한국시뮬레이션학회 논문지
Vol. 19, No. 2, pp. 107-118 (2010. 6)

자동차 엔진 생산라인 배치개념이 효율에 미치는 영향분석

허 특[1] · 문덕희[1†] · 신양우[2] · 정종윤[1]

An Effect Analysis of Layout Concepts on the Performances in Manufacturing Lines for Automotive Engine

Te Xu · Dug Hee Moon · Yang Woo Shin · Jong Yun Jung

ABSTRACT

Automotive manufacturing is a complex task that requires the production and assembly of thousands of different components or parts. The engine and the transmission are the major components that constitute a power train system. Although manufacturing processes of an engine are similar, the layouts of the manufacturing lines are different from factory to factory. It is due to the different design concept that how to combine the serial and parallel structures. In this paper, three engine lines of different factories are introduced, and the simulation technology is used to make the performance analysis for different design concepts.

Key words : Simulation, Layout Concept, Parallel, Serial, Line performance, Automotive, Engine

요 약

자동차 제조업은 수천 가지의 다른 구성품 또는 부품의 조립이 필요한 복잡한 생산시스템이다. 엔진과 트랜스미션은 자동차의 동력을 담당하는 주요 구성품이다. 엔진의 경우 생산공정이 대부분 유사한 공정들로 구성되어 있음에도 불구하고 공장별로 생산시스템의 배치안은 상이하다. 그 이유는 각 공장마다 기계들을 어떠한 직렬구조와 병렬구조를 조합하여 배치하는지에 대한 개념이 다르기 때문이다. 이 논문에서는 서로 다른 공장에서 적용하고 있는 세 종류의 엔진 라인을 소개한다. 그리고 시뮬레이션을 이용하여 각 라인의 설계개념이 라인의 성과에 미치는 영향에 대해 비교분석하고자 한다.

주요어 : 시뮬레이션, 배치개념, 병렬, 직렬, 라인효율, 자동차, 엔진

1. INTRODUCTION

As a mature technology, the automotive engine manufacturing has been applied in automotive factories for many years. The major five components of engine are camshaft, crankshaft, cylinder block, cylinder head and connecting rod which make this manufacturing process highly complex, because each of those sub-assemblies are also composed of the hundreds of parts. Figure 1 shows an example of cylinder block.

Although the manufacturing process of automotive engine is very complicated and is applied in the different factories, the process sequences are relatively similar because of the same main components and production technology. Nevertheless, with these similar processes, the layouts of manufacturing lines in different factories are quite dissimilar. It is due to the different design concept that how to combine the serial and parallel structures.

Most automotive engine production line is a typical flow line(or transfer line) with serial work stations which compose serial or parallel machines. Two approaches

*This work was partially supported by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD) KRF-2006-D00163(I00162) and partially supported by Changwon National University in 2008.
2010년 2월 21일 접수, 2010년 6월 16일 채택
1) 창원대학교 산업시스템공학과
2) 창원대학교 통계학과
주 저 자 : 허 특
교신저자 : 문덕희
E-mail; dhmoon@changwon.ac.kr

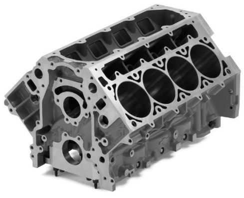

Fig. 1. Cylinder Block

have been widely used for evaluating the system performance, where the one is mathematical modeling like queueing theory and the other is computer simulation.

The researches published in early stage which applied queueing theory to the manufacturing system design are well summarized in Gershin(1994). In this textbook, he reviewed the literature on reliable two-station systems with synchronous transfer, on flow lines without buffers as well as on approximation methods for systems with more than two stations. Papadopoulos and Heavey (1996) published a survey paper, in which they provided a bibliography of material concerned with modeling of production and transfer lines using queueing networks. Magazine and Stecke(1996) developed a mathematic model in order to get the max throughput for production lines with serial work stations and parallel service facilities. Tempelmeier, and Bürger(2001) suggested an analytical approximation for the performance of nonhomogenous asynchronous flow line with finite buffer. In this paper, they considered generally distributed stochastic processing time as well as breakdown and imperfect production.

Recently researches using queueing theory were extended to the assembly/disassembly system. This type of context could be applied to the body shop design in an automotive factory(see Spieckermann et al.(2000) and Manitz(2008)).

Although these kinds of research have the significance in this area, the mathematic model is not easy to catch on and take the reins, and it is difficult to applied the mathematic algorithm to the real situation. Therefore, in this paper, the simulation technology is adopted as an intuitionist, fast and flexible way to solve the problem for a transfer line.

