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Research Article

Smart Analyses and Diagnoses of Piston Product Line Based on Virtual Manufacturing Technology

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Abstract: The virtual simulation was used for designing and rebuilding product line according to real work conditions. The simulation software QUEST was used for analyzing the appointed piston product line in this example. After modelling and simulating, some factors which caused bottle-neck processes were found. The utility ratio of machines and productivity of workers were irrational after investigating the actual working environment. In order to improve the productivity, some measures were taken to integrate the whole process, such as realigning machines, adjusting utilities ratio of machines, improving walking mode of workers, increasing the transfer canals and rebuilding product line in the virtual environment. The results showed that product line implementing the above measures could improve the productivity and the bottle-neck problem was resolved in the virtual environment.

Keywords: Bottle-neck process, design and diagnoses of product line, virtual manufacture, visual technology

INTRODUCTION

As is known, the product line of piston was complex because there were about twenty processes for machining piston. The sketch of piston structure was as Fig. 1 and there were lots of characters on it. On the piston product line, the machining efficiency was influenced by machining time, assistant time, conveying time and so on Xue-Feng *et al*. (2009). The design and adjustment of product line were analyzed by virtual manufacturing technology in this example. This new and celerity method was used on designing and reforming the layout of piston product line.

Analyzing were brought on designing machining pro the ‘a flow’ of product line was the ideal situation which had no stock in product line (Cser *et al*., 2000). How to realize the ‘a flow’ were not only just technical problems, but also systemic management problems which was a long-term perspective on economic impact. The ‘a flow’ was not only for technical and management reforms, but also a new production management concept and its popularization and application accorded with the current transformation of the companies (Korves and Loftus, 2000; Drira *et al*., 2007; Justin, 2001; Ray and Tomas, 1998).

Recently, due to particular requirement of customer and the fast updating of product, the enterprise must respond the market quickly by frequent changing products and agile manufacturing (Russell and Kai-Yin, 1996; Gunasekaran *et al*., 1999; Yin *et al*., 2002). So whether the product line was excellent became the important key to occupy the market rapidly (Zhao *et al*., 2005). The agile manufacturing pattern was correlate

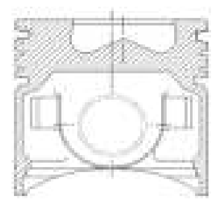

Fig. 1: The sketch of piston

with the design of manufacturing system tightly. Furthermore, the design of the product line was the base of manufacturing system.

However, the traditional design methods of product line had some defects as follows: analyses on product line were unilateral and static, the description of dynamic character for manufacture system was scarcely used in designing course; the period of design was too long and complex, the whole period must depend on experience of designer; it was too difficult to reflect the actual problems of workshop and the running status of manufacturing system directly (Zhao *et al*., 2004; Liangyu and Rakesh, 2002; Jeffrey, 2003; Gertosio *et al*., 2000). Compared with traditional methods, the virtual design of product line was based on computer technology and simulation technology. The design methods used all kinds of data, tables and figures, multimedia and so on to simulate the actual running status. In simulation environment, modelling and analyzing were brought on designing machining processes.

The configurations which were used for virtual design of product line were clear in this example,

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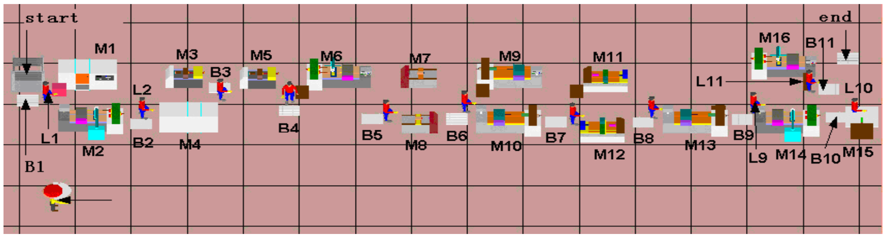


Fig. 2: Bird's eye layout of the rebuild product line in simulation environment

including higher quality figures; convenient equipments; intuitional displays, virtual glasses, headpieces and data gloves; rapid computational abilities and so on. The new technology improved the application value of virtual design of product line. In the future, the virtual environment would include vision, imagination and touch. The improvement would bring virtual reality technology into a more comprehensive field. It must be a powerful and excellent forecast method for designing product line and factory layout.

