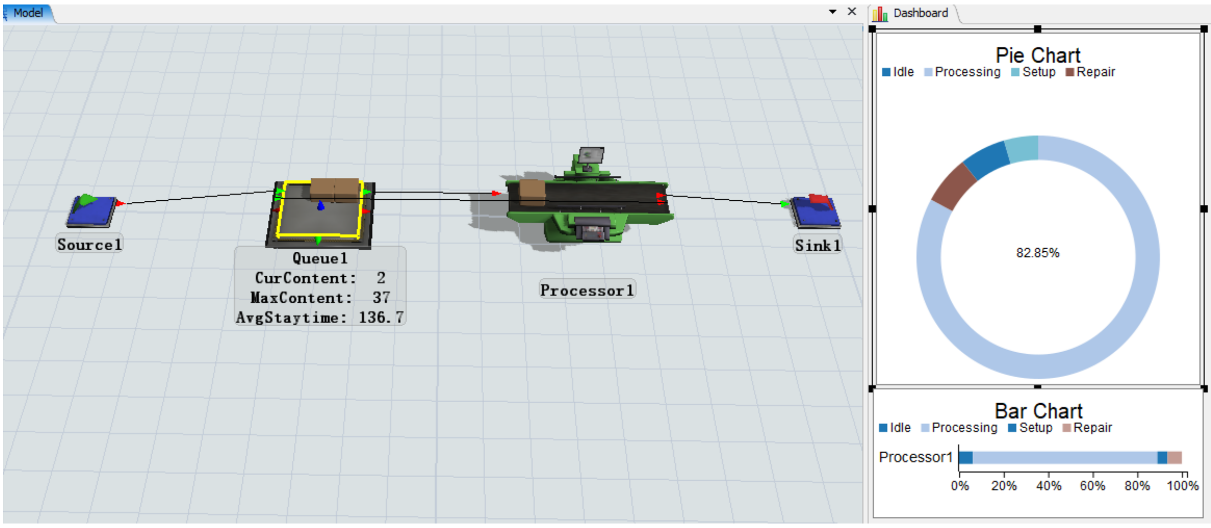

Figure 5.6 Result of changing maximum content of buffer

From the figure 5.6, when the maximum capacity of the buffer area is changed into 40, with working 30 days, the maximum content is 37 with the average stay time 136.7 minutes for the whole manufacturing process. While the idle rate is 6.15%, the percentage of repair time is 6.46% and percentage of setup time is about 4.54%.

It is clearly seen that the processing rate of the processor is increased into 82.85% and the block rate is vanished compared with 20 (maximum content of queue). In order to improve productivity and save manufacturing cost, choosing 40 as the maximum buffer area is advisable.

5.2. Line model analysis (M/M/2/b)

5.2.1. Results of line model (M/M/2/b)

In the paragraph 4.3, we have already defined a simple line model, however, considering the effect of repairing machines and the probability of defective parts, it is better to add an independent buffer area between processor 1 and processor 2, as the following figure 5.7 shown where the parameters of these two queues are set identically.

With this time, time domain has been divided into 2 parts which is 12 hours (720 minutes) and 7 days (10080 minutes).

