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A Plant Simulation approach for optimal resource utilization: A case study in the tire manufacturing industry

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ABSTRACT

In this study, the resource allocation and vital manufacturing processes in the tire manufacturing industry was comprehensively optimized. The paper deals in detail with the Banbury mixing process, which produces homogeneous rubber materials for tire components. In addition, the mixing process models were established by the Plant Simulation software to validate and compare scenarios and experiments with realistic production constraints. Discrete empirical distribution (dEmp) was proposed for population data. Various scenarios were created for different resource and process. Experiments were set as different group of compound set. Experiment manager was used as a tool to set up scenarios and the experiments to provide alternative results. The study results display the production time and machine utilization. The shortest production time of experiment results represents the best group of each scenario. As results, the scenario, which BB1 is changed from non-productive Banbury mixer to special Banbury mixer along with the normal process is combined with second special process, provides the suitable production volume which can reduce of total production time for 8.06 %. Our study provides a variety of the resource utilization of a Banbury mixing process and suggests an efficient optimization method for production performance improvement.

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1. Introduction

Many companies face problems of the production capacity, bottleneck analysis is widely used to solve such problem. Bottleneck is a capacity constraint resource (CCR) whose available capacity limits the ability to meet the product volume of the system. The bottleneck identification is performed to find the bottleneck process which provides the highest machine utilization because of unbalance amount of batch [1, 2]. The production process is analysed according to the time operations. After the bottleneck process is defined, the technique to reduce the processing time of the bottleneck process and balance the processing time in a line process called Line balancing is applied. This technique assigns the work to stations in a line process in order to achieve the desired output rate with the smallest number of workstations [3].

Recently, many companies apply digital manufacturing program to optimize their production system with respect to time, cost and quality [4]. These programs can be used to increase productivity and optimize production systems by applying visual commissioning to manufacturing process and increasing production flexibility [5]. The simulation processes model is created to test new ideas and propose options in various scenarios before actual implementation. Simulation models are created to explicitly visualize how an existing operation might perform under varied inputs and how a new or proposed operations might behave under the same or different situation: material flows and plant layouts [6]. Moreover, to increase the production rate, the optimization of production lines using line balance and discrete event simulation approach can be considered [7].

A software named Plant simulation is performed using discrete event simulation tools. This software allows the use of simulation techniques to identify and minimize various problems related to production systems [8-10]. For production planners, the use of dynamic production system simulations can improve the productivity of existing resources and reduce the cost of planning for new production resources. They can also optimize system variables under complicated constraints [11-16].

In this study, the case studied company is the tire company. Their products include Truck and Bus Radial Tire (TBR) and Private Car Radial Tire (PCR). Due to the increase of demand, the company production capacity had reached its limit. The basic analysis of the company showed that the bottleneck of the production system was Banbury mixing process. This mixing process is the process combining carbon black, natural and synthetic rubber and other various types of chemicals which are used to produce a homogeneous rubber material for tire components called Productive compound (Pro). Productive compound is produced by 1-4 steps of Banbury mixing process. The outcome of each Banbury mixing process in each step which cannot use to produce tire components is called Non-productive compound (Non-pro). The Banbury mixer can be divided into 3 types: Non-pro BB, Pro BB and Special BB. Non-pro BB is used to produce Non-productive compound. Pro BB is used to produce Productive compound. Special BB can be used to produce less step of Non-productive compound and produce Productive compound in 1 step (some compound). There are 6 Banbury mixer in the production lines shown in Fig. 1. BB1, BB3 and BB4 are Non-pro BB. BB5 and BB6 are Pro BB. BB2 is Special BB.

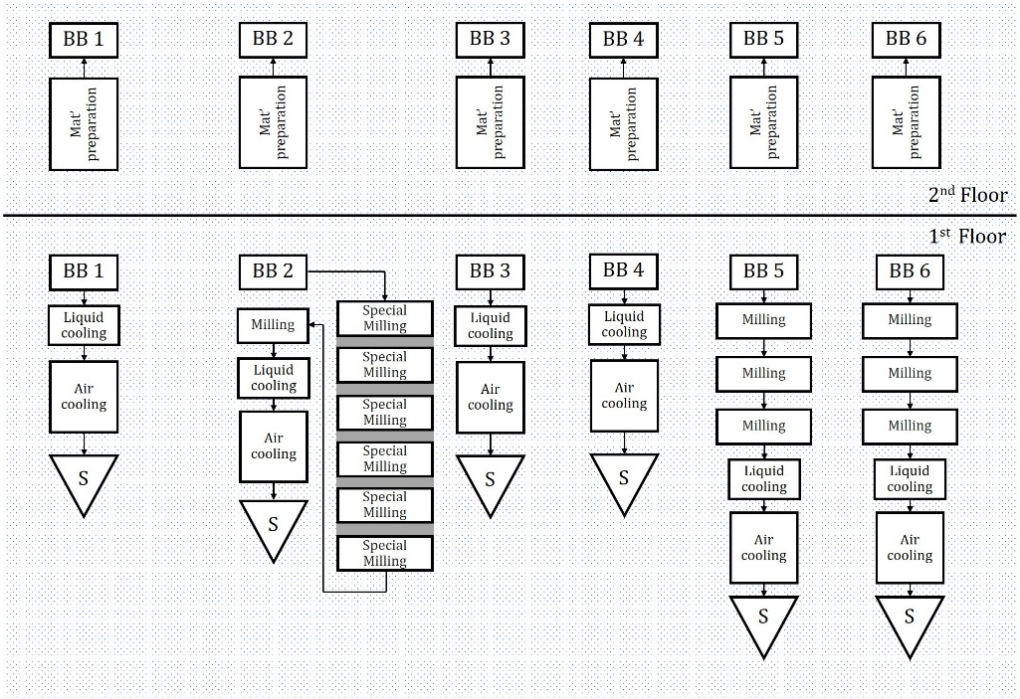


Fig. 1 Banbury mixing process flow chart and layout

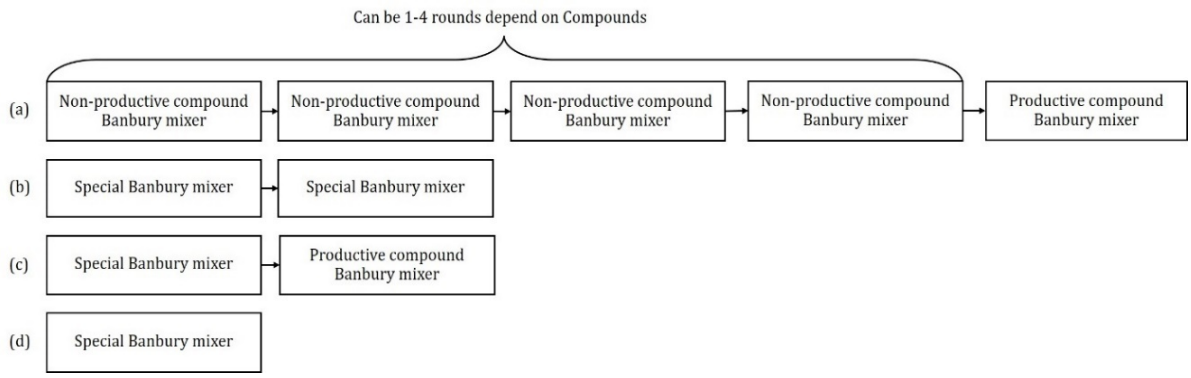


Fig. 2 Banbury mixing processes, (a) normal process, (b) first special process, (c) second special process, (d) third special process

The normal Banbury mixing process is usually done in five steps. The first four steps of mixing provide non-productive compounds and the last step provides productive compounds. However, there are some special Banbury mixing processes which can provide productive compounds in less numbers of steps. The Banbury mixing processes are described as follows.

Normal Banbury mixing process (N) is to assign Non-pro BB to mix 1 to 4 steps, depending on each compound, and Pro BB to mix 1 step as shown in Fig. 2(a). The first special Banbury mixing process (1st) is to assign Special BB to mix 2 steps as shown in Fig. 2(b). The second special Banbury mixing process (2nd) is to assign Special BB to mix 1 step and Pro BB to mix 1 step as shown in Fig. 2(c). The third special Banbury mixing process (3rd) is to assign Special BB to mix 1 step as shown in Fig. 2(d).

Because productive compounds are usually the last step in all Banbury mixing processes, the numbers of productive compound steps can be defined to a specific number. For example, if 5 compounds are needed and each compound requires 10 batches, the number of steps for productive compounds is 50 steps. However, for the same 5 compounds, the number of steps for non-productive compounds is different. Its number of steps can be 0 to 4 based on the mixing process. For example, if the normal process is chosen, 4 steps for non-productive compound and 1 step for productive compound can be performed. However, by the same compound, if the second special process is chosen, 1 step for non-productive compound and 1 step for productive compound can be performed. In addition, each compound could not be applied to all Banbury mixing processes. There were 11 compounds from 31 compounds which could be produced by special process.

To simplify sets of compounds, it was defined into 5 sets based on Banbury mixing processes. First set was the 20 compounds which could only be produced by normal process. Second set was the 1 compound which could be produced by normal or first special process. Third set was the 4 compounds which could be produced by normal or second special process. Fourth set was the 5 compounds which could be produced by normal or third special process. Fifth set was the 1 compound which could be produced by normal, first or second special process. Moreover, the compound in the first set was called normal type (20 compounds) and the rest of compound was called special type (11 compounds).

Due to the above factors, workload balance between each Banbury mixer was the critical issue when a production planner needed to design the production volume to meet the demand. This study presents the optimization of manufacturing operations by balancing production line. The concept of balancing the production line is to design the best group of Banbury mixing processes.

With simulation technique, all the types of the production process data were analysed. The input data included processing time, setting-up time, batch size, time between batch and total demand. The output data included machine utilization, total setting-up time proportion, total time between batch proportion and total production time. The simulation scenarios were created as different plans for resource allocation. The simulation experiments were set as various of total production planning of pro, non-pro and special compounds. This part of the process is

important for every simulation model because it involves various sources of system randomness. Moreover, the simulation study performed discreate empirical distribution because a standard theoretical distribution could not be found. It provided a good representation of our data while population data had been used [17, 18].

In this study, a Plant Simulation approach for optimal resource utilization: a case study in the tire manufacturing industry is presented. The outline is organized as follows. Section 2 illustrates the current performance of Banbury mixing process. Section 3 illustrates the simulation scenarios and experiments, the scenario results comparisons and estimation of production cost saving. Section 4 summarizes the conclusions and provides suggestions for future work, respectively.

2. Current performance of Banbury mixing process

After the problem was defined, the current production system was carefully analysed. The Banbury mixing process 3D simulation model was created in the Tecnomatix Plant Simulation as shown in Fig. 3. This model was called "Current capacity", described the existing state of the production capacity of each Banbury mixer. It was created with the help of tables containing recorded data concerning the time in the current production plan.

The special milling method of Special BB created in simulation model is presented in Fig. 4(b). The special method was used to order queue of the special mill machines (MM) shown in Fig. 4(a). This method was coded to check whether which MM was empty before transferring WIP to the empty MM. Fig. 5 shows that the WIP compound which is transferred from BB waits for its destination. The destination of WIP compound receives from the first row of "QrderQueue" list. After that, a MM is set as the destination of the WIP compound, then the MM is deleted from the QrderQueue list. The MM is returned after it is already empty and waits for the next WIP compound.

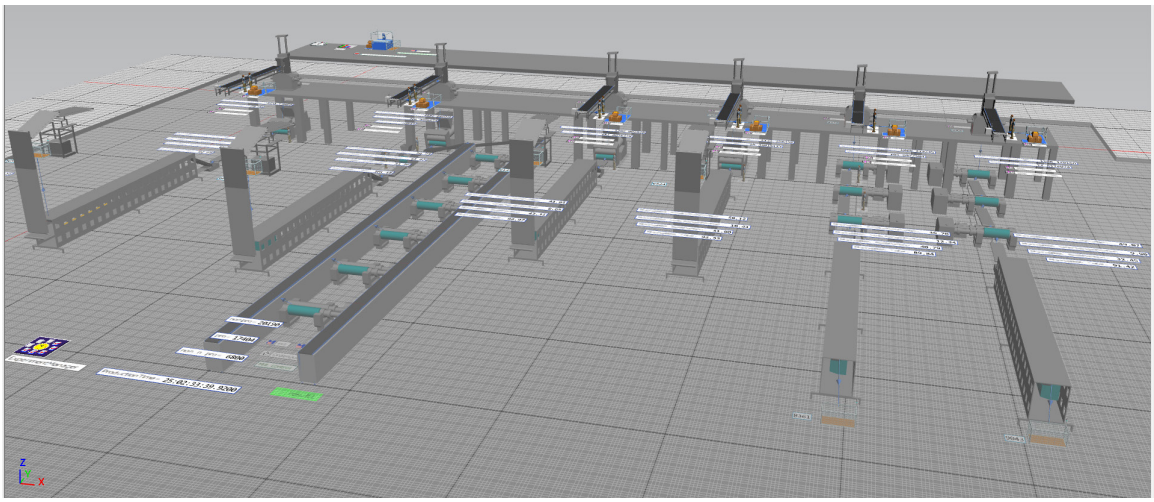
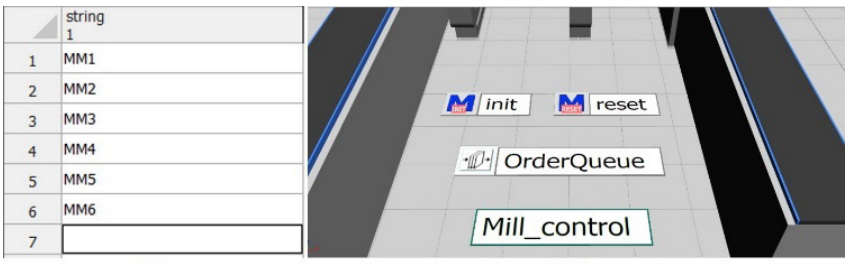


Fig. 3 The Banbury mixing process 3D simulation model



(a) (b)

Fig. 4 (a) Special milling order queue, (b) Special milling in Special BB control

Procedure 1 Special milling method

```
Waituntil OrderQueue list >= 1 then
    set WIP destination as first OrderQueue list
    Remove first OrderQueue list
Move WIP to the target Special milling
Waituntil the milling process finish
Move WIP to milling
Pop the target Special milling to OrderQueue list
```

Fig. 5 Special milling operation method

The Banbury operation time including size change time (SC), processing time (PT) and time between batch (BwB) was considered. The sequence of mixing process is described in Fig. 6. The size change time starts when a worker setting up the Banbury mixer. Then, the processing time starts when the front gate of Banbury mixer opens to feed raw materials in and finishes when the back gate of Banbury mixer opens to feed a work-in-process out. The time between batch is the waiting time between feeding the work-in-process out and feeding the next raw materials in. Batch size is the number of batches between 2 size changes. Total production volume is the total number of batches in a month.

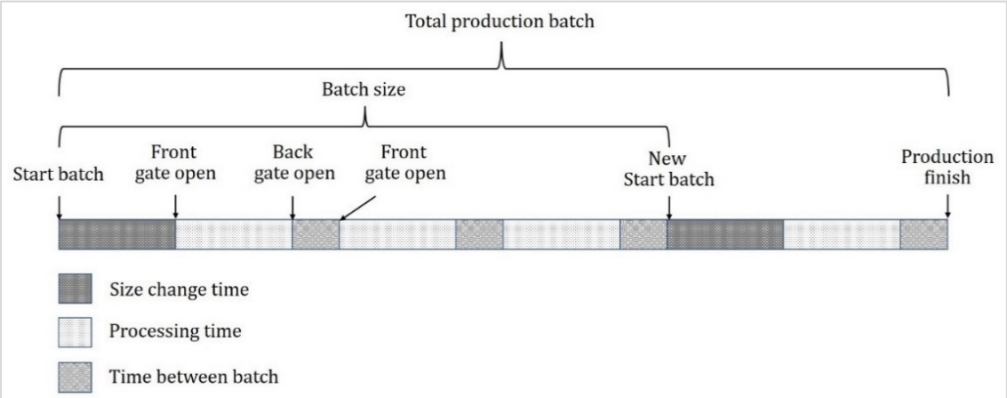


Fig. 6 Mixing process sequence

According to the described above, the system is the Banbury mixing process with the 3 types of the time consumption in the mixers. The simulation models are proposed under these 4 assumptions:

1) The system will not break down and is completely reliable.
2) Due to automation record of time, the input time is population data, the statistic theory will be Discrete empirical distribution.
3) The model will finish after passing 31 days without any break.
4) The number of areas to place the finished product (Non-pro, Pro compound) is unlimited.

Table 1 Banbury mixing process time and production volume data

Data		Banbury mixer					
		BB1	BB2	BB3	BB4	BB5	BB6
Processing time (PT)	Mode (s)	125	180	113	133	107	131
	Mode frequency (times)	531	407	482	294	1166	471
	Max (s)	467	482	288	340	380	232
	Min (s)	83	131	94	91	63	68
Time between batch (BwB)	Mode (s)	22	23	150	32	24	30
	Mode frequency (times)	1083	807	829	521	1103	2175
	Max (s)	1093	4306	186	4898	4923	3980
	Min (s)	16	18	41	21	12	13
Size change time (SC)	Mode (s)	1017	1845	1296	1544	521	1729
	Mode frequency (times)	3	3	3	3	3	3
	Max (s)	4544	4779	4743	3442	4409	4332
	Min (s)	122	175	112	111	208	110
Average batch size (batch)		38	47	46	35	34	48
Total production volume (batch)		6042	6800	7242	6906	8935	8469

Table 2 The machine utilization and the production time

Banbury mixer	Machine utilization				Production time (days)
	Processing time (PT) (%)	Set-up time (SC) (%)	Recovery time (BwB) (%)	Total (%)	
BB1	42.83	10.04	10.76	63.62	31
BB2	45.48	9.22	26.29	81.00	
BB3	39.15	7.64	39.99	86.77	
BB4	40.55	8.56	24.84	73.96	
BB5	32.61	10.77	35.00	78.38	
BB6	37.75	7.48	24.29	69.52	

The Banbury operation time, batch size and total production volume data are summarized in Table 1. According to the assumptions mentioned above, we calculated machine utilization to define current capacity. The results of each machine utilization and the production time were shown in Table 2.

The initial model, which only the properties of current production capacity were entered, provided the information about the behaviour of the current system. Processing time, Size change time (Set-up time) and Time between batch (Recovery time) were set as dEmp as illustrated in Fig. 7. After a model was run for 31 days of the simulation time, the machine utilization results were obtained as shown in Table 3.

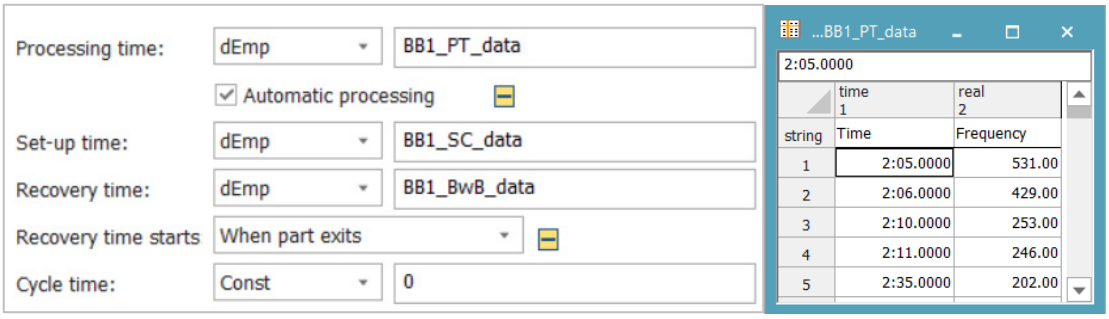


Fig. 7 Simulation setting window

Model validation was performed to validate data and information. The model output for an existing system was compared with the corresponding output for the system itself. Hypothesis testing given in Table 3 illustrates the difference values of machine utilization in the real system and the simulation model. Number of machines (n) is 6 and degree of freedom (n–1) is 5. Significant level at 0.05. After testing, the t-value is greater than –2.101 and less than 2.101 with 95 percent of confident interval. Therefore, H_0 is accepted. It can be concluded that there is no statistically significant difference between the real system and the simulation model.

After the model was validated, the production time was changed to be dynamic. This model was ended up after all production volumes were produced. The production volumes were separated into each Banbury mixing process including non-pro, pro and special. The machine utilizations were also separated including Non-pro BB, Pro BB and Special BB. The simulation results of this situation were obtained as shown in Fig. 8(b). Machine utilization was averaged for each BB type as shown in Fig. 8(a). The summary of the current performance is presented in Table 4.

Table 3 Hypothesis testing, real and simulation machine utilization (%)

Machine	Utilization (%)		$d_i = x_r - x_s$	Hypothesis
	Real (x_r)	Sim (x_s)		
BB1	63.62	63.34	0.28	Null hypothesis (H_0): $\bar{X}_r - \bar{X}_s = 0$ Alternative (H_1): $\bar{X}_r - \bar{X}_s \neq 0$
BB2	81.00	81.64	-0.64	
BB3	86.77	88.45	-1.67	
BB4	73.96	74.34	-0.38	The test statistic t
BB5	78.38	77.61	0.77	
BB6	69.52	69.08	0.43	0.1547
		$\bar{d}$	-0.20	
		S.D.	0.81	$-2.101 \leq t \leq 2.101$

Table 4 The summary results of the current performance

Production volume (batch)			Time	Machine utilization (%)			
Non-pro	Pro	Special	(days)	Non-pro BB	Pro BB	Special BB	Avg
20,190	17,404	6,800	25.11	91.50	89.85	100	93.69

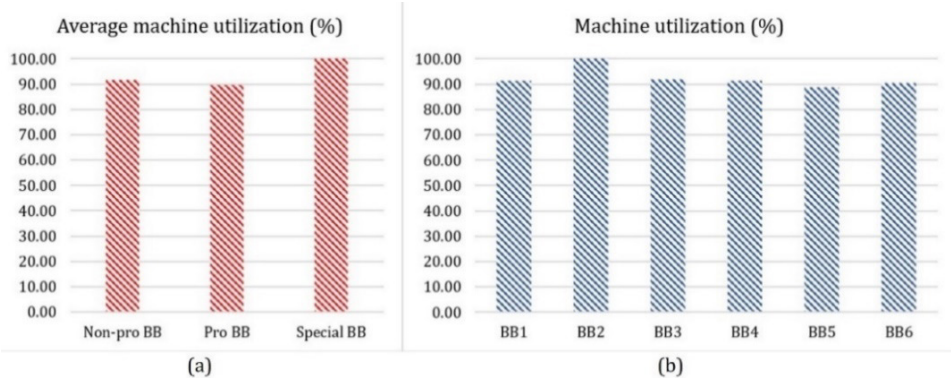


Fig. 8 (a) Average machine utilization of each BB type, (b) Machine utilization of each BB

3. Results and discussion

3.1 Simulation scenarios and experiments

Since the result of the current capacity was found that the average machine utilization of Special BB was full (100 %), the proposed idea to increase capacity was to change BB1 to Special BB in order to reduce the Special BB workload as presented in Fig. 9(a). After this idea was created and run in the Plant simulation, it was found that the workload of Special BB was reduced to 35.30 % but the machine utilization of Non-pro BB was increased to 100 % as illustrated Fig. 9(b). After changing BB1 to Special BB, the production time increased from 25.11 days to 36.20 days and the total average machine utilization reduced from 93.69 % to 65.84 % as presented in Table 5. Therefore, it was implied that this concept was not valid. The reason would probably because of the unsuitable amount of the production volume for Non-pro BB.

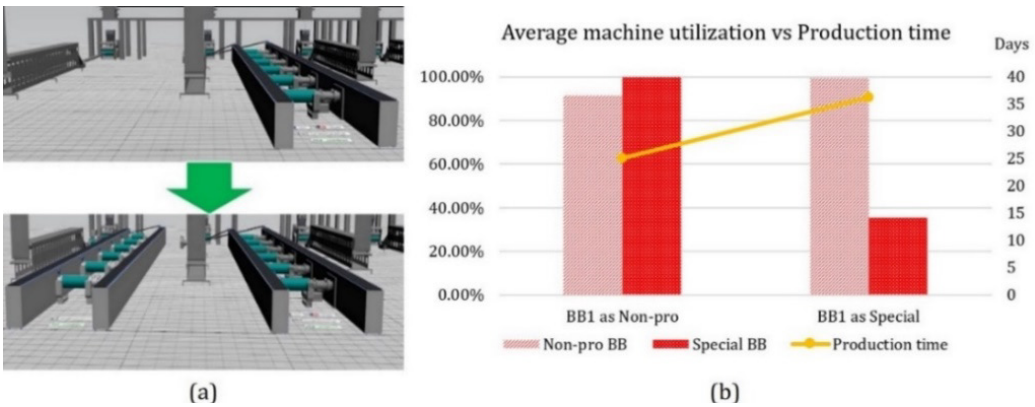


Fig. 9 (a) Changing BB1 from normal BB to Special BB, (b) The result that BB1 changing

Table 5 The summary results of Changing BB1

Production volume (batch)			Time	Machine BB1	Machine utilization (%)			
Non-pro	Pro	Special	(days)		Non-pro BB	Pro BB	Special BB	Avg
20,190	17,404	6,800	36.20	Special BB	99.40	62.82	35.30	65.84

Due to the invalid scenario above, we decided to reduce the workload from Non-pro BB by reducing numbers of steps. The numbers of steps were reduced by combining the normal process with the second special process called the fourth special Banbury mixing process (4th) as shown in Fig. 10(a). The fourth special Banbury mixing process is to assign Non-pro BB to pro-

duce 1 step, Special BB to produce 1 step and Pro BB to produce 1 step as illustrated in Fig. 10(b). However, all compounds were also not applied to the fourth special process. There were only 7 compounds which could be produced by the normal process or the fourth special process. Therefore, the amount of the normal type had been changed from 20 compounds to 13 compounds and the amount of the special type had been changed from 11 compounds to 18 compounds. The summary of compound sets and the numbers of compound in each type are shown in Table 7.

The experiments were the grouping in all compound sets. For instance, as shown in Table 6, experiment 24 means that compound set 1 is assigned to be produced by normal process (N), compound set 3 and 5 are assigned to be produced by second special process (2nd), compound set 2 is assigned to be produced by first special process (1st) and compound set 4 is assigned to be produced by third special process (3rd). As presented in Table 7, the numbers of groups were calculated by multiplying all possible processes in each condition. The number of groups in the current condition is 24 groups. The number of groups in the combined process condition is 48 groups.

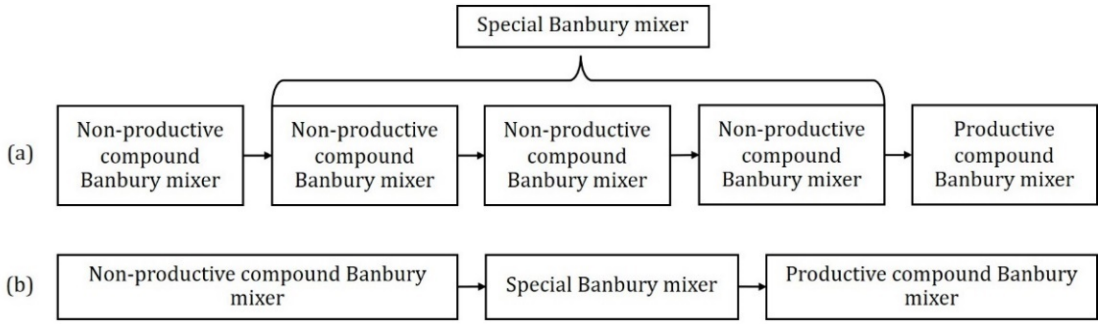


Fig. 10 (a) Mixing the normal and the second special process, (b) The fourth special Banbury mixing process

Table 6 All experiments from grouping the compound sets

Ex.	Compound set					Ex.	Compound set				
	1	2	3	4	5		1	2	3	4	5
1	N	N	N	N	N	13	N	1st	N	N	N
2	N	N	N	N	1st	14	N	1st	N	N	1st
3	N	N	N	N	2nd	15	N	1st	N	N	2nd
4	N	N	N	3rd	N	16	N	1st	N	3rd	N
5	N	N	N	3rd	1st	17	N	1st	N	3rd	1st
6	N	N	N	3rd	2nd	18	N	1st	N	3rd	2nd
7	N	N	2nd	N	N	19	N	1st	2nd	N	N
8	N	N	2nd	N	1st	20	N	1st	2nd	N	1st
9	N	N	2nd	N	2nd	21	N	1st	2nd	N	2nd
10	N	N	2nd	3rd	N	22	N	1st	2nd	3rd	N
11	N	N	2nd	3rd	1st	23	N	1st	2nd	3rd	1st
12	N	N	2nd	3rd	2nd	24	N	1st	2nd	3rd	2nd

Ex.	Compound set						Ex.	Compound set					
	1	2	3	4	5	6		1	2	3	4	5	6
25	N	N	N	N	N	4th	37	N	1st	N	N	N	4th
26	N	N	N	N	1st	4th	38	N	1st	N	N	1st	4th
27	N	N	N	N	2nd	4th	39	N	1st	N	N	2nd	4th
28	N	N	N	3rd	N	4th	40	N	1st	N	3rd	N	4th
29	N	N	N	3rd	1st	4th	41	N	1st	N	3rd	1st	4th
30	N	N	N	3rd	2nd	4th	42	N	1st	N	3rd	2nd	4th
31	N	N	2nd	N	N	4th	43	N	1st	2nd	N	N	4th
32	N	N	2nd	N	1st	4th	44	N	1st	2nd	N	1st	4th
33	N	N	2nd	N	2nd	4th	45	N	1st	2nd	N	2nd	4th
34	N	N	2nd	3rd	N	4th	46	N	1st	2nd	3rd	N	4th
35	N	N	2nd	3rd	1st	4th	47	N	1st	2nd	3rd	1st	4th
36	N	N	2nd	3rd	2nd	4th	48	N	1st	2nd	3rd	2nd	4th

Table 7 The summary of Banbury process and compound groups

No.	Compound sets	Current condition		Combined process condition	
		No. of comps.	Possible process	No. of comps.	Possible process
1	Only Normal	20	1	13	1
2	Normal/1st special	5	2	5	2
3	Normal/2nd special	4	2	4	2
4	Normal/3rd special	1	2	1	2
5	Normal/1st special/2nd special	1	3	1	3
6	Normal/4th special	0	0	7	2
	Total	31	24	31	48

Each experiment contained 3 types of batch amount for each compound including non-pro, pro and special. For Banbury production planning, production volumes of each compound can be calculated by Eq. 1.

$$\text{Production volume(batch)} = \text{Productive compound demand(batch)} \times \text{Process step} \quad (1)$$

For example, considering a productive compound in the set 5, with 1 batch of demand, if the compound is produced by normal process, production volumes will be 4 batches of non-pro and 1 batch of pro. If it is produced by first special process, production volume will be 2 batches of special. If it is produced by second special process, production volumes will be 1 batch of special and 1 batch of pro. After the production volume were calculated, the batch amount for each compound was summarized for each experiment as shown in Table 8.

Table 8 The production volumes of the experiments

Current condition				Combined process condition							
Ex.	Non-pro	Pro	Special	Ex.	Non-pro	Pro	Special	Ex.	Non-pro	Pro	Special
1	29,665	20,175	0	1	29,665	20,175	0	25	25,625	20,175	2,746
2	29,356	20,175	150	2	29,356	20,175	150	26	25,316	20,175	2,896
3	29,356	20,014	293	3	29,356	20,014	293	27	25,316	20,014	3,039
4	27,376	18,994	1,956	4	27,376	18,994	1,956	28	23,027	18,994	4,702
5	27,067	18,994	2,106	5	27,067	18,994	2,106	29	23,027	18,994	4,852
6	27,067	18,833	2,249	6	27,067	18,833	2,249	30	23,027	18,833	4,995
7	25,593	20,175	2,300	7	25,296	20,175	2,480	31	21,256	20,175	5,226
8	25,284	20,175	2,450	8	24,987	20,175	2,630	32	20,947	20,175	5,376
9	25,284	20,014	2,593	9	24,987	20,014	2,773	33	20,947	20,014	5,519
10	23,304	18,994	4,256	10	23,007	18,994	4,436	34	18,967	18,994	7,182
11	22,995	18,994	4,406	11	22,698	18,994	4,586	35	18,658	18,994	7,332
12	22,995	18,833	4,549	12	22,698	18,833	4,729	36	18,658	18,833	7,475
13	23,276	15,011	4,639	13	21,302	13,538	5,946	37	17,262	13,538	8,692
14	22,967	15,011	4,789	14	20,993	13,538	6,096	38	16,953	13,538	8,842
15	22,967	14,850	4,932	15	20,993	13,377	6,239	39	16,953	13,377	8,985
16	20,987	13,830	6,595	16	19,013	12,357	7,902	40	14,973	12,357	10,648
17	20,678	13,830	6,745	17	18,704	12,357	8,052	41	14,664	12,357	10,798
18	20,678	13,669	6,888	18	18,704	12,196	8,195	42	14,664	12,196	10,941
19	19,204	15,011	6,939	19	16,933	13,538	8,426	43	12,893	13,538	11,172
20	18,895	15,011	7,089	20	16,624	13,538	8,576	44	12,584	13,538	11,322
21	18,895	14,850	7,232	21	16,624	13,377	8,719	45	12,584	13,377	11,465
22	16,915	13,830	8,895	22	14,644	12,357	10,382	46	10,604	12,357	13,128
23	16,606	13,830	9,045	23	14,335	12,357	10,532	47	10,295	12,357	13,278
24	16,606	13,669	9,188	24	14,335	12,196	10,675	48	10,295	12,196	13,421

All resource allocation plans were set up in 4 simulation scenarios illustrated in Table 9. Scenario I is the current capacity which has 5 compound sets, 20 normal compounds and 11 special compounds. BB1 is set as Non-pro BB, and there are 24 experiments. Scenarios II is the changing BB1 which has 5 compound sets, 20 normal compounds and 11 special compounds. BB1 is set as Special BB, and there are 24 experiments. Scenario III is applying fourth special process which has 6 compound sets, 13 normal compounds and 18 special compounds. BB1 is set as Non-pro BB, and there are 48 experiments. Scenarios IV is changing BB1 and applying fourth special process which has 6 compound sets, 13 normal compounds and 18 special compounds. BB1 is set as

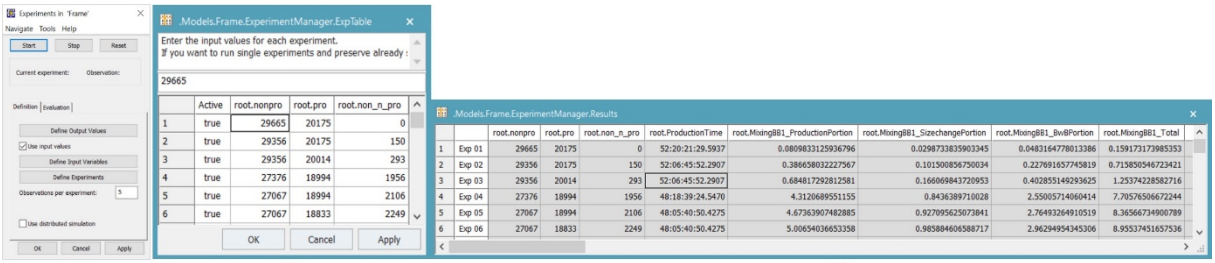
Special BB, and there are 48 experiments. All scenarios are set to run 5 replications per experiment.

Simulation scenarios were created in the Plant simulation and the simulation tool named "Experiment Manager" was used to set experiments and replication as presented in Fig. 11(a). The output values were defined including working proportion, setting-up proportion, recovery proportion, total proportion, and production time of each experiment in Fig. 11(b). The input values were defined as the production volume in each type and experiments were defined as the current input or the adjusted input in Table 6. In addition, all experiments were designed to have 5 observations per experiment as shown in Fig. 11(c).

The graphs of results from experiments were plotted to find the lowest point which represented the best production time. Fig. 12(a-d) illustrates the experiment results of scenario I, II, III and IV. These graphs provide the lowest point at experiment 16, 24, 15 and 45, respectively. Most of the production times were varied according to Special BB and Non-pro BB. At this lowest point, either Special BB or Non-pro BB would be the maximum utilization.

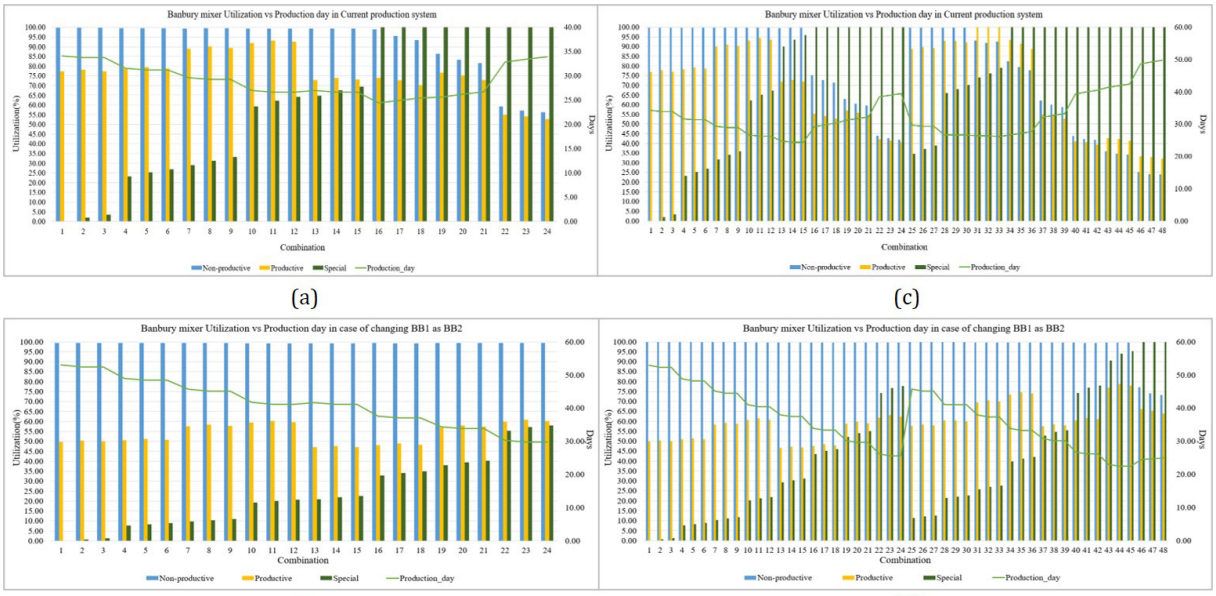
Table 9 The simulation scenarios

Scenarios	Compound sets	Types		Machine BB1	No. of exp. (based on grouping)	No. of replications per experiment
		Normal	Special			
I II	5	20	11	Non-pro BB Special BB	24	5
III IV	6	13	18	Non-pro BB Special BB	48	



(a) (b) (c)

Fig. 11 Plant simulation tool named "Experiment Manager", (a) setting window, (b) experiment table, (c) result table



(a) (c)

(b) (d)

Fig. 12 The simulation results in each experiment, (a) Scenario I, (b) Scenario II, (c) Scenario III, (d) Scenario IV

3.2 Scenario results comparisons

Five scenarios were proposed to compare various capacity levels. The best experiment result of each scenario presented Banbury mixer machine utilization and production time. The graph in Fig. 13 represents the best experiment results of Scenario C, I, II, II and IV. As Scenario I results, the shortest production time was 24.43 days at experiment 16 which decreased by 0.68 days from current capacity (-2.71 %). Machine utilization of Non-pro BB, Pro BB and Special BB were 98.94 %, 74 % and 100 %, respectively. As Scenario II results, the shortest production time was 29.76 days at experiment 24 which increased by 4.65 days from production time (+18.52 %). Machine utilization of Non-pro BB, Pro BB and Special BB were 99.34 %, 60.16 % and 58.01 %, respectively. As Scenario III results, the shortest production time was 24.31 days at experiment 15 which decreased by 0.8 days from production time (-3.19%). Machine utilization of Non-pro BB, Pro BB and Special BB were 99.63 %, 71.95 % and 95.81 %, respectively. As Scenario IV results, the shortest production time was 22.46 days at experiment 45 which decreased by 2.65 days from current capacity (-10.55 %). Machine utilization of Non-pro BB, Pro BB and Special BB were 99.58 %, 77.95 % and 95.27 %, respectively. The summary results are shown in Table 10.

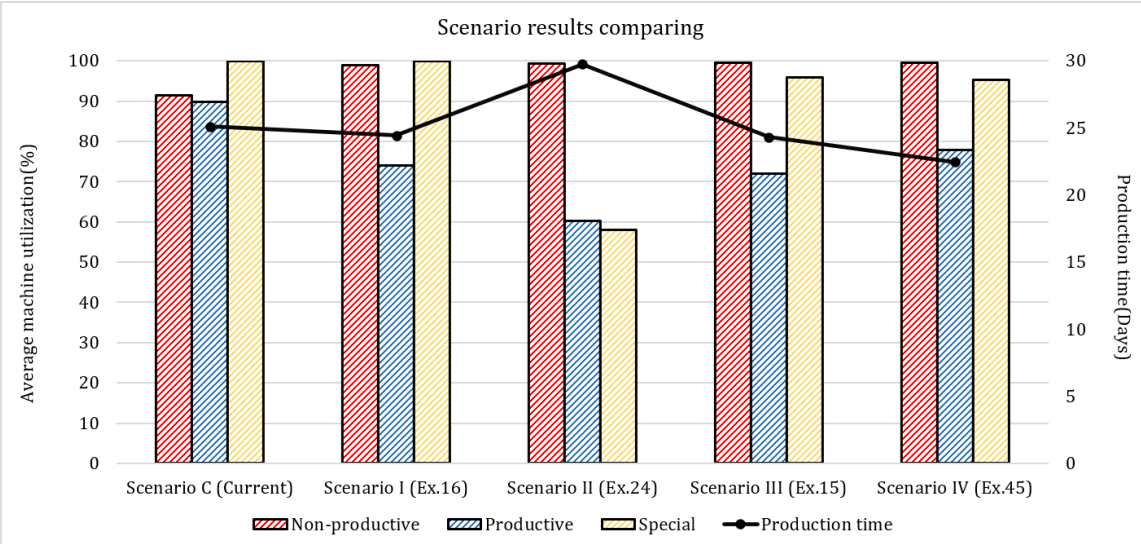


Fig. 13 The best result of each sceanrio comparison

Table 10 The summary results of each scenario at the best experiment

Sce.	Exp.	Production volume (batch)			Sets	BB1	Time (days)	Diff (%)	Machine utilization (%)			
		Non-pro	Pro	Special					Non-pro BB	Pro BB	Special BB	Avg
C	-	20,190	17,404	6,800	5	Non-pro	25.11	-	91.50	89.85	100	93.69
I	16	20,987	13,830	6,595	5	Non-pro	24.43	-2.71	98.94	74.00	100	90.98
II	24	16,606	13,669	9,188	5	Pro	29.76	18.52	99.34	60.16	58.01	72.50
III	15	20,993	13,377	6,239	6	Non-pro	24.31	-3.19	99.63	71.95	95.81	89.13
IV	45	12,584	13,377	11,465	6	Pro	22.46	-10.55	99.58	77.95	95.27	90.93

3.3 Estimation of production cost saving

As mentioned earlier, it recommended that BB1 should be changed to Special BB and fourth special process should be applied in order to reduce production time and utilize machine capacity. If the case study company implement this solution, the labor cost can be saved by production time reduction. In the current situation, BB1 required 4 workers to run the process but BB2 required 5 workers. To implement the solution, an additional worker of BB1 was recommended. Therefore, the total worker in the Banbury mixing process would be increased from 33 to 34 workers per shift. The wage per person was 1.22 USD per hours. As a result, the production time was reduced from 25.11 to 22.46 days per month. The yearly production saving was 22,834.90 USD per year as shown in Table 11.

Table 11 The summary of production cost saving after implement the solution

Cases	No. of workers	Production time per month		Wage	Month	Labor cost	Diff
		Days	Hours			Year	
Current	33	25.11	602.64	1.22	12	291,147.44	-22,834.90
Solution	34	22.46	539.04			268,312.55	

4. Conclusion

In this study, a Plant Simulation approach for optimal resource utilization was proposed. Plant simulation was applied to create Banbury mixing process 3D models and simulate the production data. Those models applied discrete empirical distribution (dEmp) to population data. Experiment manager tool set up the scenarios with the experiments and provided results. Experiment results displayed the production time and machine utilization. The shortest production time of an experiment represented the best result of a scenario. Four scenarios were compared to determine the optimal group of compound sets and number of machines. The results showed that scenario IV at experiment 45, which BB1 was changed from non-productive Banbury mixer to special Banbury mixer along with the normal process were combined with the second special process to be fourth special process, provided the shortest production time. This scenario required investment in changing Banbury mixer machine BB1. This solution could save production cost by reducing the production time by 22,834.90 USD per year.

This study provides the resource utilization for Banbury mixing process to solve the capacity limitation. The adjustment in numbers of machines and the grouping in the compound sets are the solutions to reduce the production time. Discrete empirical distribution is demonstrated to deal with population data. The suitable method for verifying and optimizing various scenarios using Plant simulation are illustrated. Software configuration for setting operation times and experiments is explained. The simulation results found the shortest production time in each experiment and used to compare the shortest production time in each scenario. Our work also estimates the production cost saving for the best scenario from simulations.

Future research can be conducted to more production situation input and output, such as worker and area. Moreover, this simulation model concept can be applied to other tire production lines or the entire tire production systems to optimize the total resource as well.

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