Production line optimization based on Man-Machine collaborative improvement

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Abstract. In many cases industrial companies’ efficiency is limited by bad man-machine collaboration. In the time of intelligent manufacturing, more data can be collected and help companies to improve their efficiency. Therefore, a production line optimization method based on Man-Machine collaboration with the help of big data tools and sensors is introduced. At first, the production line will be analyzed and main data as machine cycle time, personnel operation time, task distribution etc. will be collected. Then based on these data, a simulation model will be made in plant simulation. After that, the performance of the production line will be evaluated considering the man-machine collaboration, work task distribution etc. and the optimization will be made. Afterwords, the machine cycle time, operator motion track and labor operation time in real production situation will be collected to compare and validate the optimization model.

1. Introduction
Man-Machine systems exist in many manufacturing companies, and as a very important element influences the efficiency of the manufacturing system, especially in the time with high uncertainty.

But in many cases, production lines cost millions euro but its efficiency is limited because of the bad man-machine collaboration, which leads to waste of investment and resources, and also restricts further development of the company[1].

Therefore, over the past decade, many researches focus on the optimization of man-machine collaboration. Lu et al. introduced a method which emphasizes human role in the manufacturing system, humans and machines cognize, perceive and cooperate together, then make the best performance synergistically [2]. Schlick et al. made a comparative study on autonomous manufacturing unit and traditional flexible manufacturing unit, with the help of simulation, the man-machine collaboration was evaluated from the aspects of work efficiency and task division [3]. Robinson et al. presented a method which uses neural network and other algorithms to find the best solution with various decision rules [4]. Li proposed a method which uses restarted simulated annealing algorithm to improve the assembly line’s cycle time and man-machine relationship. Comparing to traditional method, it has better capability in both convergence and spread criteria [5]. Yang researched the influence on production line because of uncertainty, dynamic of people’s work mode and behavioral, then built a model to simulate man-machine collaboration in production cell and find the best solution [6]. Zhao et al. studied deeply on the performance of man-machine system considering dynamic scheduling problem and developed a software to realize fast scheduling according to the quick market fluctuation [7]. But because of the complexity and diversity in industrial field, simulation result usually has big difference to real production situation. Therefore, a method considering both simulation and real production situation is proposed.
The following parts of this paper are organized as follows: in section 2 the optimization approach based on man-machine collaboration is briefly presented, then in section 3, a case is applied to validate the proposed approach. Finally, the main conclusions and future researches are summarized in section 4.

2. The optimization approach

In this section, the optimization approach based on man-machine collaboration is briefly introduced. The process is shown in Figure 1.

At first, the production line will be analyzed and main data such as machine cycle time, personnel operation time, task distribution etc. will be collected. Then based on these data, a simulation model will be made in plant simulation. After that, the performance of the production line will be evaluated considering the man-machine collaboration, work task distribution etc. then the optimization will be made. Afterwords, the machine cycle time, operator motion track and labor operation time in real production situation will be collected to compare with the optimization model.

2.1. data collection and building simulation model

The production line will be analyzed, the machine cycle time, personnel operation time, task distribution etc. will be collected and the man-machine relationship as well as the whole line cycle time will be calculated.

Then based on Plant Simulation which helps to create production systems’ digital models and to explore the production systems’ characteristics as well as to optimize their performance. It can help to run experiments and what-if scenarios before the production system is build up or without disturbing an existing production system [8].

After analysis of the production system and data collection, the simulation model can be made. Not only the man-machine relationship but also the fluctuation of cycle time, MTTR (mean time to return), failure rate etc. can be also considered in the simulation model.
2.2. Simulation result analysis and optimization
After the simulation model is built up, then the simulation model will be run, and some critical criteria can be set and be tracked.

2.3. Data collection in real time
After the optimized simulation model is fixed, then in real production situation, data (order data, machine data, labor data etc.) will be collected in real time.

Order data will be acquired from MES (Manufacturing Execution System), machine data will be acquired by certain sensors and intelligent gateway which can make the communication protocol resolution. But the labor data especially the labor motion track which is the foundation of man-machine collaboration analysis, is really difficult to be acquired. Traditional technology as WIFI is easily disturbed in the complex industrial situation, therefore it can not provide a stable and high accurate location tracking service. After a lot of experiments and comparison, UWB (Ultra Wideband) is chosen to make the labor motion tracking with high accuracy.

UWB is a wireless solution for communications, and can transmit the message among peoples and devices. It has three characteristics: 1. Ultra wide band which is authorized in the range of 3G-5G, 6G-10G total 7G frequency band; 2. low-power characteristic; 3. Ultra-short pulse which can last less than 1ns.

Because the characteristic of UWB, it is quite suitable to make highly-accurate location tracking. The device using UWB can not only identify the distance but also the location of other devices with the accuracy of 10cm. Comparing to Wi-Fi and Bluetooth which use narrow frequency ranges to do the communication among devices, UWB uses a far larger frequency band to transmit data.

In this system, effective working area of operator will be set, and the labor motion will be tracked. With comparing to the labor motion tracking, the performance of the labor can be analyzed:
1. If the percentage of motion track outside the effective working area is more than the threshold value, warning message will be given;
2. If the movement distance lower than the set threshold value, then the warning message will be given;
3. If the motion track is estimated as normal, then the motion will be analyzed, and the time of every motion cycle will be calculated as labor operation cycle time, and to analyze with machine cycle time. If the labor operation cycle time is longer than machine, warning message will be also given;
4. Man-machine relationship will be calculated.

