A Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity

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1. Introduction

Countries are promoting efforts to achieve carbon neutrality (CN), one of the Sustainable Development Goals (SDGs) adopted at the 2015 United Nations Summit [(1)]. A representative example is the 14th Five-Year Plan on Industrial Green Development in China.

Especially in the manufacturing industry, where energy consumption and environmental load emissions are high, working toward CN cannot be ignored; the challenge is to reduce the environmental load without reducing current productivity.

Therefore, the Mitsubishi Electric Group has proposed a production management concept called “Environment and Energy Just In Time” that treats productivity and environmental load equally and optimizes them, and aims to solve problems using this concept.

Using simulation technology, this paper proposes a Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity, which continuously helps to determine the optimal balance between productivity and environmental load, and describes the results of demonstration experiments at our factory and future prospects.

2. Environment and Energy Just In Time Concept

The Environment and Energy Just In Time [(2)] concept is a total optimization concept that strikes a balance between productivity and environmental load by supplying producer goods such as raw materials and labor, and resources related to environmental load such as electricity and water, to the required places, in the required amounts, and at the required times. Conventional factories have generally dealt with energy conservation and environmental load measures separately from production, and focused on improvements that are not related to production. Therefore, when complying with stricter environmental laws and regulations in the future, improvements in areas related to production will also be required, so there is a risk that productivity may deteriorate due to facility shutdown, etc. (Fig. 1). On the other hand, the Environment and Energy Just In Time concept treats environmental load measures and production equivalently and quantifies the impact of environmental load measures on production (quantity, time, etc.), thereby making it possible to realize operations that maximize productivity under the constraints of environmental laws and regulations (minimizing the deterioration of productivity). Here, “treating equivalently” means converting the production and environmental load of the factory into costs and evaluating them using a unified index.

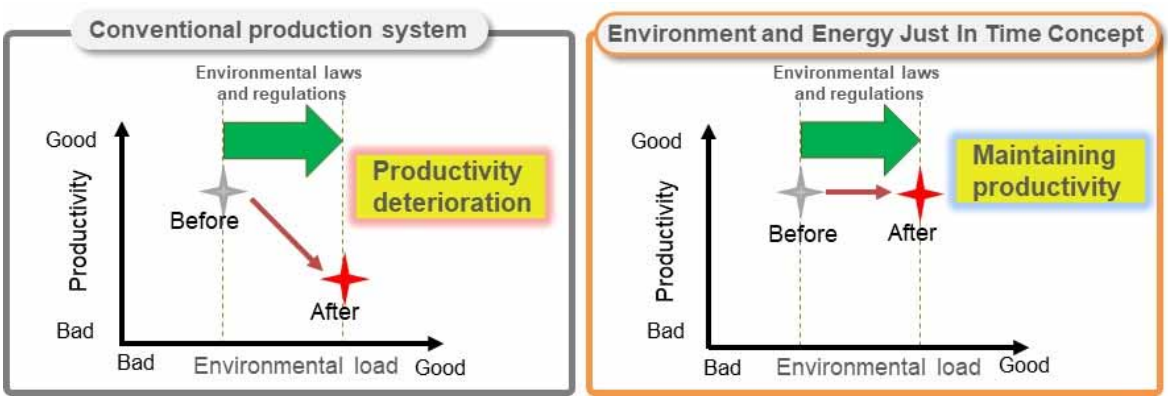

Fig. 1 Production management based on the Environment and Energy Just In Time Concept

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3. Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity

The Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity supports users (production site managers, etc.) in making improvements by presenting them with production operation plans and the magnitude of improvement effects that minimize the costs of producer goods and the costs associated with the consumption and processing of resources related to environmental load, while complying with environmental laws and regulations, before users start daily production.

To improve the efficiency of using this framework, we have developed a function to calculate baselines and optimal values from past production performance data, and a simulation function to calculate costs related to producer goods and environmental load using these values as parameters.

3.1 Calculation of baselines and optimal values

This section describes the method of calculating baselines and optimal values for the amount of electricity, water, gas, and other resources consumed in production, and the amount of greenhouse gases (CO_2) and other harmful substances emitted. In this case, the target is electricity consumption.

3.1.1 Method of calculating the baseline

Since electricity consumption depends on the product model and the operating state of the facility (startup, in production, shutdown, changeover, etc.), data aggregation is performed by combining the electricity consumption data with the production quantity performance data in preparation for calculating the baseline. As shown in Fig. 2, the median value obtained by excluding outliers is taken as the baseline from the electricity consumption data aggregated by product model and facility operating state. In other words, the baseline is the electricity consumption of the facility when "the user operates it normally." Since past experience suggests that it is rare for data to follow a normal distribution, the quartile method (box plot) was used as an outlier extraction method.

3.1.2 Method of calculating the optimal value

In the same way as calculating the baseline, the minimum value after excluding outliers from the distribution of the aggregated data was taken as the optimal value (Fig. 2). In other words, the optimal value is the electricity consumption of the facility when "the user can reach a certain level by operating it well." Here, apart from normal production, the reason for excluding outliers is that prototypes may be produced with a significantly exceeded cycle time (seconds/piece), or express orders from customers may reduce the cycle time of the original facility specifications.

3.2 Production/environmental cost simulator

Figure 3 shows an overview of the production/environmental cost simulator. This simulator adds an environmental cost simulator that calculates the amount of environmental load and associated costs, to the existing production cost simulator that calculates the usage and cost of producer goods [3].

3.2.1 Method of calculating the optimal value

This simulator inputs the three types of data shown in Table 1: production system parameters, environmental load/cost parameters, and production operation plan data, and outputs the amount and cost related to various producer goods and environmental load. Production system parameters and environmental load/cost parameters are static design data such as production capacity and the configuration of production facilities in the target factory. On the other hand, production operation plan data is dynamic data that changes each time the simulation is executed. With these detailed setting data, the behavior of the actual facilities can be

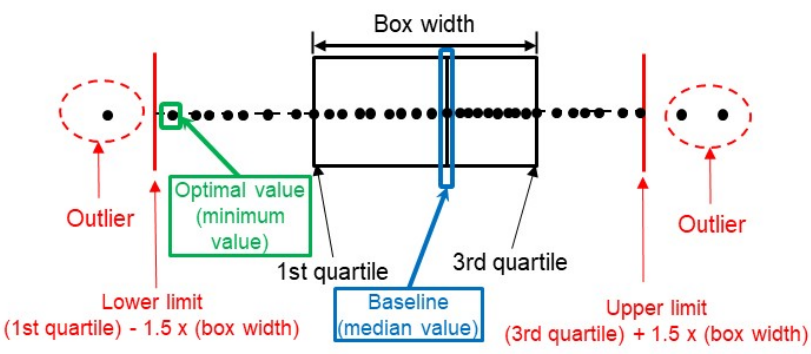

Fig. 2 Calculation of baseline and optimal values using the quantile method (box plot)

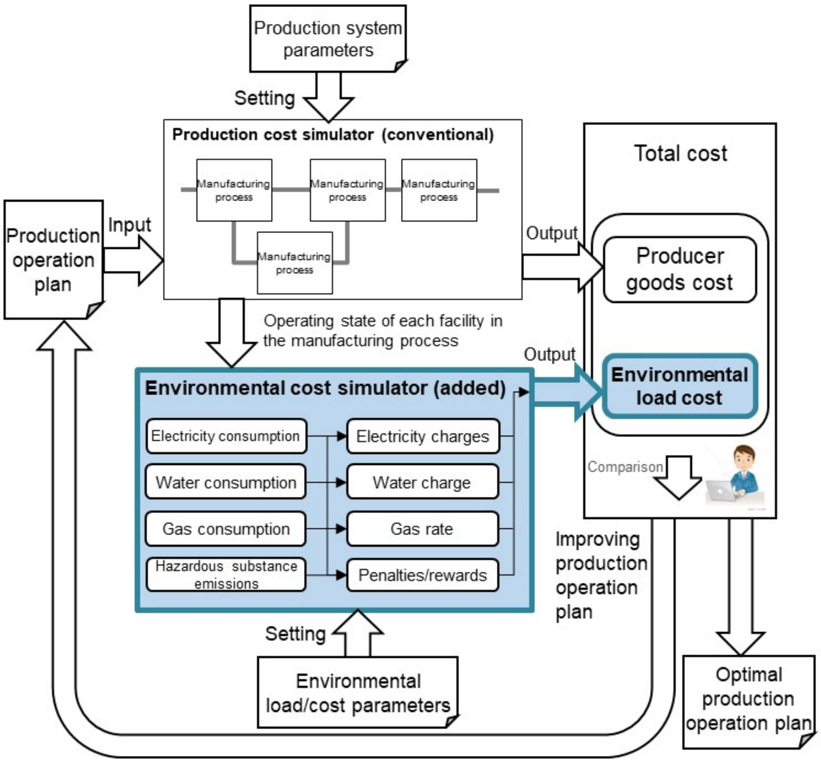

Fig. 3 Cost simulator for production and environmental load

Table 1 Input data of cost simulator for production and environmental load

Production System Parameters	Environmental Load/Cost Parameters	Production Operation Plan Data
・Production facility configuration (connection of the manufacturing processes) ・Manufacturing capacity (cycle time, lead time, etc.) ・Product model ・Amount of material used (per product) ・Labor (number of workers) ・Changeover time ・Work shift (hours) ・Workday calendar ・Unit price of producer goods	・Amount of environmental load for each operating state of various production facilities ・Price list for electricity, water, gas, etc. ・Penalties/rewards associated with environmental laws and regulations	・Production plan ・Facility operation plan

reproduced. The baselines and optimal values calculated in Section 3.1 are used as the above production system parameters and environmental load/cost parameters.

3.2.2 Usage method

According to various improvement plans, the production system parameters, environmental load/cost parameters, and production operation plan data are varied, and then the costs are calculated accordingly to confirm the effects of the improvement plans. It is assumed that the person in charge of improvement and the user will repeatedly change various data so as to maximize the improvement effect. However, since it takes many man-hours to search for the data that maximizes the effect, we are currently working on automating part of the production plan.

3.3 Procedure for implementing the framework

The Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity proposed in this study assumes that Steps 1 to 6 below will be repeated.

Step 1: Calculation of baselines and optimal values

Baselines and optimal values are calculated based on the performance data distribution of past consumption of resources such as electricity, water, and gas by production facilities and emissions of harmful substances such as greenhouse gases.

Step 2: Prediction of environmental load and cost when improvement measures are not applied

The person in charge of improvement enters the baseline and executes the simulation to calculate the amount and cost related to producer goods and environmental load under normal operation, that is, when improvement measures are not applied (hereafter referred to as the “unapplied value”).

Step 3: Prediction of environmental load and cost when improvement measures are applied

The person in charge of improvement reflects various improvement plans, such as shortening the facility startup/shutdown time and changing the combination of changeover, in the production operation plan and parameters, and calculates the amount and cost related to producer goods and environmental load by simulation (using the optimal value) (hereafter referred to as the “applied value”).

Step 4: Visualization of amount of improvement effect

To aim to bring the unapplied value closer to the applied value by applying various improvement plans, the difference between the improvement-unapplied value in Step 2 and the applied value in Step 3 is output and visualized as the amount of improvement effect.

Step 5: Improvement (by users)

The amount of improvement effect is presented to users, and after obtaining their approval, the improvement is performed mainly by the users.

Step 6: Analysis of differences between improvement-applied values and actual values

The person in charge of improvement collects the actual values during production, analyzes the causes of differences from the improvement-applied values, and extracts improvement plans for the next and subsequent times.

4. Demonstration Experiment

At an iron core press facility of our motor manufacturing factory, we conducted an experiment to demonstrate our view that it is possible to reduce environmental load without reducing current productivity, by using the Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity.

4.1 Experimental conditions

(1) Target production facilities

Three production lines in the factory, including motor iron core press facilities that consume a lot of resources related to environmental load (in this case, electricity consumption)

(2) Target period

About two weeks from January 31, 2022 to February 11, 2022

(3) Period covered by data used to calculate baselines and optimal values

April 1, 2020 to March 31, 2021 (1 year)

(4) