Optimizing the planning of IBC usage in pharmaceutical industry

by

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SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ENGINEERING IN MANUFACTURING

AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SEPTEMBER 2008

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Submitted to the Department of Mechanical Engineering

on August 19, 2008

in partial fulfillment of the requirements for the Degree of

Master of Engineering in Manufacturing

Abstract

An Intermediate Bulk Container (IBC) is used to contain raw materials and semi-products in pharmaceutical company ABC. Due to the high price of an IBC, company ABC sought to minimize the number of IBCs needed to support the production of four separate products. In this project, five IBCs drivers that affect or determine the number of IBCs required were identified. Deterministic models were established to determine the minimum number of IBCs needed for each product given the production plan in 2009. The cleaning schedule for IBCs was modified to reuse IBCs as much as possible. In this paper, we analyze the management of 600L IBCs. We simulate a two machines finite-buffer line model to estimate the optimum buffer size. We collected equipment downtime data to estimate the parameters for the simulation model. We use the simulation to determine the number of 600L IBCs needed for each campaign; the number of 600L IBCs was reduced from 12 to 8. Additional analysis examined the reduction of usage of 1800L IBCs.

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Acknowledgement

First and foremost, we wish to express our deepest appreciation to our thesis supervisor, Professor Stephen C. Graves from the Sloan School of Management in MIT, for his consistent guidance and encouragement throughout the project. We will always feel inspired by his enthusiasm, dedication to excellence, and careful attention to details.

We would also like to thank company ABC for sponsoring this work. Specifically we want to thank Mr. Ger and Mr. Kong, our corporate supervisors, for giving us valuable feedback and suggestions. Many thanks go to Mr. Sam for his support in the project. Kind thanks go to all the staffs related to the project, for providing us considerable valuable information.

We would also like to thank the other two classmates doing the other project in company ABC, Changhui Zhao and Yizhe Cen. It is always a pleasure to work with them.

I would like to thank the other team member, Hu He. His enthusiasm and hard working in this project encourages me during these eight months. This project cannot finish without team work.

I would like to thank my parents, my friends for their continual support.

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Chapter 1 Introduction

1.1 Background

1.1.1 Company background

Company ABC is a multi-national pharmaceutical company that discovers, develops, manufactures and markets a broad range of innovative health care products. Company ABC was incorporated in the year 1999 and produced its first batch of products in the year 2001.

1.1.2 Manufacturing Facilities and Products

Company ABC has three separate manufacturing facilities: Pharmaceutical Facility 1 (PF1), Pharmaceutical Facility 2 (PF2) and Pharmaceutical Facility 3 (PF3). Currently, there are two products families, Product A and B, in production and another two products, Product C and D, are under development. Product A is completely done in PF1. Product D is completely done in PF3. Product B and C have their first half of process done in PF1 and finish the second half in PF2. Product A has four kinds of strengths and two batch sizes. Products B, C and D have only one kind of strength and one batch size.

1.1.3 Production campaign

A production campaign is a period in which a pharmaceutical facility is only producing one type of product. For example, when PF1 runs a Product A campaign, this means that PF1 will only produce Product A for some period of time into the future.

1.1.4 Intermediate Bulk Container (IBC)

In the pharmaceutical industry, all the Work-In-Process (WIP) must be stored in Intermediate Bulk Containers (IBCs) to avoid exposure to the air. There are three types of IBCs, which differ in terms of their volume: 600L IBC, 1800L IBC and 2400L IBC. For example "600L IBC" means that the volume of the IBC is 600 liters. These IBCs are used in different places in the production process for different purposes. Information for each type of IBC is summarized in Table 1-1.

Table1-1 IBC information

IBC Type	Products involved with	Location	Total Number
600L	Product A B C	PF1	28
1800L	Product A B C D	PF1 PF2 PF3	30
2400L	Product B C	PF2	18

1.1.5 Cleaning activities

Due to safety and quality requirements, all equipment in contact with one product has to undergo a major cleaning (wet cleaning) before switching to another product. When the equipment switches between different strengths of the same product family, a minor cleaning (dry cleaning) is needed.

Just as with the other equipment, an IBC needs a major cleaning before switching to another product and a minor cleaning before switching to a different strength of the same product.

1.2 Project Overview

1.2.1 Motivation

When Company ABC launched the production in the year of 2001, it spent hundreds of thousands of dollars on purchasing IBCs. Since ABC had many more IBCs than it needed at the time, management did not pay close attention to the management of IBCs.

However currently as Company ABC starts to produce more types of products, the number of IBCs it needs keeps increasing. Based on the productivity report of 2008, there are some machines that were shut down due to IBC unavailability; that is the production process had to stop because an IBC was not available.

The management believes that in the future when they launch Product C and D, the management of IBCs will be more complicated and the occurrence of "IBC unavailable" will certainly increase. The motivation of the project is to manage the use of IBCs to make sure they are used efficiently. By doing this, the company also expects us to find out what is the minimum number of IBCs needed when all four products are in production so that they know whether it is necessary to purchase extra IBCs.

1.2.2 Objective and Project outline

The team project is conducted for Company ABC by two MIT graduate students. The objective of this research is to analyze and maximize the utilization of IBCs and then to make recommendations that allow the company to decide whether to buy new IBCs to support the production of Product C and Product D.

To help the company answer this question, we need to know whether the current number of IBCs is enough for the company. To determine the number of IBCs actually needed for each production activity was the main objective in the first half of the project. In this stage, we learned about the manufacturing process of products A, B and the coming products C and D. Five production activities were identified as the main IBC drivers, which affect or determine the number of IBCs needed. We collected data on each activity, analyzed the data and found out the actual number of IBCs needed for each activity. However, we cannot just add together these numbers to decide the total number of IBCs needed.

The reason for this is that IBCs can be shared between products and between uses. The second half of the project was focused on the reuse of IBCs. IBC cleaning activity affects the number of IBCs needed as well. For example if 4 IBCs are needed for a campaign of Product A and 19 IBCs are needed for a campaign of Product B, then 19 IBCs may be enough for both. The IBCs for the Product A campaign can be cleaned and reused for the campaign for Product B, and vice versa.

After the two stages, we can answer the question whether the company needs to buy new IBCs. Along the process of looking for the answer, we also identified the waste of IBC usage and can provide some suggestions to eliminate this waste. This is an integral part of the implementation of lean manufacturing in the company.

This project is divided into two individual theses. This thesis will focus on two of the five IBC drivers and the management of 600L IBCs. The second part of this thesis is about the IBC cleaning activities. The other thesis, written by Hu He [1], will analyze the other three IBC drivers and the cleaning activities of 1800L IBCs. Figure 1-1 shows the overview of the project and what will be covered in this thesis.

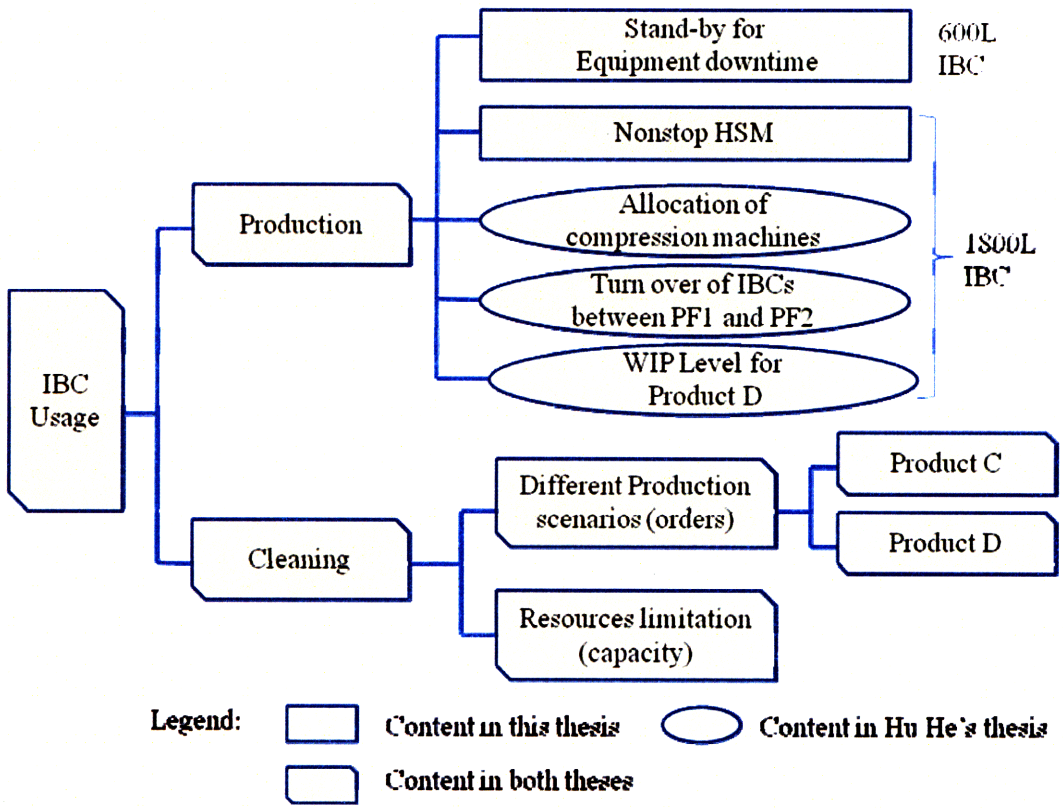


Figure 1-1 Project outline

In the production, there are five IBC drivers: stand-by for equipment downtime is the main determinant for the number of 600L IBCs needed; the other four IBC drivers affect the number of 1800L IBCs needed. In the cleaning, the effect of Product C and Product D are considered. Cleaning orders are generated based on the production plan in 2009 and resource limitations such as water and manpower are considered as the capacity constraints.

1.3 Organization of the Thesis

Chapter 2 describes in details how the manufacturing operates and the process flow for each of the product in Company ABC. Chapter 3 describes the problems we faced in reaching the objective of the project by investigating IBC drivers and cleaning activities. Chapter 4 analyzes the 600L IBC driver------stand-by for equipment downtime, including the theoretical background, methodology, data collection and analysis, and so forth. Chapter 5 is the other IBC driver------non-stop HSM. Chapter 6 is about IBC cleaning scheduling and Chapter 7 is recommendation to the company.

Chapter 2 Manufacturing Operations in Company ABC

This chapter describes how the manufacturing of four products operates and how the Intermediate-Bulk-Containers (IBC) are used in the production.

2.1 Manufacturing process

There are three pharmaceutical facilities in Company ABC, namely PF1, PF2 and PF3. Four products (Product A, B, C and D) are manufactured in these three facilities. The manufacturing process of Product A, B and C generally follow the process in Figure 2-1. The manufacturing of product D is independent of these three products and will be described later.

2.1.1 Manufacturing process for Product A, B and C

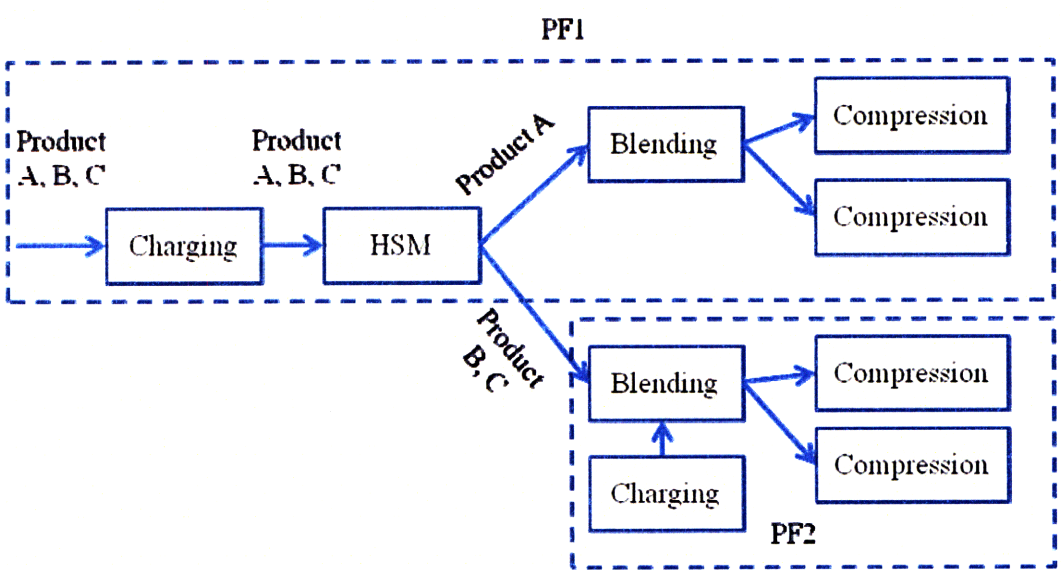


Figure 2-1: Manufacturing process of Product A, B and C

From Figure 2-1 we can see that Product A, B and C share the same process of "Charging" and "HSM" in PF1. The "Blending" and "Compression" of Product A are finished in PF1 and those processes of Product B and C are done in PF2. The only difference between producing A and producing B or C is that for Product B, C there is an extra "Charging" in PF2. This is because the tablet of Product B, C has two layers. The first layer's "Charging" is done in PF1 and the second layer's "Charging" is done in PF2. The two layers get combined at the "Blending" step in PF2. The materials in the two "Charging" are different.

Production volume in Company ABC occurs in batches. The duration of a campaign is expressed in terms of a number of batches. The batch size is in kilograms. For "Charging" at PF1, one subpart (equal to one quarter of a batch) is produced each time. After subpart 1 to subpart 4 are finished, they are sent to "HSM" as batch 1. "HSM" processes one subpart at a time, similar to Charging. After subpart 1 to subpart 4 are processed, they are sent together to blending as batch 1. The production of blending and compression are both in batches. After blending and compression, the production of batch 1 is finished.

When PF1 starts a campaign for Product A or B, C the Charging step will start one day ahead of the other steps. During that day, three to four batches (12 to 16 subparts) of products get charged and serve as standby inventories between the Charging and the HSM step. This is because the company wants the HSM to run at its maximum capacity so that it could finish the campaign for one product as quickly as possible and switch to the campaign for another product. When all of the standby products are ready, the HSM will start to produce and run continuously through the campaign. Meanwhile, instead of continuously running, the Charging will produce a new batch only when the HSM completes the production for one batch. In this way, the company attempts to maintain a buffer of three to four batches between Charging and HSM.

As mentioned in section 1.1.3, the production of Company ABC runs in campaigns. Only one product is produced during one campaign. "Product A Campaign" means that "Charging" and "HSM" in PF1 produces Product A and two compression machines in PF1 are running to produce Product A. "Product B or C Campaign" means "Charging" and "HSM" in PF1 produces Product B or C and two compression machines in PF2 are running to produce Product B or C.

2.1.1.1 Product A

Product A has four levels of strengths (a, b, c and d) and two batch sizes (x and y). Strength a and b only have one batch size x. For the other two strengths, each has two batch sizes. The cycle time of each process shown in Figure 2-1 is different for each level of strength. Table 2-1 is a summary of the cycle time for four strengths of Product A. The cycle time for compression is the cycle time of one compression machine. All of the cycle times here are target cycle times, which are the production targets; the practical cycle time may be longer or shorter than target, but the difference is not significant.

Table 2-1 Cycle time information for Product A

Process			**Charging**	**HSM**	**Blending**	**Compression**
Strength	**a**		4h	7hr	1h	26hr30min
	b		4h	7hr	1h	9hr
	c	**Batch size x**	4h	7hr	1h	8hr
		Batch size y	4h	7hr	1h	8hr
	d	**Batch size x**	4h	7hr	1h	9hr
		Batch size y	4h	7hr	1h	9hr

A minor changeover is needed for the HSM and Compression to switch from producing one level of strength to another. It takes 3 hours to do the minor changeover for the HSM and 16 hours for the compression. In order to minimize the changeover of compression, Company ABC schedules the two compression machines in PF1 that each compression machine is dedicated to two levels of strengths. For example, compression machine 1 will produce strength a, b and compression machine 2 will produce strength c, d.

2.1.1.2 Product B, C

Product B and C follow the same process. They both have one batch size and one level of strength. The cycle times for each process of Product B and C are in Table 2-2. The compression cycle time is the cycle time for one compression machine.

Table 2-2 Cycle time information for Product B and Product C

Process	**Charging**	**HSM**	**Blending**	**Compression**
Product B	4h	6hr20min	1h	22h
Product C	4h	6hr20min	1h	35h

From Table 2-2 and Table 2-1, we can see that the compression cycle time for Product B and C are generally longer than that of Product A. The cycle time for other processes are more or less the same as that of Product A.

2.1.1.3 Production campaigns for Product A, B and C

The longer compression cycle time for Product B and Product C determines that the total campaign length of "Product B or C Campaign" (in PF1 and PF2) will be longer than that of "Product A Campaign" (only in PF1). When the HSM in PF1 finishes "Product A Campaign", it can run a "Product B or C Campaign". When "Product B or C Campaign" in PF1 finishes, the intermediate or semi-products of Product B or C are sent to PF2 for blending and compression. The HSM in PF1 can start another "Product A Campaign" after a campaign changeover. The campaign changeover is about 7 days. During these days, the equipment is major cleaned and some quality tests are done.

At some times, the compression machines in PF1 and PF2 are running at the same time. It is possible that the compression machines in PF1 are producing Product A and the compression machines in PF2 are producing Product B or C.

Currently, the campaign sequence is Product A Campaign - Product B Campaign - Product A Campaign - Product B Campaign in PF1. When Product C is introduced into production, the production sequence in PF1 can either be Product A Campaign - Product B Campaign - Product A Campaign - Product C Campaign (Scenario1) or Product A Campaign - Product B Campaign - Product C Campaign - Product A Campaign (Scenario 2).