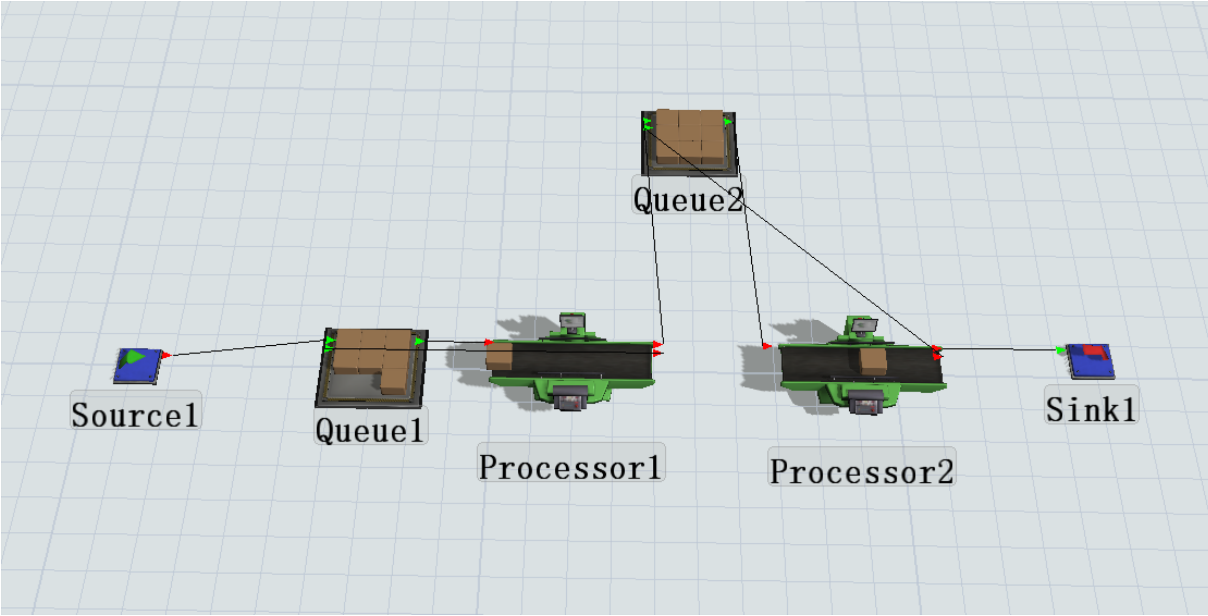

Figure 5.7 New line model layout

When time period is set under 12 hours, from the figure 5.8, the maximum content of queue 1 is 7 while average stay time is 47.4 minutes and queue 2 is 10 pieces and 56.7 minutes respectively.

For the manufacturing rate of these two processors, the processing rate of processor 1 is 78.08%, the idle rate is 7.24%, the setup rate is 4.52% and repair rate is 10.16% while for the processor 2 is 78.60%, 6.4%, 6.18% and 8.82% respectively.

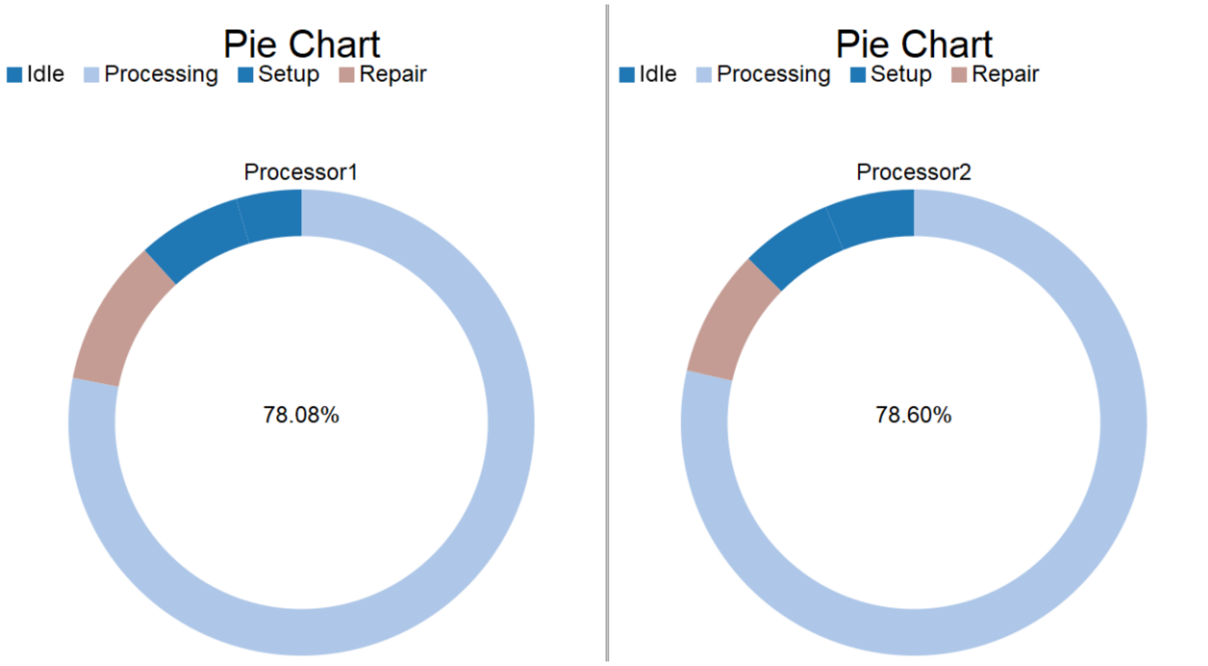

Figure 5.8 Manufacturing rate for 12 hours shift

When the time period is set into one day, the results of two processors are increased. Which the processing rate are about 84% and it is similar to M/M/1/b system. The results of two shifts 12 hours and one day are nearly similar, thus, in this time only the shift 12 hours and 7 days will be compared.

