Manufacturing Cost Reduction in a Filling Process of Aerosol Products

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งานวิจัยนี้มุ่งเน้นการลดค่าใช้จ่ายในการผลิตไลน์การบรรจุผลิตภัณฑ์สเปรย์ โดยใช้การพัฒนาฮิวริสติกมาช่วยในการแก้ปัญหาซึ่งมีความซับซ้อนของผลิตภัณฑ์ (สูตรและขนาด) รวมถึงวันกำหนดส่งของให้ทันกับความต้องการของลูกค้า ที่มีความผันผวนทางความต้องการสูง การลดค่าใช้จ่ายในการผลิตลดได้จากการลดเวลาปิดจบงาน ลดเวลาการทำงานของพนักงาน และงานวิจัยนี้ยังต้องการลดเวลาการล่าใช้ของวันที่กำหนดส่งของ รวมถึงการลดภาระงานของผู้วางแผน ผู้วิจัยทำการแก้ปัญหาด้วย TSP โดยใช้ฮิวริสติกแบบ 2-opt และ Node shift algorithm ในการช่วยแก้ไขปัญหา และใช้ Tabu search ในการจัดเก็บผลลัพธ์ที่ดีที่สุดของอัลกอริทึมและได้ทำการทดสอบโดยทดลองเปรียบเทียบกับการวางแผนในปัจจุบัน ได้มีการนำข้อมูลของแผนการผลิตมาทดลอง 6 ข้อมูล พบว่าฮิวริสติกที่นำเสนอสามารถลดเวลาปิดจบงานได้โดยเฉลี่ย 0.34% และลดเวลาการจ้างพนักงานได้ 4.94% และลดวันที่ส่งล่าช้าได้ถึง 24 วัน และยังสามารถลดภาระงานของผู้วางแผนการผลิตได้ประมาณ 20%

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This research focuses on the development of heuristics that help reduce the production cost of an aerosol filling process of a case study company, while satisfying all related constraints, including production capacity and due dates. The proposed heuristics are a two-phase one, where the initial solutions are first constructed based on simple dispatching rules, and, once completed, such solution is then iteratively improved by two different improvement heuristics, namely 2OPT and Node Shift. A tabu list is also embedded within such a framework to help reduce its computational time. We have assessed the performances of these heuristics based on 6 different data sets acquired from the case study company. When compared to the current practice, we find that the devised heuristics could help reduce makespan, labour cost, and delivery delay by 0.34%, 4.94%, and 24 days, respectively. In addition to these direct benefits, the devised heuristics could potentially reduce the workload of the planner by at most 20%.

Field of Study:	Engineering Management	Student's Signature ....
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TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

1. Introduction

Thailand is one of the large aerosol productions in Asia. Thailand aerosol production has increased every year. In 2019 Aluminum can fillings increased 13% while steel can fillings decreased 7% according to **Figure 1-1**.

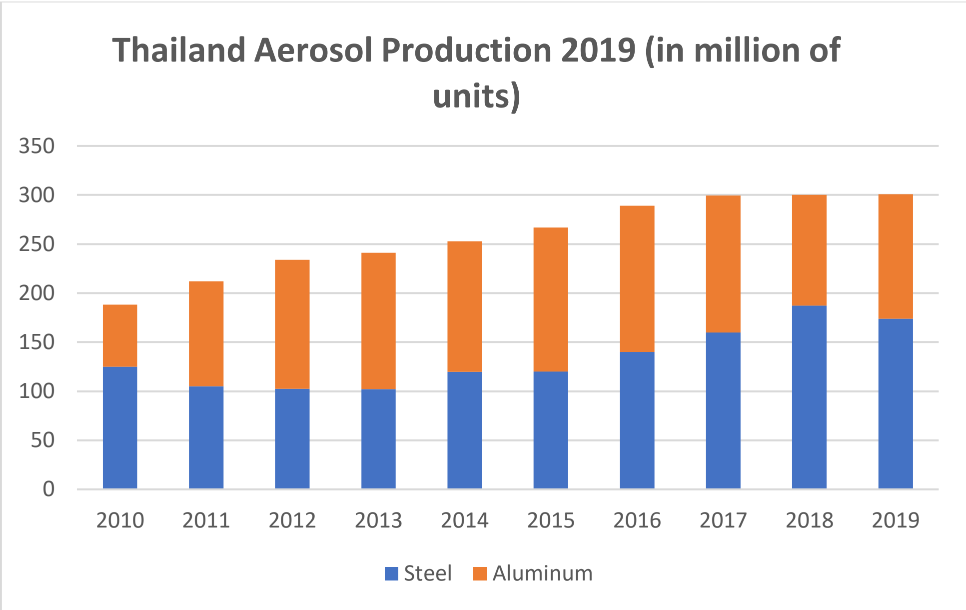


Figure 1-1: Thailand Aerosol Production 2019 (in millions of units)

According to **Figure 1-2**, market share of aerosol production has divided into 6 categories. In 2019 personal care is the largest market share following by Paint, Insecticide, Household, Industrial, and others.

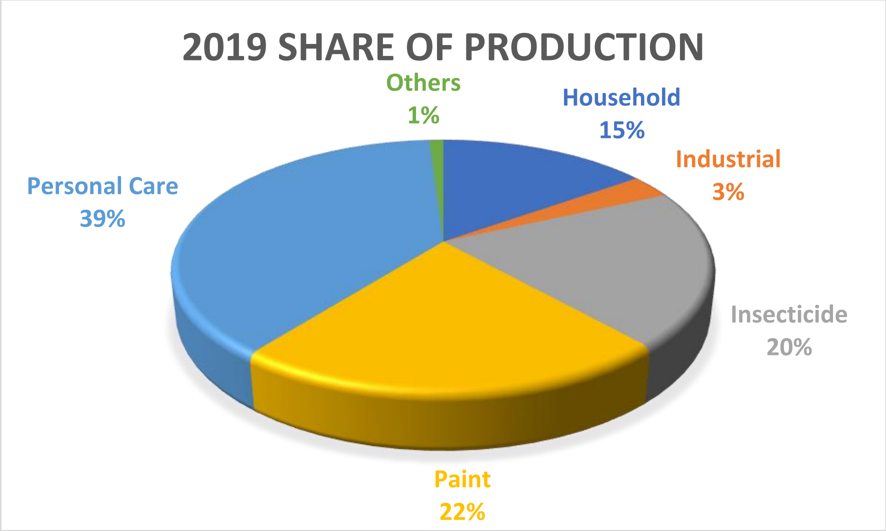


Figure 1-2: 2019 Production share in Thailand

1.1 Background

The company to be researched is a company that has operated for a long time and has been growing continuously. Cyberpax Group has established since 1958 in Bangkok, Thailand, Cyberpax Group is a contract manufacturer of wide range of products including aerosol, liquid, gel, and compound. Aerosol segment alone accounts for 90% of the total business and was divided into 5 categories: insecticide, personal care, household, automotive, and industrial. The proportion of company's sales revenue in 2019 is shown in ***Figure 1-3***.

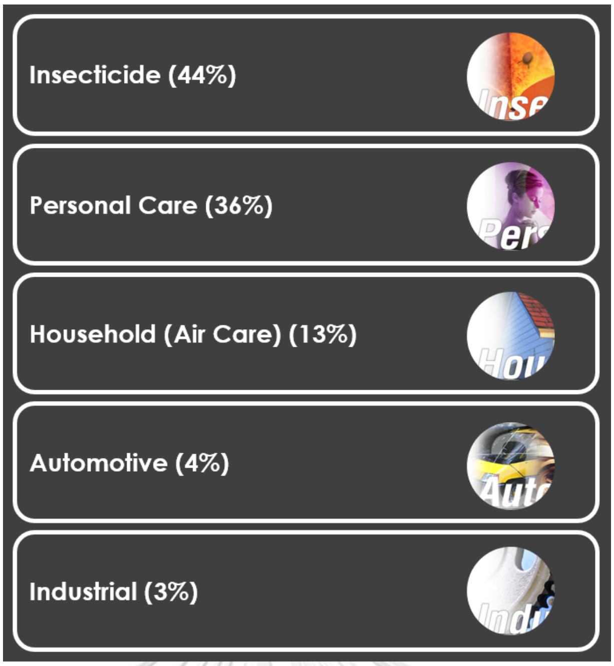


Figure 1-3: Proportion of Sales Revenue in 2019

Cyberpax Group is the largest aerosol manufacturer in Thailand in terms of quantity sells per year. Around 92 million cans are manufactured from the factory in 2019, serving both international and local brands. Company also developed a strong strategic partnership with global brands which sell aerosol or spray products. In order to fulfil the demand globally, the company needs to have enough capacity as well as plan the production unit efficiently.

The company is fully contracted manufacturer, which mean the company does not have its own brand. In the past, aerosol product is dangerous goods which require knowledge and high investment to produce a quality and safety products. So, there are few players in this field which are the same size as Cyberpax. However, the investment is lower nowadays causing small players to join in aerosol industry. In order to compete with the competitors, the efficient operation unit is essential to become more advantage in term of costs and delivery time.

There is high complexity of production plan in OEM company due to a variety of products. It is difficult to plan a production line to support customers demand while optimising the operation cost. As the variety of product is high, the operation cost will increase due to numbers of change over and clean the machine as well as line clearance. Therefore, if there is something that could assist the production planner to plan efficiently, it will fulfil customer demands and reduce operation cost.

1.2 Problem Statement

In the modern world, the competition in the consumer products business is the most essential daily necessities. In terms of cost, quality, marketing, strategy, price as well as competition with competitors in the same business area. As a result, manufacturers have to produce products to meet the different needs of consumers. Having wide variety of products to let consumers choose is essential to the modern marketing. It is directly affecting the expansion of the business. However, having a wide variety of products creates obstacles for factories in terms of making the production planning more complicated and complex. Because there are additional activities whether changing the formula and changing sizes that directly affect costs. If an efficient production schedule is established, it will help to keep the production in line with the production plan. Moreover, the production cost will be lower and keep up with delivery schedule to customers.

From the past, many researchers have come up with an efficient method of production scheduling. But production scheduling is constantly changing problem and there are many factors that affect production scheduling. In order to schedule the production unit, plan the best answer many not be possible in a short period of time. This leads to the planner of production schedule has to commit to the best possible solution with the limited time constrain. One of the factors affecting the complexity of production scheduling is the product variety result from the consumers with different age groups, choices, and tastes. As Cyberpax is a contract manufacturer for branded company, it is crucial to serve every customer needs.

The particular, the product of Cyberpax is Aerosol product which is FMCG (Fast Moving Consumer Goods) product. The product has a high fluctuation of demand. The nature of the FMCG industry means the deliveries need to happen as soon as possible, with the flexibility to adapt to seasonal fluctuations. Normally, planner can foresee the demand up to 18 months since customers provide the forecast up to this period. Company will carry inventory according to customer's forecast up to 6 months for import goods and 2 months for local goods. This is to ensure that the demand is fulfilled within time.

Customer’s forecast is divided into two types of forecast. First, the Capacity Requirements Planning (CRP) is a forecast for domestic goods where customer required to commit their order two week in advance which is week 0 and week 1. Second, Net Demand Forecast (NDF) is a forecast for export goods. This type of forecast is more stable when compare with CRP. Customer is required to reconfirm their order up to one month ahead so shipping schedule can be arranged.

It is the company policy to get a confirmed order before making any production plan. Planner will not schedule any production until a purchase order (PO) from customers is placed to guarantee their order. It is common for FMCG demand fluctuate frequently. Planner will normally face a circumstance where demand is changing every week or even every day. This will lead to the problem where planner does not have enough time to schedule an optimum production plan in a short period of time due to the complexity of production processes and the variety of the products. It is difficult to plan a longer horizon level due to the restriction between the company and the customers. Hence, aggregate planning is not reliable because the forecast of the customer is changing frequently. On the other hand, it is more beneficial to plan in the situation where the confirm order is more stable.

In this case study, a personal care or deodorant spray in the specific production line is chosen to be analysed in this research. This production line is dedicated to one major customer where their share is around 35% of the company, so the line is specifically run for this customer and for this product category. This production line produces up to 60 SKU (Stock Keeping Unit), which identify the looks of its finished product. Moreover, there are 42 formulas which is required to be changed in-between the process. As it can be seen, there are high variety of formulas and packaging materials changeover. Therefore, if the planner could plan this production line efficiently it is likely to gain a high benefit to the company.

Changeover time of filling machine and the cleaning time of mixing and moving tank is time consuming. Instead, this time spent can be used for production, it is loss due to unnecessary reason. This could lead to delay of promised delivery date apart from machine breakdown and material shortage. Moreover, changeover time is lead to additional cost. If the production line has been delayed from the changeover, production must do overtime job to deliver the product on time and keep the customer satisfied. Therefore, the ineffective plan directly affects an increasing changeover time and operational cost.

According to **Figure 1-4**, illustrated the total changeover time of each month from February to April 2020. An average of total changeover time in each month is 2,459 minutes or around 41 hours. Moreover, the graph shows that bulk changing is the most time-consuming process during this period. Therefore, if we could reduce the number of bulks changing, it could increase more production time.

As there are limited time of operation, the plan of production could not fit normal working hour. Therefore, the production schedule must be extended to produce overtime. Where overtime cost is 1.5 times more expensive than a normal working hour. **Figure 1-5** shows that cost of overtime, is relevant to **Figure 1-4**. The month with most changeover time will have the highest overtime cost. In this case is in the month of February. Company must spend 446,050.13 Baht or equivalent to £11,360 for overtime cost. It is considered as high cost because this is just the direct labor cost not including electricity, indirect labor cost, etc. In addition, changeover time reduce the machine availability of OEE (Overall Equipment Effectiveness). OEE is an indicator of the effectiveness of manufacturing operation utilized. It is divided into three parts, machine availability, performance, and quality. Thus, if there are high changeover time, OEE percentage will be affected. Company is required send this data to the customer every day to show the reliability of planner, production, and engineering teams. Therefore, changeover is one of the factors that indicate the effectiveness and if the score is low it will lead to a decrease in customer satisfaction.

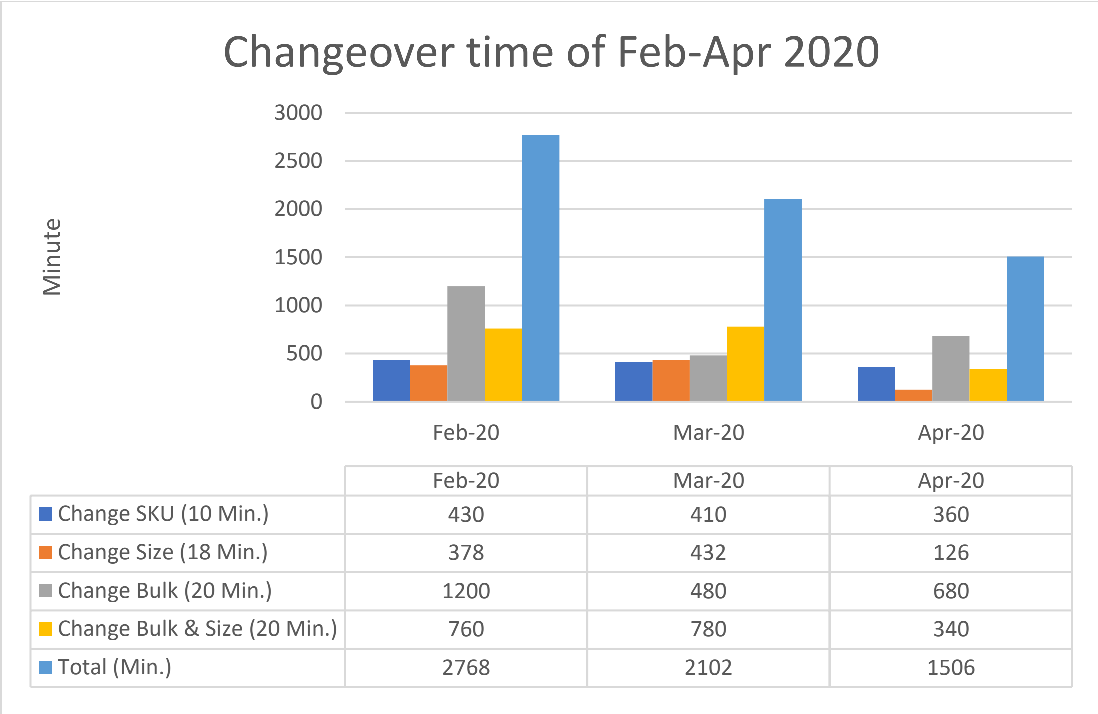


Figure 1-4: Changeover time of Feb-Apr 2020

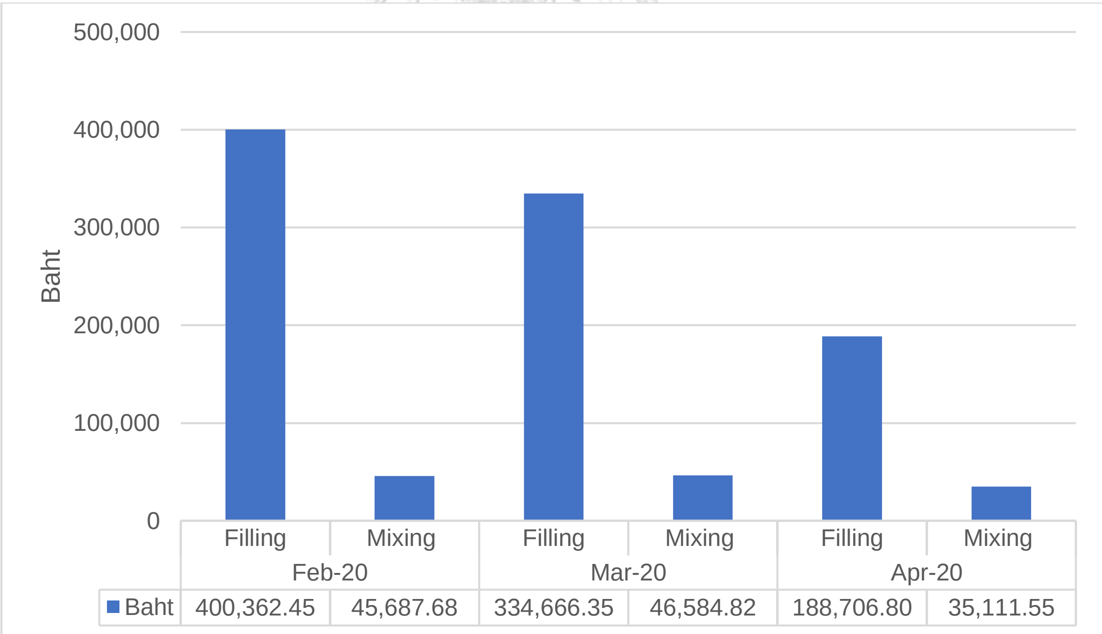


Figure 1-5: Cost of Overtime

1.3 Current Process of The Production Line

In this production line, there are two main processes which is mixing process and filling process.

1.3.1 Mixing Process

Mixing process has 5 steps which include withdrawing, weighting, mixing, quality checking, and moving of material to a storage tank. The procedures details are described below:

1. Withdraw raw materials from the warehouse. Scan the barcodes to confirm that the materials are matched with finish good that will be produced.
2. Prepare and weight the materials to get the right quantity for formula.
3. Raw materials are mixed in batch. The mixing time is around 105-160 minute depend on the machine and formula. In this process, the customer fixes the quantity of the bulk mixing from the quantity that they have validated for quality propose. Therefore, the mixing batch cannot mix the same quantity as filling the order.

Figure 1-6: Mixing Tank for 2,000 L

4. QA department perform quality check of the formula by taking a sample of the bulk.

5. After the quality passed the standard, the bulk will be moved from mixing tank to storage tank as shown in **Figure 1-6** and **Figure 1-7** where the bulk is waited to be moved to the moving tank as shown in **Figure 1-8** to fill line.

Figure 1-7: Storage Tank

Figure 1- 8: Moving Tank

1.3.2 Filling Process

The packaging materials must be prepared for filling process. In this process, the cans are loaded into the production line, bulks are filled, valve is inserted and clinched, gas is filled as shows in **Figure 1-10**, bottle ran in hot-bath testing, capping, and packed. QA will randomly check the quality every 30 minutes.

1. Prepare for packaging material such as container (aluminum can), valve, cap, and actuator depend on the design of each product as shows in **Figure 1-9**. As well as prepare bulk for filling.

Figure 1-9: Aerosol Component [1]

2. Start the line by loading the can on the can loading area and convey the can to filling station to fill bulk into the container.
3. Valve inserting station is to place the valve on the container
4. Clinching station is to clinch the valve to the container, so the container is sealed by a valve.
5. The gas filling station is to fill gas into the container through the stem of the valve.
6. Hot bath is the hot water bath which 55-60 degree Celsius. It uses to check the aerosol product if it is a leak if it is leaking the bubble will appear in the hot water and check if the product can handle the pressure that arises in the container because of the hot water.
7. After checking the quality of the product in term of leakage, the weight of the product is checked by auto-weight checker in order to check the weight of the product.
8. Capping process is to put the cap to the container.

9. After the capping process, QA will take the lab to check the quality and dimension of the finished product and approve to run the line.
10. Packing the finish goods into shrink machine in pack 3 or 6 depending on SKU and put the finish that has been packed in the carton and arrange the carton of finish good on the pallet.

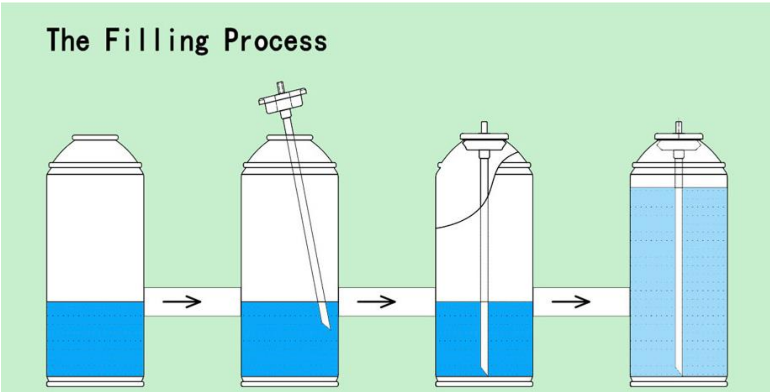


Figure 1-10: Filling process; Fill, Valve insert, Clinch, Gas fill [2]

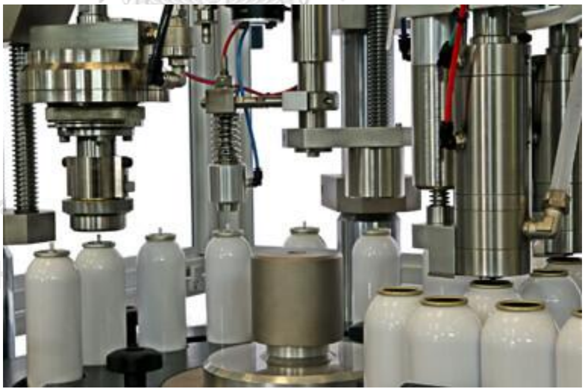


Figure 1-11: Example of filling machine, valve inserting, clinching machine

1.3.3 Changeover of Filling Process

For changeover of the machine, the machine needs to be changeover and setup when the size or formula is changed for each work order.