2.1.2 Manufacturing process for product D

The manufacturing of Product D will be done in PF3. Figure 2-2 is the manufacturing process of Product D. We can see from Figure 2-2 that the raw materials first get charged at the First Charging step and transferred to the Pre-blending step to mix with the solutions. After that the semi-products go to the Roller Compaction step and get pressed. From Roller Compaction the semi-products are transferred to the Second Charging step where a new ingredient is added. After Final Blending step where the semi-products mix with the solutions again, the semi-products get compressed into tablets which are the final products at the Compression step. The production in each step is done in batches. There is only one level of strength and one batch size of Product D. The target cycle time is listed in Table 2-3.

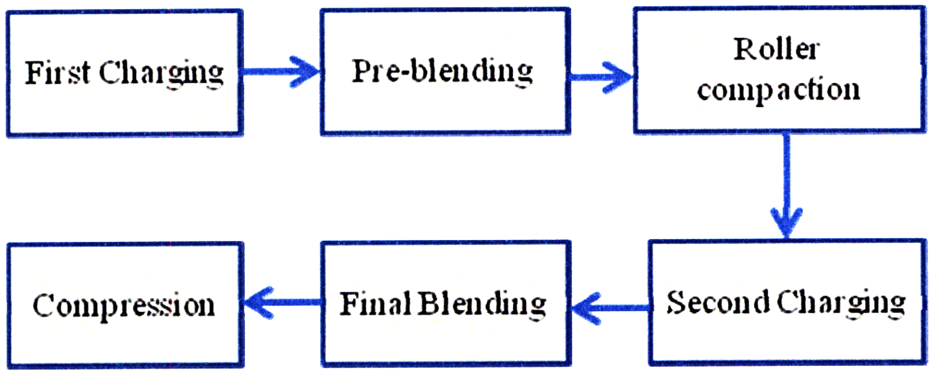


Figure 2-2 Manufacturing process of Product D

Table 2-3 Cycle time information for Product D

First Charging	Pre-blending	Roller Compaction	Second Charging	Final blending	Compression
4h	1h	3.6h	1h	1h	3.5h

2.2 IBC usage

2.2.1 IBC usage in Product A

600L IBCs and 1800L IBCs are used in Product A. Figure 2-3 shows IBC usage in Product A.

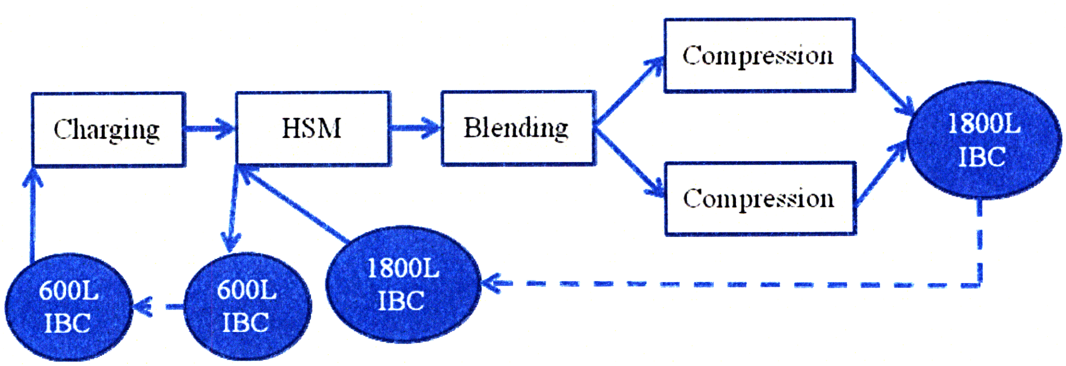


Figure 2-3 IBC usage in Product A

One 600L IBC is needed at the start of "Charging" in PF1; each time "Charging" produces one subpart. After "Charging", this subpart is sent to "HSM" by this IBC. After unloading the material, it can be sent back to "Charging" to reuse.

Once the HSM starts to process the first subpart of one batch, one 1800L IBC is needed. After four subparts (equal to one batch) are finished, they will be sent to "Blending" by this 1800L IBC. After "Blending" the semi-product is transferred by this 1800L IBC to one of the two compression machines to do the compression. When "Compression" finishes the batch, the1800L IBC is released and will be sent back to the HSM for reuse.

2.2.2 IBC usage in Product B and C

600L IBCs, 1800L IBCs and 2400L IBCs are used in Product B and C. Figure 2-4 shows IBC usage in Product B and C.

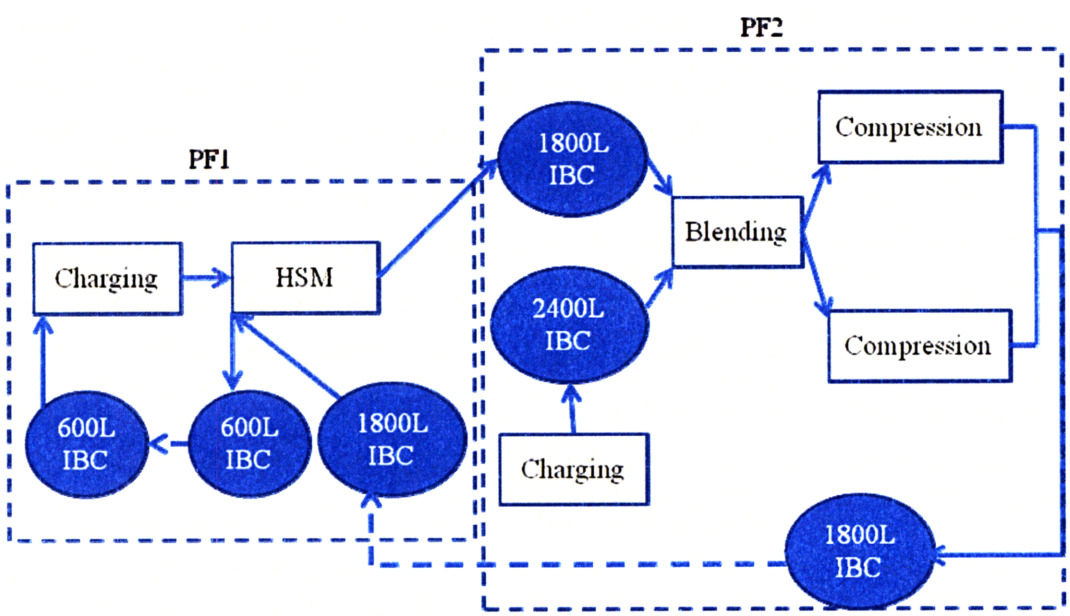


Figure 2-4 IBC usage in Product B, C

The usage of 600L IBC and 1800L IBC in PF1 are the same as the usage in Product A. After "HSM", the 1800L IBC is sent to PF2, where it is matched at "blending" with one 2400L IBC charged of materials in PF2. After "compression", the empty 1800L IBC will be sent back to PF1 for reuse.

2.2.3 IBC usage in Product D

1800L IBCs are used in Product D. Figure 2-5 shows IBC usage in Product D.

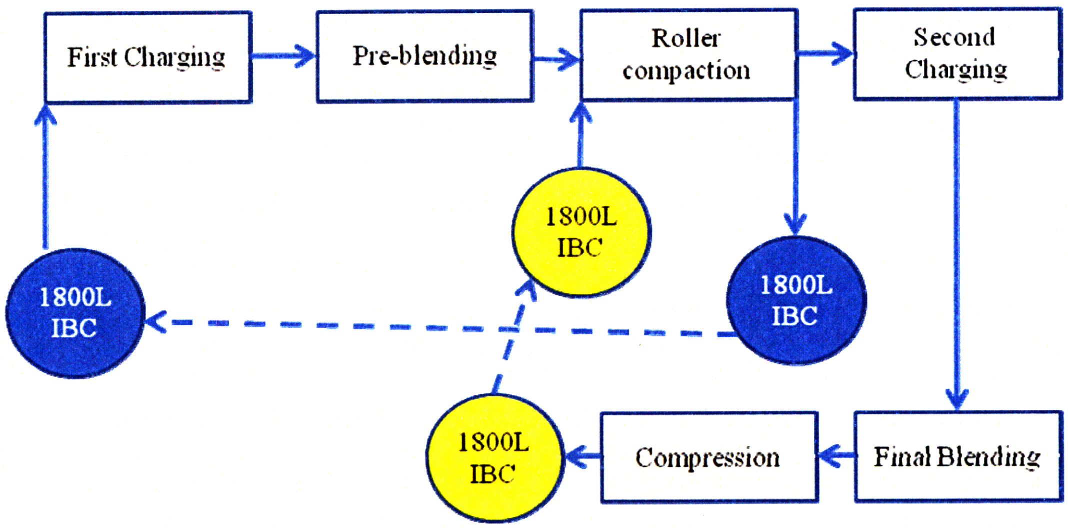


Figure 2-5 IBC usage in Product D

At the start of "First Charging", one 1800L IBC is needed. After the First Charging step, this 1800L IBCs is used to transport the product to Pre-blending to mix with the solution. It is empty after the completion of roller compaction and can be sent back to "First Charging" for reuse. At the start of roller compaction, a second 1800L IBC is needed. During "Roller Compaction", materials are transferred from one 1800L IBC to another. This second 1800L IBC can be released after compression and sent back to "Roller Compaction" for reuse.

2.3 IBC cleaning

IBC requires a minor cleaning (dry cleaning) before switching to another level of strength of the same product and a major cleaning (wet cleaning) before switching to another product. Since minor cleaning can be done very quickly, in 15 minutes, in this thesis we only study IBC major cleaning issues. IBC's major cleaning requires manpower, water, solution and washer.

The company's production runs in campaign. During one campaign, only one product is manufactured in each facility. After the campaign, equipment such as HSM needs to be cleaned as well. The major cleaning of HSM consumes a lot of water; IBCs cannot be cleaned during the HSM major cleaning period (2 days).

In regard to manpower, two people are needed to load IBCs onto the washer, and then cleaning can be done automatically by the washer for about three hours. After the cleaning, IBCs need to be unloaded by two people. Currently in the company, there are no people specifically responsible for IBC cleaning. People who help clean IBCs are quite flexible. Whoever is idle in the manufacturing process can do the IBC cleaning.

The 600L and 1800L IBCs are currently cleaned in PF1 and share the same washer WA-900. The 2400L IBCs are cleaned in PF2 using two washers WA-2900 and WA-2940; one is for part washing, the other is for body washing. The WA-2900 and WA-2940 washers can be redesigned to clean 1800L IBCs if necessary.

Chapter 3 Problem Statement

The main problem about IBC management in the company is that they do not know the actual number of IBCs needed. There are twenty-eight 600L IBCs in the company, but nobody knows whether they need this many. If 20 are enough, then there is low utilization of IBCs when you have 28. No one has carefully examined the reuse of these IBCs. As a result, considerable waste of IBC usage might occur in the production line.

The management of 20 IBCs might be different from that of 28 IBCs. IBCs involved in the manufacturing process will conduct a series of activities, such as transportation of IBCs, the storage, the maintenance and the cleaning activities. The cost of 8 more IBCs is not only the purchasing cost, but also the cost generated by the activities with IBCs. If the company cannot find the root of the problem, they will buy extra IBCs for new products. They will see more problems occurring in the logistics and cleaning activities of IBCs.

In this chapter, five IBC drivers mentioned in section 1.2 will be explained along the manufacturing process. The problem in IBC cleaning activities will be analyzed as well.

3.1 Five IBC drivers

Among the five IBC drivers, "stand-by for equipment downtime", "allocation of compression machines" and "nonstop HSM" are related to IBC usage in Product A. IBC driver "turnover of IBCs between PF1 and PF2" is related to IBC usage in Product B and C. IBC driver "WIP level for Product D" is related to Product D.

3.1.1 IBC driver 1 "stand-by for equipment downtime"

As mentioned in section 2.1.1, "HSM" in PF1 must keep running to supply compression machines in PF1 and PF2. In order to keep "HSM" running, "charging" tries to produce three or four batches in advance of the HSM. In this way, "HSM" can keep running even if "charging" were to stop running due to some random events.

One batch constitutes four subparts and needs four 600L IBCs to contain the materials. There are twelve or sixteen 600L IBCs (three or four batches) serving as stand-by between "charging" and "HSM" in PF1. Figure 3-1 shows the process.

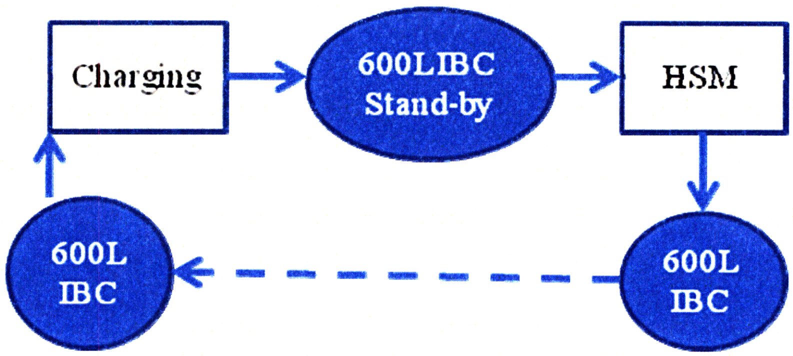


Figure 3-1 600L IBC usage in the manufacturing process in PF1

Whether 12 or 16 IBCs are too much is the key question in this part. As mentioned in section 2.1.1, Product B and C will follow the same process of "charging" and "HSM" in PF1. They would each need 12 or 16 IBCs stand-by. Thus, in total thirty-six or forty-eight 600L IBCs might be needed. In contrast, there are only twenty-eight 600L IBCs. If IBC cleaning activities are not scheduled well, which is also the current situation in the company, there is no wonder that sometimes "IBC not available" occurred in the productivity report. The objective of the research in this IBC cost driver is to determine the actual number of IBCs needed. If we can reduce the number of IBCs used, the benefit will be great to the company. Chapter 4 will analyze this problem in details.

3.1.2 IBC driver 2 "allocation of compression machines"

As mentioned in section 2.2.1, when "HSM" starts production of the first batch in a campaign, one 1800L IBC is needed. At the end of compression, this IBC is released and can be reused at "HSM". When "HSM" starts production of the second batch in a campaign, if the IBC for the first batch has not come back to "HSM", then another IBC is needed. The number of 1800L IBCs needed is determined by the difference of production rates (number of batches per hour) between "HSM" and compression machine. Figure 3-2 shows the process.

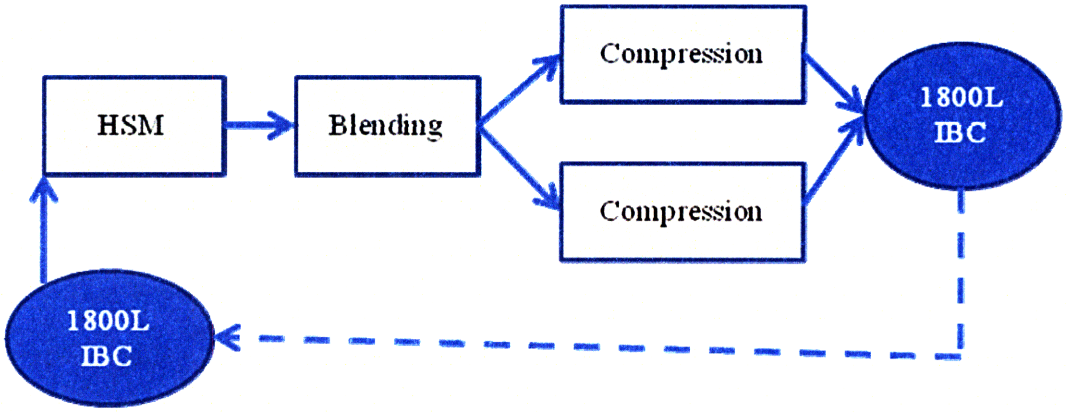


Figure 3-2 1800L IBC usage in the manufacturing process in PF1

As mentioned in section 2.1.1.1, Company ABC allocates two compression machines in PF1 in the way to minimize the changeover of compression machines. For example, the production plan for one Product A Campaign is shown in Table 3-1.

Table 3-1 Production plan for one Product A campaign

Sequence	Strength	Number of batches
1	d	8
2	c	17
3	b	25
4	a	2

In this example, the company will use one compression machine to produce strength d and strength b and the other compression machine for strength a and strength c. From Table 2-1, the cycle time of compression of strength a is much longer than the other strengths. So the machine assigned to do strength a can produce less batches than the other machine.

The company's current policy for scheduling the two compression machines in Product A Campaign has a problem. There will be more IBCs accumulated because only one compression machine is used for each level of strength. The production rate of compression is less than that of the HSM, because the cycle time for compression is longer than HSM. (Refer to Table 2-1)

If two compression machines are running to produce the same level of strength, then the average cycle time for compression will be shorter than HSM except for strength a. In this way, the number of IBCs used will be less than the current way of allocating compression machines. But there is a cost of this policy: the changeover cost between two levels of strengths will be higher than that for the current policy. Table 3-2 is a comparison between these two policies.

Table 3-2 Comparison between two allocation policies of compression machines

	The first policy	The second policy
Compression machine 1	d, b	d, c, b, a
Compression machine 2	c ,a	d, c, b, a
Number of Changeover	2	6
Number of 1800L IBCs	7	4

The research on "allocation of compression machines" is to determine the optimum policy for scheduling the two compression machines to run Product A given the production plan. The objective is to minimize the number of 1800L IBCs needed for Product A. The changeover cost is only the time cost of 16 hours; this is considered in the optimization. Hu He's [1] thesis has details about this part. Some of his findings will be used in chapter 5 and chapter 6 in this thesis.