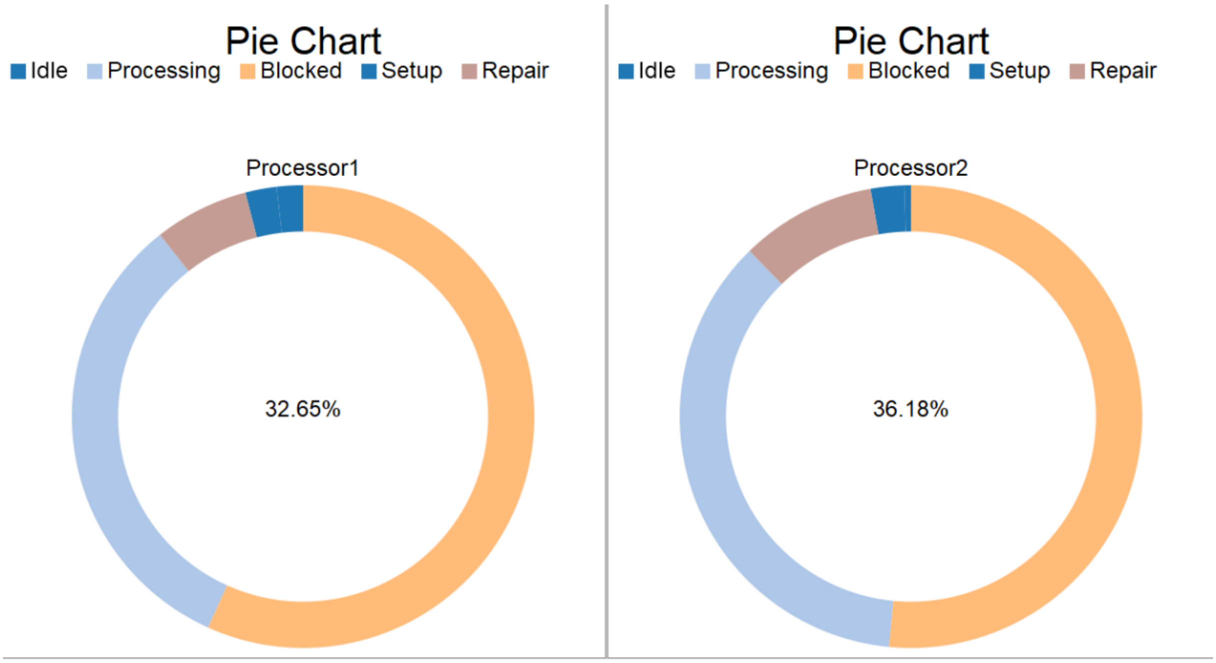

Figure 5.9 Manufacturing rate for 7 days shift

From the figure 5.9, the final working time is reach in 7 days (10080 minutes), it is clearly seen that the processing rate is only about 32.65% and the idle rate is close to 1.84% while the setup rate is 2.18% and repair rate is about 6.6%. The largest factor of the system is the blocked rate which reaches 56.73% for the processor 1. While the corresponding rate for the processor 2 are 36.18%, 0.46%, 2.35%, 9.5% and 51.51%.

From the system, all the buffer area is employed, that means no more available queue is in the system, as the same time, the input (source) is blocked as well and the block rate is about 55.2%.

5.2.2. WIP and throughput of line model

In this part, for the sake of finding a solution of the block rate, work in process (WIP) and throughput of the line model should be considered as well.

Table 5.1 Average WIP results for the system

Time period (shift)	Processor 1	Processor 2	Output (Sink)
12 hours	0.93	0.94	0.9
1 day	0.96	0.97	0.95
3 days	0.95	0.99	0.98
7 days	0.98	1	0.99
14 days	0.99	1	1
30 days	1	1	1

On account of the existing of the block rate, WIP should be divided much more so that the results could be analyzed easily. From the above table 5.1, it is classified into 6 parts instead of the previous 4 parts that 3 days and 14 days are included.