From the end of 1990's, people recognized that over 70% of the cost for a product is committed at the product design stage(see ManTech(1994)), and the digital manufacturing technology has been widely implemented in industries which enables to shorten the developing period of product. The digital manufacturing links the product development, the production planning and the facility planning using various computer solutions. The core technologies of digital manufacturing are digital mock-up (DMU) and 3D simulation, which can be used to model a current, redesigned or not yet existing process in order to determine the current and future behaviors of the process(see Moon et al.(2008)).

Meantime, many simulation researches have been implemented in engine plant. In 1990's, Ulgen et. al (1994) addressed that the applications of discrete-event simulation in design and operation of vehicle manufacturing systems can be categorized into four major domains: equipment and layout design issues, issues related to variation management, product-mix sequencing issues, and other operational issues, which still has issueig meaning of direction in today's discrete-event simulation domains. Jayaraman and Agarwal(1996) addressed a general concept when the simulation technique is applied to the engine plant. Oh et al.(2000) and Choi et al.(2002), as well as Moon et al.(2003) also suggested the simulation studies regarding the engine block line.

In this paper, three engine shops' cylinder block lines with different layout structures have been analyzed in order to find the best combination of serial or parallel machines for the lines. In real factory, the stations that should adopt the combination of serial or parallel machines depend on many impersonal situations like cost, space and producing technology. However, in this research, only throughput and efficiency are looked as the key points during the analysis phase.

2. ABSTRACT MODEL FOUNDATION

2.1 Standard Process Sequence

The cylinder block, also called engine block, is the main bottom end structure of engine, as shown in Figure 1. Commonly, the process of manufacturing cylinder

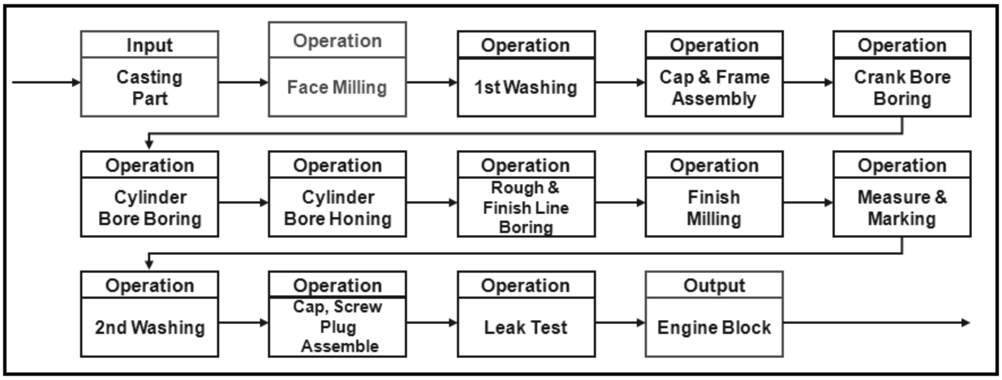

Fig. 2. Standard Process Sequence

block includes milling, boring, drilling, washing and taping. As discussed before, although the layout and the machines selected are quite different from factories to factories, the main process sequence is very similar. Therefore, a standard manufacturing process sequence is founded as in Figure 2.

2.2 Abstract Model

Base on this standard sequence, three cylinder block line in different factories are compared and analyzed. As a result, another incredible similar point is found that from the first washing to the last sequence of the process, three cylinder block lines adopt the same structure and layout of work stations. The work stations are serially connected and only one machine is set into the each station. Therefore, the only different structure of work station is just the face milling process.

After the analysis of face milling process, 6 main sequences can be established, and they are main face milling, hole drilling & reaming, front and rear face roughing & fine milling, and so on. In fact, the difference among three cylinder block line is just the different machine function combination. This will be clearer after the abstract model established.

Figure 3 shows the different structures of face milling process in three lines. A and B line is a typical serial and parallel structure production line, and C line is a mix type. Besides, the first machine of B line can looked as the combination of first and second machines in A line. Same Meaning, the third machine of C line also can be regarded as the combination of third and fourth machines in A line. Certainly, the B line can extend many generations base on the complete or partial flexibility connection between stations. This will be one extend direction of this research.

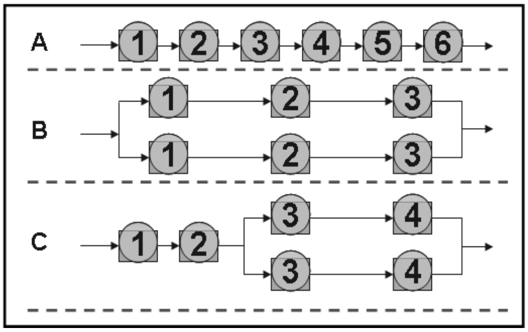

Fig. 3. Abstract Structure of Face Milling Process in three lines

3. INPUT DATA DESIGN

The cylinder block line researched in this paper is a typical transfer line, in which machines are connected by conveyor or gantry carrier. Therefore, there is no buffer between stations. However, the characteristic of transfer make itself as a long distance buffer, some numbers of cylinder block parts would stay in the transfer before entering the work stations. Therefore, in the experiments, two kinds of scenarios will be considered, and they are line with buffers and without buffers.