3.1.3 IBC driver 3 "nonstop HSM"

The third IBC cost driver "nonstop HSM" is also about the relationship between HSM and compression machines. The problem is when compression machine is in changeover, no IBCs can be released during these 16 hours. On the other hand, HSM's changeover is only 3 hours. When HSM starts, an extra IBC will be needed. At this time the maximum number of IBCs needed occurs. The research is to see what will happen to IBCs if HSM can occasionally stop and wait for the compression machine to release an IBC. The cost of this is longer campaign length; the benefit is a reduction in the number of IBCs needed. Details about the analysis are in chapter 5.

3.1.4 IBC driver 4 "IBC turnover between PF1 and PF2"

From section 2.1.1 we know that the production of Product A, B and C share the same "charging" and "HSM" in PF1 and therefore the company tries to keep "HSM" running, even though sometimes it is not the bottleneck of the process. The benefit of doing so is that "HSM" can finish one product campaign as quickly as possible and switch to another production campaign.

Figure 3-3 shows part of the process of Product B and C. From Table 2-2 we can find that when PF1 and PF2 are running a campaign for Product B or C, the compression step in PF2 is the bottleneck. In this situation, since the company still does not want to lose the capacity for "HSM", we need many 1800L IBCs to store the intermediate product between "HSM" and the compression machines, in order for "HSM" to run continuously. However, although the compression step in PF2 is much slower than "HSM" in PF1, it can still release some of the 1800L IBCs during the production campaign. Therefore we can infer that the number of 1800L IBCs needed would be less than the number of batches produced by "HSM", because of the reuse of some 1800L IBCs.

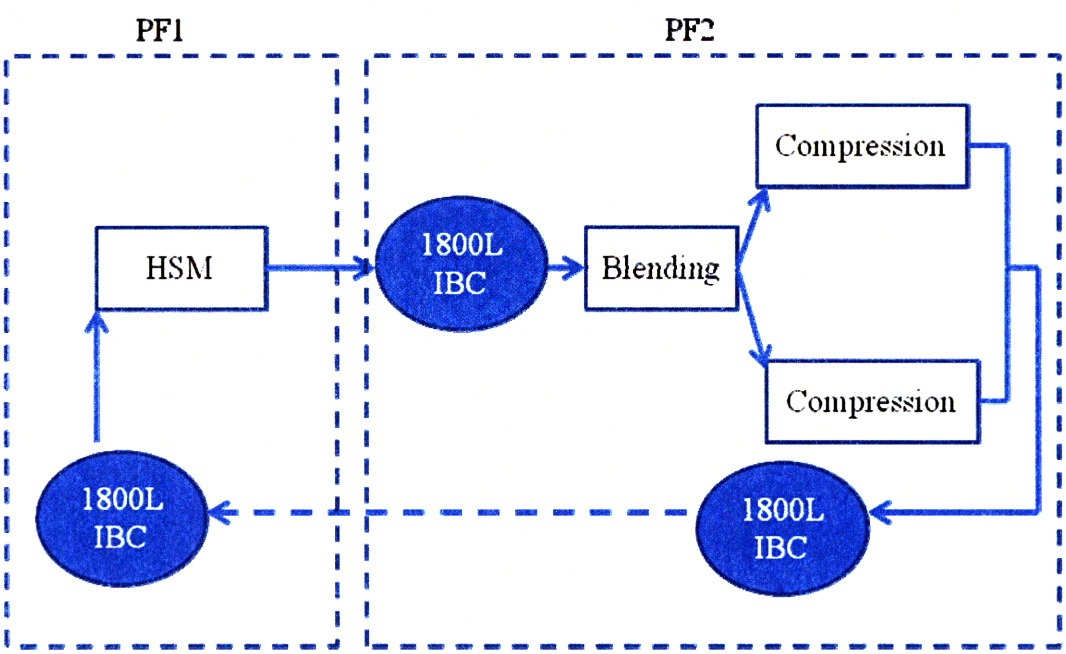


Figure 3-3 1800L IBC usage between PF1 and PF2

In the past, the company was not aware of the importance of estimating how many 1800L IBCs are needed between PF1 and PF2. This was because company had more 1800L IBCs than it needed and thus it would just use whatever it had regardless of how many were actually needed. However, as the production rates increase, 1800L

IBCs gradually become a critical issue and therefore the company starts to ask a question: Can we reduce the number of IBCs used for Product B and C? How many can we reduce?

In chapter 4 in Hu He's thesis [1], he will analyze how many 1800L IBCs are needed to support an X batches Product B or Product C Campaign.

3.1.5 IBC driver 5 "WIP level for Product D"

Product D is a new product which will be launched in the year 2009. One problem the company faces is to determine how many 1800L IBCs are needed for the production of D. As we know from Figure 2-5, the manufacturing process for Product D requires at least two 1800L IBCs, since the step called "roller compaction" transfers the product from one 1800L IBC to another. All the 1800L IBCs involved in this process will be divided into two groups. One group of IBCs will serve the first three steps and the other group will serve the last four steps.

Obviously as we increase the number of 1800L IBCs involved in the production, we will increase the throughput of the whole production line. However this is a tradeoff between the cost of WIP inventory and benefit of production line's throughput. How to distribute the 1800L IBCs in the system is also a problem that needs to be addressed. Whether the first three steps need more IBCs than the last four steps or putting more IBCs for the last four steps will bring us more benefits in terms of productivity of the whole line are the questions to be answered.

In chapter 4 in Hu He's thesis [1], he will describe how to use simulation to approach this problem and to find the relationship between the WIP level and throughput of production line in PF3. He also presents a way to use Buzacott's Line Efficiency concept to estimate the productivity considering machines' failure.

3.2 Problem for IBC cleaning

IBCs are cleaned only when necessary and there is no schedule for cleaning. Nobody knows which IBC should be cleaned by any point in time. If IBCs cannot be cleaned at the right time, then they cannot be reused efficiently. The utilization is low and more IBCs will be needed.

IBC cleaning scheduling is related to the way IBCs are used. In chapter 6, we determine the necessary number of IBCs by five IBC drivers. The last step is to schedule IBC cleaning to reuse them as much as possible. These two ways together can minimize the number of IBCs needed and determine whether the current twenty-eight 600L IBCs, thirty 1800L IBCs and eighteen 2400L IBCs are enough to support production of the four products.

Chapter 4 IBC driver for 600L IBCs

4.1 Theoretical background

In this chapter, we will determine the number of 600L IBCs that should be in stand-by between charging and HSM in PF1. Figure 3-1 is shown here to recall your memory.

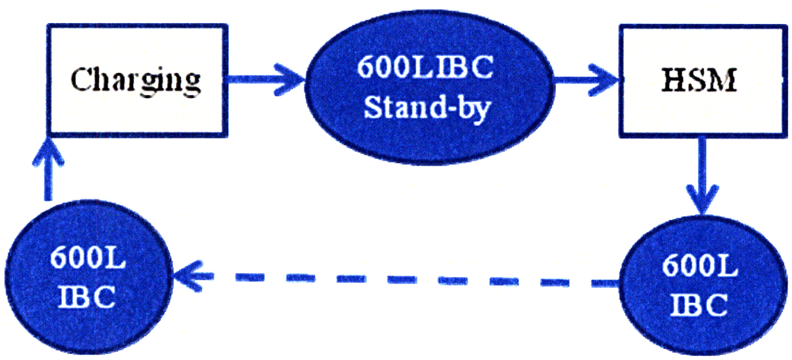


Figure 3-1 600L IBC usage in the manufacturing process in PF1

Although little or no previous work has been done in this area in the company, this research relies on the theoretical groundwork provided by Professor Stanley B. Gershwin in MIT [2].

4.1.1 Transfer lines

A transfer line is a manufacturing system with a very special structure. It is a linear network of service stations or machines (M_1, M_2,…, M_k) separated by buffer storages (B_1, B_2,…, B_{k-1}). Material flows from outside the system to M_1, then to B_1, then to M_2, and so forth until it reaches M_k after which it leaves. [2] Figure 4-1 depicts a transfer line. The squares represent machines and the circles represent buffers.

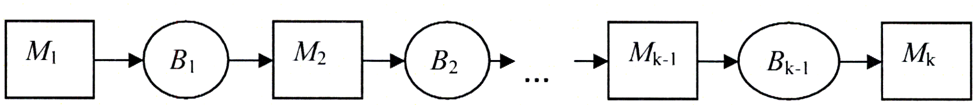


Figure 4-1 K Machine Transfer Line

4.1.2 Buffers

If machine behavior were perfectly predictable and regular, there would be no need for buffers. However, all machines eventually fail, and some stations require an unpredictable, or predictable but not constant, amount of time to complete their operations. This unpredictability or irregularity has the potential for disrupting the operations of adjacent machines, or even machines further away, and buffers are used to reduce this potential. [2]

The effects of a failure of one of the machines on the operation of others are mitigated by the buffer storages. When storages are empty or full, however, this decoupling effect cannot take place. Thus, as storage sizes increase, the probability of storages being empty or full decreases and the effects of failures on the production rate of the system are reduced. However, an undesirable consequence of buffers is in-process inventory. As buffer sizes increase, more partially completed material is present between processing stages. [2]

4.1.3 Two Machine, Finite-Buffer Lines

Figure 4-2 shows a two-machine line. Finite-buffer means the buffer size is not infinite but has a finite limit, which is the usual case in practice.

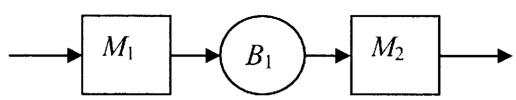


Figure 4-2 Two-machine line

Several analytical models were established to determine the relationship between production rate and buffer size. Three representatives of them are deterministic processing time or Buzacott model, exponential processing time model and continuous material or fluid model. [3]

Figure4-3 [3] is a representative graph from the analysis of a deterministic processing time model. Five lines represent the relationship between production rate and buffer size under five different repair rates. The repair rate is equal to (the average cycle time)/ (Mean Time to Repair). Five lines show the same trend that when buffer size increases, production rate increases. However, production rate cannot increase to infinity. When buffer size reaches some level, the increase of production rate is minor and stays stable in the end.

Although the graph for exponential processing time model and continuous model are a little different from this one, the general trend is the same in that there is an optimum buffer size. The cost of increasing buffer size is the in-process inventory. Higher buffer size means more materials will be accumulated, causing a high in-process inventory. Thus there is an optimum buffer size at which high production rate can be achieved with minimum in-process inventory.

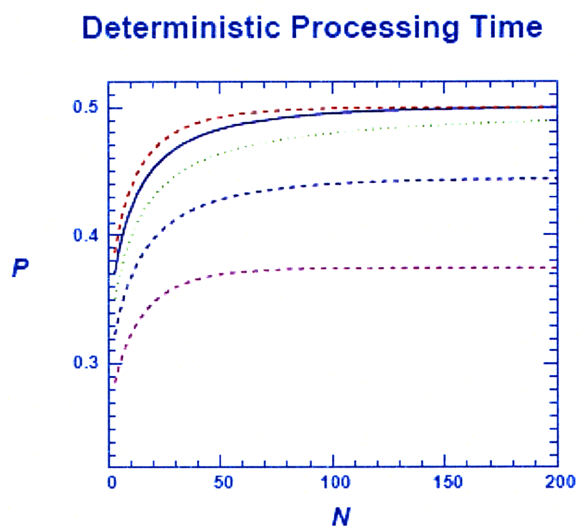


Figure 4-3 Relationship between production rate and buffer size for Buzacott model

4.2 Methodology

If we assume that charging is M_1, HSM is M_2 and the 600L IBCs stand-by between them are B_1, then we can model the system as a two machine, finite-buffer line. It may be possible that the relationship between production rate and the number of 600L IBCs stand-by follows the same trend in two machines, finite-buffer line analytical models, which means that there is an optimum buffer size at which high production rate can be achieved with minimum in-process inventory.

There are currently 12 or 16 IBCs serving as stand-by. We need to determine the position of these two numbers in Figure 4-3. If they are in the stable region, then there is some excess of 600L IBCs. Our methodology is to determine the relationship between production rate and the number of 600L IBCs stand-by by collecting the equipment downtime information. Thus we can know the actual number of 600L IBCs needed for stand-by given the required production rate by the company.

4.2.1 Equipment downtime data collection

The raw data of Time to Repair (TTR), Time to Fail (TTF), Time between Failures (TBF) and Cycle Time (CT) for both charging and HSM are needed. Because TBF=TTR+TTF, we only needed to collect TTR, TTF and CT. The relationship among TTR, TTF and TBF is shown in Figure 4-4.

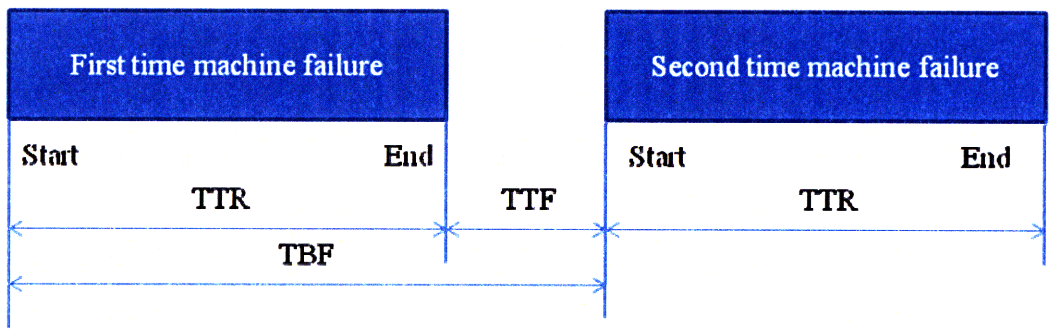


Figure 4-4 Definition of TTR, TTF and TBF

The productivity report of Product A from January to May in 2008 was used as the database. The report has the downtime information of charging and HSM, including the start time, the end time and the reason for equipment not working.

The data collection was done manually; some principles we used included equipment failure only happens during the operation of equipment. For example, if one failure happens but the time period is not in the operation period of that process, then this failure is not considered. Some of the charging and HSM failures are due to scheduled events, such as machine changeover for different strengths, training and meeting of technicians and so forth. We did not consider these events because they did not occur randomly and they can be controlled.

In regard to the CT for charging, we assumed charging was a deterministic process. The average CT is the cycle time of charging, which is 4.5hours/ batch and 1.125 hours /subpart, which is one quarter of a batch.

In regard to the CT for HSM, the data collection was different from that for charging. In Appendix A we depict the manufacturing process of Product A. The HSM process constitutes High Shear Granulator, two drying machines and two milling machines. HSM stops only when both drying machines are not working or both milling machines are not working or High Shear Granulator is not working. However, when either one of the two drying machines or two milling machines is down, we regard this as the HSM working, albeit at a degraded rate. We account for the effect of one drying machine or one milling machine not working on the process in our determination of the cycle time. To do this we collected the raw data of HSM CT.

4.2.2 Fit distribution and run simulation

Before running the simulation to generate the result, we need to estimate the probability distribution for the failure and repair times for each machine. We used Minitab 15 and Stat Fit as a tool to fit the distributions. A good approximation of raw data's probability distribution is an integral part of making the model in simulation as close as possible to the process in the company.

Cellsim and Simul 8 were both used to simulate the manufacturing process. The results of the simulation were compared with the production rate in the company to validate the accuracy of the model and software. The more accurate one was chosen to run further simulation.

4.3 Data collection

4.3.1 Charging downtime data collection

As mentioned in section 4.2.1, CT for charging is 1.125hours/subpart on average. The data collection of TTF and TTR for charging will be explained by the example in Table 4-1.

"Rx" column stands for the batch number. Company ABC's production volume is recorded as number of batches per campaign. "Charging start" and "Charging end" stand for the start time and end time of charging process for that particular batch. "DT start" and "DT end" denotes that charging is not working from "DT start" to "DT end" and "DT" is the length of that period. The last column describes the reason for charging not working.

Table 4-1 Charging example from the productivity report of Product A in 2008

Date	Rx	Charging Start	Charging End	DT Start	DT End	DT (hours)	DT reasons
1-Jan-08	WSN0040	04:02	10:10	5:59	6:27	0.47	FIBC inner liner twisted
1-Jan-08	WSN0050	10:15	14:30				
1-Jan-08	WSN006L	15:01	21:22	20:20	20:50	0.50	Dosing time out occurred for lactose changing
1-Jan-08	WSN007L	21:32	04:08	1:50	4:10	2.33	Dry clean & load cell calibration
2-Jan-08	WSP0010	04:10	09:43				
2-Jan-08	WSP0020	09:57	17:54	13:06	15:25	2.32	Lactose under tolerance
				17:55	18:30	0.58	E&I to access lid problem

Starting from "WSN0040" row in Table 4-1, the first time that charging is not working happened because of "FIBC inner liner twisted". The second time of charging not working occurred at "WSN006L"row, between "20:20" and "20:50" on "1-Jan-08". The first data for the time to failure (TTF) is equal to (20:20-6:27)-(15:01-14:30)-(10:15-10:10). "20:20" is the start time of the second failure; "6:27" is the end time of the first failure. (15:01-14:30) and (10:15-10:10) are the two time periods that charging is not in operation. The first data of time to repair (TTR) is equal to "DT" of the first failure, which is "0.47"hours, or about thirty minutes.