For short time period like half days, 1 day and 3 days, WIP of processor 1 and 2 are both smaller than 1 and of course WIP of processor 1 are never greater than processor 2 that is the difference of processing time between two processors 1 and 2. With the increase of time, the final WIP of both processors and output are equal to 1.

As the same time, throughput and throughput per hour of two processors are shown in the following table 5.2 and table 5.3,

Table 5.2 Throughput results of the system

Time period (shift)	Processor 1 (pieces)	Processor 2 (pieces)	Output (Sink) (pieces)
12 hours	44	34	32
1 day	94	69	66
3 days	280	238	229
7 days	282	238	229
14 days	282	238	229
30 days	282	238	229

Table 5.3 Throughput per hour results of the system

Time period (shift)	Processor 1	Processor 2	Output (Sink)
12 hours	3.67	2.83	2.67
1 day	3.92	2.88	2.75
3 days	3.89	3.31	3.18
7 days	1.68	1.42	1.36
14 days	0.84	0.71	0.68
30 days	0.39	0.33	0.32

Through analyzing the throughput, it is clearly seen that because of the maximum capacity of the buffer area, with time period increasing, the ultima throughput of the system keeps constant as 229 pieces when the parameters of time are set over 3 days. With time increasing, the throughput per hour is decreased.

In other words, in addition to considering about the buffer area, processing time of two different processors are important, especially for the low efficiency processor. So as to improve the throughput, reducing setup time and failure probability is a wise choice.

5.3. System optimization and improvement

Bottleneck workstation is often fully loaded during the entire production line. Therefore, as long as the tempo of one process is higher than the production tempo of the entire production line so that the overall production efficiency will be low as well and the operation load will be uneven in some processes, which will affect the smooth operation of the production line. Thus, in order to equalize the operation of each process in the production line and improve the efficiency of the production line, the improvement of the bottleneck station is often a breakthrough to improve the manufacturing efficiency of the production line.[3]

Compared with two processors, the process time, mean time to failure, repair time and setup time for processor 2 are all worse than processor 1. From the above paragraph 5.2, therefore, processor 2 is defined as a bottleneck station.

5.3.1. Queue area expansion

The reason why this block phenomenon appeared is that while the queue 2 is full of parts which are prepared to be processed, the processor 2 has just produced a defective product that leads to a congestion in the whole production line.

In order to solve to problem, it is supposed that there is no limitation in the buffer area and the results of the system will be changed into the following figure 5.10 shown, in particular, the maximum content of two queues are defined as 1000 (unlimited).

From the figure, 30 days' work period is defined in order to get the exact system results while changing the buffer area into the maximum. The block rate of the system has been vanished and the processing rate of processor 1 is 82.85% and 84.14% for processor 2 respectively. At the meantime, Idle rate of processor 1 is 6.15% and 0.11% for processor 2, the percentage of setup time of processor 1 is 4.54% and 5.8% for processor 2 and percentage of repair time is 6.46% for processor 1 while 9.95% for 2.