Changing formula

Changing the formula is the process that occurs when a product is converted from one recipe to another with different formula inside the container. In order to prevent contamination from products with different formula the require cleaning the filling cylinder and filling head. It is difficult and take time to clean the filling cylinder and head in the line. Therefore, the process is to have spare filling cylinder and when changing the formula, the new spare filling cylinder will be replaced. According to Figure 1-12, it shows the filling cylinder that need to be change and flush for every changeover of the bulk. The process of formula changeover has 6 steps as follow

1. Remove the formula of the cylinder by use it filling cylinder to pump of to the filling head.
2. Unscrew the ferrule that attached to the filling cylinder with the filling pipe
3. Remove the filling cylinder off
4. Replace with cleaned filling cylinder
5. Attach the filling tank with filling cylinder
6. After changing filling cylinder. Take the filling cylinder that has been removed to flushing room and clean with white oil solution.

Figure 1-12: Filling Cylinder of Bulk Filling

Changing size

Changing the size of the aerosol can is another important step in the process of set up, Aerosol can is changed when the size of the can is changed from one size to another according to production schedules. It is a step that requires high dexterity and elaboration. So that the machine can produce the product according to the standard without the waste. If the setting is not accurate enough, the major effect will cause damage to the product and the machine. In the minor effect, it will produce the product that out of specification and that is the waste of money. In order to set up the size, the machine has to be setup by, set the height of the column that hold each station. It takes time because there are 3 stations in the machine and its station take time to adjust the height of the can. The process of set up the size have 6 steps as follow

1. Unscrew all of the lock nut of every station
2. Adjust filling head by using a new can as a reference to adjust the filling head.
3. Adjust the volume of filling the bulk in the filling cylinder, due to the volume of the filling cylinder.
4. Adjust the height of valve inserting station with the valve checking station
5. Adjust clinching station with the height parameter that indicate the height of each can size according to specification (3 specification require in this adjustment total height, stem height, stem diameter). The example of clinching machine is shows in Figure1-13
6. Adjust the gassing head with gassing cylinder.

Figure 1-13: Clinching Station in the Filling Machine

1.4 Constrain and Problem for Production Planning

1.4.1 Changeover Time and Cost

The product has 9 sizes, 42 formulas, and 40 SKU. The changeover time of each change is depending on the activity of the changeover.

According from **Figure 1-14**, the condition for the creating production schedule of aerosol filling production line can be classified into 4 conditions of changeover by sorting the time of changeover in descending order from consume highest time to lowest time.

Condition 1 is the condition where there are work orders with different formula and different packaging size, the changeover needs to change the filling cylinder and adjusting the machine to fit the packaging size.

Condition 2 is the condition where the works orders with different formula but same packaging size, thus the filling cylinder is change due to changing the formula but the size remain the same.

Condition 3 is the condition where the size is changed but the formula remain the same, the machine needs to be re adjust to the specific packaging size.

Condition 4 is the condition where size and formula is not changed but the stock keeping unit is change, the stock keeping unit in this production line mostly will be changed on different pattern on the can with the same size.

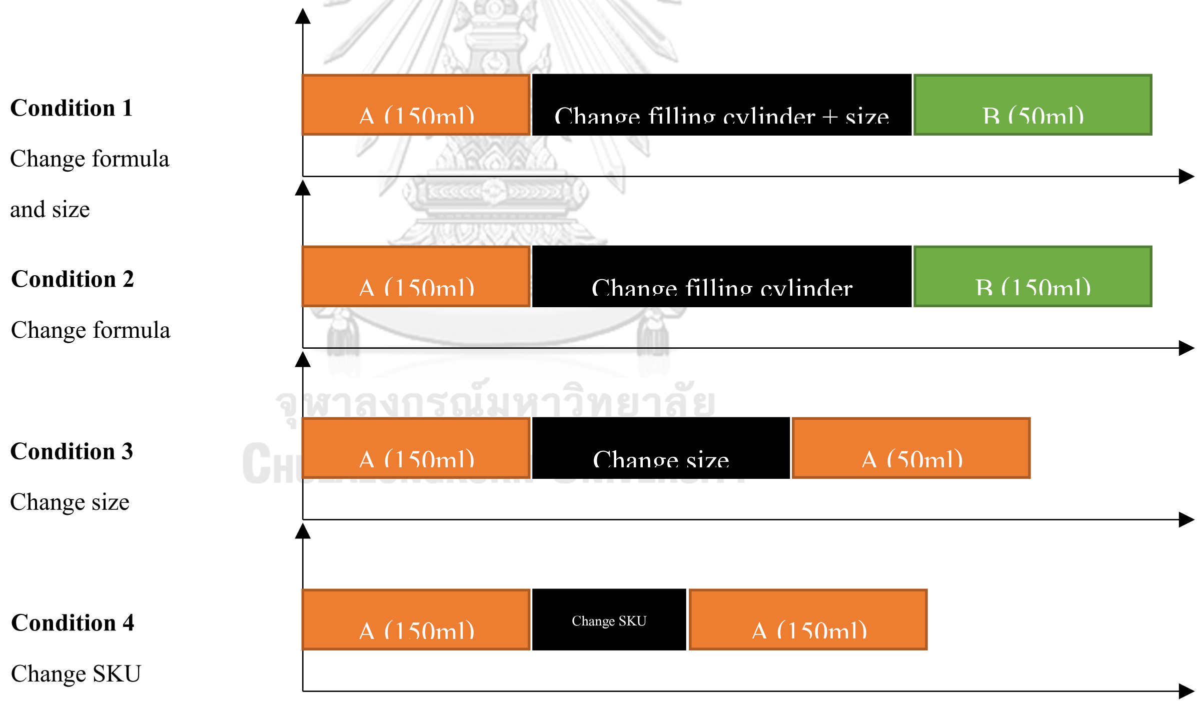


Figure 1-14: Comparison of the Condition of Changeover (Changing Formula, Size, And SKU)

In detail of changeover according to **Table 1-1**, each changeover has the standard time. The planner will use this standard time to create the production schedule. The time is shows in form of minute. For change SKU, packaging material has to be changed but the machine does not need to be adjusted so it takes around 10 minutes to change SKU. The changing formula, the filling cylinder and head need to be flush and sanitized by alcohol in the past which takes around 50 minutes. However, it has been changed to improve changeover time by changing the new cylinder instead of clean in line. This is improvement save changeover time down to 20 minutes. Lastly changing size need to readjust the height of the machine as well as change the puck that holds the can so this takes 18 minutes to change. Moreover, there are costs of chemical that use to flush filling cylinder and head around 3,300 Baht or equivalent to £84.

List of Changeovers	**Change SKU**	**Change Formula**	**Change Size**	**Change Formula and Size**
Changeover Time	10 Minute	20 Minute	18 Minute	20 Minute

Table 1-1: List of changeover and time

1.4.2 The Current Method of Production Scheduling

The current method of production scheduling is not reliable since the schedule using the experience of the planner and they are do not have the data to measure their performance and any tools to assist the production schedule. Therefore, the planner creates by considering the production order, the readiness of material, and delivery date as shown in **Figure 1-15**. Noted that the process is a rough explanation. The planner has one of the performance measures that they have to plan for delivery date. Therefore, they using Earliest due date as their priority for planning. Earliest due date is a good method to delivery on time, but in operation cost wise it is not efficient due to it consider one factor. It could lead to longer makespan due to ineffective planning and if the capacity of the line is limited. The poor production plan is lead to delivery on time and require overtime production. On the other hand, effective production schedule help minimize makespan and decrease overtime production. Moreover, a planner does not plan for the mixing process and just plan for the filling process. This makes the planner only focus on one process, which is not efficient due to the planner could not visualize the heuristic view of two process and just focus to deliver on time for the filling process. This problem could lead to overtime cost that company have to pay extra for ineffective planning. Moreover, according to the factory production data, past case studies have shown that each day the production order can be reorder to make the closing time shorter. On the current method of production schedule, focus only bulk grouping where it can focus on other aspect of changeover to increase efficiency of the production schedule.

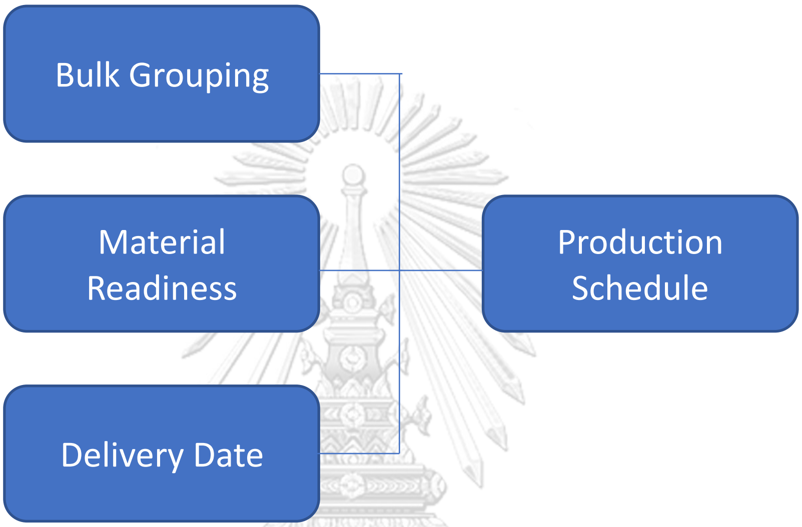


Figure 1-15: Current Method of the Production Schedule

1.4.3 Extra workload of the planner

Furthermore, the planner has extra work load in term of checking raw material readiness one by one in the system and noted the date that each product can be produced. Another job that the planner has to be done is follow up the production plan. Sometimes, the production cannot produce the product on-time because of unplan downtime such as breakdown of the machine, waiting for staff, waiting for raw material, human error, etc. The planner has to know the problem in the production line, and they have to updated the plan according from the delay.

1.4.4 Waste of Double Handling

In order to reduce the movement of the bulk, the operation team could manage to mix the bulk and move to the moving tank just in time before filling process. Therefore, the bulk does not have to move to the storage tank and move to the moving tank. The bulk is lost from moving tank to another tank around 2% so this is a huge loss from the double handling. However, the moving tank for this line has only 8 tanks. Therefore, it is difficult to plan just in time to the filling process.

1.4.5 Tank Constrains

Mixing tank constraints, the bulk has to be fix 300kg and 2000g. Therefore, the quantity of the bulk could not be planned just enough. Therefore, the leftover bulk needs to be kept in the storage tank until the new order is received. Therefore, we lost the storage tank for leftover bulk.

1.5 Research Objective

In this research, the objective is to develop the method to optimise production scheduling for aerosol production line. To optimise production scheduling of production line, the measurement of result includes following factors,

1.5.1 Reduce make span of production line or reduce changeover time.

In this case, the changeover time could be track monthly and make comparison of before and after develop the decision support system.

1.5.2 Cost reduction in terms of labour, electricity, etc.

The operating cost is depending on the time that the company have to hire labour and pay for electricity. In this case, if we could reduce labour cost of doing overtime which cost 1.5 time more than regular working hour. Moreover, there is a cost of chemical that use for changing bulk because they used for clean and flush the filling cylinder and filling head. That will cost £84 each change over.

1.5.3 Reduce workload of the planner

Planner spend a lot of time to schedule the production plan manually, this is time consuming. Therefore, if there is support system that can assist the workload of the planner, so the planner can have time to do more analytical work. And they have spare time to check for raw material and do the job that could improve continuously.

1.6 Scopes of Research

This research focuses on the improvement of production scheduling the aerosol production line by working on the followings.

1. Research and develop production schedule of aerosol production line in one week.
2. Changeover such as change SKU, formula, size is only considered as time waste in this production line
3. Focus on planning on filling process that have purchase order from the customer.

1.7 Result

This research focuses on developing the heuristic approach by use Travelling Salesman Problem (TSP) to be a model and improve the solution to suite for aerosol filling production schedule problems. Developing the heuristic approach in order to reducing closing time or makespan of each work order and changeover time to lower production costs. Furthermore, the heuristic approach solution is assisting workload of the planner in aspect of reordering the production schedule to create the efficient production schedule in terms of makespan, inventory holding cost, and delay date.

2. Literature Review

2.1 Dispatching Methods

In production planning, it can categorise into three horizon level. Long term is a plan for capacity planning which is 5 years planning horizon and planning about create demand for products and generating sufficient revenue for the company. In a medium-term plan is aggregate planning which improves the efficiency of the plan, it can minimise total costs associated with labour and inventory levels. To optimise the aggregate planning, decision support system could be applied to aggregate production planning using linear programming. According to **Emiro Antonio Campo 2018** [3]**,** the development of mathematical model providing an optimal solution for executing a production plan, and also help to determent improvement strategies, for instance, the increase of production and storage capacity to reduce total costs. However, in this research, the short-term plan is the plan that will be focused on. It is about production scheduling, prioritise the work in the shop floor with limited resource, which includes labour, machine, equipment. In order to plan production schedule effectively, Dispatching Rules is one method to schedule the plan for an acceptable result, it could minimize mean flowing, maximum flowtime, proportion tardy jobs, mean tardiness, maximum tardiness and variance of tardiness (**OliverHolthaus 1997** [4]). This method is the simplest way, and not time-consuming to manage. For instance, one of the dispatching methods is EDD (Earliest Due Date) which schedule the plan relies on the earliest due date or delivery date, then schedule for the product that delivers after in a sequence. However, EDD is the method that only reduces the lack of delivery date, it is not the solution for production plan that focus on effectiveness of the plan especially for the production plan that involves setup and changeover time. It will extend the time of closing job.

2.2 Traveling Salesman Problems

There is more advance method have been researched to solve a more complicated problem like Traveling salesman problems or TSP. According to **Rajesh Matai 2010**, travelling salesman problem is the method that finds the best possible way of visiting all cities and returning to the starting point that minimizes the travel cost and travel distance with given a set of cities and the cost of travel between each possible pair. TSP is one of the most widely studied problems in combinatorial optimisation [16]. It is remarkably effective performance of simple heuristic solution methods [21]. Moreover, it could be adapted in physicists, engineers, biologists' type of work [19]. It also has practical applications in genetics, telecommunications, and neuroscience [23]. Therefore, Tsp could potentially adapt to the production schedule by assuming the location of the customer (Node) as a production item and the routing of a salesman (Tour) as the schedule of production plan on the machine. TSP focuses on finding the route that has the lowest cost [17]. The particular route has to have the same origin and destination called (Depot). Moreover, the route will have to pass the customer location while not come to the same location again as illustrated in **Figure 2-1**.

The indicator of the problem TSP is distance or total travel time. For TSP method, it can be divided into two ways. Symmetric TSP is used in a condition where the cost of travel between two nodes is constant and not depend on the direction of the route. For the problem that the cost of travel between two nodes is not constant depending on the direction of the route, this kind of problem will use Asymmetric TSP. This method is an effective method and fasts to analyse, applicable to solve complicated production schedule to find the effective and appropriate production plan.

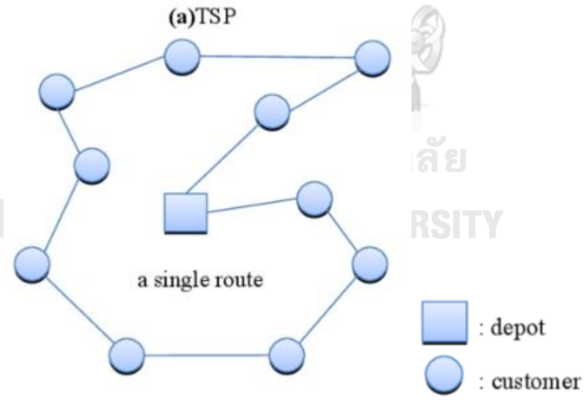


Figure 2-1: Illustration of the Traveling Salesman Problems (TSP)

Wan-Yu Liu 2014 [5]

In order to get the exact solution approach for TSP, there are a lot of heuristics and metaheuristics solution that could solve problems approximately. Heuristics and metaheuristics trade optimality of the solutions that they output with execution times. They are used to find quality solutions within short performing times. Metaheuristics are improvement algorithms, i.e., they start with one or more feasible solutions to the problem at hand and suggest methods for improving this kind of solutions. Typical examples of metaheuristics include genetic algorithm, simulated annealing, local search, and tabu search. Tabu search is one of the most widely used metaheuristic method s to solve combinatorial optimisation problems. Tabu search is an improvement heuristic based on local search. It starts with an initial solution to the problem, (a tour in case of the TSP), calls it a current solution, and searches for the best solution in a suitably defined neighborhood (a collection of tours that can be "easily" reached from the current solution) of the solution. Then set the best solution in the neighborhood as the current solution and starts the search process again [6].

In order to solve the problem for production schedule, creating variables and formula for support decision in form of a mathematical model is a difficult and time-consuming method. Especially, the problem that has a big set of number or scale, the mathematical model might not applicable due to it is a time-consuming method. Therefore, using the heuristic method is more suitable when it comes to a large scale of the problem.

2.3 Vehicle Routing Problems

TSP method is the solution for salesman that has only one route when there is more complexity of routing and logistic. There the method that is a determination of the optimal set of routes to be performed by a fleet of vehicles to serve a given set of customers called VRP (Vehicle Routing Problems). It is more complex compare to TSP because there are more routes to be calculated. It is shown that VRP method could schedule the fleet more than one route according to **Figure 2-2.** In case customer or depot have a limitation of receiving or delivering products. The Vehicle Routing Problem is the determination of the optimal set of routes to be performed by a fleet of vehicles to serve a given set of customers [22]. The particular problem in VRP called VRPTW (Vehicle Routing Problem with time window) which more complicated than normal VRP [7]. Now the vehicle has to visit a customer within a certain time frame, the vehicle may arrive before the time window opens but the customer cannot be serviced until the time windows open, it is not allowed to arrive after the time window has closed **(Nasser A. El-Sherbeny 2010)**. In order to convert the VRP to the production schedule. The variables are set as a node is batch order and

The vehicle is a sequence of the production schedule. In case that the bulk is ready to be filled and has a due date, VRPTW is suitable to solve the problem by adding the time frame into each of product item.

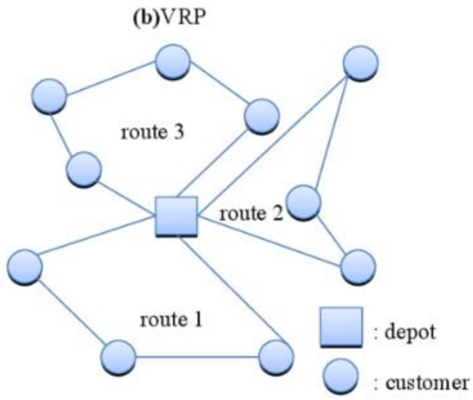


Figure 2-2: Illustration of the Vehicle Routing Problems (VRP)

Wan-Yu Liu 2014 [5]

2.4 Variable Neighborhood Search, VNS

Variable Neighborhood Search is the method suitable for a problem that is hard and complex. This method has been used to solve the routing of vehicle problem by performing a sequence of local changes in an initial solution which could improve each time the value of the objective function until a local optimum is found. (Pierre Hansen 1999 [8]) Tour improvement method is depending on the problem that considered. In this research, sequential 2OPT is suitable for this kind of problem. In order to adjust the route, intra route is for swap the node in the same route. The inter-route is for exchanging the node in the different route as illustrates in **Figure 2-3**.

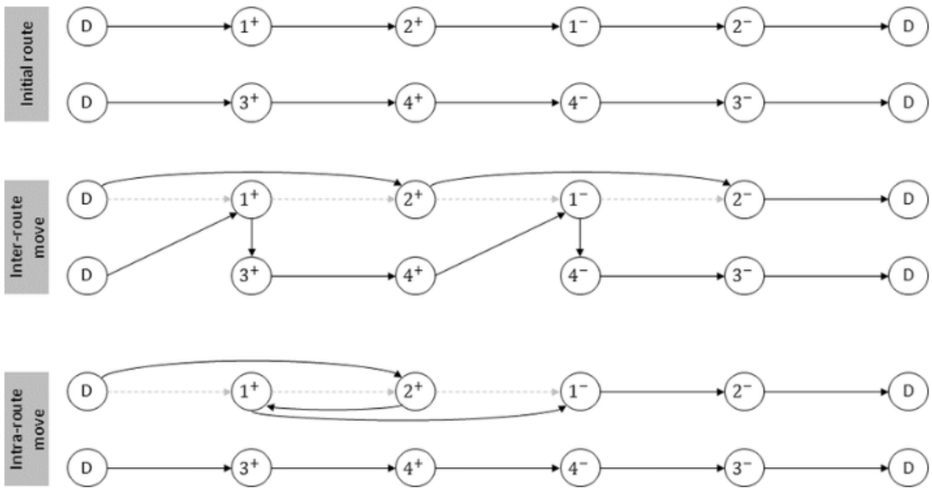


Figure 2-3: Illustration of Intra-route and Inter route exchange in VNS

Giovanni Pantuso 2019 [9]

3. Methodology

3.1 Analyse Nature of The Problem

OEM aerosol production process has various of SKU, formula, and size to fulfill the demand in every group. The nature of product and business lead to complicated production schedule. Therefore, the method that has been chosen have to be suitable for this particular problem. If the method is not suitable it would lead to inefficient production schedule. There are several constrain in this production line. The first priority is delivery date because the company need to be competitive in term of delivery on time to gain customer satisfaction. Secondly, time is the second most concerned factor due to this particular line is dedicate to one customer and their demand is close to max capacity of the line. Moreover, the cost that cause from time wasting and changeover is also concerned. However, the cost and the time is relevant to each other.

3.2 Assumption

In this research, production plan of aerosol production line has the following assumption,

1. The production schedule will be in one-week time-fence.
2. Speed of the production line is 140 piece per minute.
3. The unfortunate downtime such as breakdown from the machine, waste of the will not consider in this production plan.
4. Make span of each day will be not more than 2 shifts with no overtime equal to 16 hours – 2 hours break. In case the demand is more than capacity of 2 shifts with no over time, it can be extended to work overtime case by case.
5. The product can produce before delivery date 3-7 days but cannot produce after delivery date.
6. Changeover time of bulk changing, size changing, and SKU changing is different as illustrated in **Table 1-1**.

3.3 Methodology

In production scheduling for cosmetic aerosol line, which has its own constrain in terms of machine, change over time and cost. It is classified as a Hard problem or NP-Hard. The production line is considered as single machine production line. Therefore, Travel salesman problem with time windows (TSPTW) would be suitable for this kind of problem due to TSPTW is the method that solve for one route and it is the heuristic approach that fast to analyses and the process is not complicated [20]. It is useful for planners because they need fast and effective method to solve this kind of problem. The objective of TSPTW is to find an optimal tour where a single vehicle is needed to visit each of a given set of locations exactly once and return to its starting location. Moreover, the support system will develop under heuristic approach in terms of Variable Neighborhood Search (VNS) using 2-opt and 3opt to search and analyses the answer.