Table 1. Cycle Time of Machines

A	M1	M2	M3	M4	M5	M6
	60s	60s	60s	60s	60s	60s
B	M1		M2		M3	
	120s		120s		120s	
C	M1	M2	M3		M4	
	60s	60s	120s		120s	

Table 2. Failure Distribution of Scenario 1

Type	Major Break		Tool Change	
	MTBF	MTTR	MTBF	MTTR
A	14400	600	7200	300
B	14400	600	7200	300
C	14400	600	7200	300

3.1 Cycle Time

We assume that the cycle time of each machine in A line is 60sec, therefore, the total workload of face milling station is 360sec. In order to make the same total workload with A line, the cycle time of B line should be 120sec for each machine. Similarly, each cycle time of machine M1 and M2 in C line should be 60sec and that of M3 and M4 should be 120sec respectively. The distribution function of cycle time is assumed as the constant, because this manufacturing system is highly automated.

One of the reason that why only the face milling station has the different structure among three cylinder block lines is that the face milling operations are usually bottle-neck processes. Thus, we assume that the cycle time of face milling station is bigger than the other stations. Table 1 shows cycle time of each machine.

3.2 Failure Distribution

There are many reasons which cause the breakdown of machines, some of them are serious and some are trivial. And most machines are affected by more than one failure mode. In this paper, we assume that all the machines in work station have two failure modes, one for major breakdown and one for tool change.

Failure distribution is differently assumed in three scenarios. In Scenario 1, we assume that failure distribution for each machine is the same in three lines as shown in Table 2. Exponential distribution is used for all MTBF and MTTR.

In Scenario 2, we set more tool change breaks to the workstations which have parallel machines in B and C line, because those machines are regarded as the combination of machines in line A. For example, the workload of M1 in the line B is the same with the same of workloads of M1 and M2 in line A. This can be regarded as the machine unification. It means that we can assume that the requirement of tool change in the M1 of line B should be twice. Thus, we set two independent tool change events to each unified machine (i.e., M1 in line B and M3 in line C). Then, It reduces the mean value of MTBF of M1 in line B from 7200 seconds to 3600 seconds, but the mean value of MTTR does not be changed. And we assume that although the machines have the combination, the major break will not change.

At last in Scenario 3, base on the structure of C line, the different failure distribution will be set to the machines in order to analysis the line efficiency when bottle-neck process exists in the serial or parallel machines.

4. SIMULATION MODELING

The three-dimensional simulation models are developed with QUEST® as shown in Figure 4. The model in Figure 4 represents the production system of cylinder block with the processes as shown in Figure 2. This system has single input and single output. The face milling station in Figure 4 consists with two parallel lines(case B in Figure 3) where three machines are connected serially in each parallel line. The down-stream operations of face milling station are also flow production system, and one machine is assigned to each operation. The simulation models of case A and C in Figure 3 are developed similarly.

The merit of 3D simulation model is that it is possible to make the simulation model as real world