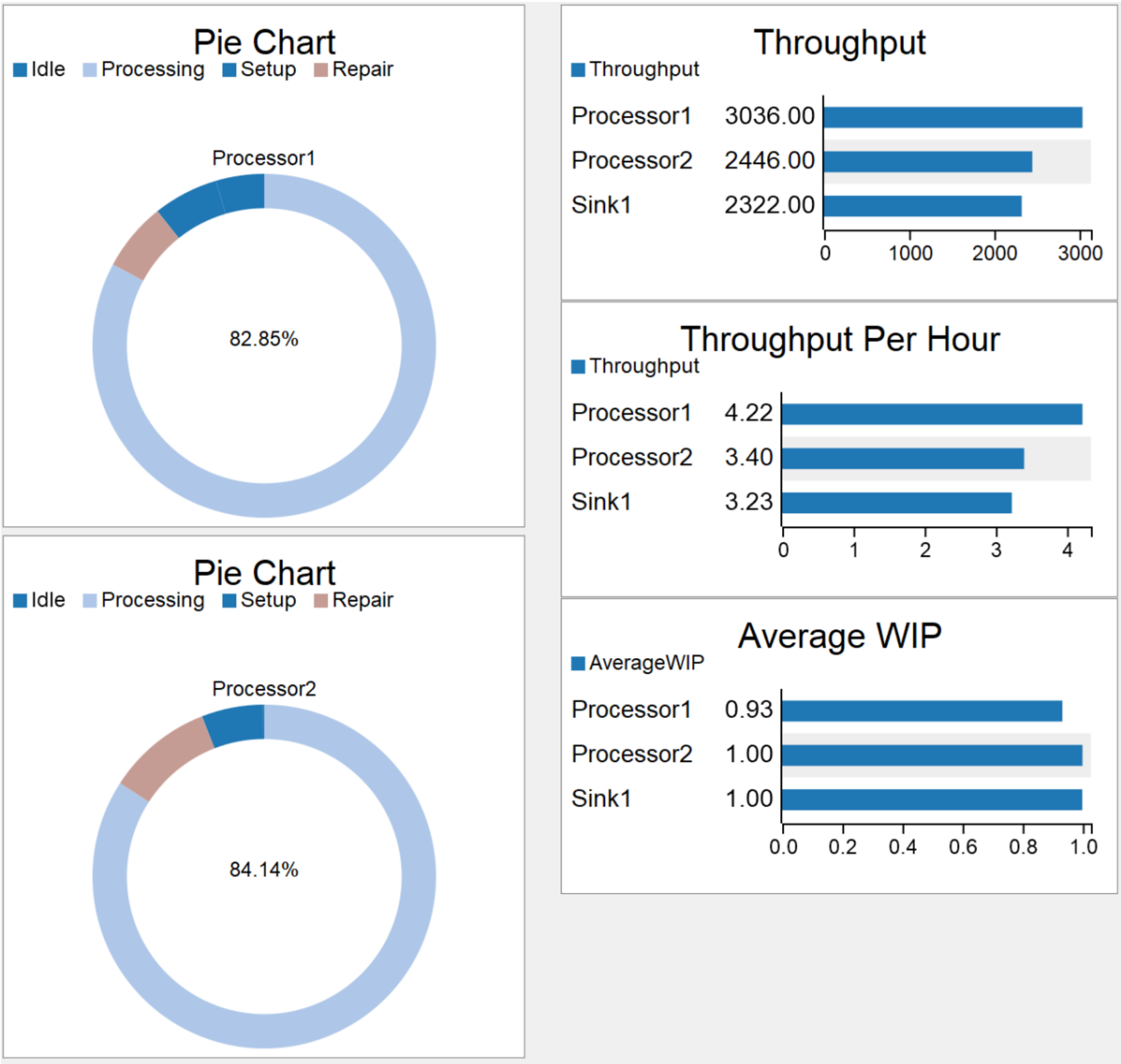

Figure 5.10 System results with unlimited buffer area

For the average WIP and throughput, as the figure shown, average WIP for processor 1 is 0.93 while 1 for both processor 2 and the output. For processor 1, the final throughput is 3036 pieces while 2446 pieces for processor 2 and 2322 pieces for the output (sink).

Especially for the processing rate 82.85% (processor 1) and 84.14% (processor 2), it is feasible for the manufacturing system running. However, in order to reach this result, the maximum content of queue 2 is reached up to 560 pieces and the stay time is about 3802 minutes while the maximum content of queue 1 is only 37. Thus, considering about the manufacturing cost and layout of the whole plant, this solution is not advisable.

5.3.2. Improvement of processor efficiency

For reaching this purpose, keeping the previous queue capacity as 40, the simplest way to eliminate the congestion is to improve manufacturing efficiency for those bottleneck processors. As the above data shown, the processing time of processor 2 is 15 minutes per piece which is far slower than processor 1.

It is supposed that the new processing time of the processor 2 is set as 12 minutes per piece which is equal to the processor 1 that means it is decreased 20% compared with the previous processing time.