METHODOLOGY

- **Investigation of product line:** The mentioned product line was a piston manufacturing system. The product line adopted the traditional production mode which single machine completed one process. The system ignored the capability and precision of different machines. So the time of every machine and the cycle time of line were illogical which brought on a mass of parts overstocked on buffers among some processes. Furthermore, the line had large rigidity, if the kinds of parts were transformed frequently, then the adjustment of clamp and measure needed a long time. Thereby, it was not the ‘a flow’ which had no block. It could not respond the market design requirement rapidly and was difficult to adapt the market alternation. The simulation layout of the real product line was as Fig. 2.

In actual environment, the current management model was hierarchical. There were a monitor and some workers in product line. The workers were differentiated as specialized worker and apprentices. The group lacked self-management and self-discipline.

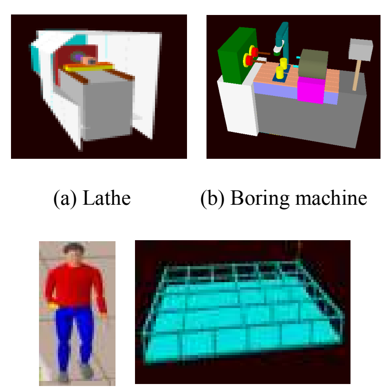
The processes data of product line were investigated in workshop. The study hours of workers were 8 h per class, including 1 h for maintaining machine and 7 h for manufacturing. The time for servicing machine; failure distributions; break time of workers and distributions of exchanging tools were included in the rest time as 30 min/class. The step velocities of workers were uniformly defined as 800 mm/s. The processes data were as Table 1.

- **Modelling and simulation:** In order to gain the corresponding designing and decision-making data,

Table 1: The process data of product line P- process no., M- machine no

P	M	Number	Worker	Cutting time/s
P1	M1	1	L1	36
P2	M2	1		36
P3	M3	2	L2	68.8
	M4			68.8
P4	M5	1	L3	31.2
P5	M6	1	L4	29.3
P6	M7	1	L5	36
P7	M8	1		36
P8	M9	1	L6	36
P9	M10	1		36
P10	M11	2	L7	61.6
	M12			61.6
P11	M13	1	L8	29.25
P12	M14	1	L9	34.4
P13	M15	1	L10	14.7
P14	M16	1	L11	39

Fig. 3: Local scene of product lin



(a) Lathe (b) Boring machine

(c) Worker (d) Buffer

Fig. 4: Some models in product line

QUEST. The geometry model of product line was re-established in computer by measuring the machines, buffers, workers and so on precisely. the whole product line was simulated by software

According to the real product line, the virtual line was arranged with all equipments on their right positions. The three-dimensional layout model of product line was reappeared in simulation environment as Fig. 3 and 4.

The appointed product line did not belong to the central control system as automated product line. Therefore each device required manual control by workers, so workers were defined control logic in order to simulate the workers behaviours. The following acts were described: routes of workers and their walking speed; the number of parts which were taken by workers at one time; rest time of workers and their distribution; private affair leave and sick leave of workers and their distribution; the shift of workers; the actions of one worker including the movements of getting parts and unloading parts.

The logic model was programmed according to the actual situation, including step track of workers, the running time of machine and so on. The dynamic simulation carried through one hour, one class and one week in computer. The results showed that the positions of bottle-neck processes were clear at a glance as Fig. 2. In another way, the numbers of left parts were showed in database of simulation results. Some numbers of left parts on bottle-neck processes buffers were listed as Table 2.