The failure due to "Dry clean & load cell calibration" in "WSN007L" is not considered because it is a scheduled event. The last failure in Table 4-1 from "17:55" to "18:30" on "2-Jan-08" is also not considered because it did not occur during the operation time of charging (from "09:57"to "17:54").

After collecting the data for TTF and TTR, we determined the data for time between failures (TBF): (TBF=TTF+TTR) All the data of TTF, TTR and TBF of charging are listed in Appendix B. In total we have 191 observations for each time.

4.3.2 HSM downtime data collection

Table 4-2 is an example taken from the productivity report of Product A in 2008. We will explain our data collection for CT, TTF and TTR of HSM by this example.

Table 4-2 HSM example from the productivity report of Product A in 2008

Date	Rx	HSM Start	HSM End	DT start	DT End	DT (hours)	Reason(s)
1-Jan-08	WSN0030	03:49	10:40	08:03	08:19	0.13	Redry
				9:17	11:40	2.35	Solution preparation delayed due to awaiting charging to complete
1-Jan-08	WSN0040	11:40	18:04	14:01	14:25	0.27	Waiting for part 1 complete conveying
1-Jan-08	WSN0050	17:03	23:49	18:36	18:52	0.13	No IBC available
				19:36	20:06	0.37	Waiting for part 1 complete conveying
				21:39	21:47	0.13	Loading valve failed for 320
1-Jan-08	WSN006L	22:35	04:56	23:57	0:09	0.20	LOD clarify calibration
2-Jan-08	WSN007L	03:43	09:44	9:45	14:46	5.02	Dry clean
				9:50	15:05	0.32	Inspect the filters of FBD320 due to "dust in exhaust"
2-Jan-08	WSP0010	14:46	01:13	17:20	20:17	2.92	FBD 320 down
				20:16	22:52	2.57	FBD 320 down

As mentioned in section 4.2.1, HSM data collection is different from charging. If everything goes well with HSM, the second batch of HSM should start about an hour before the first batch of HSM ends. For example, in Table 4-2, "WSN0030" HSM ends at 10:40; however, "WSN0040" HSM starts at 11:40. Because it should start at 9:40 (an hour earlier than 10:40), the first failure of HSM is from 9:40 to 11:40. In the same way, the second failure of HSM occurs at 08:44 on 2-Jan-08 between "WSN007L" and "WSP0010". The first data of TTF is equal to (08:44 on 2-Jan-08)-(11:40 on 1-Jan-08). The first data of TTR is equal to the duration of the first failure, which is from 9:40 to 11:40.

To account for the effects of either of the two production lines of HSM not working, CT data of HSM is collected. We determine the cycle time for a batch by CT="HSM end"-"HSM start" in each batch. "CT" is the cycle time for each batch; one batch has four subparts. "CT/4" is the cycle time for each subpart. In HSM, one subpart is produced at a time. When four subparts are finished, one batch is recorded in the productivity report. Because a subpart is the unit in simulation, "CT/4" is the cycle time data for simulation. Appendix B has all the downtime data for both charging and HSM. There are 191 data points for charging TTF, TTR and TBF; 25 data points for HSM TTF, TTR and TBF; 216 data points for HSM CT and CT/4.

4.4 Data analysis

Cellsim and Simul 8 are two software applications available to simulate the manufacturing process of charging and HSM and to determine the relationship between production rate (number of batches per campaign) and buffer size (the number of 600L IBCs stand-by). In this section, we analyzed the data by Minitab 15 and Stat Fit (statistical software) and run the simulation by Cellsim and Simul 8. A comparison was made between the simulation result and the actual numbers in company ABC so as to decide which software to run further simulation in section 4.5.

4.4.1 Cellsim with Minitab to analyze the data

"CellSim. XLSM Factory Simulator Version 3.1" is a simple factory simulator and is distributed free of charge. It is based on ideas first developed at Cornell in the factory simulation program known as XCELL+.

Figure 4-5 Models in Cellsim

Figure 4-5 shows the model established to simulate the manufacturing process of charging and HSM. Parameters of CT, TTR and TBF for both charging and HSM are needed to finish the modeling.

Minitab 15 is used as an assistant to analyze the raw data in Appendix B. We used Minitab to develop histograms of charging TTR, TBF and HSM CT/4, TTR and TBF to depict the probability distribution of raw data. Mean and standard deviation are calculated to define the distribution. Figure 4-6 shows the histogram of charging TBF, the unit of TBF is in hours; we can infer from the shape of the histogram that charging TBF is approximately following an exponential distribution. Histograms of all the other data are shown in Appendix C as a reference; all the units are in hours. The probability distributions of the failure and repair times can be chosen in Cellsim from "Uniform", "Shifted Erlang", "Shifted Exponent" and "Normal" based on the histogram of each parameter. Table 4-3 is a summary of all the parameters and distribution choices for the model in Cellsim.

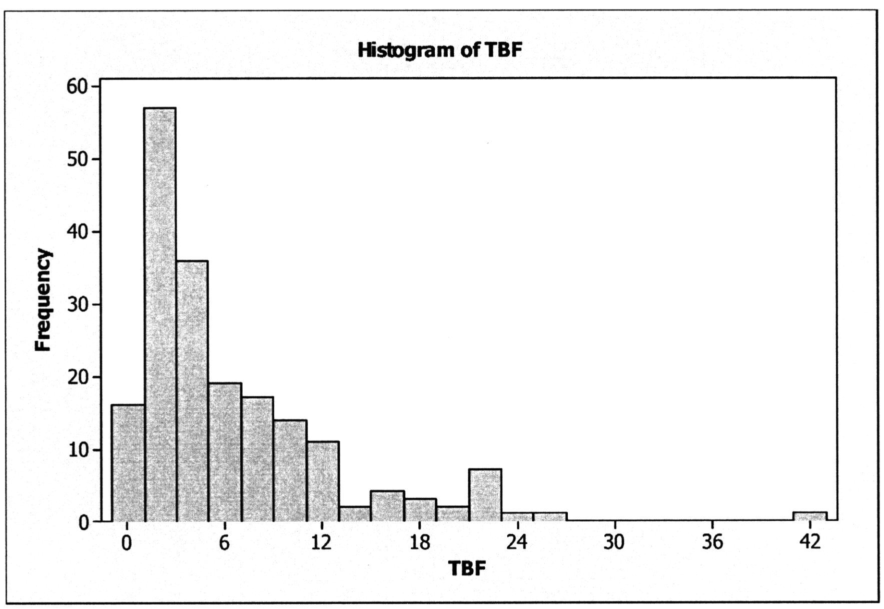


Figure 4-6 Histogram of Charging TBF

Table 4-3 Parameters in Cellsim Model

Unit: hours	Charging			HSM		
	CT/4	TBF	TTR	CT/4	TBF	TTR
Mean	1.125	6.34	0.99	1.79	56.07	5.46
Standard deviation	0	6.23	0.98	0.16	55.36	5.45
Probability distribution	Uniform	Exponent	Exponent	Normal	Exponent	Exponent

In order to make a comparison between the simulation result of Cellsim and the actual production volume, the input in Cellsim is set the same as the actual campaign. The number of 600L IBCs is 12, same as in practice. The run length of the simulation is set to be the same as a campaign length in the company. Three campaigns in the first five months in 2008 are chosen as a comparison. Five hundred replicates are made in each case to make the results more accurate. Table 4-4 is the average result with the standard deviation from the 500 replications of the simulation. The actual number of batches for each of the three campaigns is also listed as a comparison.

Table 4-4 Simulation result from Cellsim

	Campaign 1	Campaign 2	Campaign 3
Campaign length	576h	696h	600h
Average production volume (number of batches)	73.72	89.10	76.82
Standard deviation of production volume	2.87	3.32	2.95
Actual number of batches	75	84	66
Error of Cellsim	0.017	0.061	0.16

The error of Cellsim is equal to (production volume in simulation- production volume in practice)/production volume in practice. From Table 4-4 we can see that the error of Cellsim is on average 0.08. In comparison to the average production volume 80 batches, the error of 6.4 batches indicates that the simulation is not very accurate.

4.4.2 Simul 8 with Stat Fit to analyze the data

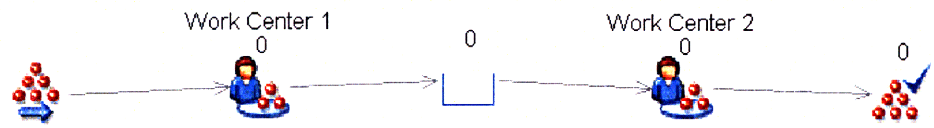


Figure 4-7 Models in Simul 8

Figure 4-7 shows the model established in Simul 8. Work center 1 and work center 2 stand for charging and HSM respectively. There is a buffer between them and the buffer size can be increased from 1 to infinity. At the end of the line, we can collect the number of finished goods.

The parameters in the model include CT, TTR and TBF for charging and HSM. The probability distribution of these data can be determined by Stat Fit (software together with Simul 8 professional). After input of raw data, Stat Fit can automatically fit the distribution for each model parameter. Table 4-5 is the result for charging TBF.

Table 4-5 Stat Fit for Charging TBF

Auto::Fit of Distributions

distribution	rank	acceptance
Lognormal(0., 1.4, 0.984)	100	do not reject
Pearson 6(0., 15., 1.69, 4.98)	90.6	do not reject
Weibull(0., 1.11, 6.61)	30.2	do not reject
Gamma(0., 1.27, 4.98)	25.	do not reject
Erlang(0., 1., 6.34)	19.7	do not reject
Exponential(0., 6.34)	19.7	do not reject
Beta(0., 160, 1.22, 29.4)	6.56	do not reject
Pearson 5(0., 1.16, 2.88)	2.59	do not reject
Triangular(0., 42.2, 0.442)	0.	reject
Uniform(0., 41.9)	0.	reject
Rayleigh(0., 6.28)	0.	reject
Chi Squared(0., 5.04)	0.	reject
Power Function(0., 73.8, 0.345)	0.	reject

From Table 4-5, we can see that the best distribution for charging TBF is lognormal distribution, not exponential distribution. Stat Fit can give a more accurate fit of the distribution than the approximation provided by histogram. The Stat Fit results for the other data are in Appendix D as a reference. Table 4-6 is a summary of all the parameters in the model in Simul 8.

Table 4-6 Parameters in Simul 8 model

Time: hours	Charging			HSM		
	CT/4	TBF	TTR	CT/4	TBF	TTR
Mean	1.125	6.34	0.99	1.79	56.07	5.46
Standard deviation	0	6.23	1.53	0.15	90.76	7.56
Probability distribution	NA	Lognormal	Pearson 5	Normal	Lognormal	Lognormal

The inputs such as run length and buffer size in the model in Simul 8 are the same as that in Cellsim for comparison. Table 4-7 is the simulation result from Simul 8 and the actual number in the company.

Table 4-7 Simulation result from Simul 8

	Campaign 1	Campaign 2	Campaign 3
Campaign length (hours)	576	696	600
Average Production volume of Simul 8	75.66	87.52	69.74
Standard deviation of production volume	6.79	7.56	7.00
Actual number of batches	75	84	66
Error of Simul 8	0.0088	0.042	0.057

From Table 4-7, we can see that Simul 8 together with Stat Fit is better than Cellsim in terms of simulating the actual process in the company because it has a smaller error. The average error of Simul 8 is 0.04, which is smaller than the error of Cellsim 0.08. Simul 8 was chosen to run further simulation to determine the relationship between production volume and buffer size (number of 600L IBCs stand-by).

4.5 Result analysis

We use Simul 8 to simulate three campaigns in the first five months of 2008. The length of the simulation is set to equal to the actual length of three campaigns. The capacity of the buffer is increased from 1 to 20 in each campaign. One unit of buffer can hold one subpart of a batch. For each buffer size, we repeat the simulation 500 times and the average and standard deviation of the results are listed in Table 4-8.

Table 4-8 Simulation results

Buffer size	Production volume					
	Campaign 1		Campaign 2		Campaign 3	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
1	69.42	6.84	80.29	7.56	64.02	7.02
2	73.25	6.93	84.76	7.70	67.56	7.13
3	74.30	6.95	85.95	7.75	68.52	7.15
4	74.80	6.95	86.55	7.72	68.99	7.15
5	75.07	6.95	86.86	7.72	69.23	7.14
6	75.22	6.94	87.04	7.74	69.37	7.13
7	75.37	6.93	87.20	7.71	69.50	7.13
8	75.46	6.88	87.31	7.67	69.58	7.09
9	75.53	6.86	87.39	7.64	69.63	7.08
10	75.60	6.84	87.46	7.61	69.68	7.06
11	75.62	6.81	87.49	7.59	69.70	7.03
12	75.66	6.79	87.52	7.56	69.74	7.00
13	75.70	6.76	87.56	7.54	69.76	6.98
14	75.71	6.72	87.57	7.50	69.77	6.94
15	75.72	6.70	87.58	7.47	69.78	6.93
16	75.72	6.69	87.59	7.45	69.79	6.92
17	75.73	6.66	87.59	7.42	69.79	6.92
18	75.74	6.65	87.60	7.42	69.79	6.91
19	75.75	6.63	87.62	7.42	69.81	6.89
20	75.74	6.62	87.60	7.40	69.80	6.88

We can divide the average of each production volume by the maximum production volume (from setting buffer equal to 20 in that campaign) to get the relative values in Table 4-9.

Table 4-9 Simulation results (relative value)

Buffer size	Production volume		
	Campaign 1	Campaign 2	Campaign 3
1	0.9164	0.9163	0.9170
2	0.9670	0.9674	0.9677
3	0.9808	0.9810	0.9815
4	0.9875	0.9878	0.9883
5	0.9910	0.9913	0.9917
6	0.9930	0.9934	0.9937
7	0.9950	0.9952	0.9956
8	0.9961	0.9965	0.9966
9	0.9971	0.9973	0.9974
10	0.9980	0.9982	0.9982
11	0.9983	0.9985	0.9984
12	0.9987	0.9988	0.9989
13	0.9993	0.9993	0.9992
14	0.9995	0.9994	0.9994
15	0.9995	0.9995	0.9996
16	0.9996	0.9997	0.9997
17	0.9997	0.9997	0.9997
18	0.9998	0.9998	0.9997
19	1.0000	0.9999	1.0000
20	0.9998	0.9997	0.9999

From Table 4-9, we can see the consistency in the results across the three campaigns. For buffer size 4, you can have 98.7% of the maximum production volume. For buffer size 8, you can have 99.6% of the maximum production volume. For buffer size 12, you can have 99.9% of the maximum production volume. Figure 4-8 shows the relationship between relative production volume and buffer size.

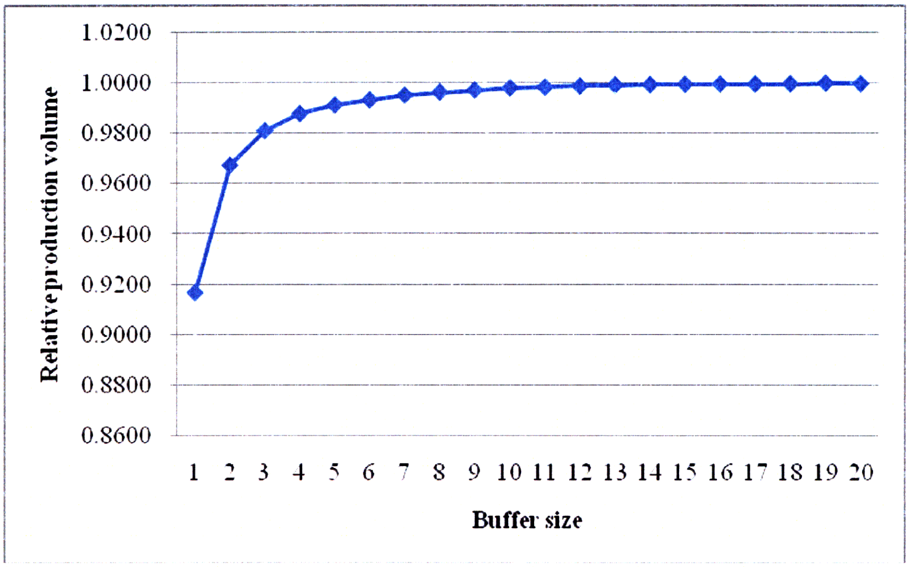


Figure 4-8 Relationship between production rate and buffer size

In company ABC, technicians in HSM would like to start HSM when they have four 600L IBCs charged with raw materials on hand because they want to make sure they can complete a batch. We assume this is the production requirement. Thus the total number of 600L IBCs needed to support the manufacturing process of charging and HSM in PF1 should be the multiple of 4.

There should be one 600L IBCs in charging and one 600L IBCs in HSM. Thus the total number of 600L IBCs needed should be the number of stand-by plus two. Let us compare with the situation of 12, 16 and 8 IBCs to decide the optimum number. Four IBCs are set as the comparison base.

Table 4-10 Comparison of different buffer sizes

Number of IBCs	4	8	12	16
Number of stand-by	2	6	10	14
Relative production volume	0.9674	0.9933	0.9981	0.9994
Benefit	0	0.0268	0.0318	0.0331
Relative benefit	NA	0.0268	0.005	0.0013

If "Number of IBCs" is increased from 4 to 8, then the relative production volume can be increased from 96.74% of the maximum production volume to 99.33%. The cost is

4 more IBCs and the benefit is a 2.68% increase in the production volume from each campaign. If "Number of IBCs" is increased from 8 to 12, we can expect a 0.5% increase in the production volume at the cost of 4 more IBCs. If "Number of IBCs" is increased from 12 to 16, we can only expect a 0.13% increase in the production volume.

To summarize, we recommend that the number of IBCs should be 8. This conclusion means we can reduce each campaign by four or eight 600L IBCs; because the company currently uses twelve or sixteen 600L IBCs for each campaign. In the next section, we analyze the feasibility of this conclusion.

4.6 Feasibility research

We examine whether eight 600L IBCs are enough in practice by considering the productivity report in 2008. The production volume of charging and HSM each day can be seen from the report.

On some days charging did more batches than HSM; on these days there would be 600L IBCs full of materials accumulated between charging and HSM. One batch means four 600L IBCs. (One 600L IBC contains one subpart and four subparts is one batch.) When technicians feel that they have charged enough IBCs to keep HSM running for some time, they will produce less each day. On these days, HSM did more batches than charging and some 600L IBCs between charging and HSM would be consumed by HSM. Thus the difference between production volume of charging and HSM each day will be a good reflection of the number of 600L IBCs in use in practice.

We observed three Product A Campaigns over 90 days in the productivity report 2008. The production volumes of charging and HSM are recorded each day. Then the difference between them is calculated. If charging did 3 batches more than HSM, we record a 3 on that day. On the contrary, if HSM did 3 batches more than charging, -3 is recorded. Table 4-11 shows the results. Frequency means the number of days. For example, in 90 days there are only two days in which HSM did 3 batches more than charging. When this situation occurs, then we would need twelve 600L IBCs and 8 is not enough. The details for these two days production are examined in the report: one is at the end of campaign, charging finished all the jobs and had zero production volume, while HSM did the last 3 batches on that day; the other is because of "SPF dispensing activity" charging was not working on that day.

Table 4-11 Difference in production volume of charging and HSM

Number of batches Charging more than HSM	Frequency
-3	2
-2	7
-1	22
0	28
1	20
2	9
3	2
Total	90

For the situation of charging did 3 batches more than HSM, the problem can be solved. HSM cannot stop because of the production requirement, but charging does not need to continue working. Thus we can restrict charging to do a maximum of two batches more than HSM each day if eight 600L IBCs are given.

To summarize, eight 600L IBCs appears to be feasible for the company except for the situation that HSM produces 3 batches more than charging in one day. This situation only happens twice in 90 days, so 8 should be enough.

4.7 600L IBCs management

After concluding that eight 600L IBCs are enough for one campaign, this section will analyze the implementation of 600L IBCs usage and cleaning. The production plan in 2009 is used to explain the method.

The production plan in 2009 in Company ABC will either follow the sequence "Product A-Product B-Product A-Product C..." or "Product A-Product B-Product C-Product A..."The time periods between two Product A campaigns are different for these two scenarios, which determines the different usage and cleaning schedule of 600L IBCs. In the following section, we will explain 600L IBCs management for each scenario. Product D does not use 600L IBCs, so it is not considered.

4.7.1 Scenario 1: Product A-Product B-Product A-Product C

At the start of this section, one thing needs to be clarified. IBCs that contain the same product do not need to be cleaned for some number of days, which is called "dirty holding days" in company ABC. Table 4-12 shows the IBC dirty holding days for Product A, Product B and Product C.

Table 4-12 IBC dirty holding days

Product	A	B	C
Dirty holding days	92	30	30

The average campaign length is about 20 to 30days. For example, Product A runs about 20 to 30days, after that Product B runs about 20 to 30 days and so forth. Our plan is that eight 600L IBCs are dedicated to the Product A campaign. After the Product A campaign, these IBCs do not need to be cleaned as long as the time period between when the first Product A campaign starts and when the second Product A campaign ends is less than 92 days.

Another eight 600L IBCs are dedicated to the Product B and Product C campaign. After the Product B campaign these eight 600L IBCs need to be cleaned in order that they may be reused for the Product C campaign. This is because the dirty holding days of Product B and Product C are only 30 days. The other twelve 600L IBCs serve as a total stand-by. If some random events happen and 600L IBCs are not enough, these IBCs can be used as a back-up. The usage of twenty-eight 600L IBCs are shown in Table 4-13.

Table 4-13 600L IBC usage

IBC Number	1	2	3	4	5	6	7	8		
Usage	Product A Campaign									
IBC Number	21	22	23	24	25	26	27	28		
Usage	Product B Campaign and Product C Campaign									
IBC Number	11	18	19	20	29	30	31	32	33	34
Usage	Total Stand-by									

Assume that it is Product A Campaign now. The IBC 1 to IBC 8 are in use. Each time charging uses one IBC; after four IBCs are charged they are sent to HSM. HSM uses one IBC each time and after use IBC should be sent back to charging one by one for reuse.

After Product A Campaign, the IBC 21 to IBC 28 can be taken from "Room TCM-740" to be used for Product B Campaign. After room cleaning, the IBC 1 to IBC 8 can be stored there to wait to be used in the next Product A Campaign. The other 12 IBCs can be stored in "IBC DRYING N1.43" in PF2.

After Product B Campaign, the IBC 21 to IBC 28 needs to be cleaned during the campaign changeover, which is about 7 days. After that, they can be stored in "Room TCM-740" and the IBC 1 to IBC 8 is taken from that room to be used in Product A Campaign. After Product A Campaign, the IBC 1 to IBC 8 need to be cleaned. After that, they can be stored in "Room TCM-740" and the IBC 21 to IBC 28 is taken from that room to be used in Product C Campaign. Then next cycle of "Product A-Product B-Product A-Product C" begins...

In Scenario 1, after every two Product A Campaigns, the IBC 1 to IBC 8 need to be cleaned and after every Product B Campaign and every Product C Campaign, the IBC 21 to IBC 28 need to be cleaned.

4.7.2 Scenario 2: Product A-Product B-Product C-Product A

In this scenario, the time period between two Product A Campaigns is likely to be longer than 92 dirty holding days. So IBCs are not dedicated for one product. The plan is 8 IBCs can be Team 1 and another 8 IBCs can be Team 2. The other 12 IBCs are Team 3 and serve as the total stand-by.

Product A Campaign uses Team 1, after that Team 1 is cleaned and stored in "Room TCM-740". Team 2 is taken from that room to be used in Product B campaign. After Product B Campaign, Team 2 is cleaned and Team 1 is taken to be used in Product C Campaign, and so forth. In scenario 2, eight IBCs need to be cleaned at the end of each campaign.

In this chapter, after data collection and analysis, simulation results show that eight 600L IBCs are enough for each product campaign. The feasibility of eight 600L IBCs is examined by comparing to data from the historical productivity report. The chapter concludes with recommendations about 600L IBC management. The findings of 600L IBC management will be used in IBC cleaning schedule in chapter 6. Chapter 5 describes the other IBC driver for 1800L IBC-nonstop HSM.

Chapter 5 IBC driver "Nonstop HSM"

In Chapter 4 in Hu He's thesis [1], the number of 1800L IBCs needed for Product A, Product B, Product C and Product D campaign has been decided. Based on his analysis, this chapter will provide a methodology on how to further reduce the number of 1800L IBCs needed. The company's production strategy is to run the HSM continuously to support Product A, Product B and Product C most efficiently.

5.1 Problem Statement

As mentioned before, Product A, B and C share the same HSM process in PF1 and therefore the company keeps HSM running even though it is not the bottleneck of the production line. The benefit is that HSM can finish one product campaign as quickly as possible and switch to another product campaign.

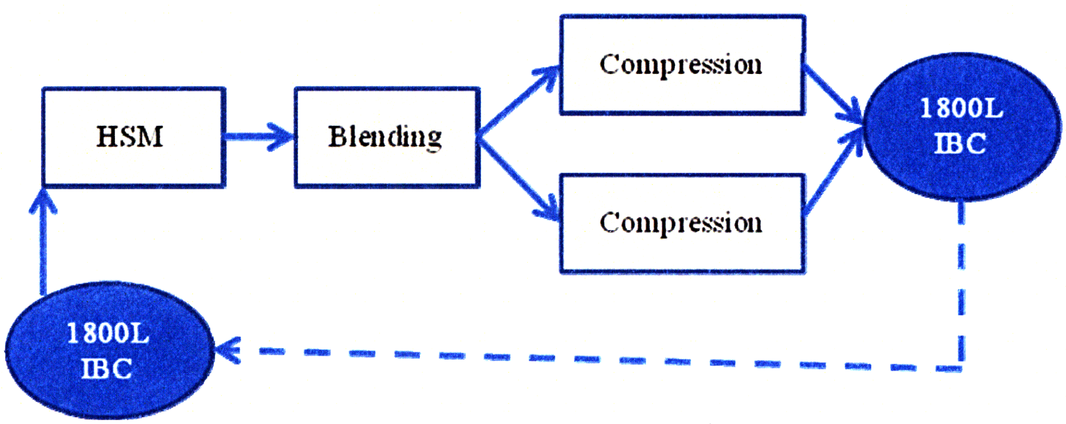


Figure 3-2 1800L IBC usage in the manufacturing process in PF1

Figure 3-2 is shown here to refresh your memory of 1800L IBC usage in PF1. There are generally two ways to reduce the number of 1800L IBCs needed for Product A, B and C: one is to make the compression machines release 1800L IBCs as quickly as possible; an example is the research on the allocation policy of two compression machines in PF1; the other is to slow down the HSM so that it requires fewer 1800L IBCs. The second way seems undesirable because it is contrary to the company's practice. No company wants to slow down its production.

The question is to make a choice between the cost of IBC and the cost of the HSM run length. If HSM has to wait one day to reduce one IBC, the company will probably not be happy. However, if the delay is only two hours or four hours, then this plan might be feasible. In next section, the analysis of the effect of the delay of HSM on the number of 1800L IBCs will be illustrated with a production plan in 2009.

5.2 Graph Analysis

The production plan used in section 3.1.2 is a typical Product A Campaign in 2009. It is also used here to illustrate the methodology.

Table 3-1 Production plan for one Product A campaign

Sequence	Strength	Number of batches
1	d	8
2	c	17
3	b	25
4	a	2

Using the methodology of allocating compression machines in Chapter 4 in Hu He's thesis [1], the best way to allocate two compression machines for this campaign is to use two compression machines to produce each level of strength. We determine the number of 1800L IBCs needed as follows: it increases by one when HSM starts to produce a batch and decreases by one when one of the compression machines completes the compression. We can then plot the number of 1800L IBCs needed over time. It is shown in Figure 5-1 and the details of HSM and two compression machines timelines during the campaign is in Table 5-1.Time represents the number of hours after the start of the campaign; thus a time of 7 means seven hours after the start of the campaign.

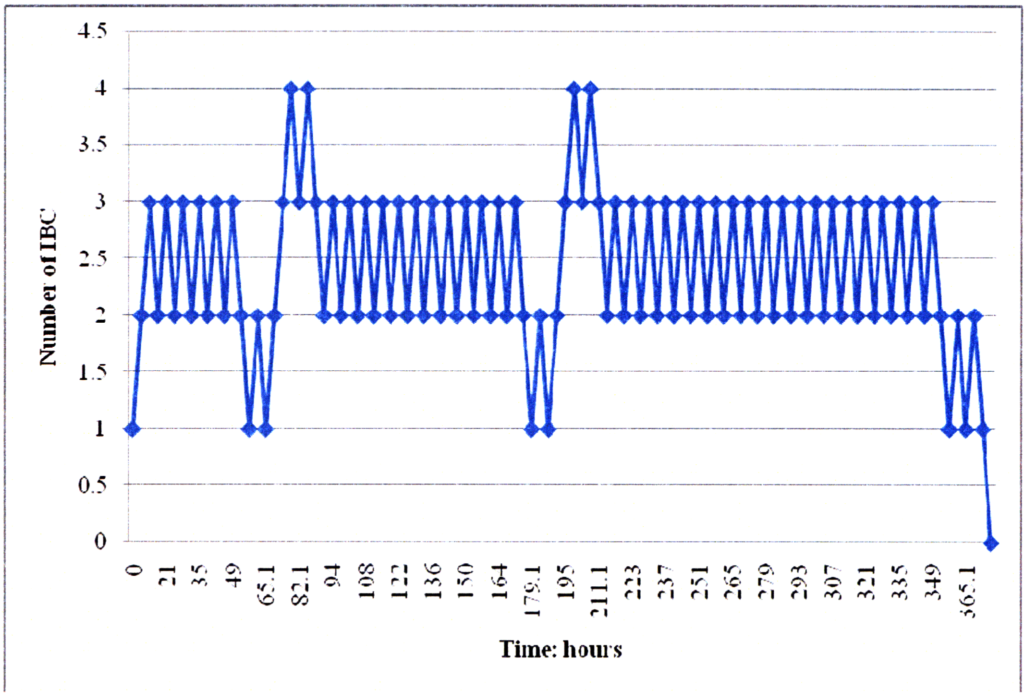


Figure 5-1 Accumulated number of IBCs along the campaign

From this graph, we can see that the maximum number of IBCs needed is 4. The maximum occurs four times in the whole campaign. For most of the campaign, three 1800L IBCs are enough. We want to find the reason for four 1800L IBCs needed and see whether it can be reduced.

Table 5-1 HSM and Two compression machines timeline

Time	Number of IBCs	Time	Number of IBCs	Time	Number of IBCs	Time	Number of IBCs
0	1	101	3	195	3	286	3
7	2	102	2	202	4	288	2
14	3	108	3	204	3	293	3
16	2	109	2	209	4	295	2
21	3	115	3	211	3	300	3
23	2	116	2	213	2	302	2
28	3	122	3	216	3	307	3
30	2	123	2	220	2	309	2
35	3	129	3	223	3	314	3
37	2	130	2	225	2	316	2
42	3	136	3	230	3	321	3
44	2	137	2	232	2	323	2
49	3	143	3	237	3	328	3
51	2	144	2	239	2	330	2
58	1	150	3	244	3	335	3
59	2	151	2	246	2	337	2
65	1	157	3	251	3	342	3
66	2	158	2	253	2	344	2
73	3	164	3	258	3	349	3
80	4	165	2	260	2	351	2
82	3	171	3	265	3	358	1
87	4	172	2	267	2	359	2
89	3	179	1	272	3	365	1
90	2	181	2	274	2	366	2
94	3	186	1	279	3	401	1
97	2	188	2	281	2	408	0

From Table 5-1, we found that at time 80, the HSM starts a batch and will need one IBC, and the compression machine will release one IBC two hours later at time 82. Because HSM cannot wait, a new IBC is needed, and the maximum number of IBCs increases to 4. The reasons for the other three "4" are the same as the first one.

(Highlighted in Table 5-1)

5.2.1 HSM wait for two hours

If HSM were to delay the start of its batch until time 82 for the compression machine to release an 1800L IBCs, then the accumulated number of IBCs along the campaign is shown in Figure 5-2 and the details of HSM and two compression machines timelines along the campaign is in Table 5-2.

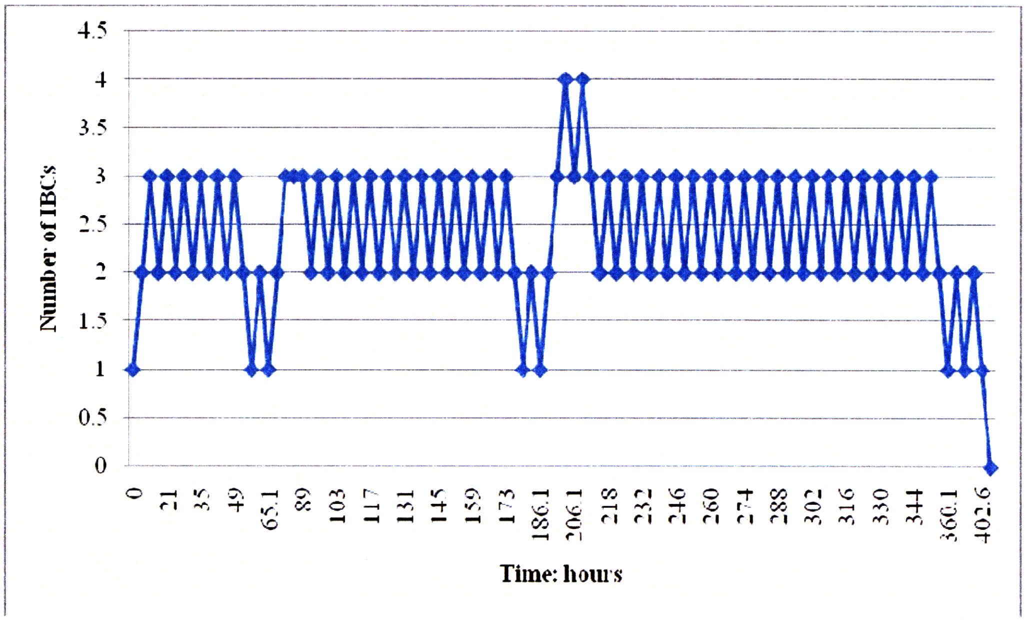


Figure 5-2 HSM delay two hours

Table 5-2 HSM delay two hours

Time	Number of IBCs	Time	Number of IBCs	Time	Number of IBCs	Time	Number of IBCs
0	1	110	3	206	3	290	2
7	2	111	2	211	4	295	3
14	3	117	3	213	3	297	2
16	2	118	2	215	2	302	3
21	3	124	3	218	3	304	2
23	2	125	2	220	2	309	3
28	3	131	3	225	3	311	2
30	2	132	2	227	2	316	3
35	3	138	3	232	3	318	2
37	2	139	2	234	2	323	3
42	3	145	3	239	3	325	2
44	2	146	2	241	2	330	3
49	3	152	3	246	3	332	2
51	2	153	2	248	2	337	3
58	1	159	3	253	3	339	2
59	2	160	2	255	2	344	3
65	1	166	3	260	3	346	2
66	2	167	2	262	2	351	3
73	3	173	3	267	3	353	2
82	3	174	2	269	2	360	1
89	3	181	1	274	3	361	2
90	2	183	2	276	2	367	1
96	3	186	1	281	3	368	2
97	2	190	2	283	2	403	1
103	3	197	3	288	3	410	0
104	2	204	4				

From Figure 5-2 and Table 5-2, we can see that the maximum number of IBCs is still 4, but it occurs only twice, not four times, and the first time appears at time 204, which is 124hours later than the nonstop HSM scenario (at time 80). The HSM run length has increased to 410 hours, 2 hours longer than 408 hours.

From Table 5-2, we note that the maximum 4 appears at time 204 and the compression machines release an IBC at time 206; if HSM were to delay its start at time 204 by 2 hours, then possibly the maximum can be 3, not 4.

5.2.2 HSM wait for another two hours

If HSM waits 2 hours at time 204, then the accumulated number of IBCs along the campaign is in Figure 5-3. As expected, the maximum number of IBCs is 3 if HSM can wait 2 hours at time 80 and another 2 hours at time 204.

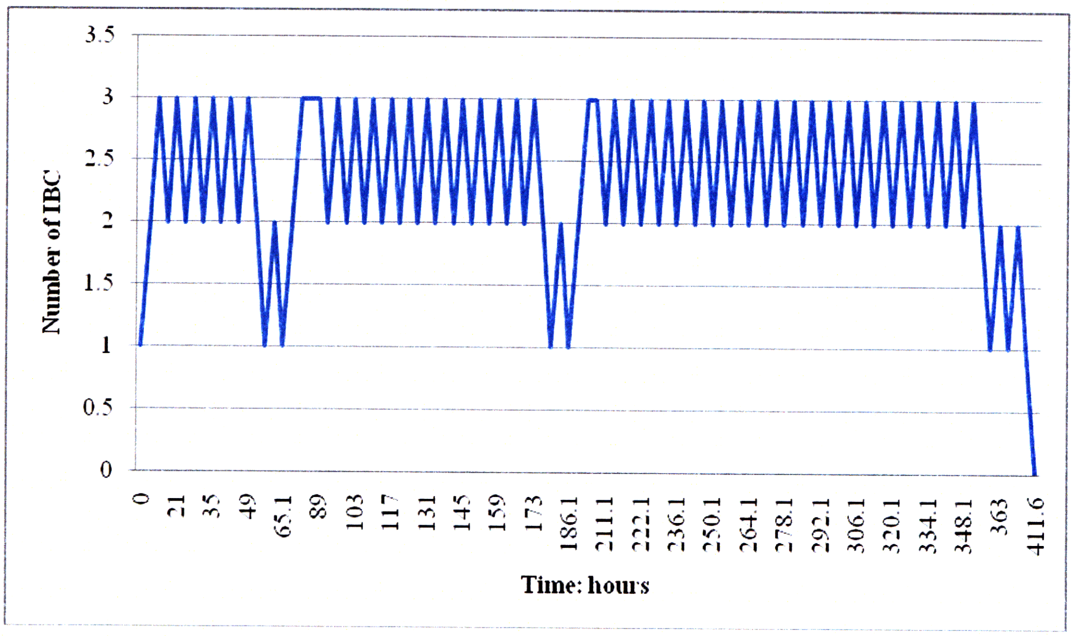


Figure 5-3 HSM delay another 2 hours

To summarize, if HSM waits two hours, the maximum number of IBCs "4" will appear 124hours later; if HSM waits four hours, the maximum number of IBCs can be reduced from "4" to "3". The length of the campaign, though, will increase by four hours.

5.3 Implementation

First, the example in section 5.2 is only used to explain the methodology. It is not practical to tell technicians in the company to stop HSM at time 80 or time 204. But it is possible that when there are only three 1800L IBCs for this particular Product A Campaign and at some time HSM has no IBCs to use, then it is better to check the progress of compression machines. If compression machine can release IBC within some time period (this time period should be decided by the senior manager in the company), then HSM can stop and wait for the IBCs to come.

Currently, there is a 7 days campaign changeover in the company. During these days, the HSM needs a major cleaning and some preparation for the next campaign needs to be done. Whether the HSM finishes a campaign at 3pm or at 7pm on that day will not have much influence on future campaigns. Four hours compared to 7 days is not a big issue. However the senior manager should decide the maximum delay that they can afford for the HSM. 4 hours is not an issue, but 8 hours might be too long.

The objective of this project is to minimize the number of IBCs needed. We focused on IBCs and found all the IBC drivers. Improvements on some IBC drivers can reduce the number of IBCs needed by a large number, while others may just reduce the number of IBCs by one or two. For example, the IBC driver "stand-by for equipment downtime" research has reduced the number of 600L IBCs needed by 4 or 8 per campaign. Its implementation requires a change on the part of 600L IBC management and human resource management. The manager should think about how to assure that the technicians send 600L IBCs to the next process with no delay.

On the other hand, "nonstop HSM" driver in this chapter can only reduce the number of IBCs by one in the example. The implementation is to challenge the basic belief that "HSM cannot stop". The company does not need to accept this suggestion as long as they have four 1800L IBCs for Product A Campaign in this case. It is highly dependent on the determination of the company's implementation on lean manufacturing. Our suggestion is to reduce the waste of IBCs to zero. But if the company can afford some waste now, then there is no need to stop HSM.

Chapter 6 IBC Cleaning

IBC Cleaning is another way to minimize the number of IBCs needed in addition to the five IBC drivers. In this chapter, we consider all the five IBC drivers together with IBC cleaning scheduling to determine the number of IBCs needed to support two production scenarios in 2009.

6.1 Scope and Assumptions

The 2400L IBCs are not considered in this chapter. They are only used in PF2 and can be cleaned by washers WA-2900 and WA-2940 in PF2. 2400L IBCs cleaning is independent from 600L and 1800L IBCs. The 600L IBCs and 1800L IBCs must share the only washer WA-900 in PF1. We assume that the washer for 2400L IBCs cannot be used to clean 600L and 1800L IBCs right now. So the cleaning scheduling of 600L and 1800L IBCs will be more complicated than 2400L IBCs.

The cleaning scheduling for the 1800L IBCs used for Product D is not considered in this chapter. The production volume for Product D in 2009 is only about 60 batches, which means 5 batches per month. Our plan is to schedule the 600L and 1800L IBCs used for Product A, B and C cleaning first, then determine the best time to clean 1800L IBCs from Product D and give recommendations to the company on the production plan of Product D.

Another assumption is that IBCs cannot be cleaned during the HSM major cleaning period, which is about 2 days at the end of campaign. The campaign changeover for different products is 7 days. So at the end of each campaign, there are 5 days to clean IBCs. We assume that this is the best time to clean IBCs because there are no labor constraints in this period. We will arrange as many cleaning jobs as possible in this period.

In the next sections, an IBC cleaning schedule will be made for two production scenarios mentioned in Chapter 4.

6.2 IBC Cleaning Scheduling

6.2.1 Scenario 1: Product A-Product B-Product A-Product C

We assume that Product A Campaign needs x 1800L IBCs, Product B Campaign needs thirty 1800L IBCs and Product C Campaign needs y 1800L IBCs. We assume that Product B uses all the 1800L IBCs, which is the worst case for cleaning. Through IBC cleaning scheduling, we can know the maximum values for x and y. For 600L IBCs, its usage can be referred to section 4.7.1.

At the end of Product A Campaign, there is no need to clean 600L IBCs. There will be x 1800L IBCs that need to be cleaned. The total time period is 5 days. We assume that the efficiency of washer is 95% and the availability of manpower is 90%. Thus the available time for washing IBCs will be 5days*24hours/day*95%*90%=102.6hours. The washing cycle time for 1800L IBC is 200minutes. In 102.6hours, the washer can wash thirty (102.6hours*60minutes/hour/200minutes=30) 1800L IBCs. There is capacity to wash (30-x) 1800L IBCs from Product D in this period.

At the end of Product B Campaign, there are eight 600L IBCs that need to be cleaned. The washing cycle time for 600L IBC is 220minutes. It takes 1760minutes (8*220=1760) to wash 600L IBCs. The available time for 1800L IBC cleaning is only 102.6hours*60minutes/hour-1760minutes=4396minutes. In 4396minutes, the washer can wash twenty-one (4396/200=21) 1800L IBCs. At the end of Product B Campaign in PF1, the compression machines in PF2 are still running. The number of IBCs that can be released from PF2 is about 2/day. So there will be fourteen (2/day*7days=14) 1800L IBCs that are available to be cleaned in this period. It still has the capacity to wash seven (21-14=7) 1800L IBCs from Product D.

At the end of the second Product A Campaign, there are eight 600L IBCs that need to be cleaned and it takes 1760minutes. The rest of the capacity of the washer can clean twenty-one 1800L IBCs. There are sixteen 1800L IBCs from the Product B campaign that have yet to be cleaned. The rest of the capacity of the washer can only clean five (21-16=5) 1800L IBCs from Product A Campaign. If Product A Campaign needs x 1800L IBCs and x is larger than 5, then maximum value for y for Product C Campaign is 35-x. This is because (x-5) 1800L IBCs cannot be cleaned and used for

Product C Campaign. Thus, if we start with thirty 1800L IBCs, there are only 30-(x-5) = (35-x) 1800L IBCs for Product C Campaign.

At the end of Product C Campaign, there are eight 600L IBCs that need to be cleaned. The washer can clean twenty-one 1800L IBCs. There are fourteen1800LIBCs released during this time (if y is larger than 14). There are still (x-5) 1800L IBCs that need to be cleaned from last campaign. The capacity is enough to wash 21-14-(x-5) = (12-x) 1800L IBCs from Product D.

At the end of the next Product A Campaign, the washer can clean thirty 1800L IBCs because 600L IBCs do not need to be cleaned. (y-14) 1800L IBCs from Product C Campaign need to be cleaned. X 1800L IBCs from this campaign need to be cleaned. The washer can wash another 30-(y-14)-x= (44-x-y) 1800L IBCs from Product D.

The analysis above is summarized in Table 6-1. The first column is the campaign sequence in Scenario 1. The second and third columns represent the number of 600L and 1800L IBCs that need to be cleaned. The fourth column is the washer's capacity for 1800L IBCs. It is equal to the total capacity of the washer minus 600L IBC cleaning activities. The last column stands for the remaining capacity of the washer that can wash 1800L IBCs from Product D. The value of x and y can be decided using the IBC drivers given the production volume in each campaign.

Table 6-1 IBC Cleaning job for Scenario 1

Production campaign sequence	600L IBC	1800L IBC	Total capacity for 1800L IBC	Rest capacity for 1800L IBC
Product A Campaign	0	x	30	30-x
Product B Campaign	8	14	21	7
Product A Campaign	8	(30-14)+x	21	5-x
Product C Campaign	8	14+(x-5)	21	12-x
Product A Campaign	0	y-14+x	30	44-x-y

For example, if the production plan for Product A Campaign is the same as Table 3-1, then the number of IBCs needed is x=4 by the IBC driver "allocation of compression machines". If the production volume for Product B is 45 batches and 30 batches for

Product C, then the number of IBCs needed is 19 (instead of 30) for Product B and y=20 for Product C determined by the IBC driver "turnover of IBCs between PF1 and PF2". [1] Input the value of x and y, Table 6-2 shows the result for this example. The total number of 1800L IBCs needed is 20.

Table 6-2 IBC Cleaning job for Example in Scenario 1

Production campaign sequence	600L IBC	1800L IBC	Total capacity for 1800L IBC	Rest capacity for 1800L IBC
Product A Campaign	0	4	30	26
Product B Campaign	8	14	21	7
Product A Campaign	8	(19-14)+4	21	12
Product C Campaign	8	14	21	7
Product A Campaign	0	20-14+4	30	20

We can see that the total number of IBCs needed in Scenario 1 is the maximum number of IBCs among Product A, B and C Campaign. The cleaning job at the end of each campaign has not reached the maximum cleaning capacity. The best time to clean 1800L IBCs from Product D is at the end of Product A Campaign especially when no 600L IBCs need to be cleaned.

6.2.2 Scenario 2: Product A-Product B-Product C-Product A

6.2.2.1 IBC cleaning at the end of campaign

We assume that Product A Campaign needs x 1800L IBCs, Product B Campaign needs thirty 1800L IBCs and Product C Campaign needs y 1800L IBCs. Through IBC cleaning scheduling, we can determine the maximum values for x and y. For 600L IBCs, their usage can be based on the analysis from section 4.7.2.

In scenario 2, at the end of each campaign, there are eight 600L IBCs that need to be cleaned. The washer can then clean a maximum of twenty-one 1800L IBCs.

At the end of Product A Campaign, there are x 1800L IBCs that need to be cleaned. The maximum x is 21. The remaining capacity of the washer can clean (21-x) 1800L IBCs from Product D.

At the end of Product B Campaign, there are fourteen 1800L IBCs that are available to be cleaned. The remaining capacity of the washer can clean seven (21-14=7) 1800L IBCs.

At the end of Product C Campaign, there are sixteen 1800L IBCs from Product B Campaign yet to be cleaned and fourteen 1800L IBCs from the Product C Campaign that are available to be cleaned. The total capacity is only 21, so there will be (9+(y-14)) (if y is larger than 14) IBCs that cannot be cleaned.

At the end of the second Product A Campaign, there are (9+(y-14)) IBCs from the prior campaign and x IBCs from this campaign that need to be cleaned.

The above analysis can be summarized in Table 6-3. The value x can be decided by the IBC driver "allocation of compression machines" given the production plan of Product A Campaign. The value y has to be at most 14 in this case; because Product B Campaign uses all the thirty 1800L IBCs and only 14 can be released after the campaign.

Table 6-3 IBC Cleaning job for Scenario 2

Production campaign sequence	600L IBC	1800L IBC	Total capacity for 1800L IBC	Rest capacity for 1800L IBC
Product A Campaign	8	x	21	21-x
Product B Campaign	8	14	21	7
Product C Campaign	8	30	21	0
Product A Campaign	8	y+x-5	21	26-x-y

If we use the same example in section 6.2.1, x is 4 determined by the IBC driver "allocation of compression machines". The number of IBCs needed for Product B is 19, instead of 30 as assumed above. The number of IBCs needed for Product C is 20, instead of y as assumed above. Table 6-4 is the cleaning job in this example. The total number of IBCs needed is 25. The nineteen 1800L IBCs from Product B Campaign can only release 14 for Product C Campaign, so an extra six 1800L IBCs are needed. In total there will be twenty-five (19+6=25) 1800L IBCs.

Table 6-4 IBC Cleaning job for example in Scenario 2

Production campaign sequence	600L IBC	1800L IBC	Total capacity for 1800L IBC	Rest capacity for 1800L IBC
Product A Campaign	8	4	21	17
Product B Campaign	8	14	21	7
Product C Campaign	8	5+14	21	2
Product A Campaign	8	6+4	21	11

We can see that Scenario 2 needs more 1800L IBCs than Scenario 1 for the same example. At the end of Product C Campaign, the cleaning job almost reaches the washer's maximum capacity. If the washer's efficiency and manpower availability are lower than our expectation, there will be not enough cleaning capacity to clean IBCs. Our suggestion is that the company should not run the production in Scenario 2 due to the impact on the IBCs requirements.

If they have to run Scenario 2 to satisfy the demand from customers, IBCs have to be cleaned during the campaign or else more IBCs will be needed. During the campaign, most of the technicians are involved in the production. It is better to let them know when they should clean IBCs. In the next section we consider the worst case in which both Product B and Product C need thirty 1800L IBCs. In this situation, there will be the most cleaning jobs. We consider this worst case and will try to develop an IBC cleaning schedule for this case. We assume that four 1800L IBCs are needed for Product A Campaign.

6.2.2.2 IBC cleaning during the campaign

At the end of Product A Campaign, four 1800L IBCs can be cleaned; then all the thirty 1800L IBCs can be used in Product B Campaign. At the end of Product B Campaign, fourteen 1800L IBCs can be released and cleaned. Then once the Product C Campaign starts, every 7 hours they need one 1800L IBCs (the cycle time for HSM is 7 hours). So the fourteen 1800L IBCs can support the production for the first 98 hours. Two IBCs are released every 22 hours from Production B Compression machines (the cycle time for two compression machines is 22hours/2). After 98 hours of the Product C Campaign, there will be nine 1800L IBCs released from compression and cleaned ready to use for Product C Campaign. These nine 1800L IBCs can support the production for another 63hours (9*7=63). Within 63 hours, there will be five 1800L IBCs released and cleaned ready to use for Product C Campaign. These five 1800L IBCs can support the production for the next 35hours (5*7=35). Within 35hours, there will be two 1800L IBCs released and cleaned ready to use for Product C Campaign. Thus there are total 30 (14+9+5+2=30) IBCs for Product C Campaign.

In scenario 2, at the start of Product C Campaign, the 1800L IBCs released from Product B Campaign need to be cleaned as soon as possible until there are enough IBCs to run Product C Campaign.

6.3 Summary

From the analysis in section 6.2, we can see the relationship between IBC cleaning and the number of IBCs needed and the relationship between number of 600L IBCs needed and number of 1800L IBCs needed.

For example, in scenario 2, if IBCs can be cleaned during the campaign as soon as they are released, then the number of IBCs needed can be reduced. The company has twenty-eight 600L IBCs and they do not care much about the number of 600L IBCs needed. However, 600L IBCs share the washer with 1800L IBCs. The total capacity of washer is limited. If fewer 600L IBCs need to be cleaned, then the washer can clean more 1800L IBCs and reduce the number of 1800L IBCs needed. Figure 6-1 shows the relationship between them.

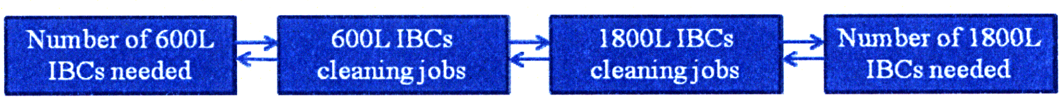


Figure 6-1 Relationship between 600L IBCs and 1800L IBCs

At the end of this chapter, we can see that twenty-eight 600L IBCs, thirty 1800L IBCs and eighteen 2400L IBCs can support four products production as long as the waste in IBC usage can be eliminated and the production volume of Product B and Product C are at some ranges (Less than 76 batches for Product B and less than 48 batches for Product C).

To eliminate the waste in IBC usage, it will require a change in human resource management to assure that technicians send back the 600L IBCs immediately from HSM to charging and clean 1800L IBCs as soon as they are released from compression.

Chapter 7 Recommendation

7.1 Conclusion

Senior managers in company ABC thought that the IBC cleaning schedule determines the number of IBCs needed. However, after eight months study in the company, we conclude that both production activities (IBC drivers) and IBC cleaning scheduling determine the number of IBCs needed. Before scheduling IBC cleaning, the company should take some steps to reduce the number of IBCs needed for each product by examining the five IBC drivers mentioned in this thesis. By doing so, we find that the current number of IBCs can support the production of four products.

7.2 Recommendation

7.2.1 600L IBCs

For 600L IBCs, eight is enough for each campaign in PF1. In order to guarantee that eight 600L IBCs can support the production, management needs to supervise the technicians in charging and HSM to eliminate the waste in 600L IBCs usage.

7.2.2 1800L IBCs

For 1800L IBCs, a recommendation is to consider delaying the HSM for a short time to wait for compression machines to release IBCs. This can reduce the number of IBCs needed, as it reduces the maximum number of IBCs needed.

7.2.3 IBC cleaning

We recommend that the company hold 600L IBCs within their dirty holding days and only clean them when necessary, because 600L IBCs and 1800L IBCs share the same washer. There will be more capacity to clean 1800L IBCs when less 600L IBCs need to be cleaned.

It is better to clean 1800L IBCs from Product D at the end of Product A campaign. This should be considered in making the production plan for Product D. For Product A, B and C, we do not recommend running the production campaign in scenario 2 (Product A-Product B-Product C-Product A) due to the impact on the IBC requirements.

7.3 Future work

The conclusion that eight 600L IBCs are enough for each campaign is made based on the equipment downtime information from January to May 2008. This information should be updated in future and the simulation should be rerun to determine the optimum number of 600L IBCs needed for stand-by between charging and HSM.

2400L IBCs management is out of the scope of this project. Future work can be done in consideration of 2400L IBCs together with 600L and 1800L IBCs.

This project focuses on the planning of IBCs usage. Future work can be done in optimizing the logistics of IBCs, such as the transportation and storage of IBCs.

References

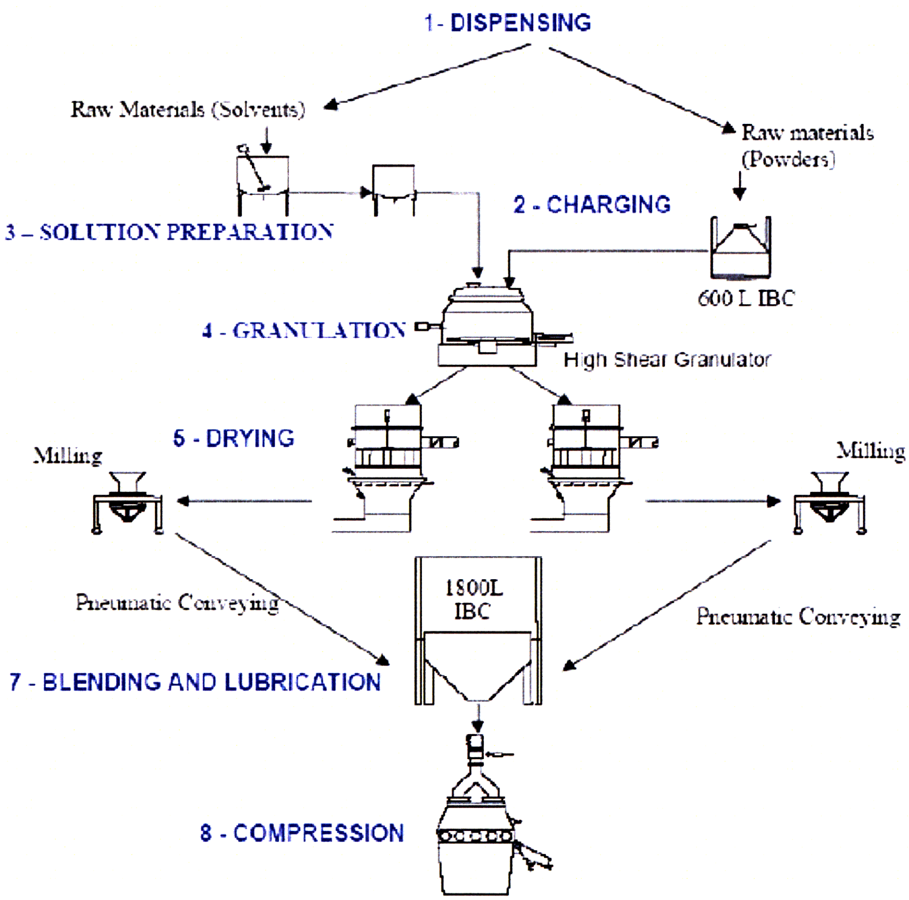
[1] Hu, He, Master of Engineering Thesis, August 19, 2008, unpublished work;

[2] Stanley B. Gershwin, 1994, Manufacturing System Engineering, Prentice-Hall, Chapter 3;

[3] Stanley B. Gershwin, Lecture notes, MIT 2.853/2.854, 2007, unpublished work;

Appendix

Appendix A------ Manufacturing process of product A



Appendix B------Downtime data of Charging and HSM (Unit: hours)

	Charging			HSM				
	TTF	TTR	TBF	CT	CT/4	TTF	TTR	TBF
1	0.32	0.08	0.40	6.35	1.59	21.07	6.03	27.10
2	0.33	0.10	0.42	6.02	1.50	9.45	1.38	10.83
3	0.33	0.10	0.43	6.48	1.62	64.03	3.23	67.27
4	0.40	0.10	0.50	6.05	1.51	13.18	4.12	17.30
5	0.40	0.12	0.50	6.17	1.54	19.00	4.37	23.37
6	0.38	0.12	0.50	6.23	1.56	200.15	2.48	202.63
7	0.43	0.13	0.55	6.25	1.56	399.17	39.48	438.65
8	0.43	0.17	0.57	6.77	1.69	30.78	5.08	35.87
9	0.42	0.17	0.58	6.30	1.58	51.25	9.27	60.52
10	0.50	0.17	0.67	6.87	1.72	6.12	2.05	8.17
11	0.58	0.17	0.75	6.88	1.72	4.80	1.63	6.43
12	0.58	0.17	0.75	6.90	1.73	5.47	3.13	8.60
13	0.63	0.17	0.80	6.42	1.60	21.42	1.05	22.47
14	0.72	0.17	0.88	6.47	1.62	25.50	1.05	26.55
15	0.75	0.17	0.92	6.81	1.70	66.48	3.63	70.12
16	0.75	0.17	0.92	6.48	1.62	46.38	3.03	49.42
17	0.88	0.17	1.05	6.53	1.63	11.75	1.92	13.67
18	0.92	0.17	1.08	6.35	1.59	28.37	2.27	30.63
19	1.05	0.18	1.22	6.70	1.68	23.18	2.28	25.47
20	1.03	0.18	1.22	6.55	1.64	32.73	8.62	41.35
21	1.08	0.20	1.27	6.55	1.64	6.23	3.08	9.32
22	1.10	0.20	1.30	6.58	1.65	52.30	9.08	61.38
23	1.12	0.22	1.32	6.58	1.65	114.95	8.93	123.88
24	1.12	0.22	1.33	6.05	1.51	5.93	2.15	8.08
25	1.12	0.23	1.33	6.62	1.65	5.67	7.07	12.73
26	1.13	0.23	1.37	6.62	1.65			
27	1.18	0.25	1.42	6.63	1.66			
28	1.17	0.25	1.42	6.65	1.66			
29	1.20	0.25	1.45	6.67	1.67			

30	1.23	0.25	1.48	6.67	1.67			
31	1.25	0.25	1.50	6.68	1.67			
32	1.33	0.25	1.58	6.28	1.57			
33	1.33	0.25	1.58	6.70	1.68			
34	1.38	0.25	1.63	6.70	1.68			
35	1.42	0.25	1.67	6.43	1.61			
36	1.42	0.25	1.67	6.73	1.68			
37	1.52	0.27	1.77	6.75	1.69			
38	1.52	0.30	1.78	6.75	1.69			
39	1.53	0.30	1.83	6.75	1.69			
40	1.60	0.30	1.90	6.75	1.69			
41	1.62	0.30	1.92	6.50	1.63			
42	1.68	0.32	1.98	6.52	1.63			
43	1.68	0.32	2.00	6.77	1.69			
44	1.68	0.32	2.00	6.77	1.69			
45	1.68	0.33	2.00	6.77	1.69			
46	1.68	0.33	2.02	6.78	1.70			
47	1.68	0.33	2.02	6.80	1.70			
48	1.70	0.33	2.03	6.80	1.70			
49	1.70	0.33	2.03	6.80	1.70			
50	1.73	0.33	2.07	6.22	1.55			
51	1.77	0.33	2.10	6.82	1.70			
52	1.77	0.33	2.10	6.83	1.71			
53	1.80	0.33	2.13	6.83	1.71			
54	1.83	0.33	2.17	6.33	1.58			
55	1.85	0.33	2.18	6.85	1.71			
56	1.88	0.33	2.22	6.45	1.61			
57	1.92	0.33	2.25	6.87	1.72			
58	1.95	0.33	2.28	6.87	1.72			
59	1.97	0.33	2.30	6.87	1.72			
60	2.00	0.33	2.33	6.07	1.52			
61	2.13	0.33	2.47	6.47	1.62			
62	2.17	0.35	2.50	6.88	1.72			
63	2.23	0.35	2.58	6.88	1.72			

64	2.27	0.35	2.62	6.88	1.72			
65	2.28	0.37	2.63	6.42	1.60			
66	2.30	0.37	2.67	6.00	1.50			
67	2.30	0.38	2.67	6.00	1.50			
68	2.33	0.38	2.72	6.92	1.73			
69	2.37	0.38	2.75	6.93	1.73			
70	2.45	0.38	2.83	6.93	1.73			
71	2.45	0.40	2.83	6.00	1.50			
72	2.53	0.40	2.93	6.95	1.74			
73	2.55	0.40	2.95	6.97	1.74			
74	2.68	0.42	3.08	6.00	1.50			
75	2.67	0.42	3.08	6.98	1.75			
76	2.67	0.42	3.08	7.00	1.75			
77	2.80	0.42	3.22	7.00	1.75			
78	2.85	0.42	3.27	7.00	1.75			
79	2.85	0.43	3.27	7.00	1.75			
80	2.85	0.43	3.28	7.02	1.75			
81	2.88	0.43	3.32	7.00	1.75			
82	2.88	0.43	3.32	7.03	1.76			
83	3.02	0.45	3.45	7.00	1.75			
84	3.00	0.47	3.45	7.05	1.76			
85	3.10	0.47	3.57	7.05	1.76			
86	3.12	0.48	3.58	7.05	1.76			
87	3.12	0.48	3.60	7.07	1.77			
88	3.12	0.48	3.60	7.07	1.77			
89	3.27	0.50	3.75	7.07	1.77			
90	3.33	0.50	3.83	7.00	1.75			
91	3.42	0.50	3.92	7.08	1.77			
92	3.48	0.50	3.98	7.08	1.77			
93	3.48	0.50	3.98	7.08	1.77			
94	3.50	0.50	4.00	7.00	1.75			
95	3.50	0.50	4.00	7.10	1.78			
96	3.57	0.50	4.07	7.10	1.78			
97	3.67	0.50	4.17	7.12	1.78			

98	3.75	0.50	4.25	7.12	1.78			
99	3.80	0.50	4.30	7.12	1.78			
100	3.83	0.50	4.33	7.12	1.78			
101	3.83	0.50	4.33	7.12	1.78			
102	4.08	0.52	4.58	7.00	1.75			
103	4.07	0.53	4.58	7.00	1.75			
104	4.07	0.55	4.60	7.15	1.79			
105	4.12	0.57	4.67	7.00	1.75			
106	4.27	0.58	4.83	7.00	1.75			
107	4.30	0.58	4.88	7.17	1.79			
108	4.35	0.58	4.93	7.17	1.79			
109	4.38	0.58	4.97	7.17	1.79			
110	4.42	0.58	5.00	7.18	1.80			
111	4.50	0.58	5.08	7.00	1.75			
112	4.57	0.58	5.15	7.00	1.75			
113	4.58	0.58	5.17	7.20	1.80			
114	4.58	0.58	5.17	7.00	1.75			
115	4.58	0.58	5.17	7.00	1.75			
116	4.78	0.58	5.37	7.00	1.75			
117	4.80	0.58	5.38	7.23	1.81			
118	5.08	0.58	5.67	7.23	1.81			
119	5.30	0.58	5.88	7.25	1.81			
120	5.35	0.60	5.93	7.00	1.75			
121	5.62	0.62	6.22	7.27	1.82			
122	5.62	0.63	6.23	7.27	1.82			
123	5.67	0.67	6.30	7.00	1.75			
124	5.82	0.67	6.48	7.00	1.75			
125	6.03	0.68	6.70	7.28	1.82			
126	6.25	0.73	6.93	7.28	1.82			
127	6.25	0.73	6.98	7.28	1.82			
128	6.25	0.73	6.98	7.00	1.75			
129	6.30	0.75	7.03	7.30	1.83			
130	6.35	0.75	7.10	7.30	1.83			
131	6.45	0.75	7.20	7.32	1.83			

132	6.75	0.75	7.50	7.32	1.83			
133	6.80	0.75	7.55	7.32	1.83			
134	6.83	0.75	7.58	7.00	1.75			
135	6.92	0.78	7.67	7.33	1.83			
136	7.18	0.80	7.97	7.33	1.83			
137	7.19	0.83	7.99	7.33	1.83			
138	7.20	0.90	8.03	7.33	1.83			
139	7.27	0.92	8.17	7.00	1.75			
140	7.35	0.92	8.27	7.37	1.84			
141	7.37	1.00	8.28	7.38	1.85			
142	7.67	1.00	8.67	7.38	1.85			
143	7.68	1.00	8.68	7.38	1.85			
144	7.68	1.00	8.68	7.38	1.85			
145	7.92	1.00	8.92	7.38	1.85			
146	8.15	1.12	9.15	7.40	1.85			
147	8.12	1.12	9.23	7.40	1.85			
148	8.15	1.17	9.27	7.00	1.75			
149	8.18	1.17	9.35	7.00	1.75			
150	8.25	1.17	9.42	7.00	1.75			
151	8.27	1.17	9.43	7.43	1.86			
152	8.40	1.17	9.57	7.43	1.86			
153	8.50	1.17	9.67	7.00	1.75			
154	9.25	1.22	10.42	7.00	1.75			
155	9.47	1.25	10.68	7.00	1.75			
156	9.43	1.25	10.68	7.45	1.86			
157	9.45	1.25	10.70	7.45	1.86			
158	9.50	1.25	10.75	7.00	1.75			
159	9.70	1.33	10.95	7.00	1.75			
160	9.68	1.33	11.02	7.00	1.75			
161	9.68	1.43	11.02	7.50	1.88			
162	10.02	1.43	11.45	7.00	1.75			
163	10.10	1.47	11.53	7.52	1.88			
164	10.10	1.58	11.57	7.52	1.88			
165	10.03	1.58	11.62	7.52	1.88			

166	10.22	1.62	11.80	7.53	1.88			
167	10.80	1.65	12.42	7.53	1.88			
168	10.80	1.67	12.45	7.00	1.75			
169	10.85	1.75	12.52	7.55	1.89			
170	11.00	1.82	12.75	7.55	1.89			
171	11.68	1.83	13.50	7.00	1.75			
172	11.95	2.00	13.78	7.00	1.75			
173	13.32	2.00	15.32	7.63	1.91			
174	13.50	2.25	15.50	7.63	1.91			
175	13.50	2.32	15.75	7.65	1.91			
176	14.47	2.42	16.78	7.67	1.92			
177	14.60	2.50	17.02	7.67	1.92			
178	15.08	2.80	17.58	7.67	1.92			
179	15.77	2.80	18.57	7.68	1.92			
180	16.62	2.83	19.42	7.00	1.75			
181	17.72	2.87	20.55	7.00	1.75			
182	18.37	3.30	21.23	7.70	1.93			
183	18.10	3.50	21.40	7.72	1.93			
184	18.30	3.50	21.80	7.00	1.75			
185	18.92	4.00	22.42	7.75	1.94			
186	18.47	6.02	22.47	7.00	1.75			
187	16.57	7.58	22.58	7.78	1.95			
188	15.18	8.00	22.77	7.78	1.95			
189	16.97	9.07	24.97	7.80	1.95			
190	16.37	9.42	25.43	7.80	1.95			
191	32.52	10.08	41.93	7.85	1.96			
192				7.85	1.96			
193				7.88	1.97			
194				7.92	1.98			
195				7.93	1.98			
196				7.93	1.98			
197				7.98	2.00			
198				8.00	2.00			
199				8.00	2.00			