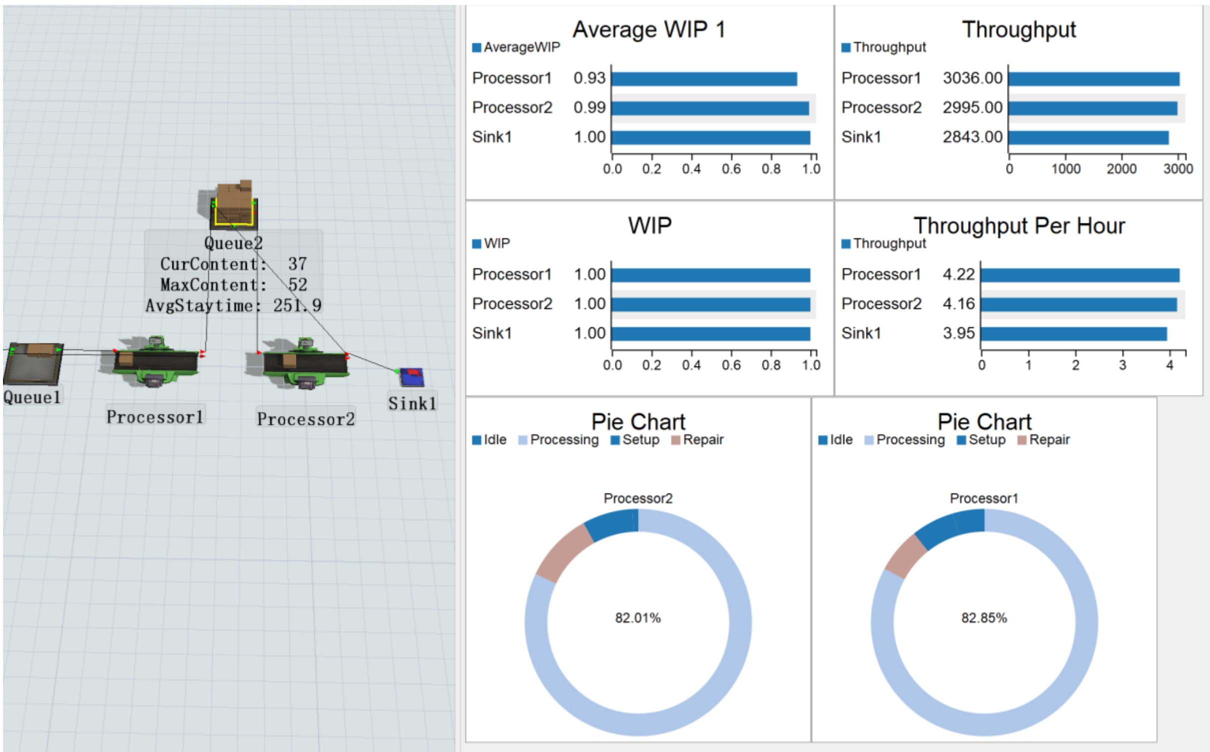

Figure 5.11 Results with decreasing processing time

From the above figure 5.11, the maximum content of queue 2 is even arrived at 52 which is greater than 40, however, this is still acceptable. Compared with expanding queue area in the paragraph 5.3.1, the percentage of processing time is changed from 84.14% to 82.01%, while the throughput of processor 2 is increased into 2995 pieces instead of 2446 that means the processing rate is increased.