2.4. Result comparing
After the simulation result and the result in real production situation are collected, two results will be compared, the optimization result will be found according to the comparison results.

3. Case study
In this section, a semi-automation assembly line for bearing is studied: the customer demand is 8200pic/d, the production is organized 3 shifts/d, 7.5 hour/shift, the OEE (Overall Equipment Effectiveness) is 85%. Therefore, the Takt time for this assembly line is 8.39s.

The semi-automation assembly line for bearing contains 16 workstations, 4 workers are arranged in this assembly line. Every workstation is assigned to finish certain tasks with certain process time and workers carry pieces of product from one workstation to another as well as make some treatment (e.g assemble different parts together and packing). Process time of workstations is stable and the worker operational time follows the normal distribution.

Then the simulation model is built up by plant simulation. 1 worker is arranged to operate workstation 1-5, 1 worker is assigned to operate workstation 6-9, 1 worker is responsible for workstation 10-13 and the last one is in charge of workstation 14-16.

The initial information (load-unload time, treatment time, process time and MTTR (Mean Time To Repair)) of the assembly line is shown in Table 1.
Table 1  Information of the bearing assembly line

| Workstation | Worker | Load-unload time(s) | Treatment(s) | Process time(s) | MTTR min |
|-------------|--------|---------------------|--------------|-----------------|----------|
| AP1         | Worker1| 0.0                 | 0.9          | 5.4             | 0        |
| AP2         | Worker1| 0.7                 | 2            | 3               | 0        |
| AP3         | Worker1| 0.7                 | 1.6          | 5               | 60       |
| AP4         | Worker1| 0.3                 | 0.6          | 6.4             | 0        |
| AP5         | Worker1| 1.0                 | 0            | 2               | 0        |
| AP6         | Worker2| 0.0                 | 1.8          | 6               | 60       |
| AP7         | Worker2| 0.7                 | 0.7          | 1.1             | 0        |
| AP8         | Worker2| 0.3                 | 0.7          | 5.5             | 60       |
| AP9         | Worker2| 1.0                 | 2.2          | 3               | 60       |
| AP10        | Worker3| 0.0                 | 0.8          | 6.5             | 0        |
| AP11        | Worker3| 0.7                 | 2.5          | 3.1             | 0        |
| AP12        | Worker3| 0.0                 | 0            | 4.4             | 0        |
| AP13        | Worker3| 1.0                 | 2            | 5               | 0        |
| AP14        | Worker4| 0.0                 | 2.5          | 5               | 120      |
| AP15        | Worker4| 0.7                 | 0.8          | 6.5             | 60       |
| AP16        | Worker4| 1.0                 | 1            | 3               | 0        |

The worker operational time (load-unload time and treatment time) for each worker and cycle time for each workstation are calculated in Figure 2 and Figure 3.

From Figure 3 and Figure 4 it is clear that both cycle time for each station and each worker is lower than Takt time, which means the performance of the semi-automation assembly line can meet customer requirement. The man-machine relationship is shown in Figure 6, it can be deduced that sometimes worker4 will be blocked, when worker 4 already finishes his tasks for AP16, AP14 and AP15, but the machine in workstation 15 still works for last part.

Figure 2  Operational time
Afterwards, the simulation model is run for 30 days in simulation situation, the average cycle time is 8.94s which means the solution cannot meet the customer requirement. The machine utilization and the worker utilization are shown in Figure 4.

From the Figure 5, we can see that worker 4 has 7.3% block time which is mainly occurred in bottleneck AP 15, therefore it will cause the increase of production cycle time. Meanwhile, except worker 4, worker 3 also has about 4.4% block time because of the operational time variation (follow the normal distribution), and it also occurred mainly in bottleneck AP13. Therefore, the AP13 and AP 15 should be optimized.

After deeply study in AP13 and AP15, some improvement is made:
1. By using two-hand operation, reducing move distance and improving fixtures, the treatment time of AP13 can be reduced to 1.3s;
2. By decreasing the pressing distance from 30cm to 15cm, process time in AP15 is reduced from 6.5s to 5.7s.

After the optimization, worker operational time and cycle time each station are shown in Figure 5 and Figure 6:

Afterwards, the man and machine data is collected in real time, and the labor motion is tracked.

Comparing the simulation result and result in real production situation, the average cycle time in real production situation is 8.23s which is a little bit higher than simulation result because workers need to treat some abnormal cases and bring material from former process at the time of material shortage.

4. Conclusions
In the time of intelligent manufacturing, everything is redefined, with the big data tools and sensors, more data is collected and analyzed, then help companies to improve their operation management.
In this study, a production line optimization model based on man-machine collaboration is introduced. With help of simulation model, the production line is simulated, man-machine relationship is studied and the optimization is made. Afterwards, by using certain sensors, intelligent gateway, the machine data is collected and with the help of UWB the labor motion track is also gotten. Then comparing with the result from simulation and real production situation, and the optimization is made.

![Operational time after optimization](image1)

**Figure 5** Operational time after optimization

![Workstation cycle time](image2)

**Figure 6** Workstation cycle time after optimization

In the future study, mechanism model as well as data model will be deeply researched and artificial intelligent algorithm will be introduced to make the optimization suggestion automatically which will help to make the optimization more efficiently and rapidly.

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