The walk routings of workers were set as a real situation in simulation as Fig. 5.

As showed in Fig. 4, there were some parts on the B5, B6 and B11. It was obvious that the processes 5, 6 and 11 were the bottle-neck processes. The results of simulation accorded with the real scene.

After investigated, the bottle-neck processes were improved for optimizing the product line. According to the standard of real line, the B5 and B11 were the bottle-neck processes, they needed adjust. But if some parameters were adjusted just in bottle-neck processes, it was very possible to bring on others bottle-neck processes. So, the utilities ratio of machines and the productivities of workers were detailed analyzed at running time in order to provide the gist for balancing the product line.

In dynamic simulation environment, there were some factors blocking the flow of piston at some processes and the 'a flow' became impossibility. The main factors were as follows: the processing time of machines (processing parameters); the time of machine-assisted; walking speed of workers; state of workers; the number of devices; production management (period, workers, rest time and its distribution); production scheduling; the time of equipment maintenance, the maintenance rate.

- **The analyses of utilities ratio and productivities:** In simulation environment, the virtual product line was visible compared with real line. After simulation, the data for every unit were gained by statistics including running times, utilities ratio and so on. The utilities ratio of machines reflected the machining abilities in the processes, the productivities of workers revealed the busyness degree of workers. According to the data, it was known obviously the work intensity in one process.

Table 2: Left parts on bottle-neck processes buffers of different simulation time time-simulation time, B-buffer

Time	Number of B5	Number of B6	Number of B11
1 hour	17	6	15
1 class	52	13	40
1 week	205	48	95

Table 3: Utilities ratio of machines and productivities of workers P-process no., L-worker no., M-machine no

			Utilization (%)			
P	L	M	1 Class		1 Week	
P1	L1	M1	13.64	88.93	13.66	88.92
P2		M2		88.64		88.86
P3	L2	M3	23.06	85.68	22.91	85.01
		M4		85.72		85.11
P4	L3	M5	14.78	78.02	14.63	77.25
P5	L4	M6	19.45	73.52	19.18	72.50
P6	L5	M7	23.64	83.03	23.68	83.02
P7		M8		82.90		82.98
P8	L6	M9	26.62	81.55	26.63	81.66
P9		M10		81.69		81.69
P10	L7	M11	17.68	71.08	17.42	70.16
		M12		71.27		70.13
P11	L8	M13	16.28	68.45	15.89	66.78
P12	L9	M14	15.02	80.96	14.60	78.63
P13	L10	M15	8.89	34.57	8.60	33.42
P14	L11	M16	13.77	86.23	13.77	86.23

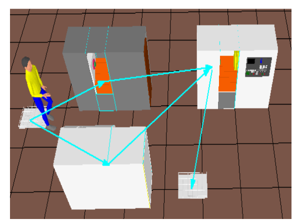


Fig.5: The routing of one worker in simulation

The utilities ratio of machines and the productivities of workers provided the load situation in the product line. At the same time, they were the data which were propitious to production management integrating with abilities of equipments and workers. At the beginning of building the workshop, they were the important data for optimizing, adjusting and reforming the product line. The utilities ratio of machines and the productivities of workers were listed in Table 3 with 1class and 1week.

The productivities of workers and utilities of machines were as Fig. 6 and 7. As showed in Fig. 6, the productivities of workers were all less than 30 percent in different processes. Among the different processes, the productivities were inequality; the maximum productivity was about 3 times than minimum. Obviously, working intensities of L1, L3 and L10 were