In order to get the optimum result of production schedule, the method will be Two-phase heuristic. In first phase, the basic dispatching method is used to analyses the production schedule by using Earliest Due Date (EDD) strategy to sequence the production schedule. The reason that using EDD to order the sequence of schedule is the Delivery date is the most concerned factor for the planner. The flow process is to first get the customer requirement or Purchase order from the customer. Then check for material readiness, if the material is not ready the planner has to follow up material with Material Requirement Planning (MRP). If the material is ready to produce, the planner will plan the production schedule by using EDD strategy to plan. After create Earliest Due Date production schedule, then further improve the production schedule by using Travel Salesman Problem to get the best possible solution or path with in time constrain as shows in the flow chart from **Figure 3-1**.

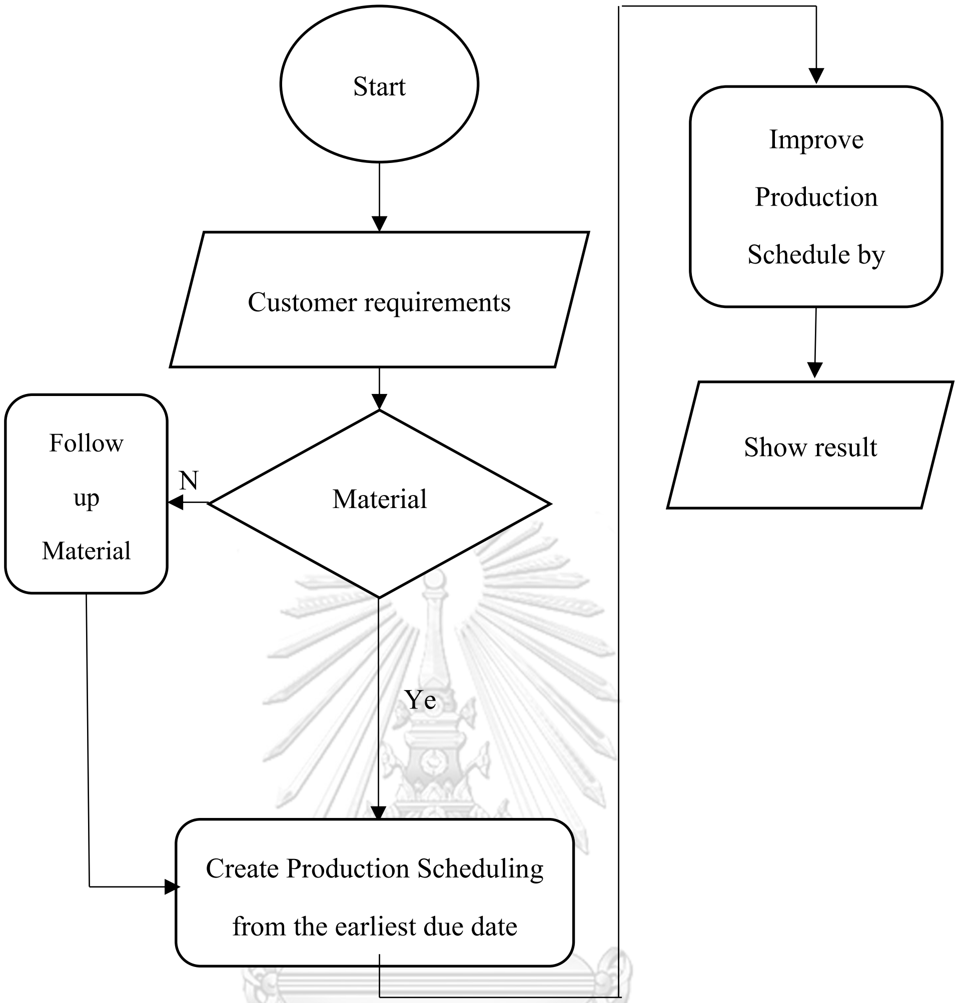


Figure 3-1: Flow chart of analysis using EDD strategy and improving by TSD

The second phase of the heuristic approach is to use TSPTW to computerized the best possible to reduce makespan of production schedule as well as the cost of changeover each time. The strategy that uses to calculate is VNS strategy using 2-opt and node shift move to get the best result. 2-opt and node shift algorithms are used to get solution of production schedule. Furthermore, the improvement method needs the data collection base in order to memorised the sequence of the work order that already reorder by algorithm. The data collection base is called tabu search, using tabu search to collect the data that have been calculated by the algorithm and set the end result for production schedule.

3.3.1 The Algorithm of Improving Methods

1. 2-opt is one of the most basic and widely used heuristic to get approximative solution. It starts with random initial tour and improves the tour by exchanging 2 edges in the tour with two other edges and analyse whether it is the better solution. The illustration of **Figure 3-2** shows that 2-opt algorithm deletes edges A to B and D to C and reconnects edges A to C and B to D. Algorithm will end when no further improving step is found.

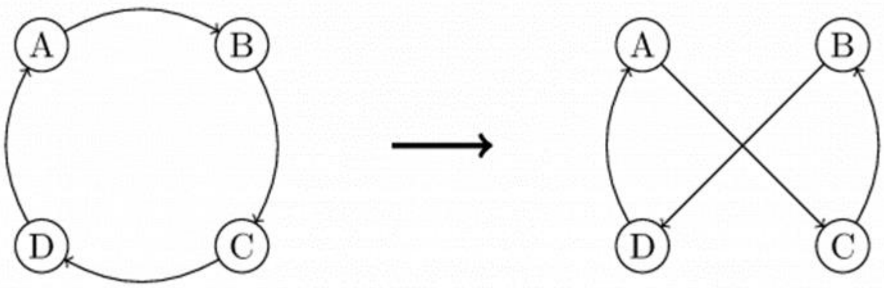


Figure 3-2: 2-opt heuristic approach algorithms [9]

2. Node shift move is also basic but not widely used as 2-opt. The concept of move is close to 2-opt but it is a special case. According to Figure 3-3, node shift move is obtained by removing three links and adding three new links [11].

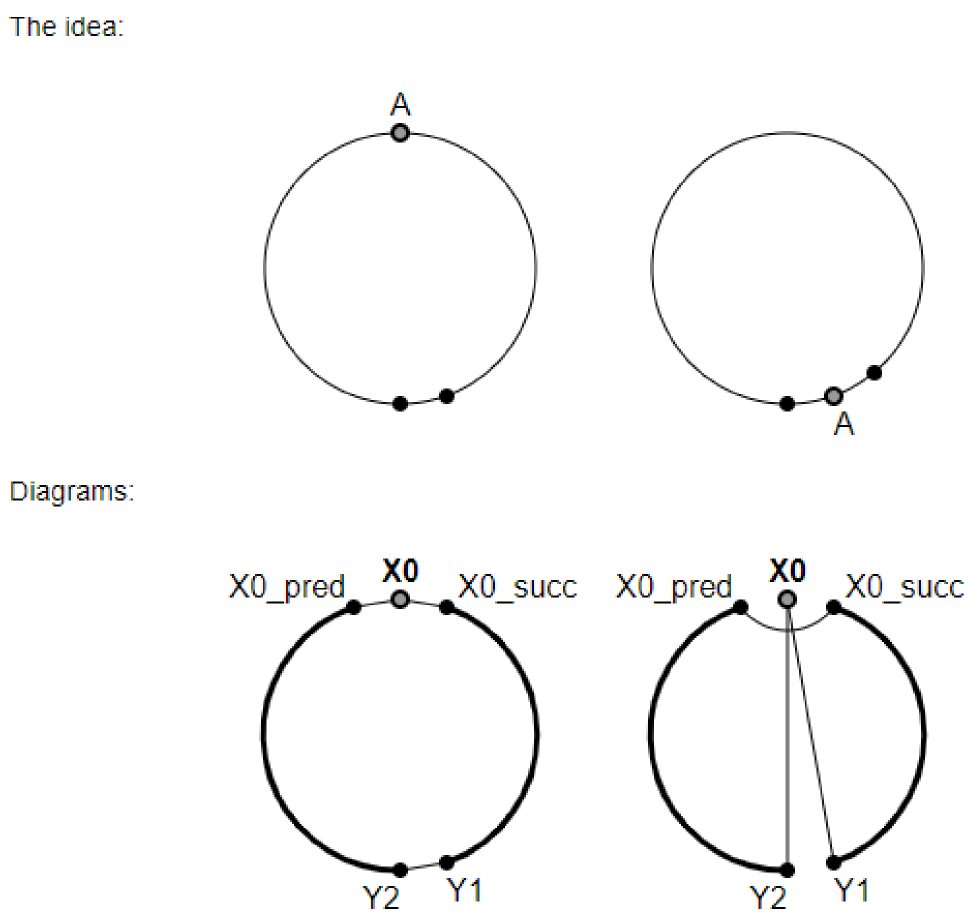


Figure 3-3: Node shift move algorithm

From the result of the simple statistics calculation between 2-opt and 2-opt with node shift shows in Figure 3-4, it is indicating that 2-opt with node shift perform better than 2-opt only in every aspect including best length, average length, and worst length. This sample created by NN heuristic and improved by 2-opt and 2-opt plus node shift algorithms. Therefore, it can conclude that 2-opt plus node shift perform better in term of length of the tour.

Problem #	Method	Time	Best	Avg	Worst
1	NN	100	100.00	106.01	114.87
	NN + 2opt	1253	84.38	89.83	96.82
	NN + 2opt + NodeShift	1459	83.94	87.90	91.71
2	NN	100	100.00	107.45	116.93
	NN + 2opt	1562	88.05	92.40	96.60
	NN + 2opt + NodeShift	1562	87.16	90.34	94.04
3	NN	100	100.00	111.21	121.46
	NN + 2opt	1566	87.41	91.52	95.76
	NN + 2opt + NodeShift	1666	84.99	88.79	92.92
4	NN	100	100.00	106.14	116.83
	NN + 2opt	1146	90.52	93.42	96.88
	NN + 2opt + NodeShift	1353	90.18	91.90	95.45
5	NN	100	100.00	106.30	111.75
	NN + 2opt	833	89.63	93.35	98.55
	NN + 2opt + NodeShift	1253	88.58	91.68	95.80
6	NN	100	100.00	112.73	120.18
	NN + 2opt	1253	89.46	93.60	98.49
	NN + 2opt + NodeShift	1459	88.27	92.00	96.30
7	NN	100	100.00	109.50	124.34
	NN + 2opt	1460	88.66	91.05	96.24
	NN + 2opt + NodeShift	1566	86.47	89.27	92.40
8	NN	100	100.00	108.63	117.53
	NN + 2opt	1146	92.47	96.80	102.24
	NN + 2opt + NodeShift	1566	91.86	95.44	101.14
9	NN	100	100.00	105.75	112.56
	NN + 2opt	400	88.70	91.68	96.63
	NN + 2opt + NodeShift	465	87.85	90.03	94.57
10	NN	100	100.00	115.43	123.97
	NN + 2opt	1460	91.77	95.11	100.35
	NN + 2opt + NodeShift	1459	90.88	93.87	98.72

Figure 3-4: The simple statistics calculation between 2-opt and 2-opt with node shift move

3.3.2 Tabu Search for TSPTW Method

The job-shop scheduling problem is one of the most studied problems in combinatorial optimization the numerous procedures that have been proposed to solve it, including several tabu search implementations [25]. In order to use TSPTW as a heuristic approach. The algorithm needs to have the short or middle data base that called tabu search. In particular, the nature of the TSPTW requires an algorithm that is robust according to parameter settings across a broad spectrum of constraints, objective functions and time window widths. Tabu search is a general heuristic procedure for global optimization which has been successfully applied to several types of difficult combinatorial optimization problems [18]. Tabu search is one of the primary metaheuristic search technique regarding these considerations. The proposed algorithm is applied to Traveling Salesman Problems, that is typical combinatorial optimization problem, to verify the performance of search [24]. Principally, tabu search avoids becoming trapped in local optima by utilizing memory and data structures that prevent them from moving back to the previously examined solution, and prevent moving to solutions that share some of the data together with the previous solutions. A neighborhood structure is enabling the algorithm to develop solutions from the current solution. A candidate list which is the algorithm of the move is find the best move in terms of the selected objective function. The current solution is updated to the new best of the neighbors that is not tabu. The primary parameter required for this type of memory is 'tabu length', which is the memory of the tabu search of the algorithm steps. The amount of tabu length increase and decrease as input parameters. Th algorithm proceeds as follows

1. The tabu algorithm moves to a neighbor solution

2. The algorithm determines whether this particular solution has been visited before.

   (a) If the solution has been visited within the minimum cycle length, the tabu length is enhanced by a factor that has determine before.

   (b) If the solution has never visited, the solution is added to the solution structure.

The algorithm also tracks the number of repetitions. Since last time the tabu length was changed if the selected number of repetitions has been passed, the tabu length is reduced as suggested by Battiti and Tecchiolli (1994), the algorithm calculate the cycle moving average length less than the allowable length. The tabu length is decreased if the algorithm runs move repetitions than this moving average without changing tabu length.

3. If candidate neighbors are tabu and none meets the criteria, the algorithm will move the smallest move value and unconcerned its tabu status. A concurrent decrease in the tabu length is performed. (This issue can be happened when the tabu length is very large and the current solution has a very small number of allowable moves.)

4. Heuristic Approach for production planning

In this thesis, the objective is to reduce set up time and cost in production planning of aerosol filling line using heuristic approach to calculate the optimum plan of particular production line. The optimum plan of the production line needs to serve's customer requirement as well as produce lowest cost as possible. However, as the company is OEM company which manufacture product for customer that has their own brand. Therefore, due date or delivery date is crucial part for the company. If production plan is not effective, due date might be delayed and caused several problems such as, customer satisfaction, cost of transportation, etc. The effective plan which considers with time and cost is complicated to plan. In order to plan the production schedule, work order will create from readiness of material and due date. Then adapt Travelling Salesman Problem (TSP) method to solve the most effective plan for the production line, the method is popular in solving the problem of production plan which has single machine and do not require a lot of time to solve the problem. The process is simple and fast. Furthermore, we require time window to solve the problem of delivery date, as our delivery date is fixed due to customer requirement. Therefore, Travelling Salesman Problem with Time Windows (TSPTW) will be implemented to solve this particular production schedule

This chapter explains the detail of data input. As well as the decision-making process in scheduling the filling process of aerosol products using heuristic method. Which can be divided into 3 main topics

1. Information used for production planning
2. The heuristic decision-making process
3. Sample of heuristic calculation result

4.1 Information used for production planning

4.1.1 Filling Process Information

In order to use heuristic approach, the improvement process is beginning with set up the input to put in the initial plan. The initial plan requires earliest start date and latest due date. The earliest start date depends on the readiness of the material. The material should be ready. On the other hand, The latest due date is set by sales department according to customer requirement. Purchase order of the customer is divided in to two types, domestic and export. For domestic type, sales order is received weekly by local customer, therefore the production plan is updated weekly by production planner. Moreover, the delivery date is not fixed but by day but fixed be week. Whereas, export type is received monthly (Day 15 of every month) by international customer and the delivery date is fixed due to the transportation constraint. The shipment has to be booked in advance, so the delivery date is fixed two days before transportation date.

According from **Table 4-1**, it shows sale order that received from customer and already put in ERP system before arrange in the production planning. first column indicates countries that has to be shipped to. Apart from TH (Thailand), the others are export type order that already booked the shipment as shown in scheduled pick column. Order number column is generated by ERP system. Where, 2nd item number is customer's item number which indicate different SKU of the order. Description 1 column shows the detail of the order in short form, it shows the size, perfume, and type of the can. The quantity column shows the purchase quantity in pieces. Whereas, WO FG is work order number of the finish goods product.

Zone	Order Num	Scheduled Pick	2nd Item Number	Description 1	Quantity	WO FG
EX	20000306	7/10/2020	BDF80020-06000-29C-EX	NDEO SPY XTR_WHT_SRM_PLC 100ML	7,776	63002547
MX	20000307	7/10/2020	BDF80020-06000-29C-EX	NDEO SPY XTR_WHT_SRM_PLC 100ML	50,724	
EX	20000308	16/10/2020	BDF80027-08600-30-EX	NMEN DEO SPRY_DEEP 150ML	12,360	63002548
EX	20000309	16/10/2020	BDF80027-08600-30-EX	NMEN DEO SPRY_DEEP 150ML	7,200	
MY	20000312	7/10/2020	BDF81600-08600-29B-EX	NDEO SPY FRS_ACT_ML 150ML	37,080	63002549
MY	20000313	16/10/2020	BDF81600-08600-29B-EX	NDEO SPY FRS_ACT_ML 150ML	19,200	63002550
PH	20000314	16/10/2020	BDF81600-08600-29B-EX	NDEO SPY FRS_ACT_ML 150ML	7,200	
EX	20000315	30/10/2020	BDF81600-08600-29B-EX	NDEO SPY FRS_ACT_ML 150ML	19,200	63002551
EX	20000316	16/10/2020	BDF81602-08600-28E-EX	NDEO SPY DRY_IMP_ML 150ML	9,600	63002552
MY	20000317	16/10/2020	BDF81602-08600-28E-EX	NDEO SPY DRY_IMP_ML 150ML	4,800	
PH	20000318	16/10/2020	BDF81602-08600-28E-EX	NDEO SPY DRY_IMP_ML 150ML	4,800	
EX	20000319	16/10/2020	BDF82241-08600-30C-EX	NDEO SPY INV_BLC&WHT_PWR_ML150	14,400	63002553
MY	20000320	16/10/2020	BDF82241-08600-30C-EX	NDEO SPY INV_BLC&WHT_PWR_ML150	37,080	
EX	20000321	16/10/2020	BDF82241-08600-30C-EX	NDEO SPY INV_BLC&WHT_PWR_ML150	12,000	
PH	20000322	16/10/2020	BDF82241-08610-30C-EX	NDEO SPY INV_BLC&WHT_PWR_ML150	23,832	63002554
EX	20000323	16/10/2020	BDF82883-08600-28D-EX	NDEO SPY CL_KCK ML 150 ML	14,400	63002555
MY	20000324	16/10/2020	BDF82883-08600-28D-EX	NDEO SPY CL_KCK ML 150 ML	32,136	
EX	20000325	16/10/2020	BDF82959-08600-29D-EX	NDEO SPY SLV_PRTT 150ML MALE	24,720	63002556
MY	20000326	16/10/2020	BDF82959-08600-29D-EX	NDEO SPY SLV_PRTT 150ML MALE	9,600	
EX	20000327	16/10/2020	BDF82959-08600-29D-EX	NDEO SPY SLV_PRTT 150ML MALE	9,600	
MY	20000328	16/10/2020	BDF82967-08600-28D-EX	NDEO SPY EXT_WHT_FML 150ML	42,024	63002557
TW	20000329	16/10/2020	BDF82967-08600-28D-EX	NDEO SPY EXT_WHT_FML 150ML	4,800	
EX	20000330	15/10/2020	BDF83409-06000-29B-EX	NDEO SPY EXT_WHT_SRM_LLC 100ML	10,368	63002558
MX	20000331	15/10/2020	BDF83409-06000-29B-EX	NDEO SPY EXT_WHT_SRM_LLC 100ML	21,864	
MY	20000332	16/10/2020	BDF83486-08600-30B-EX	NDEO SPY B&W_ULT_IMP_FML 150ML	14,400	63002559
MY	20000333	16/10/2020	BDF83486-08600-30B-EX	NDEO SPY B&W_ULT_IMP_FML 150ML	7,200	
EX	20000334	7/10/2020	BDF83731-08600-28D-EX	NDEO SPY PRL&BTY FML 150ML	12,000	63002560
MY	20000335	7/10/2020	BDF83731-08600-28D-EX	NDEO SPY PRL&BTY FML 150ML	19,776	
EX	20000336	7/10/2020	BDF83731-08600-28D-EX	NDEO SPY PRL&BTY FML 150ML	12,000	
MY	20000337	9/10/2020	BDF85304-08600-29E-EX	NDEO SPY HKKD_RS_FML 150ML	74,400	63002561
MY	20000338	9/10/2020	BDF85304-08600-29E-EX	NDEO SPY HKKD_RS_FML 150ML	12,840	
MY	20000339	8/10/2020	BDF85308-08600-29E-EX	NDEO SPY SKR_FML 150ML	50,400	63002562
MY	20000340	8/10/2020	BDF85308-08600-29E-EX	NDEO SPY SKR_FML 150ML	13,344	
MY	20000341	15/10/2020	BDF85312-08610-29B-MY	NDEO SPY LLY_FML 150ML	29,664	63002563
MY	20000342	15/10/2020	BDF85312-08610-29B-MY	NDEO SPY LLY_FML 150ML	14,400	
MY	20000343	6/10/2020	BDF85388-08600-30C-EX	NDEO SPY B&W_ULT_IMP_ML 150ML	7,200	63002564
MY	20000344	6/10/2020	BDF85388-08600-30C-EX	NDEO SPY B&W_ULT_IMP_ML 150ML	14,328	
MY	20000345	15/10/2020	BDF85974-08600-30C-EX	NDEO SPY_BLC&WHT_FRESH ML150ML	10,992	63002565
MY	20000346	15/10/2020	BDF85974-08600-30C-EX	NDEO SPY_BLC&WHT_FRESH ML150ML	9,600	
MY	20000360	16/10/2020	BDF82241-08620-30B-MY	NDEO SPY INV_BLC&WHT_PWR_ML150	21,000	63002652
TH	20000347	29/9/2020	BDF85304-07700-29E-TH	NDEO SPY HKKD_RS_FML 150ML	21,744	63002577
TH	20000348	29/9/2020	BDF85308-07700-29D-TH	NDEO SPY SKR_FML 150ML	52,152	63002578
TH	20000349	30/9/2020	BDF80027-07700-30-TH	NMEN DEO SPRY_DEEP 150ML	21,744	63002579
TH	20000350	30/9/2020	BDF82865-07700-28D-TH	NDEO SPY EXT_WHT_FML 60ML	31,632	63002580
TH	20000351	30/9/2020	BDF83739-07700-28D-TH	NDEO SPY CL_KCK ML 50ML	31,128	63002581
TH	20000352	30/9/2020	BDF81600-07700-29A-TH	NDEO SPY FRS_ACT_ML 150ML	27,000	63002582
TH	20000354	29/9/2020	BDF83731-07700-28E-TH	NDEO SPY PRL&BTY FML 150ML	21,744	63002584
TH	20000355	29/9/2020	BDF82883-07700-28D-TH	NDEO SPY CL_KCK ML 150 ML	21,744	63002585
ID	20000356	30/9/2020	BDF82241-04800-30C-ID	NDEO SPY INV_BLC&WHT_PWR_ML150	21,000	63002586

Table 4-1: Example of Purchase order from customer

After checking raw material, planner has to generate work order from sales order that has been checked raw material. This means that planner know the incoming date of last incoming raw material. After that the work order that ready to be produce. The planner has to generate Then the set of work order will be sort for dispatching method, which is earliest due date, and ready to calculated in heuristic approach. However, the data generated from ERP system has to be adjusted to provide the complete information in order to calculated in heuristic method. The original data that generate from ERP is missing size of the product. Therefore, size will be added to the file according to **Table 4-2**. Furthermore, the ERP system will generate Earliest due date method in the file. Therefore, the sequence of the order is sort from earliest due date to latest due date.