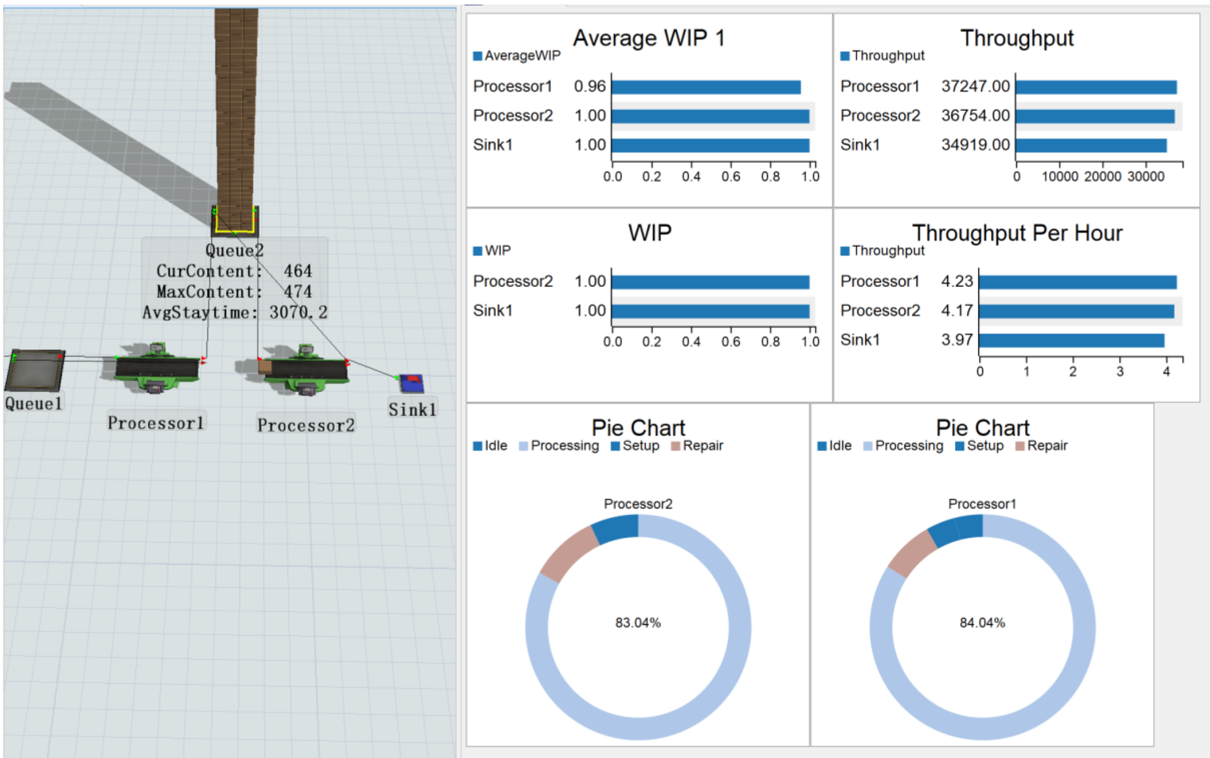

Figure 5.12 Results under 1 year

However, when the whole time period is set into 1 year, the stock of queue 2 is even reached up to 474 with average stay time 3070 minutes. With observing other results like the percentage of processing time, WIP and throughput are all under normal range.

Other than this method of reducing processing time, reducing defective rate, setup time, and repair time with increasing mean time to failure are all good ways to decrease queue area and save manufacturing cost.

As the following table 5.4 shown, it is supposed that the processor 2 can be totally upgraded by 20% from the old.

Table 5.4 New parameters defined for processor 2

New processor 2	Symbol	Value
Mean effective process time	t_e	12 min
Coefficient of variation of effective process time	c_e	1
Mean time to failure	m_f	3.6 h
Coefficient of variability of failure times	c_f	1
Mean time to repair	m_r	16 min
Coefficient of variability of repair times	c_r	1
Mean number of parts manufactured between two setups	N_s	8
Mean setup time	t_s	6.4 min
Coefficient of variation of setup time	c_s	1
Probability of a defective part	p	5%

As the following table 5.5 shown, the maximum content of queue 2 is sharply decreased into 28, when the time period is set as 30 days and 37 for the queue 1, that both are under the maximum range 40.

Table 5.5 Maximum content of the system

	30 days	1 year
Queue 1	37	107
Queue 2	28	80

While we are checking the whole year working results, the maximum content becomes to 107 and 80, which means the processor 1 is becoming a bottleneck workstation. However, the percentage of processing time, WIP and throughput of these two processors are all under the normal range.

And of course, with the development of manufacturing plants, new working processors would be purchased and added into the production line whatever parallel manufacturing lines or line manufacturing lines are used. In this case, we do not discuss about these expanding layouts.

6. Conclusion

With the dramatical development of manufacturing production lines, simulation technology is playing a more and more important role instead of traditional analytical approach in solving potential problems like bottleneck workstations, low efficiency, and etc. Flexsim, a simulation software, is used to simulate and model the predesign, virtual operation, test, and etc. of production lines. Following that, companies can analyze and get an optimal solution in the future as well.