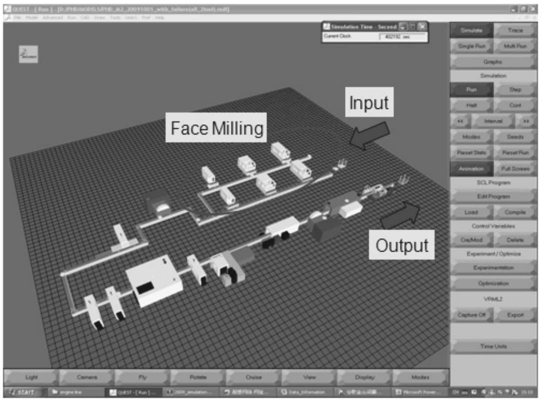

Fig. 4. Snapshot of 3D Simulation Model

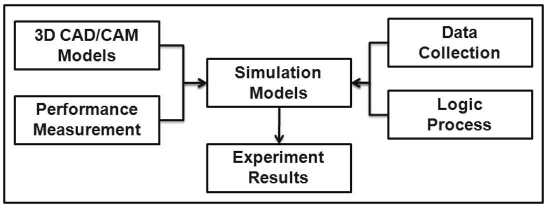

Fig. 5. 3D Simulation Modeling Approach

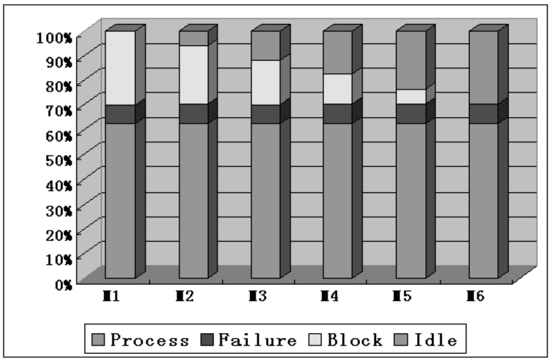

Fig. 6. Machine Utilization of A Line

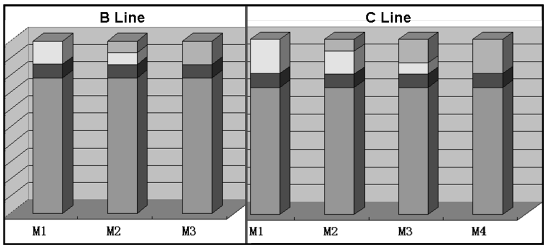

Fig. 7. Machine Utilization of B & C Line

system. Therefore, the procedure of making a 3D simulation model is much more complex than 2D simulation model. The approach of simulation modeling follows as in Figure 5. The logics to control the operations which are used in the simulation model are coded with the Simulation Control Language(SCL) which is supported by QUEST®.

5. EXPERIMENTS AND RESULTS

The simulation run time is set to seven months, while the warm-up period is set to one month. For each scenario, five replications are conducted.

5.1 Performance Measures

Generally, more than one measure are selected for the complex manufacturing system in order to provide a comprehensive analysis. In this research, we focus only on the throughput and efficiency of the line, and the performance measures are determined as follows:

- Machine utilization,
- Throughput;
- Work In Process(WIP).

5.2 Results and Analysis of Scenarios

5.2.1 Line With No Buffers

Scenario 1.1(Same CT and failure distribution)

Because that the cycle time and failure distribution of each machine is the same, the utilization of machines are very similar. Figure 6 shows the machine utilizations of A line. However, although the processing and failure percent are similar, the blocking and idle times are quite different. This is typical proposition in a serial transfer line. When the downstream machine is in the state of break down, the upstream machine can not transfer the part to it, thus change the state to block. This problem also happened in B and C line because of the parallel structure(see Figure 7).

Although the block break frequency happened in upstream machines among three lines, the throughput still are quite different. The reason is that the different structures of machines lead the different utilization.

Table 3. Simulation Results of Scenario 1

Type	Throughput	Machine Utilization
A	53939	62.43%
B	67852	78.53%
C	62553	72.40%

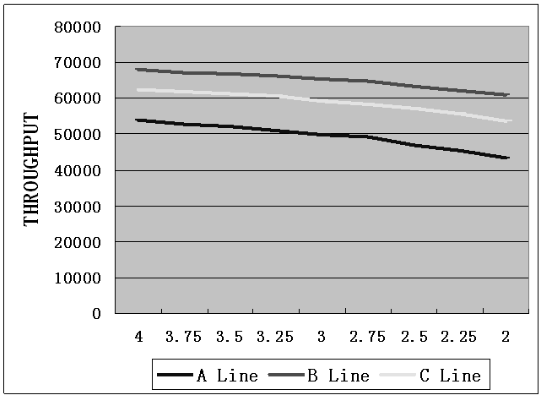

Fig. 8. Throughput Decline Rate

When there are no buffers between machines, the parallel structure has more advantages than serial structure.

The simulation results(see Table 3) indicate that the throughput of A line is much less than B and C line, and the utilization of machines is also the lowest. The reason caused this is that block break frequently occurred as expatiated before.

Scenario 1.2(Variation of failure distribution)

The purpose of this scenario is to find the effect of failure rate to the system performance in each type of layout. Therefore, base on the Scenario 1, the failure rate is changed gradually. The major break is chosen for the variational failure rate, and the MTTF is changed gradually from four hours to two hours. Figure 8 shows the declining pattern of throughput by variational failure distribution. Obviously, three decline rates are very similar. This means that the effect of failure rate to the throughput is similar among line structures.

Scenario 2(Same CT and different failure distribution)

In Scenario 2, two independent tool change events are set to all machines of B line, and M3 and M4 in C line. Tool changes are occurred frequently when more operations are allocated in one machine. Table 4 shows the simulation results. Obviously, the throughput decreases when more failures occur on machines, and the utilizations of machines in both B and C line decrease about 6%. However, the throughputs of two lines are still more than that of A line.

Table 4. Simulation Results of Scenario 2

Type	Throughput	Machine Utilization
B	62570	72.42%
C	57594	66.66%

In fact, although the workload allocated on a machine is two times of original workload, the frequency of tool change is not two times, but less than two times. It means that in spite of the increasing tool change frequency, parallel system(line B or line C) is better than serial system(line A) with respect to the throughput when there is no buffer between two machines. This is the reason that many factories adopt parallel system though it needs more investment cost.