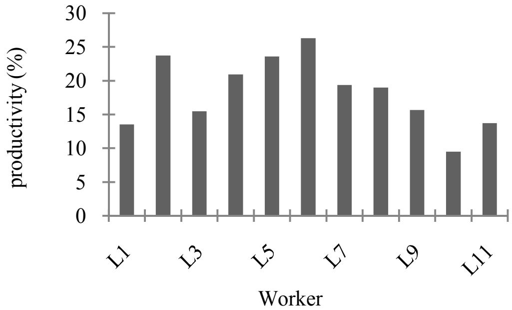


Fig. 6: Productivities of workers

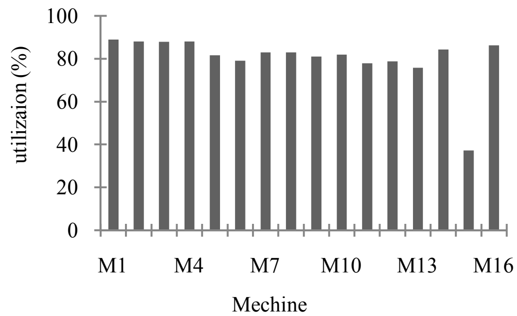


Fig. 7: Utilities ratio of machines

lower than other processes. The working intensities of L2, L5 and L6 were higher than other processes.

As showed in Fig. 7, the utilities ratios of machines were equilibrium by and large. The utility ratio of M15 was lowest in all processes reached 37%. After investigating the phenomena, the former process was the bottle-neck process because the machining time was very short in M15 which brought on much leisure time and lowest utility ratio.

RESULTS AND DISSCUSSION

The aim of simulation was to investigate bottle-neck processes and rebuild the product line. There were some factors must be adjusted for improving the productivity. So in simulation environment, some different adjustment situation were built, such as adjustments of utility ratios of machines and processes parameters, improving walking mode of workers, increasing the number of machines which were operated by workers, increasing the transfer canal for reducing the transit time and reforming the layout of product line.

- **Aadjustments of utility ratio of machines:** The utility ratios of machines and the productivities of workers reflected the busy or leisured situation of whole product line and provided the basic data for diagnosing the bottle-neck processes. So the reform of product line depended on above data as following rules. Firstly, the product line was rearranged and the workers were optimized and adjusted to operate suitable machines according to simulation results. Secondly, the manufacturing technology was improved including production plans and managements, group managements, workers qualities, cutting parameters. The cutting parameters were the most important key for reforming. Thirdly, after the manufacturing technology was decided, the equipments were rebuilt for combining processes and multi-abilities machines were reformed for manufacturing part.

Based on original product line, the simulation showed that the P6, P7, P8, P9 and P14 were the bottle-neck processes. According to the scene condition and manufacturing abilities of M7, M8, M9, M10 and M16, the cutting parameters were adjusted to 33.2s, 33.2s, 33.6s, 33.8s and 34.3s; the worker L10 operated the M15 and M16, the worker L11 and buffer B11 were canceled. After simulated one class, the left parts on B5, B6 and B10 were 12, 12 and 10; the output of one class was 569 pistons. The average manufacturing technology time was about 41.2s. The utility ratio of machines and productivity of workers trended to the average. The simulation results were satisfied with the requirement of equilibrium of product line, although the adjusted project was not the best optimization, it satisfied the requirement of workshop and the course time was very quick, the cost was very low. Figure 8 was the simulation of rebuilt product line.