As the above paragraphs shown, simple line model and buffered model are both deep developed and analyzed. As the production increases and the accumulation of the shift, more and more queue space is needed. At the same time, considering about saving the manufacturing cost and reasonable spatial distribution of the factory, through two different proposals, which the first is to enlarge the buffer area and the second is to improve the production efficiency no matter what reducing defective product rate, setup time or increasing mean time to failure combing with increasing the result of WIP and throughput, to have an optimal solution for solving potential problems.

In this simple research, the layout of parallel machines is only simple discussed, however, it is almost the most frequently occurring layout in modern factories instead of the line model. In that situation, though, it becomes much more complicated to solve potential problems, they will be amended finally.

All in all, as time goes, the manufacturing production line will become more complicated and the research will always be developed at the same time, and the journey will never end.

References

[1] Flexsim Software Production. (2018). Retrieved from https://www.flexsim.com/company/

[2] Hopp, Wallace J., and Mark L. Spearman. Factory Physics Foundations of Manufacturing Management. 2nd Ed International ed. Boston: McGraw-Hill, 2001. Print. Management and Organization Ser.

[3] Wenlong. Research on balance improvement of LCD production line for C corporation, 2013. Chengdu. SWJTU.

[4] Yokoyama, M. and Santos, D.L., 2005. Three-stage flow-shop scheduling with assembly operations to minimize the weighted sum of product completion times. European Journal of Operational Research, 161(3), pp.754-770.

[5] Anglani, Grieco, Pacella, and Tolio. "Object-oriented Modeling and Simulation of Flexible Manufacturing Systems: A Rule-based Procedure." Simulation Modelling Practice and Theory 10.3 (2002): 209-34. Web.

[6] Guang-zhang, G.A.O. and Jian-hua, S.U.N., 2007. The application of program analysis method in streamline balance [J]. Machinery Design & Manufacture, 7.

[7] Ye Xiaosu and Cai Yong, 2009. "Research on production line balance under lean production mode".

[8] Womack, J.P., Womack, J.P., Jones, D.T. and Roos, D., 1990. Machine that changed the world. Simon and Schuster.

[9] Oh, K.H., 1997. Expert line balancing system (ELBS). Computers & industrial engineering, 33(1-2), pp.303-306.

[10] Pierreval, H., Caux, C., Paris, J.L. and Viguier, F., 2003. Evolutionary approaches to the design and organization of manufacturing systems. Computers & Industrial Engineering, 44(3), pp.339-364.

[11] Shao Renyu. 2014. "Production line balance and optimization based on industrial engineering".

[12] Zhang Xuelong. 2015. "Work research applied to enterprise production line optimization redesign - case study". Modern Manufacturing Engineering, 3, pp.27-32.

[13] Yuan Han, Luo Yabo. 2007. "Process simulation and optimization based on Flexsim".

[14] Wang Xuelan. 2007. "Production sequence simulation of mixed flow production line based on Flexsim".

[15] Zhang Guohui and Zhang Lingjie, 2015. Simulation and optimization of mixed flow production line based on Flexsim. Logistics Technology, 34(23), pp.83-86.

[16] Qiu Yijian and Tu Haining, 2015. Research on simulation and optimization of mixed flow production line based on Flexsim and genetic algorithm. Combined machine tool and automatic processing technology, 8, pp.119-123.

[17] Nordgren, William. "Flexible Simulation (Flexsim) Software: Flexsim Simulation Environment." Proceedings of the 35th Conference on Winter Simulation (2003): 197-200. Web.

[18] Cao Yuhua, Peng Hongguang and Ma Hangyu, 2009. Application research on production line based on Flexsim simulation technology. Journal of Zhejiang University of Science and Technology, 21(1), pp.10-14.

[19] Feng Xiaoli and Liu Tongjuan, 2013. International logistics process model simulation based on Flexsim.

[20] Zhang Weide, Yan Hongsen and Xu Cheng, 2005. Production line simulation and application based on Flexsim.

[21] Wang Fuxin and Xianghao, 2010. Optimization of production line simulation based on Flexsim software. Mechanical Engineer, 11, pp.88-89.

[22] Gong Lixiong, Tan Guo and Huang Min, 2014. Simulation and optimization of motorcycle painting production line based on Flexsim.

[23] Alfieri, Arianna, Manuela De Maddis, Paolo Chiabert, and Agostino Villa. Programmazione E Controllo Della Produzione Esercizi. Torino: CLUT, 2007. Print.