Added column

PD Line Name	2nd Item Number	Item Description	Size	Count	Refer	Refer Nu	Refer Re
Cosmetic Line 7.4	BDF81682-07700-30C-TH	NDEO SPY INV_BLC&WHT_ML50ML	50 ml	TH	SO	20000751	4/1/2021
Cosmetic Line 7.4	BDF82241-02900-30-CN	NDEO SPY INV_BLC&WHT_PWR_ML150	150 ml	CN	SO	20000662	4/1/2021
Cosmetic Line 7.4	BDF82244-02900-30-CN	NDEO SPYMINI INVBLC&WHTPWRML35	35 ml	CN	SO	20000499	4/1/2021
Cosmetic Line 7.4	BDF82865-06200-28C-KR	NDEO SPY EXT_WHT_FML 60ML	60 ml	KR	SO	20000759	4/1/2021
Cosmetic Line 7.4	BDF82865-07700-28D-TH	NDEO SPY EXT_WHT_FML 60ML	60 ml	TH	SO	20000752	4/1/2021
Cosmetic Line 7.4	BDF82883-02900-28D-CN	NDEO SPY CL_KCK ML 150 ML	150 ml	CN	SO	20000769	4/1/2021
Cosmetic Line 7.4	BDF82883-02900-28D-CN	NDEO SPY CL_KCK ML 150 ML	150 ml	CN	SO	20000663	4/1/2021
Cosmetic Line 7.4	BDF82883-07700-28D-TH	NDEO SPY CL_KCK ML 150 ML	150 ml	TH	SO	20000730	4/1/2021
Cosmetic Line 7.4	BDF82884-06200-28C-KR	NDEO SPY CL_KCK ML 200 ML	200 ml	KR	SO	20000760	4/1/2021
Cosmetic Line 7.4	BDF82972-02950-28B-CN	NDEO SPY MINI EXT_WHT FML 35ML	35 ml	CN	SO	20000664	4/1/2021
Cosmetic Line 7.4	BDF83732-06200-28D-KR	NDEO SPY PRL&BTY FML 200ML	200 ml	KR	SO	20000761	4/1/2021
Cosmetic Line 7.4	BDF83739-07700-28D-TH	NDEO SPY CL_KCK ML 50ML	50 ml	TH	SO	20000635	4/1/2021
Cosmetic Line 7.4	BDF83750-02900-28B-CN	NDEO SPY ENR_FRS FML 150ML	150 ml	CN	SO	20000659	4/1/2021
Cosmetic Line 7.4	BDF84481-07700-30A-TH	NDEOSPYINV_B&W_RDNT&SMTH FM150	150 ml	TH	SO	20000691	5/1/2021
Cosmetic Line 7.4	BDF80018-07740-31-TH	NDEOSPYTWN_PCK CL_KCK 2X150ML	150 ml	TH	SO	20000606	6/1/2021
Cosmetic Line 7.4	BDF80025-07700-30-TH	NMEN DEO SPRY_DP 50ML	50 ml	TH	SO	20000763	6/1/2021
Cosmetic Line 7.4	BDF82883-07700-31-TH	NDEO SPY CL_KCK 150 ML	150 ml	TH	SO	20000605	6/1/2021
Cosmetic Line 7.4	BDF80012-07740-30B-TH	NIVEA MEN INVISIBLE B&W2x150ml	150 ml	TH	SO	20000762	7/1/2021
Cosmetic Line 7.4	BDF81604-06210-28E-KR	NDEO SPY DRY_CMF_FML 200ML	200 ml	KR	SO	20000758	7/1/2021
Cosmetic Line 7.4	BDF82241-04800-30C-ID	NDEO SPY INV_BLC&WHT_PWR_ML150	150 ml	ID	SO	20000755	7/1/2021
Cosmetic Line 7.4	BDF82959-09819-28D-IN	NDEO SPY SLV_PRTT_DYN_PWRML150	150 ml	IN	SO	20000757	7/1/2021
Cosmetic Line 7.4	BDF82967-04800-28F-ID	NDEO SPY EXT_WHT_FML 150ML	150 ml	ID	SO	20000756	7/1/2021
Cosmetic Line 7.4	BDF83165-07700-31-TH	NDEO SPY SP_DRY_CL_XTR_ML150ML	150 ml	TH	SO	20000607	7/1/2021
Cosmetic Line 7.4	BDF83185-07700-31-TH	NDEO SPY SP_DRY_CL_XTR_ML 50ML	150 ml	TH	SO	20000608	7/1/2021
Cosmetic Line 7.4	BDF85305-07700-29B-TH	NDEO SPY HKKD_RS_FML 60ML	60 ml	TH	SO	20000764	7/1/2021
Cosmetic Line 7.4	BDF83739-07700-31-TH	NDEO SPY CL_KCK MALE 50ML	150 ml	TH	SO	20000609	8/1/2021
Cosmetic Line 7.4	BDF81601-07700-28B-EX	NDEO SPY FRS_NTR_N_AP_FML150ML	150 ml	EX	SO	20000555	25/1/2021
Cosmetic Line 7.4	BDF81601-07700-28B-EX	NDEO SPY FRS_NTR_N_AP_FML150ML	150 ml	EX	SO	20000556	25/1/2021
Cosmetic Line 7.4	BDF81601-07700-28C-TH	NDEO SPY FRS_NTR_N_AP_FML150ML	150 ml	TH	SO	20000554	25/1/2021
Cosmetic Line 7.4	BDF82885-07700-31-TH	NDEO SPY CL_KCK 250 ML	250 ml	TH			
Cosmetic Line 7.4	BDF82883-07780-31-VN	NDEO SPY CL_KCK 150 ML	150 ml	VN	SO	20000604	1/6/2021

Table 4-2: The example of added size for the input data

The production schedule is set as shown in **Table 4-3**, it is the example of weekly production plan which mainly focus on delivery date. This table is already arranging the order that has to be produce, the detail is identical from **Table 4-1** apart from the speed of the machine shows in capacity/minute column and the hour require in each order. The set up and changeover is highlighted in yellow, orange, and green stripes. This set up and changeover time is considered as idle time which should be minimize. Changeover time in this production schedule consume 3.47 hours from total production time, which is 51.47 hours or equivalent to 6.74% from total production time.

ITEM CODE (SKU)	ITEM DESCRIPTION (Size)	Zone	DELIVERY DATE	QTY.	ITEM BULK	Capacity/ Minute	Hour
BDF83731-08600-28D-EX	NDEO SPY PRL&BTY FML 150ML	EX	7-Oct-20	12,000	43032-40003-00	140	1.43
BDF83731-08600-28D-EX	NDEO SPY PRL&BTY FML 150ML	MY	7-Oct-20	19,776	43032-40003-00	140	2.35
BDF83731-08600-28D-EX	NDEO SPY PRL&BTY FML 150ML	EX	7-Oct-20	12,000	43032-40003-00	140	1.43
	Change Bulk						0.33
BDF85388-08600-30B-EX	NDEO SPY B&W_ULT_IMP_ML 150ML	MY	6-Oct-20	7,200	44190-40001-00	140	0.86
BDF85388-08600-30B-EX	NDEO SPY B&W_ULT_IMP_ML 150ML	MY	6-Oct-20	14,328	44190-40001-00	140	1.71
	Change Bulk and Size						0.33
BDF80020-06000-29C-EX	NDEO SPY XTR_WHT_SRM_PLC 100ML	EX	7-Oct-20	7,776	41747-40001-00	140	0.93
BDF80020-06000-29C-EX	NDEO SPY XTR_WHT_SRM_PLC 100ML	MX	7-Oct-20	50,724	41747-40001-00	140	6.04
	Change Bulk and Size						0.33
BDF85974-08600-30B-EX	NDEO SPY_BLC&WHT_FRESH ML150ML	MY	15-Oct-20	10,992	42211-40001-00	140	1.31
BDF85974-08600-30B-EX	NDEO SPY_BLC&WHT_FRESH ML150ML	MY	15-Oct-20	6,308	42211-40001-00	140	0.75
	Change Bulk						0.33
BDF81600-08600-29C-EX	NDEO SPY FRS_ACT_ML 150ML	MY	16-Oct-20	19,200	42284-40025-00	140	2.29
BDF81600-08600-29C-EX	NDEO SPY FRS_ACT_ML 150ML	PH	16-Oct-20	7,200	42284-40025-00	140	0.86
	Change Bulk						0.33
BDF80027-08600-30-EX	NMEN DEO SPRY_DEEP 150ML	EX	16-Oct-20	12,360	42546-40008-00	140	1.47
BDF80027-08600-30-EX	NMEN DEO SPRY_DEEP 150ML	EX	16-Oct-20	7,200	42546-40008-00	140	0.86
	Change Bulk						0.33
BDF81602-08600-28E-EX	NDEO SPY DRY_IMP_ML 150ML	EX	16-Oct-20	9,600	40204-40016-00	140	1.14
BDF81602-08600-28E-EX	NDEO SPY DRY_IMP_ML 150ML	MY	16-Oct-20	4,800	40204-40016-00	140	0.57
BDF81602-08600-28E-EX	NDEO SPY DRY_IMP_ML 150ML	PH	16-Oct-20	4,800	40204-40016-00	140	0.57
	Change Bulk						0.33
BDF82241-08600-30C-EX	NDEO SPY INV_BLC&WHT_PWR_ML150	EX	16-Oct-20	14,400	43309-40002-00	140	1.71
BDF82241-08600-30C-EX	NDEO SPY INV_BLC&WHT_PWR_ML150	MY	16-Oct-20	37,080	43309-40002-00	140	4.41
BDF82241-08600-30C-EX	NDEO SPY INV_BLC&WHT_PWR_ML150	EX	16-Oct-20	12,000	43309-40002-00	140	1.43
	Change SKU						0.17
BDF82241-08610-30C-EX	NDEO SPY INV_BLC&WHT_PWR_ML150	PH	16-Oct-20	21,120	43309-40002-00	140	2.51
	Change Bulk						0.33
BDF83486-08600-30B-EX	NDEO SPY B&W_ULT_IMP_FML 150ML	MY	16-Oct-20	14,400	44165-40002-00	140	1.71
BDF83486-08600-30B-EX	NDEO SPY B&W_ULT_IMP_FML 150ML	MY	16-Oct-20	7,200	44165-40002-00	140	0.86
	Change Bulk						0.33
BDF82967-08600-28D-EX	NDEO SPY EXT_WHT_FML 150ML	MY	16-Oct-20	42,024	43960-40010-00	140	5.00
BDF82967-08600-28D-EX	NDEO SPY EXT_WHT_FML 150ML	TW	16-Oct-20	4,800	43960-40010-00	140	0.57
	Change Bulk						0.33
BDF82959-08600-29D-EX	NDEO SPY SLV_PRTT 150ML MALE	EX	16-Oct-20	24,720	40758-40009-00	140	2.94
BDF82959-08600-29D-EX	NDEO SPY SLV_PRTT 150ML MALE	MY	16-Oct-20	9,600	40758-40009-00	140	1.14
BDF82959-08600-29D-EX	NDEO SPY SLV_PRTT 150ML MALE	EX	16-Oct-20	9,600	40758-40009-00	140	1.14

Table 4-3: Example of Weekly Production Plan

4.1.2 Machine information

Machine information contain machine speed and set up time for each changeover, which is informative data to set production schedule. Since, it is single machine schedule, the speed of this production line is 140 pieces per minute. This production line consists of 11 machines which is connected with conveyer which start from loading the can, bulk filling, inserting the valve, clinching the valve, gassing in to the can, hot bath, check weighting, lot printing, leak detecting, capping, shrinking from the layout of production line in Figure 4-1. The production line is continuous line. The changeover of the machine illustrates in Table 4-4. From the changeover information, SKU changing is change order number but size of the can and formula remain the same. While, changing formula has the bottle neck of formula changeover is occurred in bulk filling machine which need to swap the filling cylinder and clean the formula in the cylinder, this takes 20 minute or 0.33 hour to finish. In changing size, the machine has to be readjusted the height of each station to fit with the product. Then, changing formula and size is change both formula and size of the can.

List of Changeovers	Change SKU	Change Formula	Change Size	Change Formula and Size
Changeover Time (Hr.)	0.17	0.33	0.3	0.33

Table 4-4: Time consumption of changeover in hour

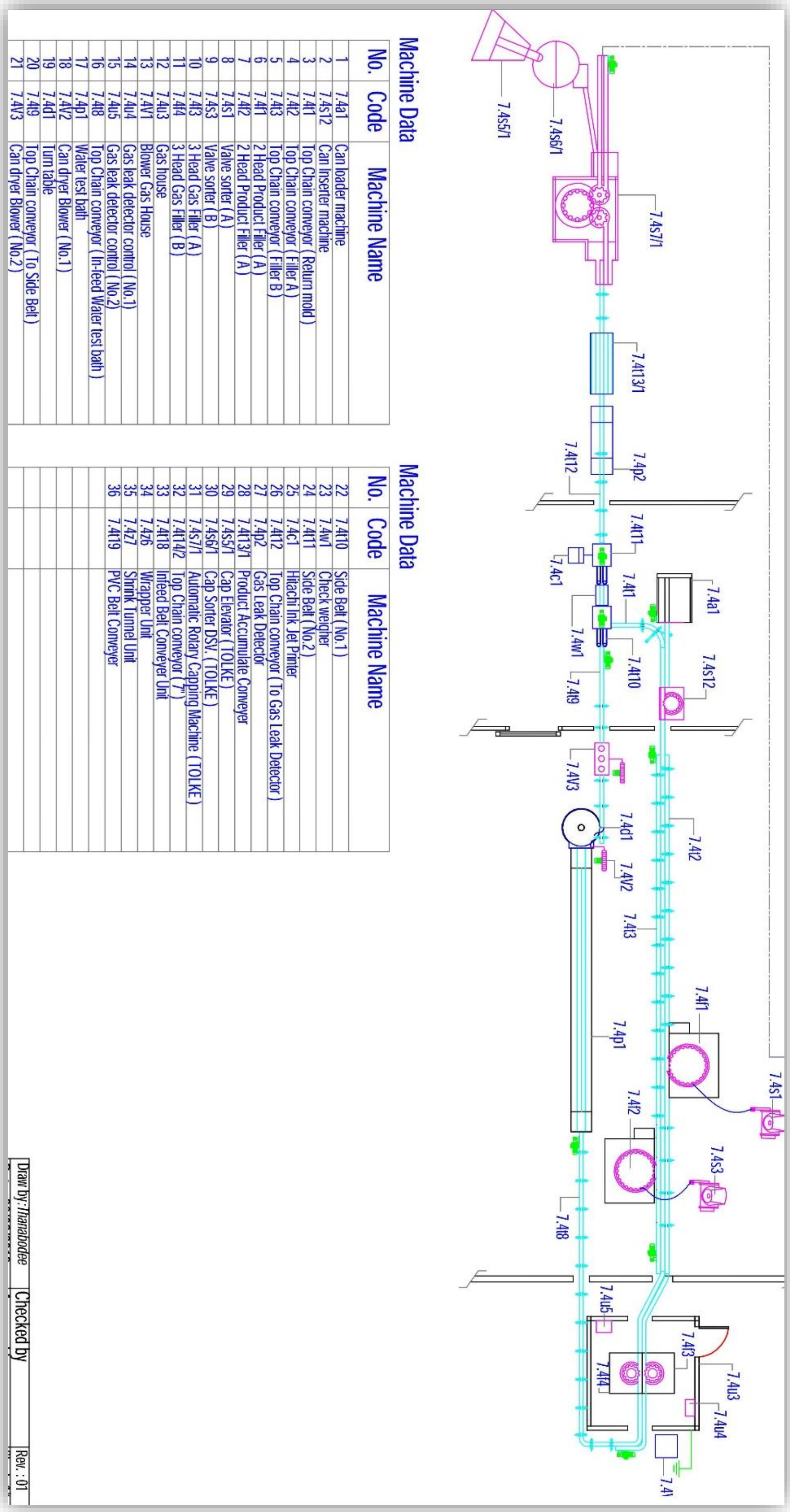


Figure 4-1: Production line machine layout of deodorant aerosol product

4.2 The Heuristic Decision-Making Processes

The heuristic decision-making process will include the input measure of heuristic method which is crucial to the program. If the input measure is not precise. The program of heuristic approach will perform inefficiently. Furthermore, the heuristic decision-making process is including the detail of heuristic approach, including flow process of tabu search and pseudo code of the tabu search.

4.2.1 Input measure

This input measure of heuristic decision-making process is the illustration of the detail of the input data to create heuristic decision making by using Travelling Salesman Problem with Time Windows (TSPTW). In production planning case, manufacturing cost is the easiest measures to track the performance and efficiency of the plan. However, the cost does not necessary to be actual cost. It can be the cost that set to let the program known as the measure unit. It could be changed depend on the result of the plan. Cost of manufacturing include cost of labour to produce and manpower to do changeover. Moreover, every time that the bulk has been changed over, flushing with cleaning solution which has the cost for cleaning solution. In terms of the finish product that is waiting for shipping, there will be holding cost that the company has to pay while the finish product is in the warehouse. And there is a penalty for the delay that the finish good could not deliver on time so it is a cost of delay.

Manufacturing Cost = Cost of labour + Changeover Cost + Holding Cost + Penalty Cost

Cost of labour is depending on working hour of labour. To clarify this, working hour of labour has maximum hour at 22 hours per day. Day-shift is 8 hours between 8:00-17:00 exclude 1-hour break, which is the lowest cost per hour, in this case day shift cost around 80 baht per hour. Moreover, Over Time day-shift is 3 hours between 17:00-20:00 and cost 1.5 times of normal day shift, which can calculate to 120 baht per hour. Then there is a normal night shift which is 20:00-5:00 exclude 1-hour break and charge 1.1 times of normal day-time shift. Likewise, overtime night shift cost 1.5 of normal night shift which equal to 1.1x1.5 =1.65 times of normal day-time shift and overtime starts from 5:00 to 8:00 as shows in **Table 4-5**.

Cost of labour = Total Day-shift cost + Total Night-shift cost

Detail	Cost	Time
Day-shift cost	1.0x80x(8 hr) = 640	8:00-17:00 1-hour break
Day-shift with OT cost	1.0x80x(8 hr) + 1.5x80x(3 hr) = 1,000	17:00-20:00
Night-shift cost	1.1x80x(8 hr) = 704	20:00-5:00 1-hour break
Night-shift with OT cost	1.1x80x(8 hr) + 1.1x1.5x80x(3 hr) = 1,100	5:00-8:00

Table 4-5: Detail of Labour Cost and Time

Changeover cost or set up cost identify the cost that subjected to each set up. The cost of set up will constrain the program to minimize set up time and makespan. Therefore, it determines the minimum total amount of time set-up. There are three variables of setup.

1. Change the SKU
2. Change size
3. Change the formula

In which these 3 variables are related as shows in Figure 4-2, every changeover requires changing SKU. Change size need 0.3 hours to finish. Change formula need 0.33 hour to finish. Then, change size and formula is the most effective way to change due to it require 0.33 hour to finish similar to change formula but can change both size and formula. Therefore, the cost set up for this particular production line is 50,000 for changing bulk, 47,500 for changing bulk and size, 25,000 for changing size, and 5000 for changing SKU as shown in Table 4-6.

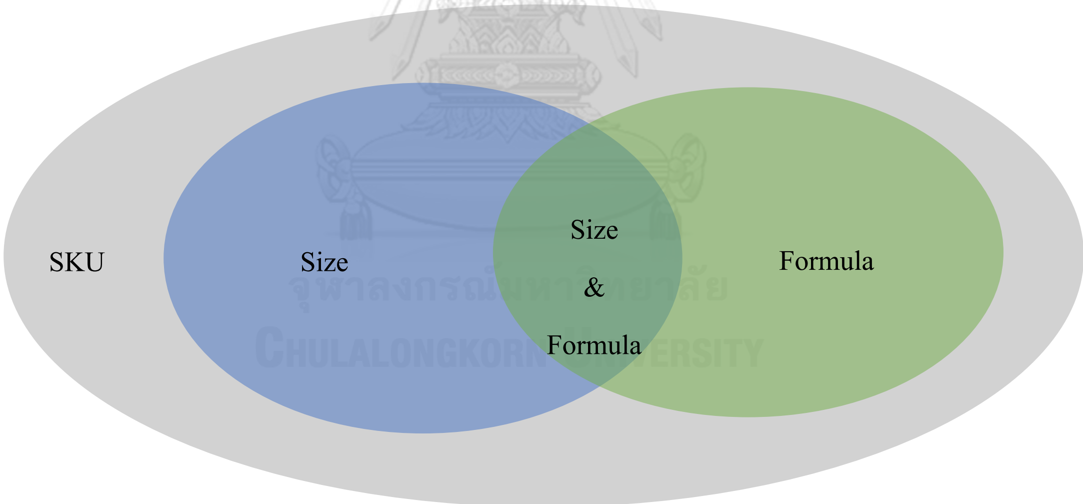


Figure 4-2: Relation between change size, formula, and SKU.

Description	Cost of changing
Total Change bulk	50,000
Total Change bulk and size	47,500
Total Change Size	25,000
Total Change SKU	5,000

Table 4-6: Cost of changing for each change

After finished goods have been produced, they have to be kept in finished goods warehouse. The longer the company keeps the finished product, the cost of carrying finished goods increases with the number of days stored. Therefore, the production must be as close as possible to the deadline according to the Just in Time principle, but in fact, many companies cannot do just in time perfectly. In this case, the company still has to store the finished goods for about two days before shipping. Because there is a need to allow time for handling matters before shipping and make sure that the product is ready for delivery in case of an emergency in the matter of machinery failure, etc. Holding cost is 500 per day per order, so it is 500 times the accumulation of difference between delivery date and job done date.

Holding cost = 500 x (Delivery Date – Job done date)

Moreover, there are penalty cost that derive from late cost and over timespan cost. Penalty cost indicates the delay of delivery and over machine capacity.

Total penalty cost = Late cost + Over timespan cost

Holding cost shows the number of days that production line produces before due date. While, late cost is the cost that production line done the finished goods after delivery date. This causes the delay of promised date between customer and it will decrease the customer satisfaction. Therefore, the charge of this cost is greatly high compare to holding cost because the delay impact on customer satisfaction. Late cost is 20,000 times accumulation of the different between job done date and delivery date. To be more obvious, Figure 4-3 clarify the definition of holding cost, late cost, due date and delivery date in timeline form.