Scenario 3.1~3.4(Bottleneck exists in different position of line)

Although the face milling station is the bottleneck station of whole cylinder block line, it still may have its own bottleneck machine inside. Until now, we assume the same cycle time, same failure and repair distribution to the machines, and this assumption is not realistic. Therefore, a bottleneck process is established by setting the different cycle time, failure and repair distribution for machines.

As shown in Table 5, we investigate two cases, the one is that the first machine is the bottleneck and the other is that the last machine is the bottleneck. In order to make bottleneck arbitrary, we change the failure and repair distribution for three lines. The input data of all the other machines will keep the original data as defined in Scenario 1. In the machine M1 of scenario 3.1 the percentage of major break downtime is 8.33%, but that of scenario 1 is 4.17%.

In the same manner, the different cycle times are

Table 5. Failure Distribution of Scenario 3

Scenario 3.1			
Type	Bottleneck	Major Break	
		MTBF	MTTR
A	M1	10800	900
B	M1	10800	900
C	M1	10800	900
Scenario 3.2			
Type	Bottleneck	Major Break	
		MTBF	MTTR
A	M6	10800	900
B	M3	10800	900
C	M4	10800	900

Table 6. Cycle time of Scenario 3

Type	Scenario 3.3		Scenario 3.4	
	Machine	CT	Machine	CT
A	M1	80	M6	80
B	M1	160	M3	160
C	M1	80	M4	160

Table 7. Throughput Result of Scenario 3

Type	S3.1	S3.2	S3.3	S3.4
A	51704	52152	42201	42223
B	65365	65376	51928	51926
C	60229	60033	50342	48770

also set into the machines of lines as shown in Table 6, and the purpose is same with Scenario 3.1 and 3.2.

From the throughput results listed in Table 7, we can conclude that no matter where the bottleneck machines exist, there is no effect on the throughput in case of lines A and B considering confidence interval. On the other hand, the location of bottleneck machine has an effect on the throughput in line C. The throughputs of scenarios 3.2 and 3.4 are smaller than those of scenarios 3.1 and 3.3 respectively. The reason of this observation is that there is only one machine in the first machine(M1) but two machines(M4) are in the last position. It means that the impact of bottleneck machine is twice when its position is the last in line C. It is the limitation of this kind of experiment.

Scenario 3.5(Variation of failure distribution)

Base on what has been found in last paragraph about B and C line, Scenario 3.5 focuses to find how the cycle time and failure break affect the throughput of line with bottleneck machine. Different from Scenario 1.2, the cycle time or failure break changing just happened in bottleneck machine.

Bottleneck Exists at the Beginning of Line

Figure 9 shows the throughput patterns by changing CT of bottleneck machine from 65sec to 100sec, when bottleneck machine is located at the front of line. Obviously, the decline rate of B line is slower than the other two. In addition, when CT is bigger than 95sec, the throughput of C line is greater than that of B line. The reason is that total workload of M1 in line B is bigger than those of line A and C. For example, when CT is set to 95sec, the total workload of A and C line is 395sec, but for B line, it is 430sec.

However, when the bottleneck is made by failure break, the decline rate of throughput has no such orderliness because of the same workload of machine (see Figure 10).

Bottleneck Exists at the End of Line

When the Bottleneck exists at the end of line, the decline rate of throughput by failure break is similar

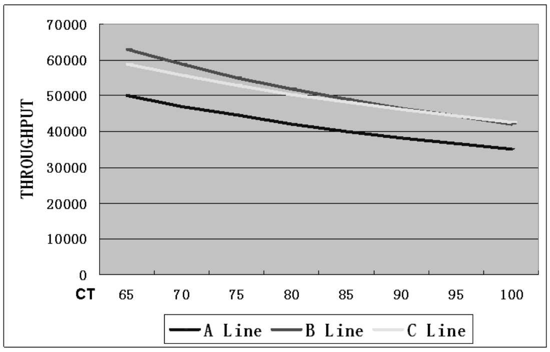

Fig. 9. Throughput Decline Rate by CT

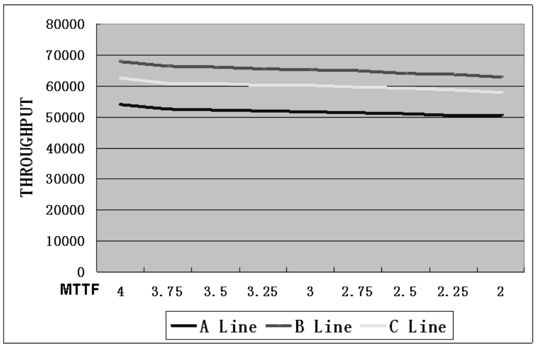

Fig. 10. Throughput Decline Rate by Failure Break

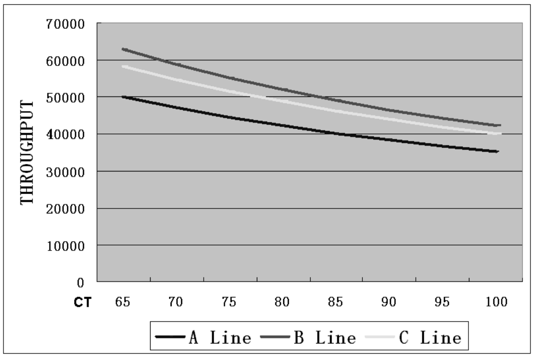

Fig. 11. Throughput Decline Rate by CT

with Figure 10. However, as shown in Figure 11, the variation of throughput by CT is a little different from Figure 9.

In fact, the only different thing between Figure 9 and Figure 11 is that the throughput decline rate of C line. When the bottleneck exists at the end of line, the total workload is the same with A line, whatever the CT changed. This is the reason why the decline rate in Figure 11 is acuter than that in Figure 10.

5.2.2 Line With Buffers

Unless the transfer is applied in the product line, most factories would like to fix the buffers between machines in order to defend the failure break. It may improve the line performance and increase the throughput. However, the cost related with WIP will increase too. Therefore, the capacities or positions of buffers also are influential factors in the design of manufacturing system. Although only a few buffers are supposed to be installed between machines, the throughput and WIP may have many variations.

Scenario 4.1(With Infinite Buffer Base on Scenario 1.1)

At first, we suppose that there is an infinite buffer between every upstream and downstream machine, and the simulation model is based on the model in Scenario 1.1. Then the throughputs of A, B and C lines are 78957, 79153 and 79181, and the average WIPs are 753, 397 and 490 respectively. The average WIP of A line is almost twice than that of B line, although the throughput is similar.

Scenario 4.2(With Infinite Buffer Base on Scenario 2)

Similar with scenario 2, two independent tool change events are set into all machines of B line, and M3 and M4 machines in C line. In addition, an infinite buffer is also allowed between every upstream and downstream machine. Then the throughputs of B and C lines are 76197 and 76003, and the average WIP is 214 and 2505 respectively. Obviously, the average WIP of C line is too high, and it is almost ten times than in B line. The reason is that the buffer between serial and parallel structure machines(machine 2 and machine 3, 4) has a serious crowded queue problem, because in this scenario, the parallel structure machines are the bottleneck of whole cylinder block line.

Scenario 5.1~5.2(With Finite Buffer Base on Scenario 3)

In these scenarios, we focus on finding out how the buffer capacity affects the performance of product line when there is a bottleneck machine. However, only the situation when bottleneck exists at the end of line by changing CT is chosen as the basic model, because when the bottle-neck machine exists at the upstream machines, small buffers for downstream machines are required. We make two options for the experiments, one is that there is an finite buffer between every upstream and downstream machines, the other is that there is only one finite buffer before the bottleneck machine.

Table 8. Throughput Result of Scenario 3

Buffer Capacity	Scenario 5.1		
	A	B	C
1000	59730	59741	59723
100	59730	59741	59723
10	58120	59493	59326
9	57773	59410	59190
8	57351	59159	59004
7	56821	59126	58753
6	56153	58895	58411
5	55290	58596	57938
4	54180	58165	57274
3	52706	57496	56347
2	50664	56467	54977
1	47633	54863	52783
0	42223	51926	48770

Table 8 shows the result of first option. It is found that once the buffer size is more than 100, the throughput dose not increase any more, and this is related with the maximum utilization of bottleneck machine. Figure 12 shows the decline rate of throughputs when the buffer size is decreasing. Obviously, in the second option, when there is only one buffer ahead of the bottleneck machine, the throughput is less than the first option, but the decline rate has smooth slope.

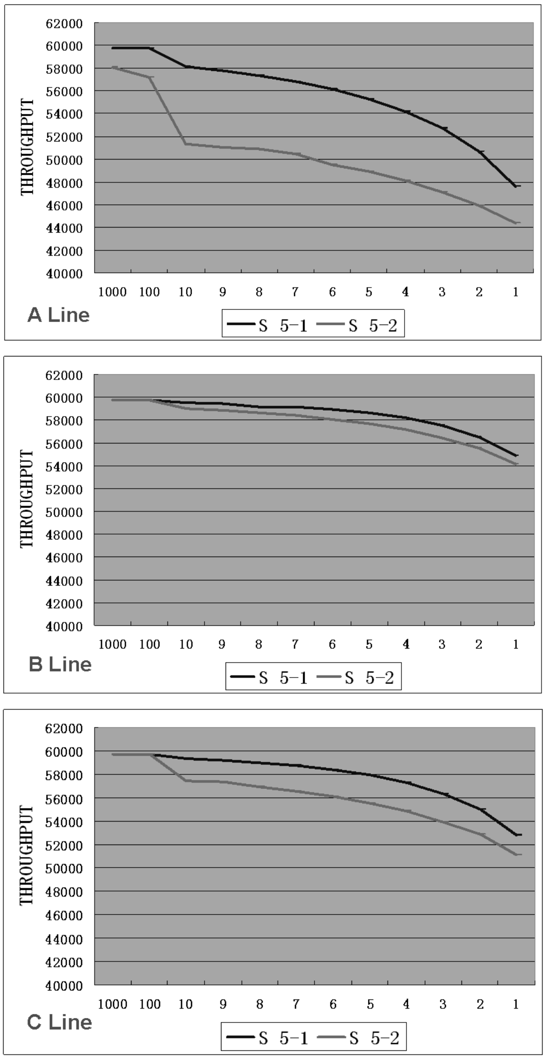

Fig. 12. Throughput Decline Rate by Buffer Size

Scenario 6(Parallel Connected Method)

This is an extended experiment for the concept of parallel machines, because the different connecting method may cause the different performance. Base on the research before, we divided the connecting methods into two types, one is "connected cell", and the other is "disconnected cell"(see Figure 13). Then, the disconnected type also is composed with two different types, one is "disconnected cell with partial flexibility", and the other is "disconnected cell with complete flexibility". Therefore, there are total three connecting methods, as shown in Figure 13. The difference between connected and disconnected methods is in that the downstream machine receives a part from one or more upstream machines. Practically the parallel machines with connected method are directly connected using conveyor or transfer.

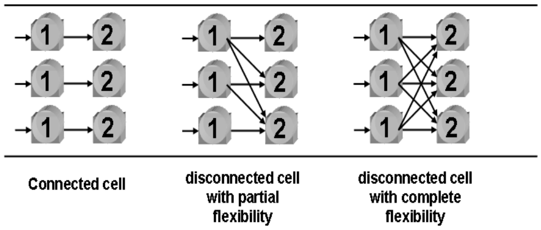

Fig. 13. Parallel Connected Method

On the other hand, the disconnected parallel machines

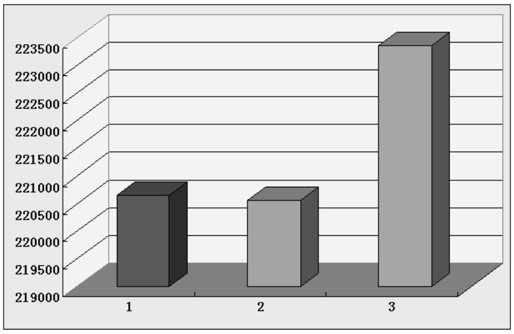

Fig. 14. Throughputs of different connected parallel machines

mostly can not be connected by common automatic transfer system, because the upstream machine supplies a part to more than one downstream machines. In this case additional dispatching machine is required in practice.

Figure 14 shows the throughputs of the three types of connecting methods in parallel machines. For the convenient explanation, let's denote T1 as "connected cell", T2 as "disconnected cell with partial flexibility" and T3 as "disconnected cell with complete flexibility". Obviously, the throughputs of T1 and T2 are similar, but the throughput of T3 is greater than T1 and T2.

Base on the results of throughput, the T3 method has the best performance. However, in real factory, if we disconnect machines for transferring the part from upstream machine to downstream machine, the labor or advanced dispatching control system using hardware should be applied, and this may increases the invest cost.

6. CONCLUSION

In this paper, a simulation study on the design concept of the manufacturing system for automotive engine is discussed. Simulation technology is applied for comparing and analyzing the line efficiency of three different cylinder block lines, which have the similar process sequence but quite different layout and structure. It is related with the choice for combination of serial or parallel machines in a transfer line.

Results of experiments indicate that the B line has the best performance in every scenario, but in some scenarios, C line also has almost the same results with B line. From the experiments, we can conclude as follows.

At first, the workload allocation is very important factor that can affect the throughput of product line. If the workloads of the different line structure are same, changing cycle time or failure break make the similar decline rate. Secondly, line B shows the best performance in every scenario, but when there are buffers between machines, C lines almost has the same performance in throughput with B line. The third conclusion is that the performance of "disconnected cell with complete flexibility" is much better than the other two connecting types. With this research, we try to suggest a way to get the best layout concept when design a new transfer line is needed. The conclusion can be applied not only in the automotive engine line but also in the other transfer lines.