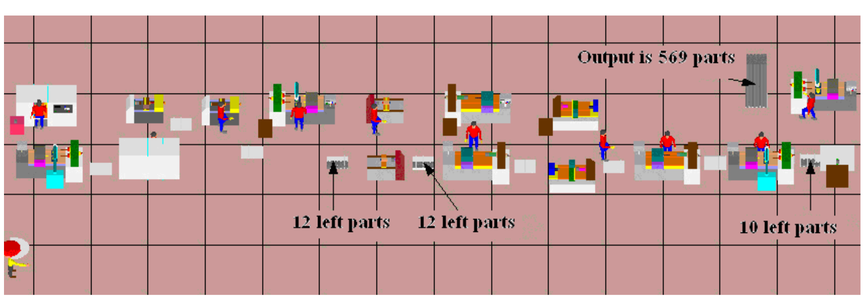
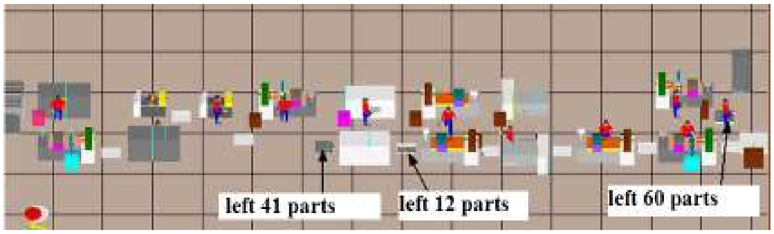
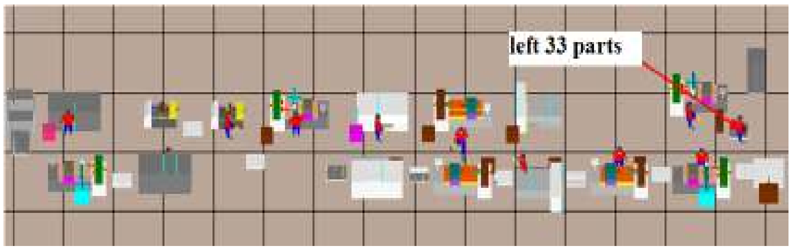


Fig. 8: The simulation results of rebuilt product line



(a)



(b)

Fig. 9: The contrastive results with different walking speed, (a) The left parts on buffers when walking speed was 0.8m/s, (b) The left parts on buffers when walking speed was 1.2 m/s