Late cost = 20,000 x Max (Job done date - Delivery Date)

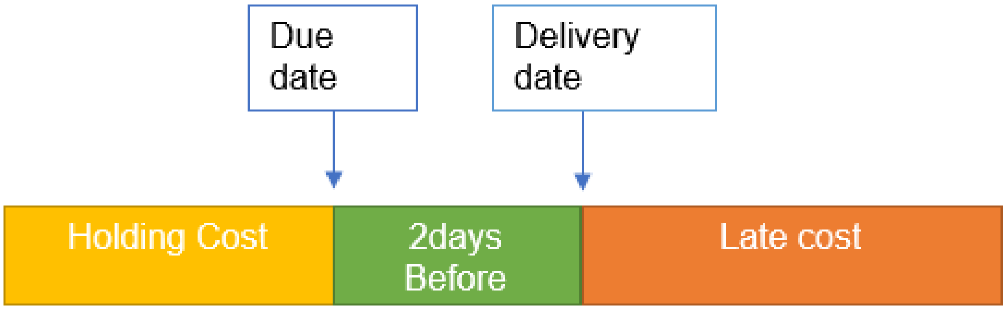


Figure 4-3: Clarification of Holding cost, Late cost, Due date, and Delivery date

Over timespan cost is the cost that demand more than the capacity of the machine with full time day shift and night shift (22 hours). This cost is very rarely occurred due to the demand mostly still in the capacity of the machine that can produce. However, if the demand is more than the capacity of this machine the cost of over timespan will cost at 10,000,000 time the different between total hour of plan and total available hour. 10,000,000 is imaginary number and don't want this cost to be happen so the cost that set on this time is extremely high.

Over timespan cost = 10,000,000 x 1: If (Total hour of plan –Total available hour >0) else 0

4.2.2 Flow process of heuristic algorithm

Heuristic decisions begin with the receipt of information in this case the cost that mentioned above will be calculated by the heuristic algorithm using Tabu search which is a metaheuristic local search method. Local search methods usually stuck in suboptimal regions. Tabu search increases the performance of these techniques by restricted the already visited solutions or others constrain of user provided rules. According to Figure 4-4, Tabu search flow chart is the process of Tabu search start with generate current solution (S). Then generate candidate list of neighbour's solutions from the current solution (S). The candidate list of neighbour's solutions that is chosen are 2-opt and Node shift due to the simplicity of the algorithm and the speed of solving the problem. Then find the best solution S from the candidate list. After finding the best solution, it will get S* which is the best solution from candidate list. If S* is not in tabu list the flow will go to update S* in to Tabu list. However, if S* is in Tabu list, S* has to be deleted from candidate list and find new best solution. The tabu length of this flow process is 50. This indicate that number of work order that tabu could memorised is 50 work orders. After update S* in tabu list and make current solution S* then repeat until stopping condition when there is no new best solution for 50 cycles.

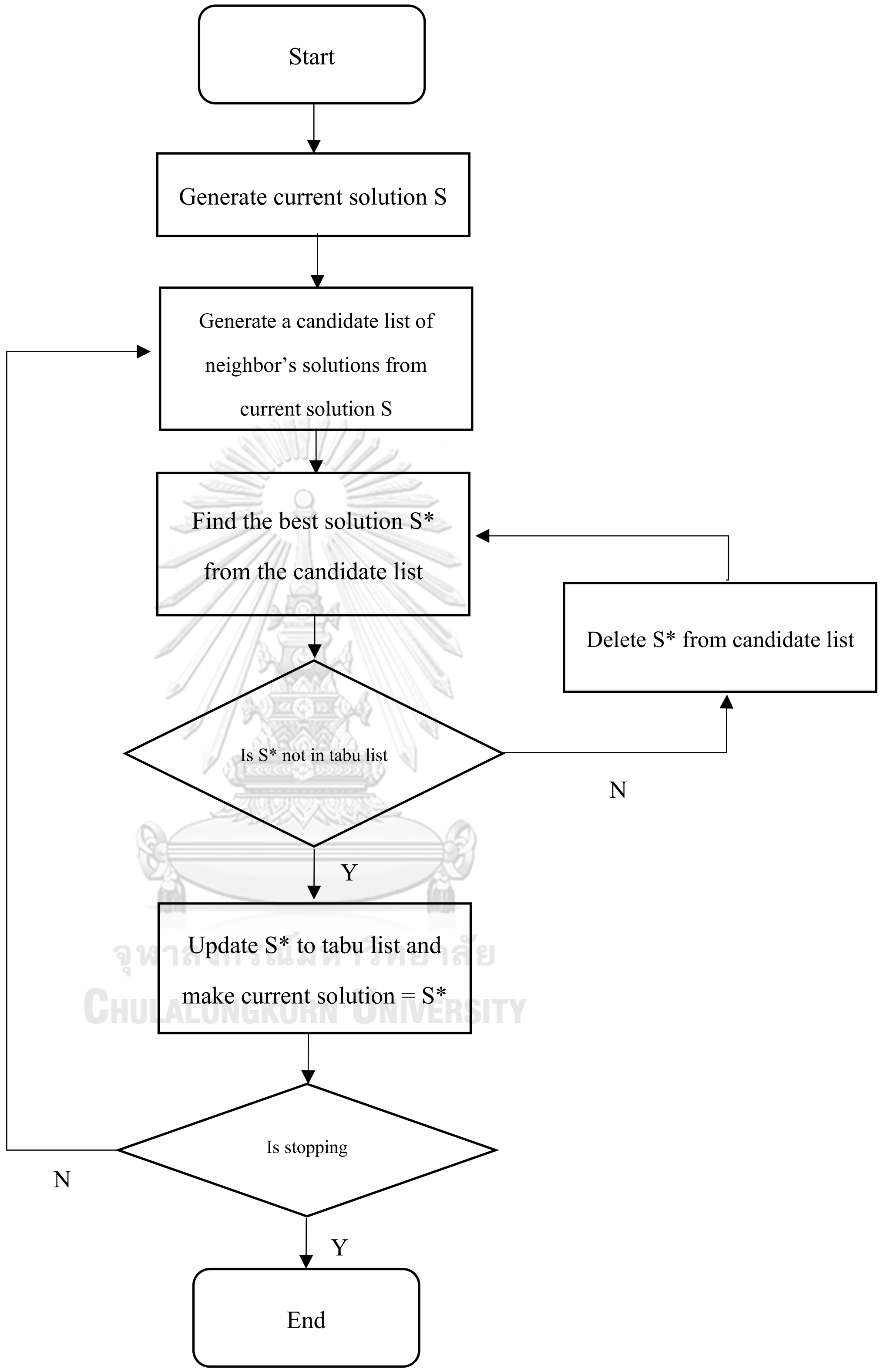


Figure 4-4: Tabu search flow chart

After visualizing the process of tabu search by tabu search flow chart, Pseudo code is another way of understanding the idea of the specific tasks within a program. Pseudo code will not include keywords in any specific computer language in order to let the reader that is not experience in writing code understand the tasks and process of the algorithm [12]. In this case, pseudo code for tabu search, will explain the tabu search algorithm in step by step. Start from the input of tabu search, the initial solution should be put in the program in form of excel file. Tabu list size is determine by the size of the problem, in particular the number of work orders. The initial output that receives from the algorithm will be best solution, it is current solution because the algorithm hasn't calculated and swap the sequence yet. Then the tabu search will generate the neighbour solution be using algorithm of candidate list, the candidate list will swap the sequence and give the neighbour solution from the current solution. Then select the best candidate solution from the candidate list that already run the neighbour solution and add the best candidate solution to the tabu list, which is the memory of tabu. If the best candidate solution is better than best solution which is current solution, the best candidate solution will place instead of current solution. And the tabu list has the capacity of 50 lists. The logic of elimination using First in first out principle. That's mean, if the tabu length is larger than 50 lists it will remove the first solution of tabu list. In this case, if the tabu list has 51 lists the list number 51 will be replace list number 1.

Pseudo code for Tabu search

Tabu search algorithm

Input: Initial solution, Tabu list size

Output: The best solution

Initialize the Tabu list as empty list

best solution = current solution

while stopping condition not met do

Generate candidate list of neighbor solution from current solution

Select the best candidate solution from candidate list

Add the best candidate solution to the Tabu list

Set current solution equal to best candidate solution

if fitness (best candidate solution) > fitness (best solution) do

best solution = best candidate solution

if size of Tabu list > Tabu list size do

remove first solution of Tabu list

end while return the best solution

The candidate lists algorithm that used in this heuristic is 2-opt algorithm and Node shift move algorithm. The reason 2-Opt heuristic is used because it is one of the simplest algorithms for finding good solutions to the metric Traveling Salesman Problem. Likewise, node shift move is a simple tour optimization heuristic. It consists in shifting a city to other position in tour [13].

In this case, node shift move algorithm will create neighbour's solutions. While input S is current solution and N is neighbour's size.

Node shift move algorithm will create neighbour's solutions by randomly select one of the indexes (work order) from current solution, then randomly insert at another index. Then the output of the algorithm will be neighbour solution according to Figure 4-5. The pseudo code explains the algorithm step by step of process of node shift move turn current solution in to neighbour's solution.

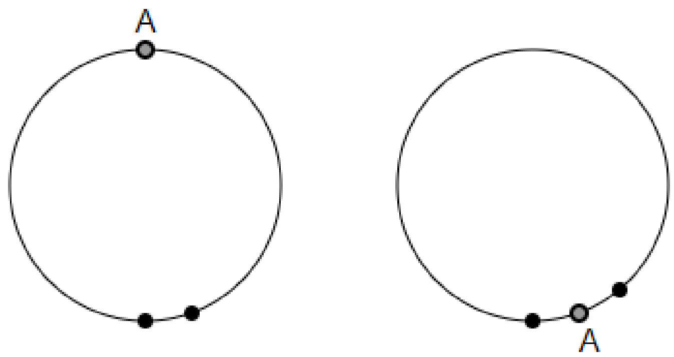


Figure 4-5: Node shift move algorithm

Pseudo code for node shift move algorithm

Input: Current solution S, neighbor size N

Output: List of neighbor's solutions

for i = 1 to N do:

A = randomly select one index from S

B = randomly select one index from S

New Solution = remove A index element of S and then insert it at B index of S

end for return List of neighbor's solutions

Therefore, the algorithm of TSPTW that will be used and compare in this case has two candidate lists.

Option 1: 2opt move with tabu search

Option 2: Node shift move with tabu search

Key words

Tabu List: The instrument that lends a short-to-medium size memory to the algorithm. The List "remembers" and disables movements from previous searches. These disabled movements are referred to as Tabu Moves.

Candidate list: The algorithm that use to find best solution such as 2-opt,3opt, node shift, etc.

Tabu length: Number of algorithm steps for which the designated attribute is declared tabu.

4.3 Sample of heuristic calculation result

The sample of heuristic result will illustrate the sequence of algorithm compare to planner’s plan as a reference. Moreover, the summary of heuristic result will be showed and compared to current planning in order to track the advantage and disadvantage of each heuristic result.

The sample of heuristic algorithm according to Figure 4-6, shows the comparison between current planning and node shift algorithm for four days with the changes of work order from current plan to heuristic. The sequence is almost entirely change because heuristic algorithm is to move the order to the best possible solution. The algorithm will change until there are no new best solution then it will stop. However, this sample is illustrating the Gantt chart to acknowledge of how the sequence can be change with heuristic calculation, the result of this sample has the same makespan as current planning because the current planning already plans the best possible solution due to the scale of the plan is not big enough to differentiate the result of the plan. Therefore, the author decided to compare the summary result in the bigger scale of the plan.

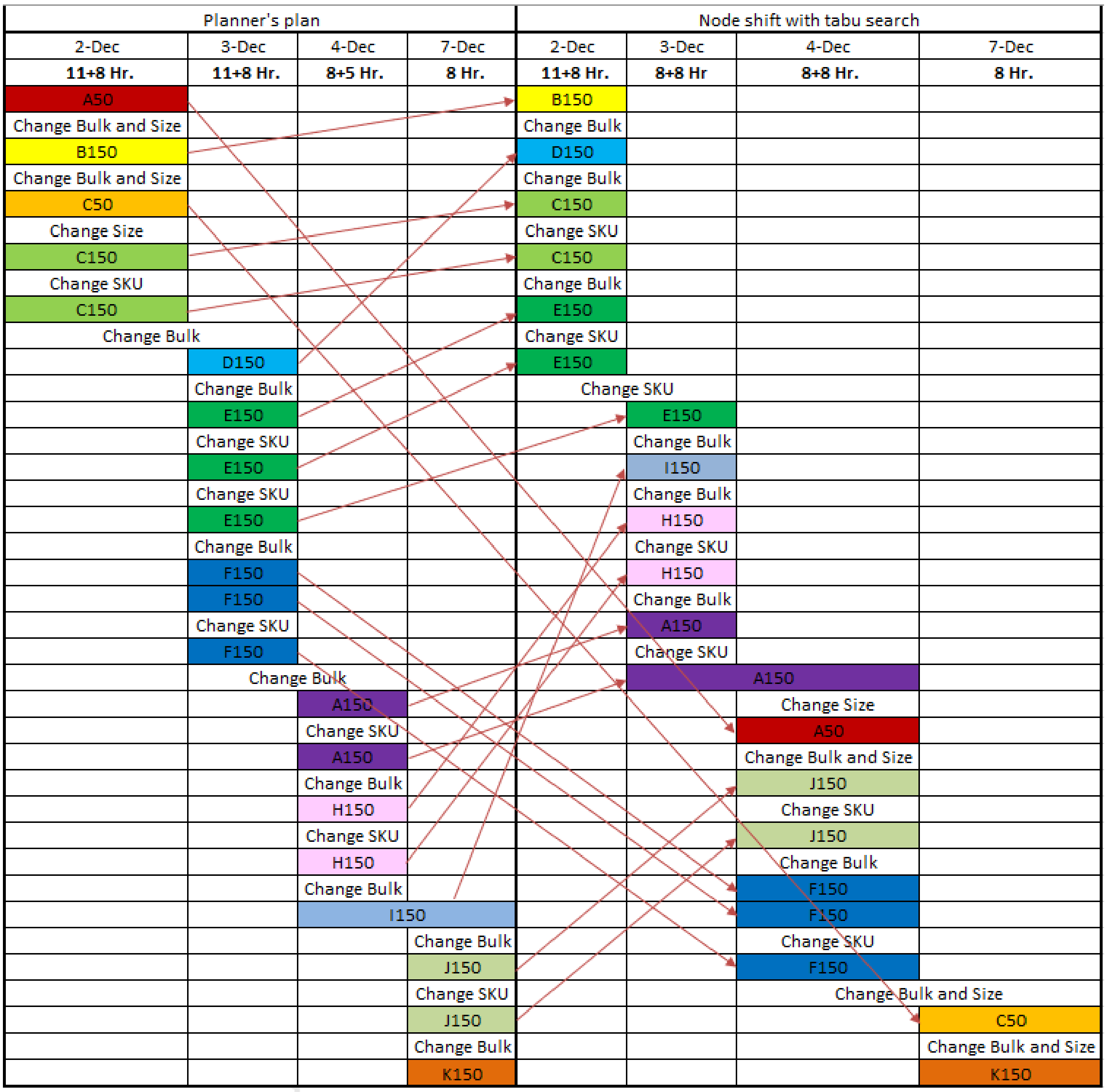


Figure 4-6: The way algorithm changes the sequence of work order

4.3.1 Comparing planner's plan and 2-opt with tabu search 1st run

From the proposed heuristic method, two candidate lists will be compared in each factor as well as compare to the current planning method of the planner to understand the effectiveness of heuristic calculation result. The sample production plan is produced 110 orders with various delivery date, bulk, size, and SKU. Total production is 2,301,449 cans. The plan has to finish within two weeks' time. Planner's plan will be set as a reference and compare to heuristic in aspect of makespan, changeover times, early days, late days.

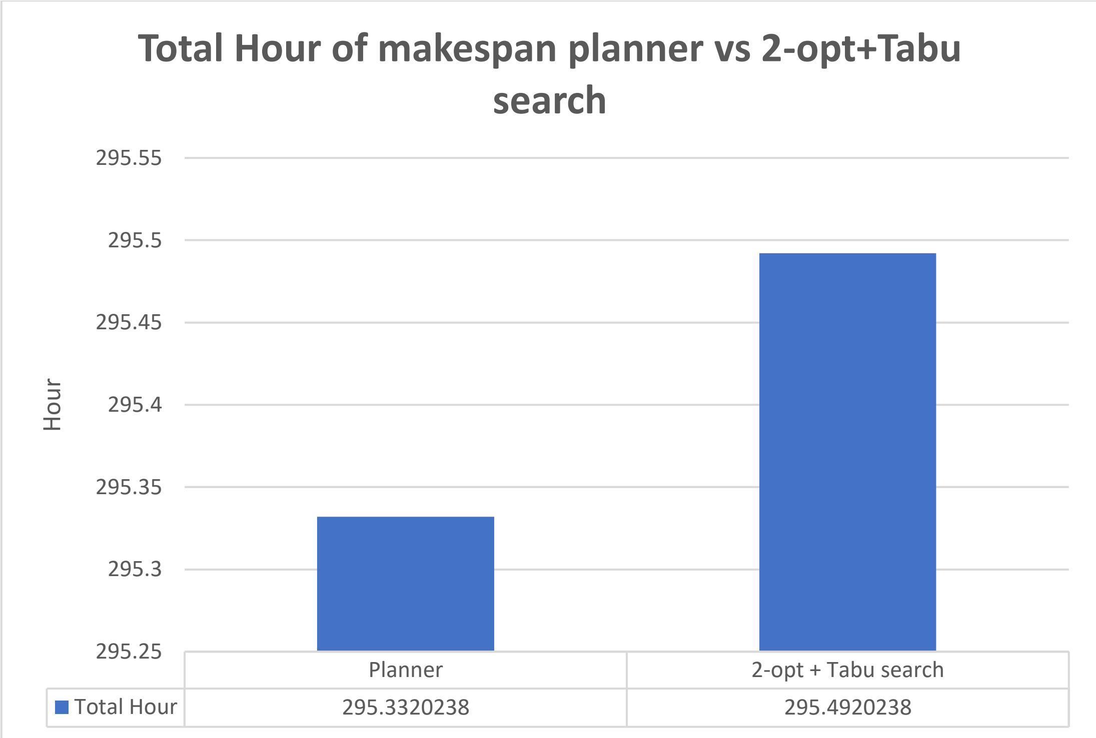
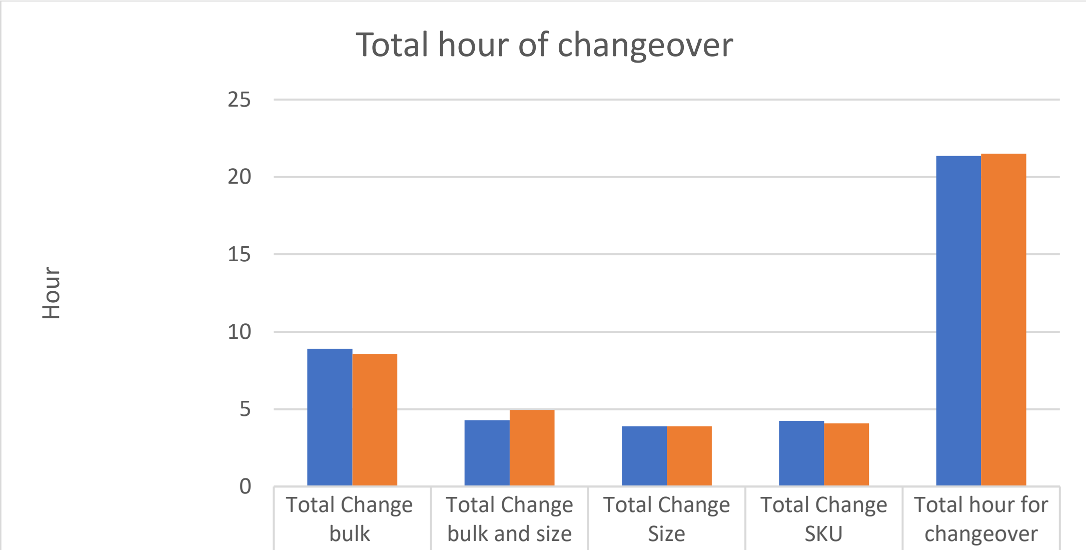


Figure 4-7: Comparison of total makespan between current planning and heuristic approaches with 2-opt with tabu search

Heuristic sample using same production order to simulate the production plan and comparing makespan with current planning shows in Figure 4-7, the table shows the makespan of planner which is 295.33 hours, planner plan relatively goods due to experience of planner. However, heuristic approach in optimisation 1, which run on 2-opt with tabu search algorithm took 295.49 of makespan. Therefore, on optimisation 1, it took 0.16 hour more than planner.



	Total Change bulk	Total Change bulk and size	Total Change Size	Total Change SKU	Total hour for changeover
Planner	8.91	4.29	3.9	4.25	21.35
2-opt + Tabu search	8.58	4.95	3.9	4.08	21.51

Figure 4-8: Comparison of total hour of changeovers between current planning and heuristic approaches with 2-opt with tabu search

According to Figure 4-8, total number of changeovers between planner and 2-opt with tabu search indicates that the changeover times of two plan is different. Planner consume more time on change bulk and SKU. Whereas, 2-opt with tabu search consume more time on total change bulk and size. However, in summary planner use less time compare to heuristic approach. Moreover, the time uses on the planner's plan is 0.16 hour less than heuristic's (2-opt), which same as the different of total makespan between the two as mentioned above. Therefore, the makespan that use more time come from changeover.