200				8.10	2.03				
201				8.13	2.03				
202				8.20	2.05				
203				8.27	2.07				
204				8.33	2.08				
205				8.37	2.09				
206				8.00	2.00				
207				8.55	2.14				
208				8.63	2.16				
209				8.65	2.16				
210				8.00	2.00				
211				8.82	2.20				
212				9.00	2.25				
213				9.02	2.25				
214				9.03	2.26				
215				9.10	2.28				
216				9.95	2.49				

Appendix C------ Histograms of downtime data of charging and HSM

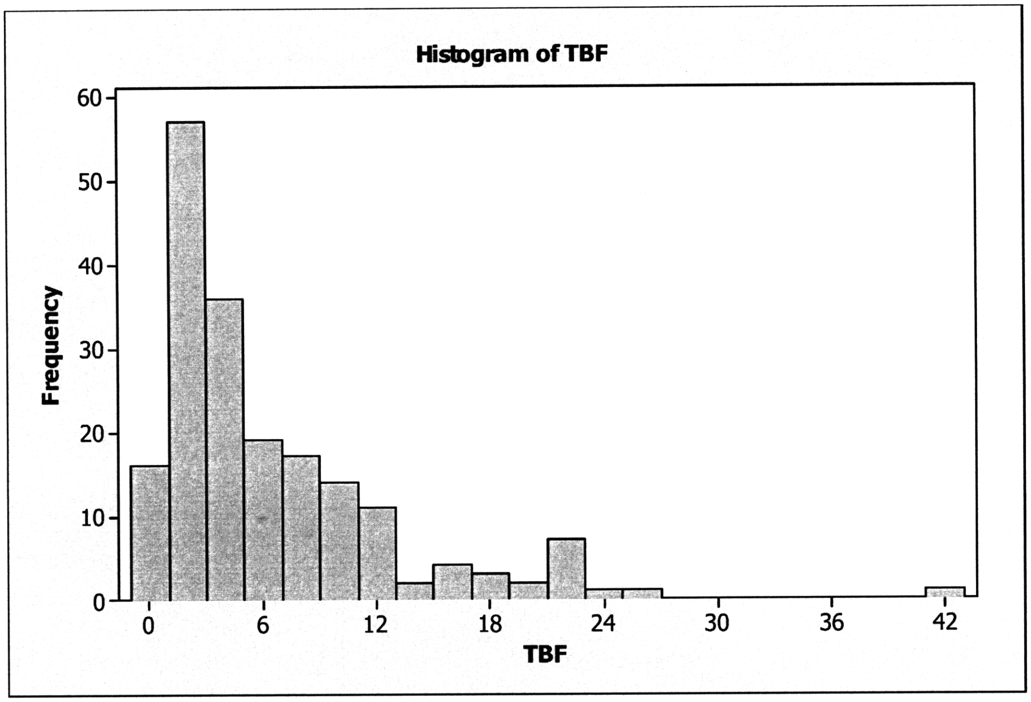


Figure A-1 Histogram of Charging TBF

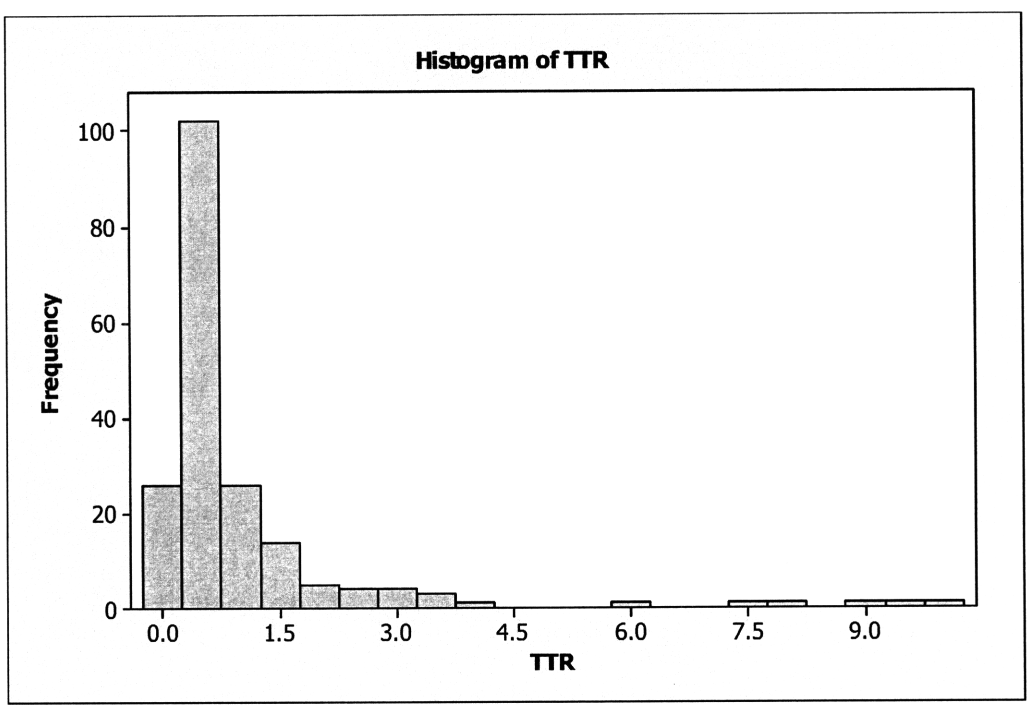


Figure A-2 Histogram of Charging TTR

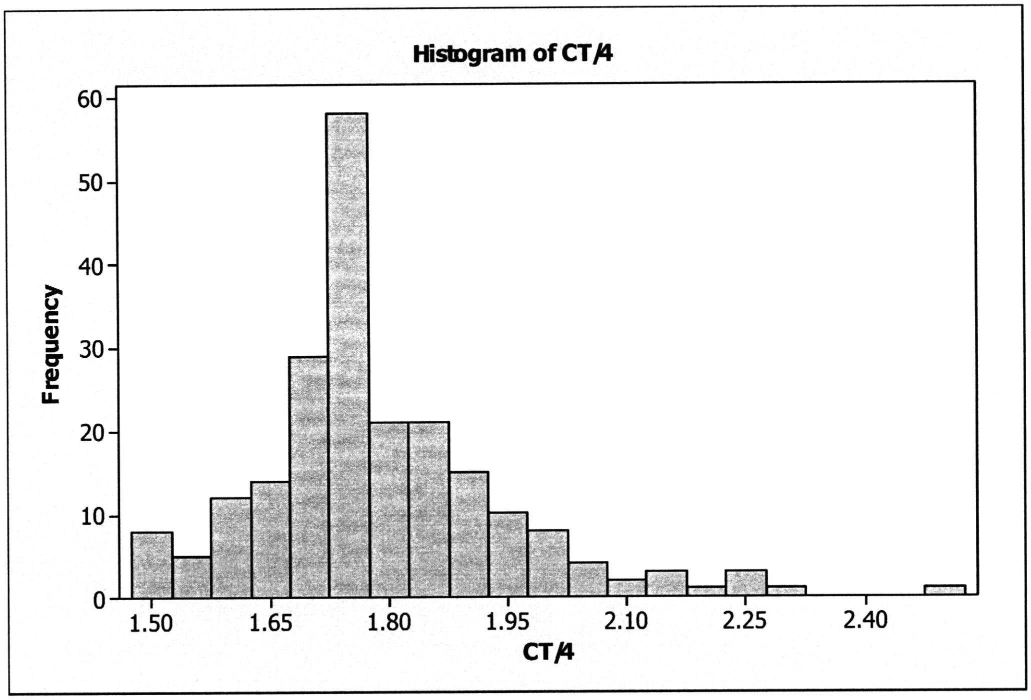


Figure A-3 Histogram of HSM CT/4

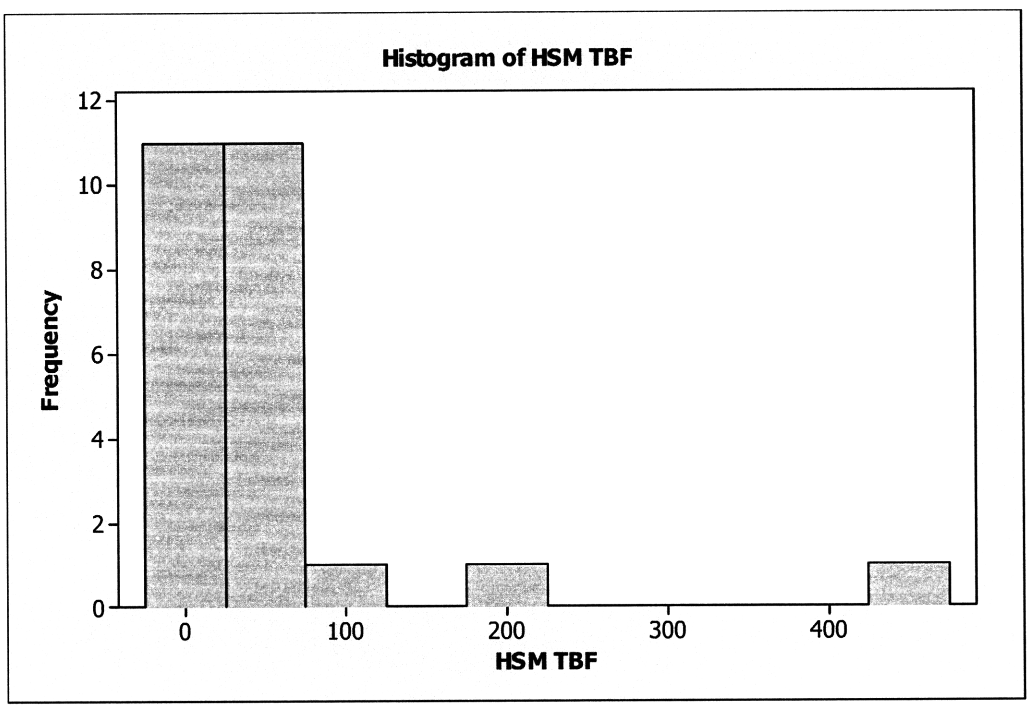


Figure A-4 Histogram of HSM TBF

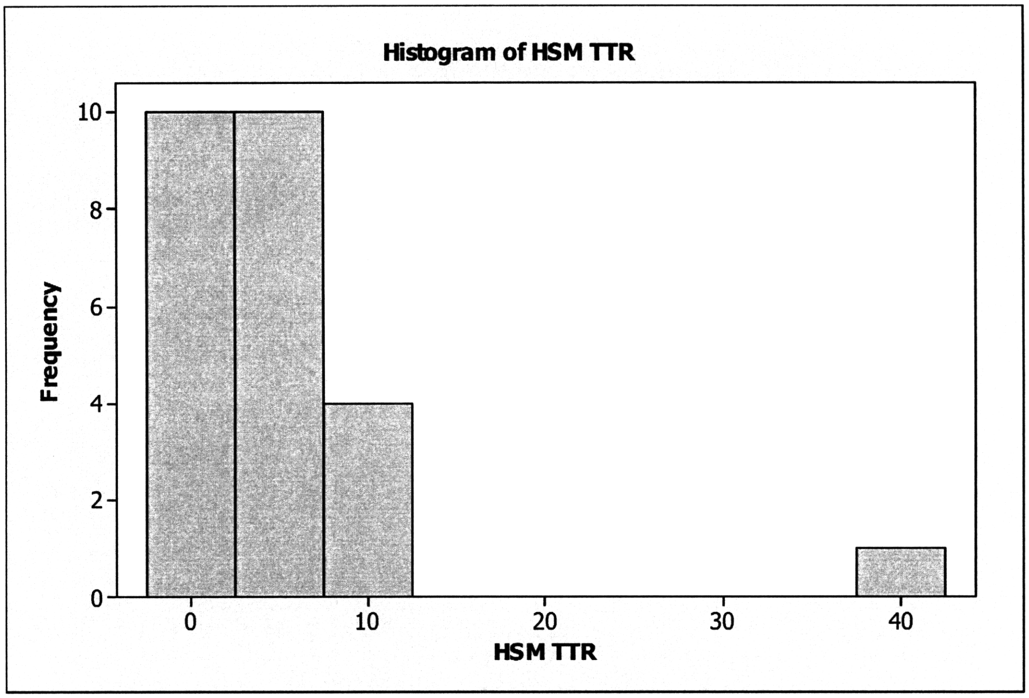


Figure A-5 Histogram of HSM TTR

Appendix D------ Stat Fit of downtime data of charging and HSM

Table A-1 Stat Fit for charging TBF

Auto::Fit of Distributions

distribution	rank	acceptance
Lognormal(0., 1.4, 0.984)	100	do not reject
Pearson 6(0., 15., 1.69, 4.98)	90.6	do not reject
Weibull(0., 1.11, 6.61)	30.2	do not reject
Gamma(0., 1.27, 4.98)	25.	do not reject
Erlang(0., 1., 6.34)	19.7	do not reject
Exponential(0., 6.34)	19.7	do not reject
Beta(0., 160, 1.22, 29.4)	6.56	do not reject
Pearson 5(0., 1.16, 2.88)	2.59	do not reject
Triangular(0., 42.2, 0.442)	0.	reject
Uniform(0., 41.9)	0.	reject
Rayleigh(0., 6.28)	0.	reject
Chi Squared(0., 5.04)	0.	reject
Power Function(0., 73.8, 0.345)	0.	reject

Table A-2 Stat Fit for charging TTR

Auto::Fit of Distributions

distribution	rank	acceptance
Pearson 5(0., 1.56, 0.632)	100	do not reject
Pearson 6(0., 5.6e-002, 13.5, 1.73)	62.6	do not reject
Lognormal(0., -0.547, 0.928)	0.454	reject
Weibull(0., 0.934, 0.948)	3.95e-004	reject
Erlang(0., 1., 0.988)	7.45e-006	reject
Exponential(0., 0.988)	7.43e-006	reject
Gamma(0., 1.07, 0.923)	9.78e-007	reject
Beta(0., 2.45e+003, 1.05, 2.62e+003)	0.	reject
Triangular(0., 10.1, 0.106)	0.	reject
Uniform(0., 10.1)	0.	reject
Rayleigh(0., 1.28)	0.	reject
Chi Squared(0., 1.39)	0.	reject
Power Function(0., 10.1, 0.349)	0.	reject

Table A-3 Stat Fit for HSM CT/4

Auto::Fit of Distributions

distribution	rank	acceptance
Pearson 5(0., 146, 259)	100	reject
Lognormal(0., 0.577, 8.36e-002)	48.5	reject
Pearson 6(0., 2.37, 251, 334)	43.	reject
Gamma(0., 140, 1.27e-002)	22.5	reject
Erlang(0., 141, 1.27e-002)	22.1	reject
Beta(0., 2.49, 35.4, 14.)	3.96e-002	reject
Weibull(0., 9.92, 1.86)	9.65e-003	reject
Exponential(0., 1.79)	0.	reject
Triangular(0., 2.51, 1.85)	0.	reject
Uniform(0., 2.49)	0.	reject
Rayleigh(0., 1.27)	0.	reject
Chi Squared(0., 2.7)	0.	reject
Power Function(0., 2.57, 2.73)	0.	reject

Table A-4 Stat Fit for HSM TBF

Auto::Fit of Distributions

distribution	rank	acceptance
Lognormal(0., 3.38, 1.04)	99.5	do not reject
Pearson 6(0., 0.207, 123, 1.32)	99.1	do not reject
Pearson 5(0., 1.31, 25.)	98.8	do not reject
Weibull(0., 0.862, 50.9)	40.4	do not reject
Gamma(0., 0.9, 62.3)	25.5	do not reject
Erlang(0., 1., 56.1)	16.3	do not reject
Exponential(0., 56.1)	16.3	do not reject
Beta(0., 555, 0.675, 5.04)	1.28	do not reject
Power Function(0., 439, 0.369)	7.4e-004	reject
Triangular(0., 459, 0.)	0.	reject
Rayleigh(0., 74.3)	0.	reject
Chi Squared(0., 30.3)	0.	reject
Uniform(0., 439)	0.	reject

Table A-5 Stat Fit for HSM TTR

Auto::Fit of Distributions

distribution	rank	acceptance
Pearson 6(0., 0.241, 26., 2.17)	100.	do not reject
Pearson 5(0., 2.04, 5.66)	99.9	do not reject
Lognormal(0., 1.29, 0.804)	82.5	do not reject
Weibull(0., 1.04, 5.57)	26.9	do not reject
Gamma(0., 1.36, 4.01)	24.2	do not reject
Exponential(0., 5.46)	21.7	do not reject
Erlang(0., 1., 5.46)	21.7	do not reject
Chi Squared(0., 4.57)	20.	do not reject
Beta(0., 1.24e+005, 1.41, 3.24e+004)	12.9	do not reject
Power Function(0., 39.5, 0.418)	4.44e-005	reject
Rayleigh(0., 6.51)	6.52e-007	reject
Triangular(0., 41.3, 0.)	0.	reject
Uniform(0., 39.5)	0.	reject