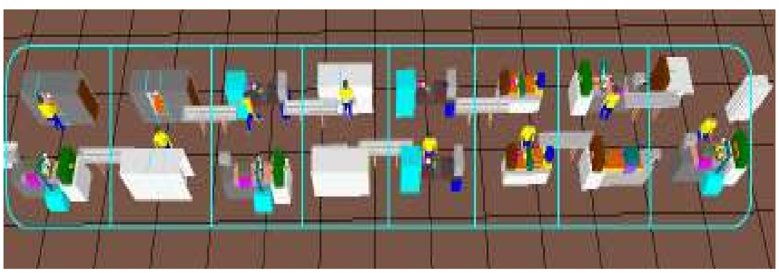


Fig. 10: The layout of product line with transfer canals

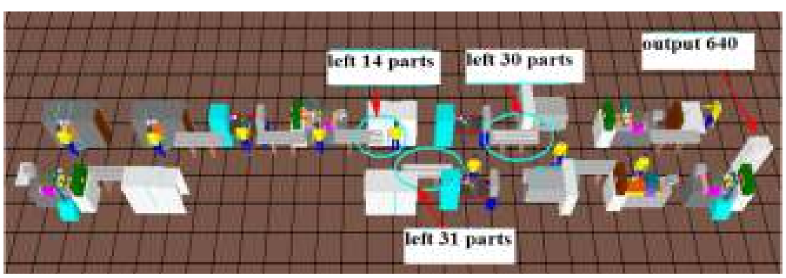


Fig. 11: The simulation results of product line with transfer canals

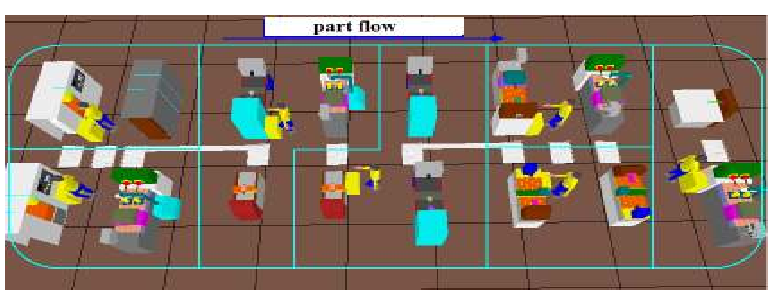


Fig. 12: The layout of reforming product line

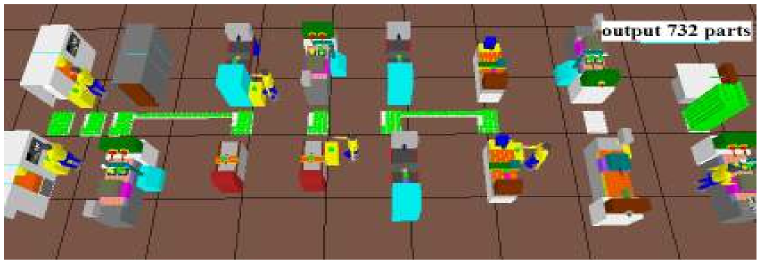


Fig. 13: The simulation results of reforming product line

- **Improvement of walking mode of workers:** Based on original product line, the simulation showed that workers' walking speed was 0.8 m/s, undoubtedly the improvement of workers' walking speed of bottle-necked processes could gain more productivity. A blue print of simulation increased the walking speed of workers of L5, L6 and L11 from 0.8 m/s to 1.2 m/s and the walking strategy became straight. After simulated one class, the left parts on B10 were reduced from 60 to 33. The contrastive simulation results were as Fig. 9a and b.
- **Increasing the transfer canals:** In the product line, the transfer canals were added for conveying parts, in order to reducing the work intensity and walking distance of workers. The blue print of simulation was as Fig. 10, it showed that the parts were taken to transfer canals by workers after manufactured and the number of workers was reduced from 11 to 9. So the manufacturing cost was decreased by product line reforming.

The simulation results of product line with transfer canals were as Fig. 11. It showed that the output of per class was 640 parts and the output was higher than the previous model. But there were some left parts on transfer canals.

- **Rebuilding product line by integrating processes and realignment of machines:** The product line was realigned based on integrating processes. After investigated, some processes were integrated in one process. Every machine burdened more tasks for machining parts. So the utility ratio of machines became higher than previously real situation. And then, the number of workers was reduced from 11 to 7, the cost of workers was saved by reforming. The layout of product line was as Fig. 12.

The simulation results of reformed product line with transfer canals were as Fig. 13. It showed that the output of per class was 732 parts and the output was more than the previous model.

CONCLUSION

- The analysis and diagnoses of product line based on virtual manufacturing technology were used for reforming piston processes. The virtual design and modeling method were introduced through the real case. After research and rebuilding, the utility ratio of machines and the productivity of workers trended to average and the bottle-neck processes were solved quickly and basically through visual simulation and adjusting the manufacturing technology.
- The methods with virtual design and simulation not only simulated the product line status rapidly by dynamic diagnosing the bottle-neck processes, but also provided the basic data for adjusting and optimizing product line. So this method could design, analyze and rebuild the product line rapidly. It was a predictable analysis method for manufacturing programming of production in order to response the market and satisfied the individual requirements of clients.
- The rational design of product line with virtual manufacturing technology was proved not only feasible, but also rapid and efficient for rebuilding of product line. Under the given boundary conditions, product line could be preliminary simulated according to the real conditions of situation. The simulation results could respond the alterative conditions quickly. Based on product line simulation results, initial improvements were rebuilt rapidly in the virtual environment and easy to analyze the results and optimize the different improving projects
- Recombinant of processes, equipment renewal and changing the layout of workshop were preferred for rebuilding a new line. If a product line needs to be rearranged, the cost would include the equipment cost, tooling, transfer canals and so on which must be considered. The method needed more financing for reforming. A simple method for rebuilding product line was improving the processes conditions. Processing capabilities of machines were increased for solving bottle-neck processes. The method could be used for rebuilding line in low cost. The method with transfer canals could improve the manufacturing conditions of product line, increase the output and reduce the work intensity. But this method needs investments in transfer canals and the production was closely related with various devices. To reduce the number of workers was another method for reforming

product line. This method doesn't need invest, but increased work intensity and the output was low.

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