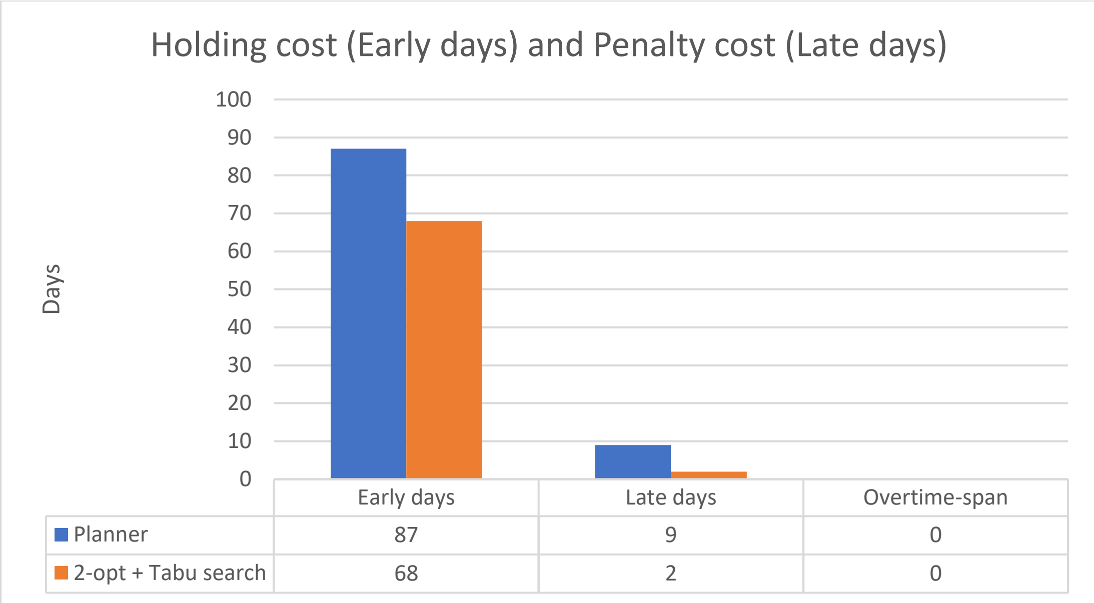


Figure 4-9: Comparison of early days and late days between current planning and heuristic approaches with 2-opt with tabu search

Considering early days and late days of planner and 2-opt with tabu search according to Figure 4-9, the day in this figure shows the accumulate days of the total plan. The heuristic has dramatically improved in term of number of early days that finish goods has to be hold in the warehouse. The early days is 19 days better than planner’s plan. Furthermore, late days from delivery date is 7 days better from planner’s plan.

4.3.2 Comparing planner's plan, 2-opt with tabu search 2nd run, and node shift with tabu search

The result received from 2-opt with tabu search in the first calculation, still relatively worse compare in terms of makespan and changeover time to planner's plan. Therefore, the author decided to calculate 2nd run of 2-opt with tabu search. Moreover, node shift move with tabu search will be compared to determine the best solution of this particular plan.

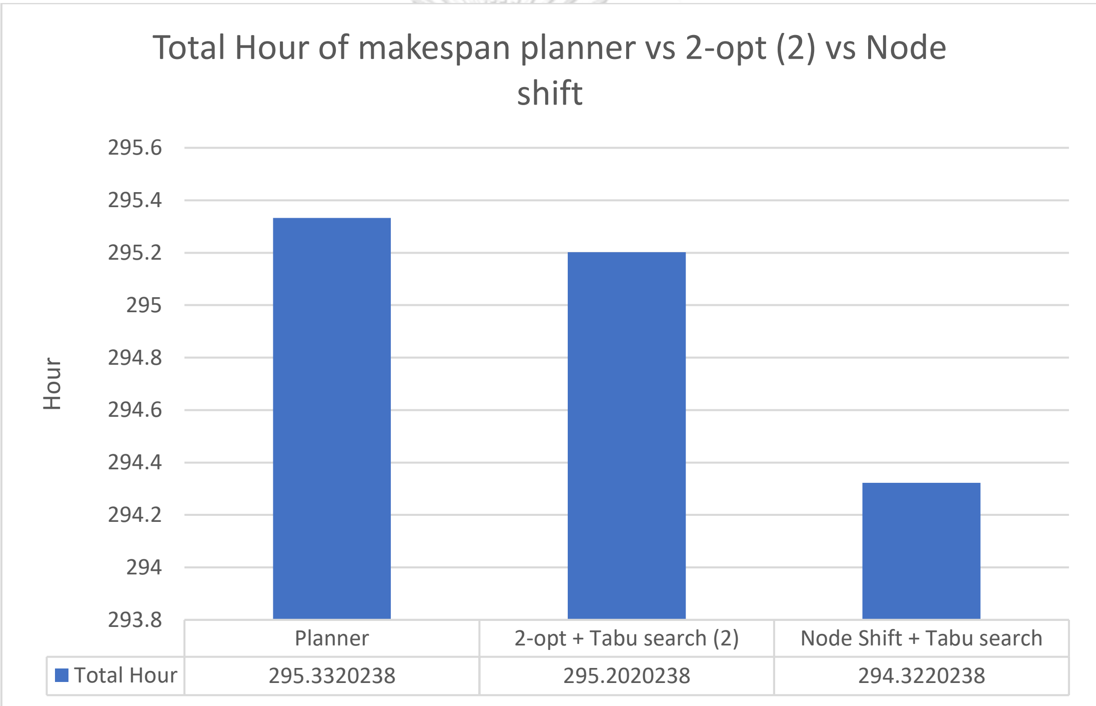


Figure 4-10: Comparison of total makespan between current planning, 2-opt with tabu search 2nd run, and Node shift with tabu search

According to Figure 4-10, the comparison between planner's plan, 2-opt with tabu search 2nd run, and node shift with tabu search illustrates that 2-opt improve makespan and turn out to be better than planner. While, the new candidate list which is node shift with tabu search has the best makespan among three. Node shift is 1.01 hour better than planner's plan and 0.88 hour better than 2-opt with tabu search.

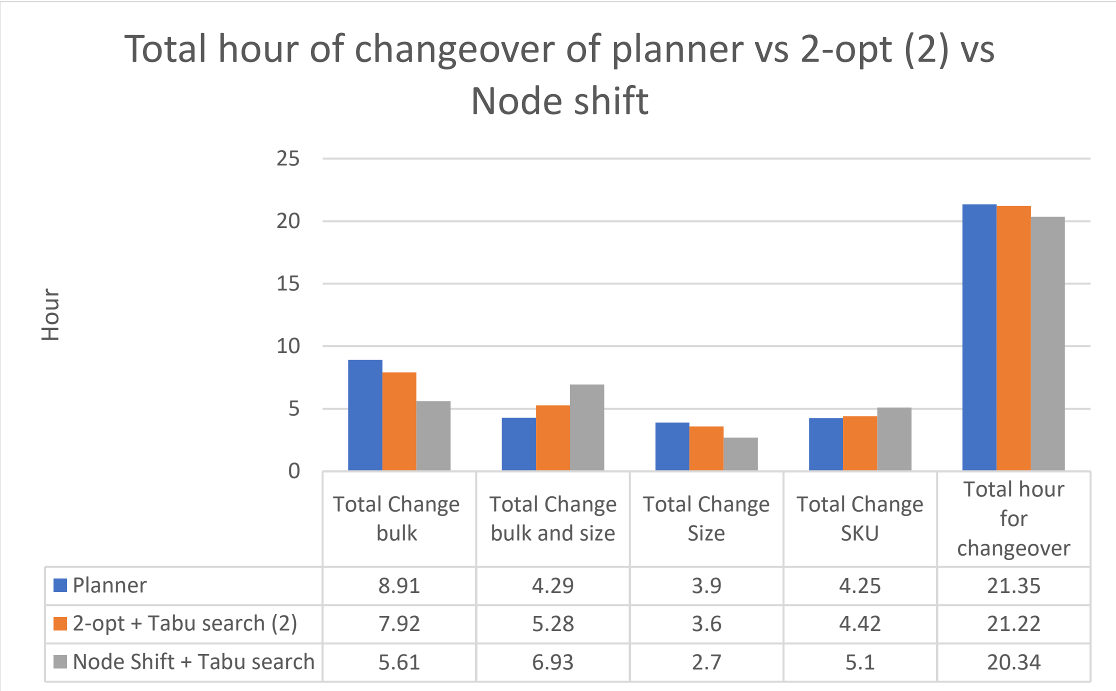


Figure 4-11: Comparison of total hour of changeover between current planning, 2-opt with tabu search 2nd run, and Node shift with tabu search

As illustrate above, makespan is depend on changeover time. The heuristic, run the sequence different from planner's plan. Therefore, the result of hour consuming in each changeover is not identical. This leads to different changeover times and better makespan. The total changeover time of node shift with tabu search perform the best out of three. In detail, node shift has less changeover of changing bulk than 2-opt and planner. Where node shift has more changeover time on bulk and size. Therefore, node shift uses more on bulk and size than 2-opt and planner according to Figure 4-11.

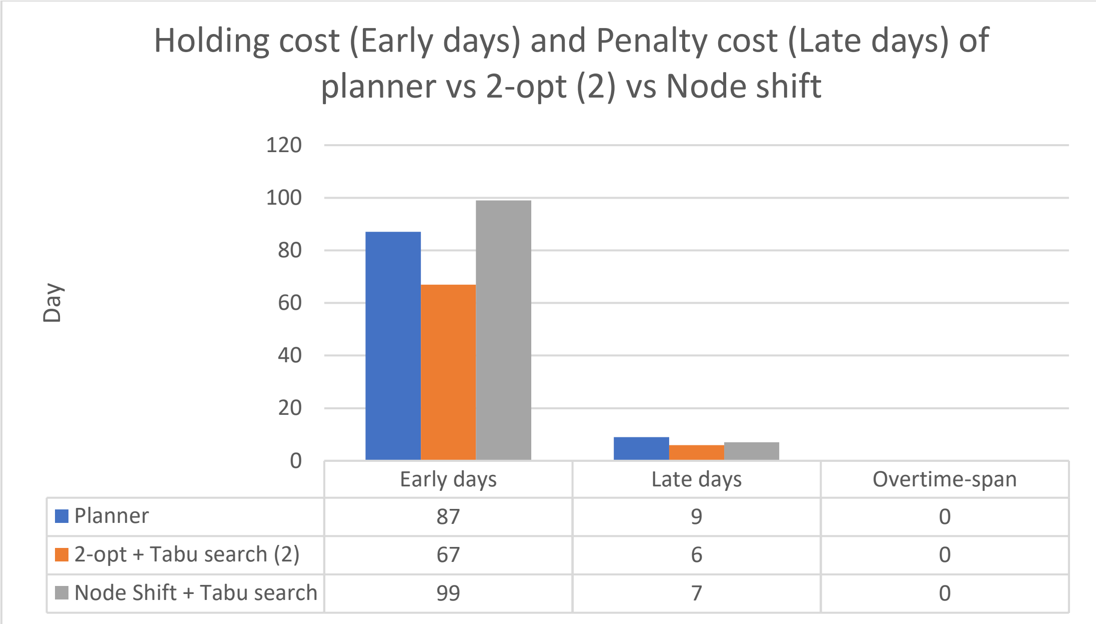


Figure 4-12: Comparison of early days and late days between current planning, 2-opt with tabu search 2nd run, and Node shift with tabu search

Early days and late days of node shift with tabu search is the worst compare to 2-opt and planner according to Figure 4-12. That's mean node shift is the best on makespan and changeover time, where it is the worst on early days and late days. This indicates that planner has 87 early days where 2opt- with tabu search perform better in 67 days. However, in node shift with tabu search result in 99 days in early day. Calculated this in cost parameter that the program has been input will be the planner, 2-opt, and node shift are 133,500, 93500, 119,500 consequently. The result in this comparison 2-opt perform the best in terms of early days and late days.

5. Result and Discussion

Researchers focus on creating and develop heuristic for aerosol filling process. Heuristic efficiency was measured by comparing makespan closing times of production scheduling by heuristic TSPTW method. The sample of production schedule is currently use in real production plan of filling process in major aerosol contract manufacturer in Thailand. The result will show 6 samples of the heuristic approach that calculate from the python program on computer that has Intel® Core™ i5-8265U CPU @ 1.60GHz 1.80 GHz with ram 8. 00GB.Each sample will run 10 reps; 5 reps will use node shift move and another 5 reps will use 2-opt move. The makespan of the improving heuristic averaging at 0.34%. The average computing time of 6 samples and 5 reps from each method is 24 minute and 34 seconds which shows in Table 5-1. The computing time is quite impressive compare to manually plan by planner which could takes up to 6-8 hours to plan the production schedule. The full result is illustrated in Appendix 8.1.

Computing time	**H:M:S**
Set1 Av.	0:01:13
Set2 Av.	0:01:20
Set3 Av.	0:56:16
Set4 Av.	0:04:05
Set5 Av.	0:33:35
Set6 Av.	0:50:56
Total Av.	0:24:34

Table 5-1: Total average computing time and average time of each set

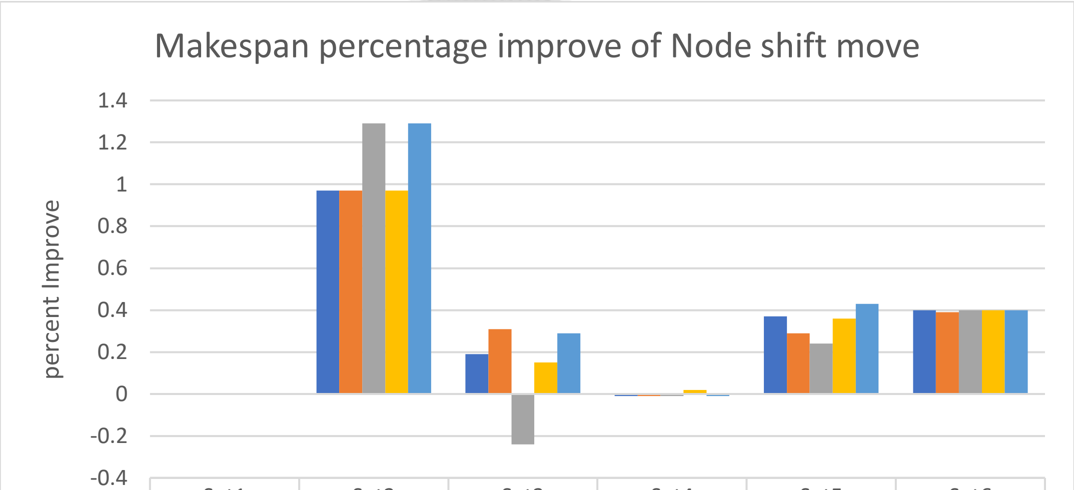
5.1 Result of Makespan of Heuristic Methods Compare to Current Planning

The researcher compared the makespan between current production planning and heuristic methods of 2-opt and node shift as shown in Figure 5-1. The result will be calculating in percentage different according to the equation below.

$$\%Difference\ makespan\ =\left(\frac{Current\ Plan-Heuristic\ Solution}{Current\ Plan}\right)x100\%$$

5.1.1 Makespan Comparison Between Node Shift Move and Current Planning

From the result of percent improvement of makespan according to Figure 5-1, it was found that the heuristic method of production schedule has less makespan than the current production planning, with the sample data being able to reduce the makespan by an average of 0.34% compare to makespan of current production planning.



	Set1	Set2	Set3	Set4	Set5	Set6
Node1	0	0.97	0.19	-0.01	0.37	0.4
Node2	0	0.97	0.31	-0.01	0.29	0.39
Node3	0	1.29	-0.24	-0.01	0.24	0.4
Node4	0	0.97	0.15	0.02	0.36	0.4
Node5	0	1.29	0.29	-0.01	0.43	0.4

Figure 5-1: Percentage improvement of makespan of node shift move compare to current planning

From the result, the improvement of makespan in the heuristic method on node shift move has the average of 0.328%. On Set2, it performs the best which is around 1.95% improvement. However, on set3 and set4 there are some of the plan that perform slightly worse than current planning. The reason behind this result is the parameter that control the algorithm of the heuristic method. The parameter in this case is cost of changeover and date. Moreover, the result shows that different workorder type, the heuristic will perform differently.

Parameter	planner	Set3 Node3
Total cost	2668316	2547712
Total hour	295.332	296.052
Total changeover cost	2417500	2402500
Total change bulk	27	19
Total change bulk and size	13	21
Total change size	13	12
Total change sku	25	31
Total labor cost	28212	28212
Day-shift	14	14
Day-shift OT	14	14
Night-shift	14	14
Night-shift OT	11	11
Total inventory cost	43000	33500
Early days	86	67
Total penalty cost	180000	80000
Late days	9	4
Runtime	0	34:55.8

Table 5-2: Sample of Set 3 node shift move rev 3

According to Table 5-2, it shows the comparison of sample 3 with node shift move in third run. The particular sample set that run from heuristic method has slightly increase makespan compare to current planning. As mentioned earlier, the program relies on the cost parameter which indicate the best solution of heuristic method. In this sample it has better Objective value, which is the sum of total changeover cost, total labour cost, total inventory cost, and total penalty cost. The objective value of the heuristic is less than current planning. Because inventory cost and penalty cost has significantly less than current plan. The program will sacrifice the changeover cost to inventory cost and penalty cost. That is the reason of why the heuristic method will has more makespan time than current planning.

In set4 of production plan, the heuristic approach performs worse than current plan for makespan in every run because the current plan has lower makespan for around 0.1% or 0.01 hour but late days is 122 late days. Therefore, the heuristic approach has to sacrifice makespan to improve late days according to Table 5-3.

Parameter	**planner**	**Set4 Node1**
Total cost	3708572	1286572
Total hour	131.0479	131.0579
Total changeover cost	1005000	960000
Total change bulk	13	10
Total change bulk and size	6	8
Total change size	2	2
Total change sku	4	6
Total labor cost	13920	12152
Day-shift	15	14
Day-shift OT	12	3
Night-shift	0	3
Night-shift OT	0	0
Total inventory cost	12500	15000
Early days	25	30
Total penalty cost	2780000	340000
Late days	139	17
Runtime	0	02:49.5

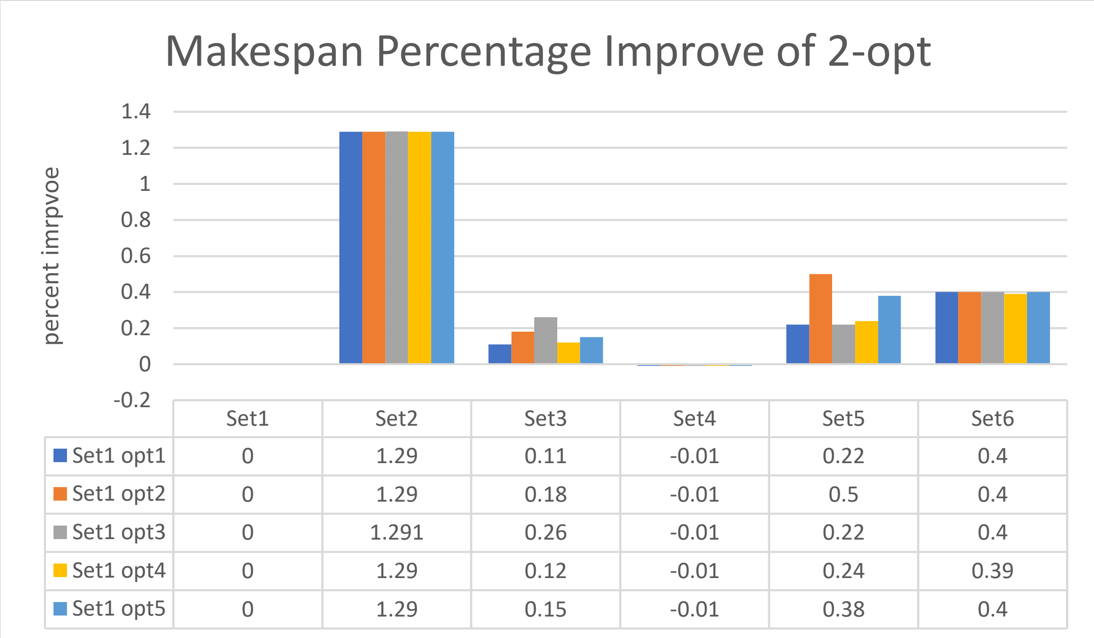
Table 5-3: Sample of Set 4 node shift rev 1

Note:

Total cost =Total changeover cost + Total Labour cost + Total inventory cost + Total penalty cost

5.1.2 Makespan Comparison Between 2-opt Move and Current Planning

After illustrate the result of makespan of node shift move. Then the 2-opt move is compared to current planning which showed in Figure 5-2, running on 2-opt has slightly better makespan than node shift moves in the average of 5 runs on 6 samples. The average percent improvement of 2-opt is 0.359 and there is no data set perform worse than current planning on set 3, where node shift has one set perform worse than current planning.



	Set1	Set2	Set3	Set4	Set5	Set6
Set1 opt1	0	1.29	0.11	-0.01	0.22	0.4
Set1 opt2	0	1.29	0.18	-0.01	0.5	0.4
Set1 opt3	0	1.291	0.26	-0.01	0.22	0.4
Set1 opt4	0	1.29	0.12	-0.01	0.24	0.39
Set1 opt5	0	1.29	0.15	-0.01	0.38	0.4

Figure 5-2: Percentage improvement of makespan of 2-opt compare to current plan

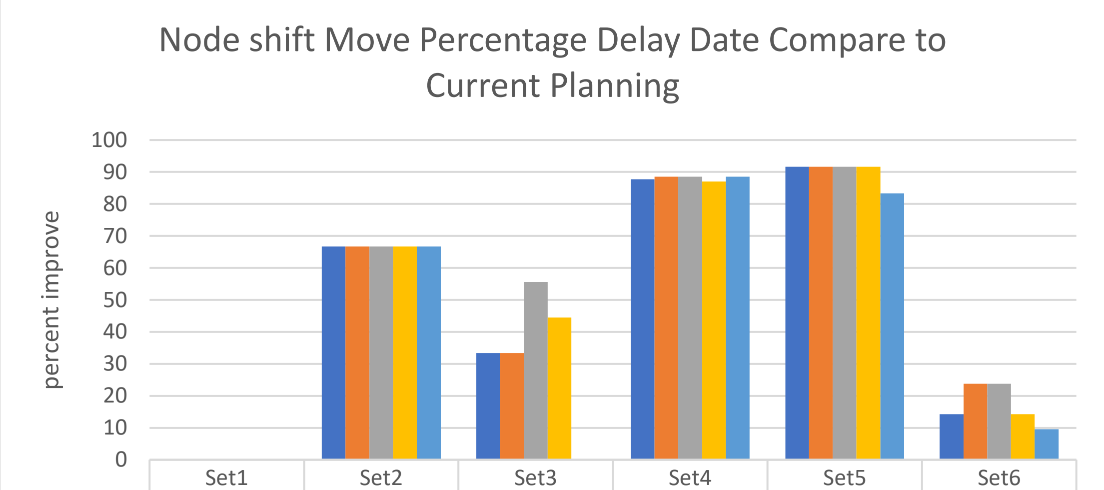
5.2 Result of Delay Date of Heuristic Methods Compare to Current Planning

After focus on the makespan time which is the main objective of this method. The delay time is the crucial aspect to consider in this production schedule as well. Therefore, the delay date will be compared to the current planning to determine late days improvement after calculating the heuristic approach. The calculation of percentage different of delay date is demonstrate in following equation.

$$\%Difference\ delay\ date\ = \left(\frac{Currenlyt\ Plan\ Delay\ Date\ Accumulation - Heuristic\ Approach\ Delay\ Date\ Accumulation}{Currently\ Plan\ Delay\ Date\ Accumulation}\right) x100\%$$

5.2.1 Delay Dates Comparison of Node Shift Move and Current Planning

The node shift and 2-opt heuristic approaches will be compared to current plan. According to Figure 5-3, node shift move shows the percentage improvement of delay date compare to current plan. Similar to makespan graph, data set has 6 sets of production planning and each set run five times of heuristic method to determine the reliability of the method. The improvement is significant in terms of delay date, the average of delay time running on node shift move is 49.2%. Moreover, on set 5 it performs average of 90% which is dramatically high compare to current plan.