In fact, many researches using queueing network have been developed for analyzing the manufacturing design concept. However, mathematical modeling approach is very restricted since it is difficult to make the models considering various design factors. Furthermore, it is more difficult to solve the problems mathematically, and thus various kinds of decomposition and approximation methods are researched. In the queueing network, more design parameters mean tremendous number of states. This is the reason why simulation is better than mathematical approach. For further research, the design concept in an assembly line(for example, body shop in an automotive factory) should be analyzed in a similar way.

References

1. Choi, S.D., Kumar A.R. and Houshyar A., "A Simulation Study of an Automotive Foundry Plant Manufacturing Engine Blocks", Proceedings of the 2002 Winter Simulation Conference, San Diego, pp. 1035-1040, 2002.
2. Gershwin, S., Manufacturing System Engineering, Prentice-Hall International, London, U.K., 1994.
3. Jayaraman, A. and Agarwal A., "Simulating an Engine

Plant”, Manufacturing Engineering, Vol. 117, No. 5, pp. 60-68, 1996.
4. Magazine, M.J. and Stecke, K.E., “Throughput for Production Lines with Serial Work Stations and Parallel Service Facilities”, Performance Evaluation, Vol. 25, pp. 211-232, 1996.
5. Manitz, M., “Queueing-model Based Analysis of Assembly Lines with Finite Buffers and General Service Times”, Computers & Operations Research, Vol. 35, No. 8, pp. 2520-2536, 2008.
6. ManTech Task Force., DOD's manufacturing technology (ManTech) program, Technical report, ManTech, 1994.
7. Moon, D. H., Sung J. H. and Cho H. I., “A Case Study on the Verification of the Initial Layout of Engine Block Machining Line Using Simulation”, Journal of Korea Society for Simulation, Vol. 12, No. 3, pp. 41-53, 2003.
8. Moon, D.H., Xu, T. and Shin, W.Y., “A Case Study of Simulation for the Design of Crankshaft Line in an Automotive Engine Shop”. Journal of the Korea Society for Simulation, Vol. 17, No. 2, pp. 1-12, 2008.
9. Oh, P.B., Rim, S.C. and Han, H.S., “Improved Design of Engine Manufacturing Line Using Simulation”, Journal of Korea Society for Simulation, Vol. 9, No. 1, pp. 1-8, 2000.
10. Papadopoulos, H.T. and Heave, C., “Queueing Theory in Manufacturing Systems Analysis and Design: A Classification of Models for Production and Transfer Lines”, European Journal of Operational Research, Vol. 92, No. 1, pp. 1-27, 1996.
11. Spieckermann, S., Gutenschwager, K., Heinzel, H. and Voß, S., “Simulation-based Optimization in the Automotive Iindustry - Case Study on Body Shop Design”, Simulation, Vol. 75, No. 5, pp. 276-286, 2000.
12. Tempelmeier, H, and Bürger, M., “Performance Evaluation of Unbalanced Flow Lines with General Distributed Processing Times Failures and Imperfect Production”, IIE Transactions, Vol. 33, pp. 293-302, 2001.
13. Tumay, K., “Business Process Simulation”, Proceedings of the 1996 Winter Simulation Conference, pp. 93-98, 1996.
14. Ulgen, O., Gunal, A. Grajo, E. and Shore, J., “The Role of Simulation in Design and Operation of Body and Paint Shops in Vehicle Assembly Plants”, Proceedings of the European Simulation Symposium, Society of Computer Simulation International, pp. 124-128, 1994.

허 특 (xute2004@gmail.com)

2002 중국 동북대학교 컴퓨터과학과 공학사
2004~ 창원대학교 산업시스템공학과 공학석사
2006~2010 창원대학교 산업시스템공학과 공학박사

관심분야 : 3D 시뮬레이션, 공장 Layout 설계

문 덕 희 (dhmoon@changwon.ac.kr)

1984 한양대학교 산업공학과 공학사
1986 한국과학기술원 산업공학과 공학석사
1991 한국과학기술원 산업공학과 공학박사
1990~현재 창원대학교 산업시스템공학과 교수

관심분야 : Facilities Planning, 시뮬레이션 응용, Scheduling

신 양 우 (ywshin@changwon.ac.kr)

1984 경북대학교 수학과 이학사
1986 한국과학기술원 응용수학과 이학석사
1991 한국과학기술원 수학과 이학박사
1991～현재 창원대학교 통계학과 교수

관심분야 : 응용확률론, Queueing Theory

정 종 윤 (jyjung@changwon.ac.kr)

1980 한양대학교 산업공학과 공학사
1987 미국 Ohio State University 산업시스템공학과 공학석사
1991 미국 West Virginia University 산업공학과 공학박사
1992～현재 창원대학교 산업시스템공학과 교수

관심분야 : CAD/CAM, 곡면의 설계 및 가공, 역설계