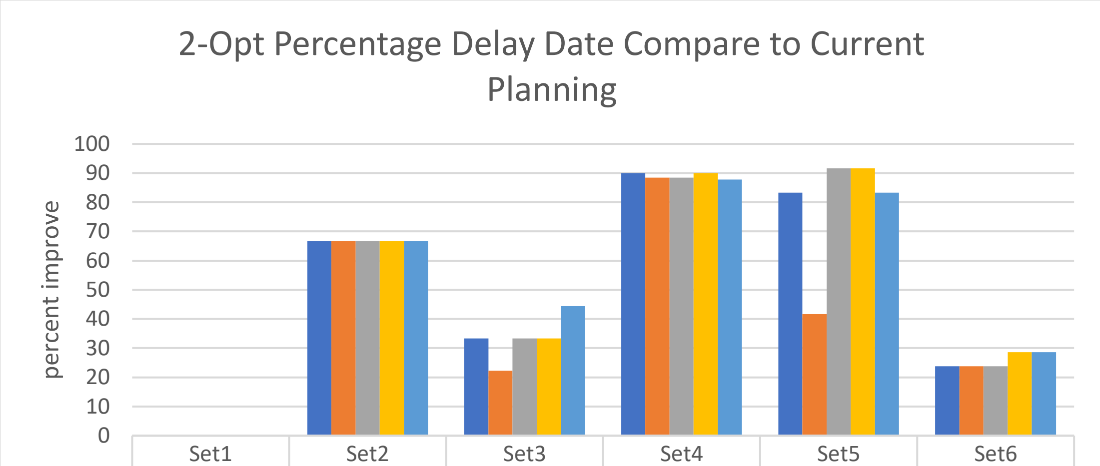


	Set1	Set2	Set3	Set4	Set5	Set6
Node1	0	66.66666667	33.33333333	87.76978417	91.66666667	14.28571429
Node2	0	66.66666667	33.33333333	88.48920863	91.66666667	23.80952381
Node3	0	66.66666667	55.55555556	88.48920863	91.66666667	23.80952381
Node4	0	66.66666667	44.44444444	87.05035971	91.66666667	14.28571429
Node5	0	66.66666667	0	88.48920863	83.33333333	9.523809524

Figure 5-3: Percentage improvement of delay date of node shift move compare to current plan

5.2.2 Delay Dates Comparison of 2-Opt Move and Current Planning

On the other hand, 2-opt performs slightly worse than node shift in terms of delay date according to Figure 5-4. The average percent improvement for 2-opt is 48.82% compare to current plan.



	Set1	Set2	Set3	Set4	Set5	Set6
opt1	0	66.66666667	33.33333333	89.92805755	83.33333333	23.80952381
opt2	0	66.66666667	22.22222222	88.48920863	41.66666667	23.80952381
opt3	0	66.66666667	33.33333333	88.48920863	91.66666667	23.80952381
opt4	0	66.66666667	33.33333333	89.92805755	91.66666667	28.57142857
opt5	0	66.66666667	44.44444444	87.76978417	83.33333333	28.57142857

Figure 5-4: Percentage improvement of delay date of 2-opt compare to current plan

According to comparison of makespan and delay time that discussed, the percentage improvement between node shift moves and 2-opt in makespan and delay time is not much of a different, the node shift is slightly better on maekspan (0.031%), where 2-opt is slightly better on delay time than node shift move (0.38%). Therefore, two methods of heuristic approach have almost similar result. The delay time improvement is satisfied, it can produce the production schedule earlier than current plan by a large number. However, for makespan time, heuristics approach could not perform by a large number of improvement due to the constrain of delivery date.

In the result of average delay date improvement, the accumulative average delay date improvement will be illustrating in form of day to be more obvious. Figure5-5 will show the average delay date improvement from the current plan. It can be conclude that the average delay date improvement is 24 days. The formula of different delay date is shows below.

$$Difference\ delay\ date = Accumulate\ Current\ plan\ delay\ date\ - Accumulate\ \ Heuristic\ Plan\ Delay\ Date$$

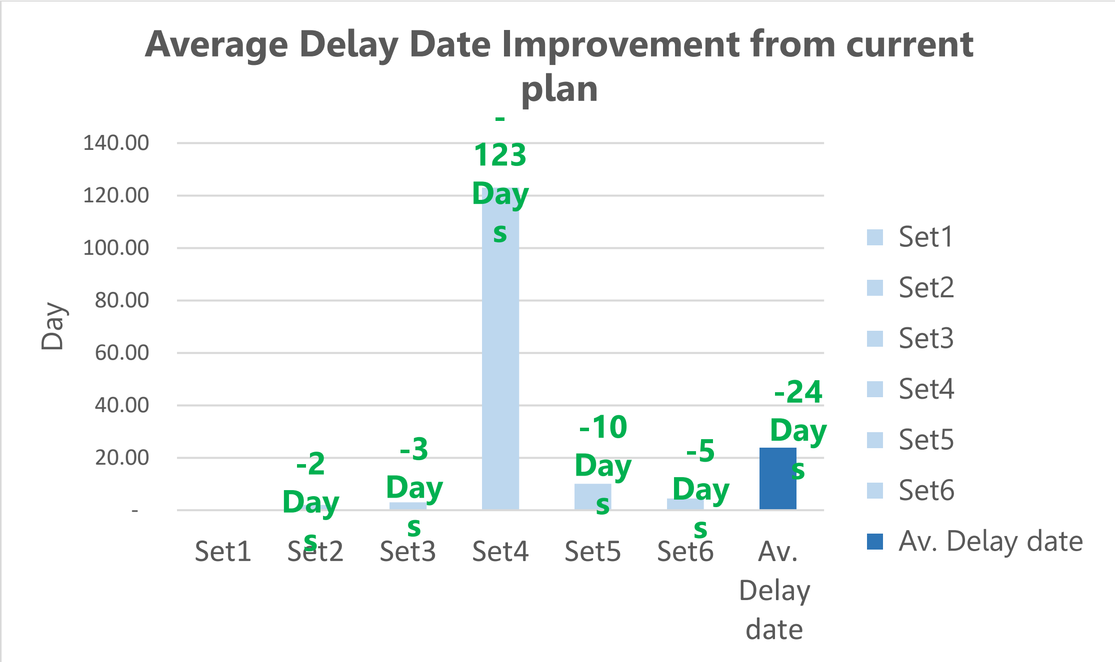


Figure 5-5: Average Delay Date Improvement from current plan

5.3 Result of Labour Cost of Heuristic Methods Compare to Current Planning

The labour cost is considered as the cost of production. If the labour cost can be decrease it means that the production schedule is more efficient in terms of cost saving. The Heuristic method is saving labour cost due to the decreased of makespan. The difference of labour cost is defined by the equation below.

$$\%Difference\ Labour\ cost = \left(\frac{Currently\ Plan\ Labour\ cost - Heuristic\ Approach\ Labour\ cost}{Currently\ Plan\ Labour\ cost}\right) x100\%$$

According to ***Figure 5-6***, it shows the percent improvement of labour cost between Heuristic approach and current plan. The average labour cost improvement is 4.94%. While, set 5 is performing worse that current plan due to heuristic method calculate the delay date as well as holding date.

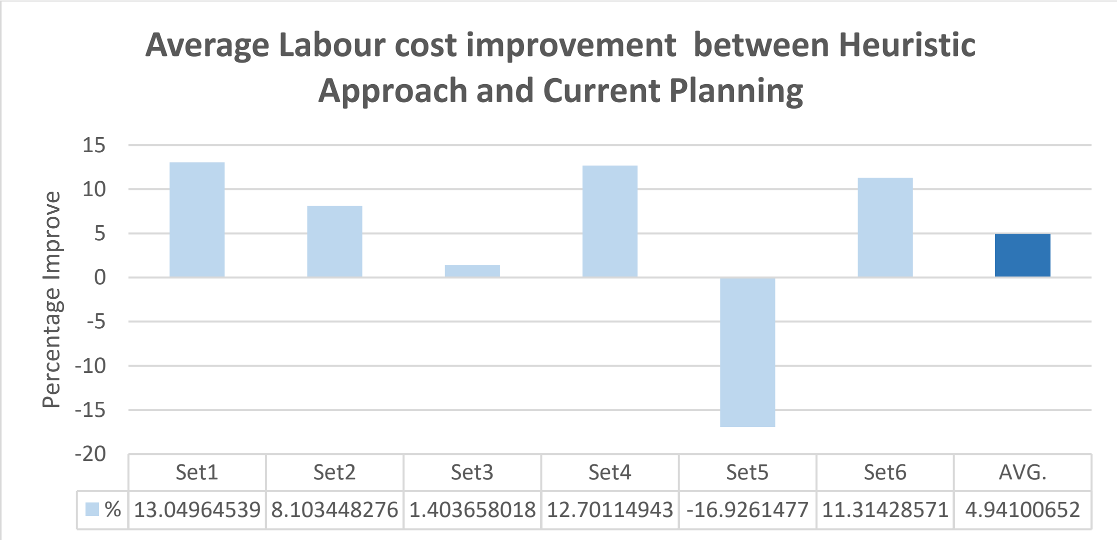


Figure 5-6: Percentage improvement of Labour cost of Heuristic Approach to Current Plan

5.4 Optimise Makespan by Eliminate Holding Date and Delay Date Approach

In order to minimise the makespan of production schedule, the fixed delivery date has to be eliminated, so the work order can move freely and will not fixed with delivery date. Therefore, the author tries this method by change the parameter of the heuristic method in Early days and Late days cost in to zero. The program doesn’t see this as a cost and it will only focus on makespan and changeover time.

The early day will depend on parameter of holding cost. The current parameter of holding cost is 500 per day, the new parameter will be 0 per day.

Current parameter

Holding cost = 500 x (Delivery Date – Job done date)

New parameter

Holding cost = 0 x (Delivery Date – Job done date)

The Late days of the heuristic approach will depend on late cost. The current parameter of late cost is 20,000 per day, the new parameter will be 0 per day.

Current parameter

Late cost = 20,000 x Max (Job done date - Delivery Date)

New parameter

Late cost = 0 x Max (Job done date - Delivery Date)

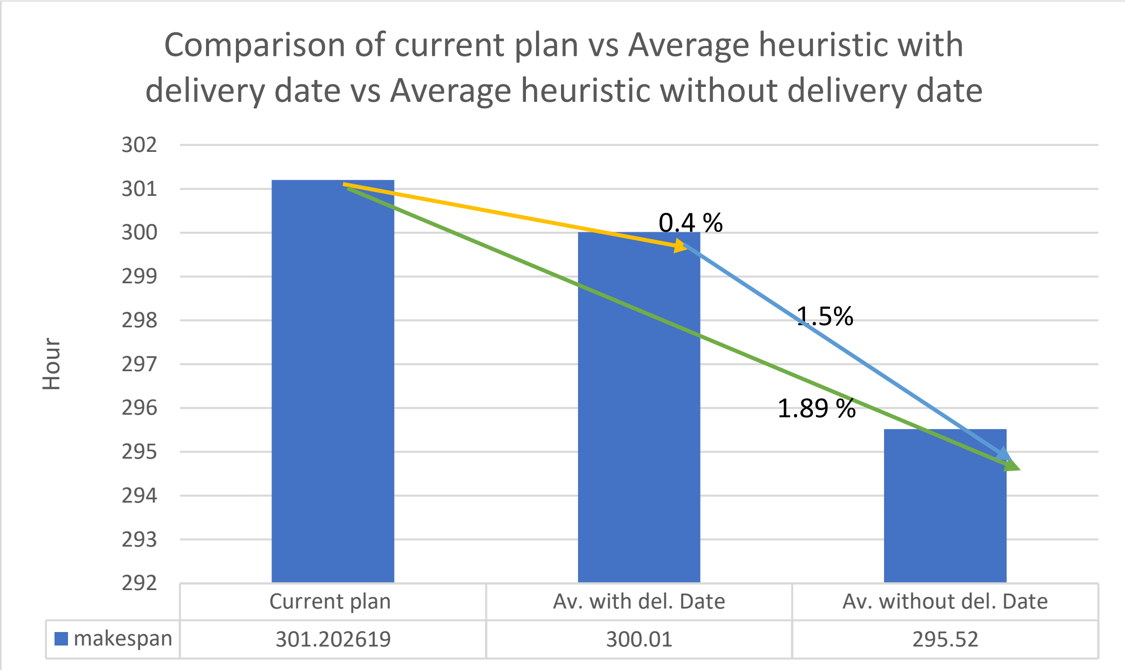


Figure 5-7: Comparison of current plan vs Average heuristic with delivery date vs Average heuristic without delivery date

According to Figure 5-7, it shows the comparison of makespan between current plan, the average heuristic approach with delivery date, and the average heuristic approach without delivery date. The result shows that without the constrain of delivery date, the heuristic approach perform significantly improve from the heuristic approach with delivery date which is 4.49 hours. Moreover, the time improve from current plan is 1.89% or 5.68 hour in particular production schedule. The heuristic approach without consider delivery date is the most efficient in terms of makespan. This is because of delivery date is the constrain of minimizing makespan and changeover time. Therefore, if the production schedule doesn't concern on delivery date and mainly focus on minimising changeover time and makespan. The production schedule could save the labour cost of the production unit. Moreover, the changeover cost will be significantly decrease due to flexibility of the work order. Work order could be grouped together to produce with less changeover. According to Table 5-4, The total number of changeovers is decrease in total change bulk cost for 22 times, change bulk and sizes 6 times, change size remain the same, and increase in change SKU 19 times. This is a good improvement due to change bulk require more time to set up and need the cleaning agent to clean the bulk from the filling cylinder, where change SKU need only change the packaging material or lot size. Therefore, it requires less man power, time and cost to change.

Changeover	Current plan	Heuristic No Date
Total change bulk cost	2910000	1670000
Total change bulk	33	12
Total change bulk and size	20	14
Total change size	9	9
Total change SKU	17	36

Figure 5-8: Comparison of changeover cost and time between current plan and heuristic approach without delivery date

5.5 Heuristic Approach discussion

When comparing the closing time between production scheduling using heuristic method with current production scheduling, it was found that the heuristic method can reduce makespan and delay date less than current production plan. It was also found that if the makespan is less, the production running time will be less. Therefore, the cost of labour will be less than current production schedule. Consider that the improvement is depend on the different of formula and different of packaging size. To be more specific in the result of heuristic approach in aerosol filling production schedule, as the result shows the two methods of heuristic approaches have improve in terms of makespan of the production schedule in almost similar improvement. Two methods, node shift and 2-opt can be used to scheduling the production plan in the different sequence the result is the average of delay date improvement in 2-opt is slightly better than node shift by 0.38%. On the other side, node shift has performed the average makespan improvement better than 2-opt by 0.03% according to Table 5-5. Thus, these two methods are both suitable for the particular aerosol filling production schedule depend. However, it could perform differently depend on the set of work order in production schedule. The result is it might not reduce high number of makespan due to the constrain of delivery date in each order. Therefore, the author has tried to eliminate delivery date, this mean that the program does not require holding cost and late cost to consider in the calculation in heuristic process. The result shows in Figure 5-7, the makespan of heuristic without delivery date is 1.5% improve from heuristic approach with delivery date. However, in real situation the customer demand which is fluctuate, and to be competitive in the market of OEM we need to sacrificed some of low cost by mass production to serve the customer as fast as possible while set the quality at first priority. This mean the company focus on fast and good product, so it will be in the orange area shows in Figure 5-8. It is extremely difficult to get three aspect (fast, cheap, good) perfect in the business world. These three aspects have trade-off between each other. In this case, the trade-off between fast and cheap is in a different world. If the product that could produce fast that's mean it is not mass production and could not control low cost. And this is the strength of the OEM company is the flexibility and ability to changeover upon on fluctuating demand. Otherwise, the big brand customers like the case study customer will return to produce at their in-house factory which is focus more on low cost by mass production rather than changeover frequently. However, the production schedule that performed by heuristic approach has gain in makespan and significantly improve on late day. This could be helpful for planner and company benefit.

	Delay date improvement
Av. Node Shift	49.20%
Av. 2opt	48.82%
	Makespan improvement
Av. Node Shift	0.33%
Av. 2opt	0.36%

Table 5-4: Average Improvement of delay date and makespan of Node shift move and 2-opt

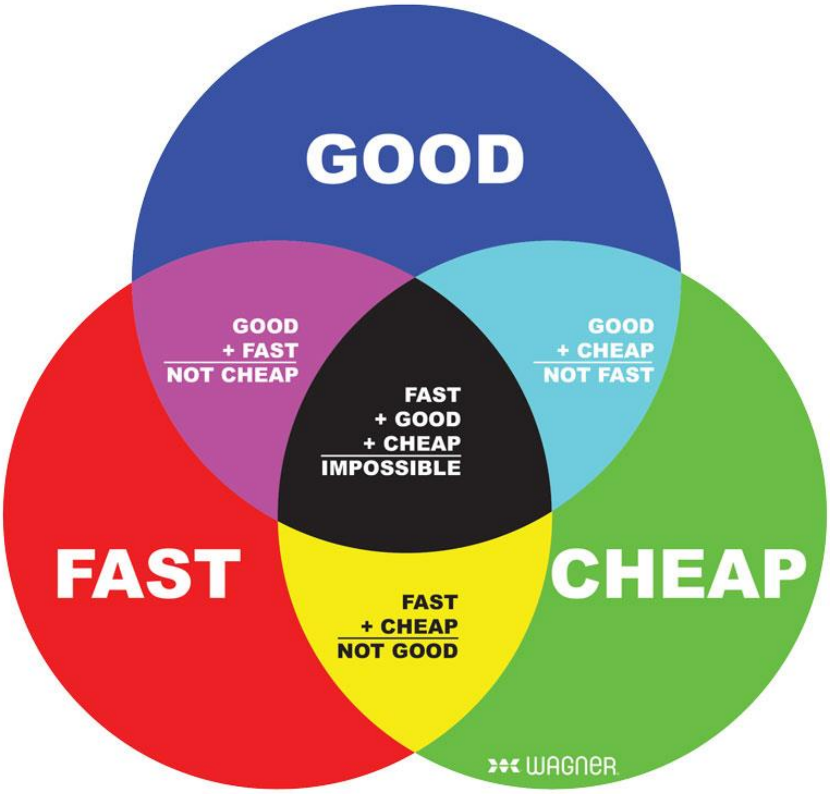


Figure 5-9: The coordination and tradeoff between fast, cheap, and good [14

5.6 Benefit of production planning

The major benefit of this heuristic process, is to save the cost of production in terms of decreasing the makespan time by reduce the number of changeovers. Moreover, it could further decrease the makespan of the production schedule by ignore delivery date of the work order. However, in real situation no delivery date can be done if the forecast of the customer is very accurate. In fact, the demand forecast of the customer is not accurate enough to produce according to forecast because the product is fast moving consumer goods. Therefore, the production could only produce when the customer generates sale order to the company. The approach that could be done is negotiate with the customer to generate work order earlier than two weeks to have the spare time to group the work order together. Besides being able to reduce production time and reduce production costs with heuristic approach program that helps in planning the production of the planner. The benefit is that we help the planner's workload so that planner can go to work that is not on a regular basis for example planner could go to manage more on the production site and increase their spare time to think of improving the work that the planner is doing.

5.7 Planner opinion

The author would like to receive the opinion of users to this heuristic approach program. Therefore, the program is showed to the planner and inform the detail of the program briefly. Then, the planner will be interviewed with five questions about the program. In particular, the question will be asked about the opinion to the program as an overview, How the program will assist the workload of the planner, disadvantages of the program in planner perspective, and the issue that recommend to be fixed in the program. Name of interviewee is Ms. Nittaya Charoensuk, she is a planner officer in department of production control. Responsible for production planning in Cosmetic Factory in Cyberpax co., ltd. She is currently taking care of planning this production line. The ethical approval confirmation is already approved by WMG Overseas Programs Course Office, the reference number is REGO-2020-WMGOS-1072 according to Appendix8.2. The interview is taken place in Cyberpax head office, 16 December 2020. Four questions will be asked and the answer will begin as follow.

1. What do you think about the program?

I think the program look very helpful to our job; it can simulate the best solution with the short amount of time. However, I still need to learn and get used to the program to use it fluently. Because the program is new to me, in the first phase I might do the work that currently doing parallel with the program and see What is the problem and to make sure that the program is doing correctly.

2. How much will this program help planner?

It helps in terms of the fact that I do not have to plan the production schedule ourselves, reducing the certain amount of planning time. If approximate the workload that assist planner in percentage, it is about 20%, but as I said, planning must check raw material incoming date and follow up with production whether it can work in time. If not, there must be an adjustment of the production schedule in order to keep the plan updated. Furthermore, I see that the program could potentially reduce the changeover time of the production schedule. Because this is quite a big problem, so having program to assist the workload it is better do it manually.

3. Do you see any disadvantages of the program?

According to my understanding, the program is calculated from the parameter that we input to the program. Thus, it doesn't know which order is urgent and which order needs to produce more than two days before delivery due to the particular product has to be micro tested to pass the specification of the customers. Therefore, the program can't provide such solution to the planner.

4. Is there anything that needs to be modified in the program?

Everything works brilliantly. But there are other areas that need to be revised, such as the Gantt chart that indicates what products will be produce per day and how many hours each product takes. The part that indicates in hour, I would like to have a number of pieces instead. Because in real life, production which use the production schedule is used to pieces rather than hours.

According to interview, the answer of the planner seems to be satisfied with the program but need some times to get used to the program. However, the program could help the planner in terms of work load about 20% because the job of the planner has to check raw materials and follow up the plan. In terms of planning aspect, the program will assist the workload of the planner fully except the reason that the planner has to do some of the work order manually. The question that asks about, the issue that need to be modified in the program to make the program more user friendly. The answer of the planner is Gantt chart of the production schedule will have to change of hour to piece. Therefore, to make it easier for planner and production, the Gantt chart will be changed and generate the work order in pieces. The example shows in Figure 5-9.

Before (hour)

2-Dec	3-Dec	4-Dec	7-Dec
11+8 Hr.	**8+8 Hr**	**8+8 Hr.**	**8 Hr.**
2.5			
0.33			
2.511904762			
0.33			
5.177142857			
0.17			
2.571428571			
0.33			
2.214285714			
0.17			
2.619047619			
0.076190476	0.093809524		
	2.588571429		
	0.33		
	2.523809524		
	0.33		
	2.071428571		
	0.17		
	2.523809524		
	0.33		
	2.588571429		
	0.17		
	2.28	0.542857143	
		0.3	
		3.705714286	
		0.33	
		0.334285714	
		0.17	
		2.18952381	
		0.33	
		2.588571429	
		2.588571429	
		0.17	
		2.5	
		0.25047619	0.07952381
			3.705714286
			0.33
			2.547619048

After (Piece exclude) set up)

2-Dec	3-Dec	4-Dec	7-Dec
11+8 Hr.	**8+8 Hr**	**8+8 Hr.**	**8 Hr.**
21000			
21100			
43488			
21600			
18600			
22000			
	21744		
	21200		
	17400		
	21200		
	21744		
	19152	4560	
		31128	
		2808	
		18392	
		21744	
		21744	
		21000	
			31128
			21400

Figure 5-10: Changing hour in to piece

6. Conclusion

This thesis aims to create and develop production scheduling methods in aerosol filling process to be able to produce aerosol product at low cost by reducing production time and decrease makespan under delivery date to scheduling problems which has a variety of products and various factors and limitation. Whether it is a different size and formula of the product and constrain of the delivery date. Researcher has studied and develop two weeks aerosol filling schedule which has work order up to 150 work orders. Moreover, the complexity of this production schedule is increased due to the commit delivery date of the customer.

According from the study of the past research, it was found that the use of problem solving in Mathematical Model can provide the best solution or optimal solution for small problems. However, when it come to a big problem or the problem that has high complexity. The mathematical model method takes lone period of time to compute. Therefore, this method is not suitable for practical use. Making heuristic a suitable choice in practical application.

6.1 Conclusion Discussion

The author has created and developed production planning in filling process of an aerosol product to be able to produce at low cost and shortened makespan under the deadline for delivery. This is a solution that can resolve problems in a matter of minutes. This led to better result in production schedule for filling process of aerosol product. Comparing the results of production schedule using heuristic method with the current production schedule. According to **Figure 6-1**, it was found that heuristic method for filling process of aerosol product can reduce makespan in average of 0.34% compare to current production scheduling with delivery date in concern. However, the author has explored the heuristic approach method without delivery date to be a constraint of the production scheduling. The result of makespan improve is 1.89%. But in realistic, the delivery date still needs to be considered as the company has committed to customer to fulfil their demand. Moreover, with delivery date in concern the heuristic can improve the delay date in average of 24 days better that current production scheduling. The improvement in each sample depends on the variety of sample produces being performed. Furthermore, in planner work load aspect, the workload in planning the production schedule will be eliminate from planner job for an approximate 6 to 8 hours per week. Therefore, the planner will reduce their routine job and shift to improvement job instead.

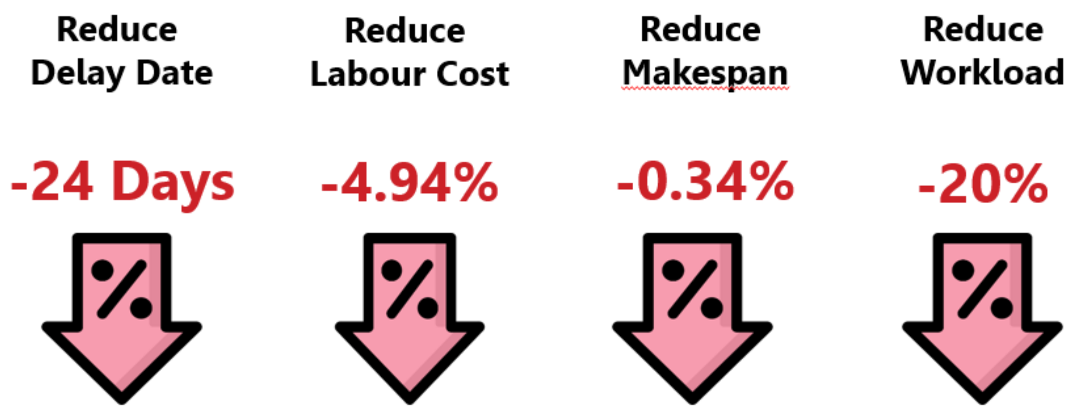


Figure 6-1: Percent Improvement of Delay date, Labour cost, Makespan, and Workload

6.2 Further Implementation

The further implementation could be separate in several aspects. The result of the presented method in this thesis is only focuses on filling process of the aerosol production process.

6.2.1 Heuristic Approach on Parallel Machine to Reduce Makespan

In terms of further implementation in to others production line that has more complexity to plan the production schedule. As the result of heuristic approach, it is shows that implementing heuristic approach to reduce operational cost and makespan reduction in a filling process of aerosol products is satisfactory in terms of reducing makespan for this particular problem, which has high constrained in several aspect; in terms of delivery date, which has the tight schedule from the customer and has rather low lead time, this causes inflexible plan to swap the sequence. Therefore, the result of improving is relatively low. In the further implementation, the propose method of implementation will be the heuristic approach for solving complex parallel machines. These machines are for filling process in another filling machine in the same factory. In particular the parallel machine problem is forced to reduce costs as well as increase productivity, and efficient scheduling is an important factor to achieve them (Dastidar and Nagi 2004). Generally speaking, the parallel machine scheduling problem has two obvious decision, which are sequencing and allocation. Sequencing is to order the job assigned to each machine. While, allocation is a decision concerning the assignment of jobs to machines. Moreover, the parallel machine has to be concern on the type of machine (identical or non-identical machine), job type (dependent or independent), sequence dependent setup times and ready times. Therefore, compared parallel machine to single machine scheduling, the parallel machine has more complexity in terms of choosing the machine to produce the order in order to minimize the total tardiness. While, single machine is only working on the sequence of the order on one machine. Thus, the algorithm to solve the problem of parallel machine will be more complex than single machine [15]. In particular, single machine problem with different due dates and minimizing total weighted earliness and tardiness penalties is already np-hard problem. In related parallel machine, the meta-heuristic approach to the parallel machine needs to investigate further about the method of algorithm and process in order to solve the complex problem. However, if this implementation can be done, it will be significantly beneficial to the production schedule on makespan reduction. Figure 6-2 is illustrates the example of parallel machine with the set of jobs on waiting queue, set of machine, and processing sequence.

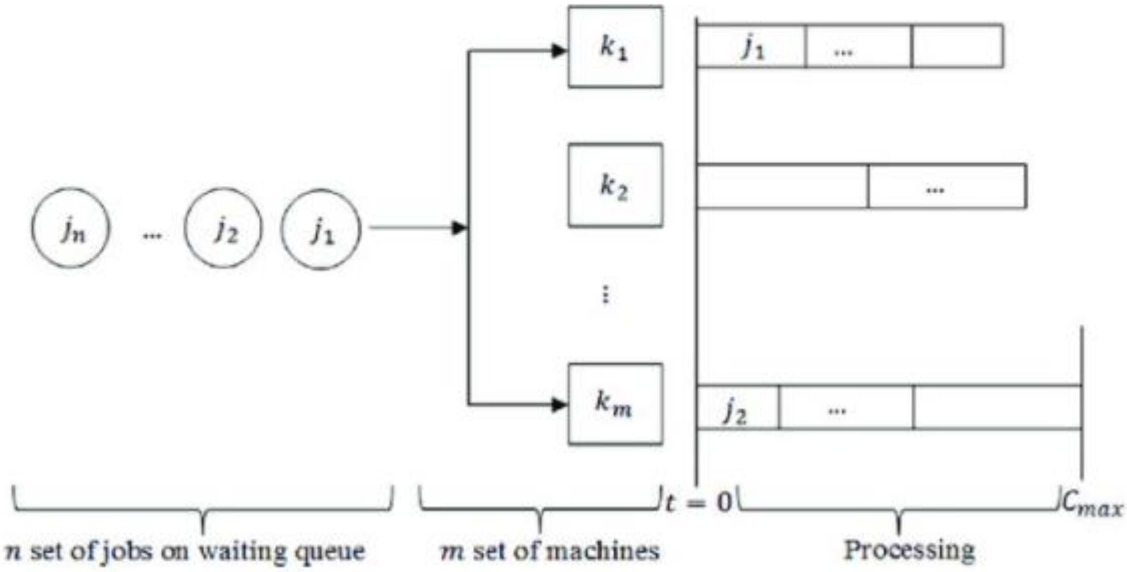


Figure 6-2: Example of parallel machine[27]

6.2.2 Implement the output to provide the flexibility to the production schedule and training the program to user

The output of python program will generate excel file to be more user friendly to the user. In real situation, planner will need to change and adapt the plan according to each specific constrain of the order. For instant, some of the works will need to be hold before shipping for about 5 days because the specification of the customer of this particular order needs to be micro tested. Therefore, the different of due date and delivery date of this order has to be increase. And this has to be done manually in the plan. Moreover, according to job of the planner, the planner has to check for incoming material. And in some cases, the raw material is not sufficient for the entire work order. Therefore, the work order has to be split related to the raw material incoming day. In real life, this has to be done separately and manually. In the further implementation in term of improving the flexibility to the program. The implementing program, the step of implementing the program by first training and educating the program to planner. Then start using the program parallel to the current planning process and compare the result. After the planner familiar with the program, we will then fully use the program.

6.2.3 Filling and Mixing Process Integration Solving by Heuristic Approach

The further implementation could be separate in several aspects. The result of the presented method in this thesis is only focuses on filling process of the aerosol production process. It could be further implemented to upstream streams process which is mixing process. If the program could calculate the whole process of the manufacturing, it could be reduced makespan of the whole process. Furthermore, the cost of labour will be decreased because the makespan reduction. In addition, work in process of the bulk that have to be stored when the mixing plan is not efficient. Furthermore, the bulk has to be double handling, when they need to be stored. In particular, the bulk has to be kept in another storage when it hasn’t use more than two days. That means, worker has to move the bulk from filling tank to storage tank. But If the bulk could be fill after mixing, it will be more efficient of the worker to just move the bulk only single time. Moreover, the waste will be less because of double handling.

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7. Appendix

7.1 Heuristic Algorithm output on 6 Sets of Data and 10 runs in each set

Set1											
Parameter	**planner**	**Set1 Node1**	**Set1 Node2**	**Set1 Node3**	**Set1 Node4**	**Set1 Node5**	**Set1 opt1**	**Set1 opt2**	**Set1 opt3**	**Set1 opt4**	**Set1 opt5**
Obj value	549544	525044	525044	525044	525044	525044	524044	524044	524044	524044	524044
Total hour	51.47	51.47	51.47	51.47	51.4	51.47	51.47	51.47	51.47	51.47	51.47
Total change bulk cost	500000	502500	502500	502500	502500	502500	502500	502500	502500	502500	502500
Total change bulk	8	9	9	9	9	9	9	9	9	9	9
Total change bulk and size	2	1	1	1	1	1	1	1	1	1	1
Total change size	0	0	0	0	0	0	0	0	0	0	0
Total change sku	1	1	1	1	1	1	1	1	1	1	1
Total labor cost	5640	4904	4904	4904	4904	4904	4904	4904	4904	4904	4904
Day-shift	6	6	6	6	6	6	6	6	6	6	6
Day-shift OT	5	1	1	1	1	1	1	1	1	1	1
Night-shift	0	1	1	1	1	1	1	1	1	1	1
Night-shift OT	0	0	0	0	0	0	0	0	0	0	0
Total inventory cost	25000	18000	18000	18000	18000	18000	17000	17000	17000	17000	17000
Early days	50	36	36	36	36	36	34	34	34	34	34
Total penalty	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000
Late days	1	1	1	1	1	1	1	1	1	1	1
Runtime	0	01:23.2	01:21.6	01:20.6	01:21.0	01:23.5	01:29.3	00:55.4	00:57.4	00:55.9	00:58.7
Set2											
Parameter	**planner**	**Set2 Node1**	**Set2 Node2**	**Set2 Node3**	**Set2 Node4**	**Set2 Node5**	**Set2 opt1**	**Set2 opt2**	**Set2 opt3**	**Set2 opt4**	**Set2 opt5**
Obj value	846264	714264	714264	669764	714264	668764	669264	669764	669264	669264	670264
Total hour	50.57	50.08	50.08	49.92	50.08	49.92	49.92	49.92	49.92	49.92	49.92
Total change bulk cost	777500	682500	682500	637500	682500	637500	637500	637500	637500	637500	637500
Total change bulk	14	12	12	11	12	11	11	11	11	11	11
Total change bulk and size	1	1	1	1	1	1	1	1	1	1	1
Total change size	1	1	1	1	1	1	1	1	1	1	1
Total change sku	1	2	2	3	2	3	3	3	3	3	3
Total labor cost	4640	4264	4264	4264	4264	4264	4264	4264	4264	4264	4264
Day-shift	5	5	5	5	5	5	5	5	5	5	5
Day-shift OT	4	1	1	1	1	1	1	1	1	1	1
Night-shift	0	1	1	1	1	1	1	1	1	1	1
Night-shift OT	0	0	0	0	0	0	0	0	0	0	0
Total inventory cost	4500	7500	7500	8000	7500	7000	7500	8000	7500	7500	8500
Early days	9	15	15	16	15	14	15	16	15	15	17
Total penalty	60000	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000
Late days	3	1	1	1	1	1	1	1	1	1	1
Runtime	0	01:00.8	01:01.4	01:18.0	01:07.8	01:41.9	01:30.5	01:07.5	01:52.5	01:25.5	01:09.8

Set3											
Parameter	**planner**	**Set3 Node1**	**Set3 Node2**	**Set3 Node3**	**Set3 Node4**	**Set3 Node5**	**Set3 opt1**	**Set3 opt2**	**Set3 opt3**	**Set3 opt4**	**Set3 opt5**
Obj value	2668316	2479316	2407816	2547712	2453816	2512316	2490816	2424816	2386316	2469816	2451816
Total hour	295.33	294.78	294.42	296.05	294.88	294.48	295.01	294.79	294.56	294.98	294.88
Total change bulk cost	2417500	2290000	2222500	2402500	2290000	2265000	2305000	2215000	2197500	2282500	2285000
Total change bulk	27	17	18	19	18	17	16	15	15	16	16
Total change bulk and size	13	22	19	21	20	22	22	20	21	21	22
Total change size	13	10	11	12	12	9	13	15	12	14	12
Total change sku	25	29	29	31	28	29	27	28	30	27	28
Total labor cost	28212	27816	27816	28212	27816	27816	27816	27816	27816	27816	27816
Day-shift	14	14	14	14	14	14	14	14	14	14	14
Day-shift OT	14	14	14	14	14	14	14	14	14	14	14
Night-shift	14	14	14	14	14	14	14	14	14	14	14
Night-shift OT	11	10	10	11	10	10	10	10	10	10	10
Total inventory cost	43000	38500	34500	33500	33000	36500	34500	39000	38000	36500	36000
Early days	86	77	69	67	66	73	69	78	76	73	72
Total penalty	180000	120000	120000	80000	100000	180000	120000	140000	120000	120000	100000
Late days	9	6	6	4	5	9	6	7	6	6	5
Runtime	0	25:52.4	35:40.2	34:55.8	53:19.2	27:19.6	08:15.1	26:36.4	25:41.1	17:48.0	07:12.9
Set4											
Parameter	**planner**	**Set4 Node1**	**Set4 Node2**	**Set4 Node3**	**Set4 Node4**	**Set4 Node5**	**Set4 opt1**	**Set4 opt2**	**Set4 opt3**	**Set4 opt4**	**Set4 opt5**
Obj value	3708572	1286572	1286072	1286072	1284072	1286072	1245572	1285572	1285572	1245572	1272572
Total hour	131.04	131.05	131.05	131.05	131.02	131.05	131.05	131.05	131.05	131.05	131.05
Total change bulk cost	1005000	960000	960000	960000	937500	960000	960000	960000	960000	960000	955000
Total change bulk	13	10	10	10	10	10	10	10	10	10	8
Total change bulk and size	6	8	8	8	7	8	8	8	8	8	10
Total change size	2	2	2	2	3	2	2	2	2	2	2
Total change sku	4	6	6	6	6	6	6	6	6	6	6
Total labor cost	13920	12152	12152	12152	12152	12152	12152	12152	12152	12152	12152
Day-shift	15	14	14	14	14	14	14	14	14	14	14
Day-shift OT	12	3	3	3	3	3	3	3	3	3	3
Night-shift	0	3	3	3	3	3	3	3	3	3	3
Night-shift OT	0	0	0	0	0	0	0	0	0	0	0
Total inventory cost	12500	15000	14000	14000	15000	14000	13500	13500	13500	13500	25500
Early days	25	30	28	28	30	28	27	27	27	27	51
Total penalty	2780000	340000	320000	320000	360000	320000	280000	320000	320000	280000	340000
Late days	139	17	16	16	18	16	14	16	16	14	17
Runtime	0	02:49.5	02:51.4	02:43.8	02:08.2	02:21.5	06:05.5	03:11.5	05:53.5	05:03.5	07:45.0
Set5											
Parameter	**planner**	**Set5 Node1**	**Set5 Node2**	**Set5 Node3**	**Set5 Node4**	**Set5 Node5**	**Set5 opt1**	**Set5 opt2**	**Set5 opt3**	**Set5 opt4**	**Set5 opt5**
Obj value	2547752	2138252	2145252	2210252	2165752	2142752	2217252	2159252	2156752	2216752	2102252
Total hour	221.11	220.29	220.46	220.58	220.32	220.16	220.62	220.01	220.63	220.58	220.27

Total change bulk cost	2217500	2065000	2070000	2132500	2092500	2047500	2120000	1962500	2080000	2137500	2002500
Total change bulk	28	22	22	24	24	23	25	21	24	26	21
Total change bulk and size	13	16	16	15	15	15	14	15	14	13	15
Total change size	4	4	4	5	3	3	4	3	4	5	5
Total change sku	20	21	22	19	21	22	21	25	23	19	23
Total labor cost	20040	23432	23432	23432	23432	23432	23432	23432	23432	23432	23432
Day-shift	16	15	15	15	15	15	15	15	15	15	15
Day-shift OT	15	13	13	13	13	13	13	13	13	13	13
Night-shift	4	13	13	13	13	13	13	13	13	13	13
Night-shift OT	4	0	0	0	0	0	0	0	0	0	0
Total inventory cost	71500	34500	36500	39000	34500	36500	38500	38000	38000	40500	41000
Early days	143	69	73	78	69	73	77	76	76	81	82
Total penalty	240000	20000	20000	20000	20000	40000	40000	140000	20000	20000	40000
Late days	12	1	1	1	1	2	2	7	1	1	2
Runtime	0	31:57.6	18:36.7	21:21.3	23:12.8	15:39.2	43:36.1	49:36.2	51:28.4	36:49.8	43:34.3
Set6											
Parameter	**planner**	**Set6 Node1**	**Set6 Node2**	**Set6 Node3**	**Set6 Node4**	**Set6 Node5**	**Set6 opt1**	**Set6 opt2**	**Set6 opt3**	**Set6 opt4**	**Set6 opt5**
Obj value	3419436	3055436	3068436	2955436	3036436	3008936	2976936	2998436	3000436	2975936	2938936
Total hour	301.20	300.00	300.02	300.01	300.00	300.01	300.00	300.00	300.00	300.03	300.01
Total change bulk cost	2910000	2622500	2687500	2587500	2615000	2587500	2625000	2622500	2622500	2645000	2582500
Total change bulk	33	25	27	26	22	26	26	25	25	25	24
Total change bulk and size	20	21	21	19	24	19	20	21	21	22	21
Total change size	9	11	10	11	11	11	11	11	11	10	11
Total change sku	17	20	18	22	20	22	20	20	20	20	22
Total labor cost	31500	27936	27936	27936	27936	27936	27936	27936	27936	27936	27936
Day-shift	15	15	15	15	15	15	15	15	15	15	15
Day-shift OT	15	15	15	15	15	15	15	15	15	15	15
Night-shift	15	15	15	15	15	15	15	15	15	15	15
Night-shift OT	15	6	6	6	6	6	6	6	6	6	6
Total inventory cost	61500	45000	33000	40000	33500	33500	24000	28000	30000	23000	28500
Early days	123	90	66	80	67	67	48	56	60	46	57
Total penalty	420000	360000	320000	320000	360000	380000	320000	320000	320000	300000	300000
Late days	21	18	16	16	18	19	16	16	16	15	15
Runtime	0	35:47.7	23:39.1	39:20.2	20:54.1	30:49.9	06:44.3	04:36.1	49:07.2	53:48.7	04:36.5
No Delivery date											
Parameter	**planner**	**rep1**	**rep2**	**rep3**	**rep4**	**rep5**	**rep1**	**rep2**	**rep3**	**rep4**	**rep5**
Obj value	2937936	1697144	1697144	1699644	1702144	1699644	1697144	1699644	1697144	1697144	1697144
Total hour	301.20	295.52	295.52	295.52	295.52	295.52	295.52	295.52	295.52	295.52	295.52
Total change bulk cost	2910000	1670000	1670000	1672500	1675000	1672500	1670000	1672500	1670000	1670000	1670000
Total change bulk	33	12	12	13	14	13	12	13	12	12	12
Total change bulk and size	20	14	14	13	12	13	14	13	14	14	14
Total change size	9	9	9	9	9	9	9	9	9	9	9
Total change sku	17	36	36	36	36	36	36	36	36	36	36
Total labor cost	31500	27144	27144	27144	27144	27144	27144	27144	27144	27144	27144

Day-shift	15	15	15	15	15	15	15	15	15	15	15
Day-shift OT	15	15	15	15	15	15	15	15	15	15	15
Night-shift	15	15	15	15	15	15	15	15	15	15	15
Night-shift OT	15	4	4	4	4	4	4	4	4	4	4
Total inventory cost	61500	146000	159000	160500	138000	128500	157500	159000	132500	132500	137000
Early days	123	292	318	321	276	257	315	318	265	265	274
Total penalty	420000	3980000	4320000	3800000	3480000	3100000	5240000	4580000	4480000	5720000	4320000
Late days	21	199	216	190	174	155	262	229	224	286	216
Runtime	0	25:14.3	29:37.5	22:16.6	21:02.3	21:35.8	21:27.6	19:55.5	17:20.0	22:49.4	23:12.9

7.2 Interview Ethical Approval Confirmation

wmg-overseas@warwick.ac.uk
พฤ 12/11/2020 19:15
ถึง: CHAROENBUNSUPKARN, NATTAGUN (PGT)
สำเนาถึง: pisit.ja@chula.ac.th; cuse.chula@gmail.com

WARWICK
THE UNIVERSITY OF WARWICK

Ethical Approval Confirmation

Dear Mr Charoenbunsupkarn,
Warwick ID Number: 1740677
Thank you for submitting your Supervisor's Delegated Approval form to the Overseas Programmes Course Office for the project: Operation Cost and Makespan Reduction in a Filling Process of Aerosol Products.
Your reference number is REGO-2020-WMGOS-0172.
You now have the appropriate approval in place to begin your study.
Please ensure you insert a copy of this email into the appendices of your project.
Best Wishes
Mengjiao Han
WMG Overseas Programmes Course Office
wmg-overseas@warwick.ac.uk
warwick.ac.uk/fac/sci/wmg/overseas/

VITA

NAME	Mr.Nattagun Charoenbunsupkarn
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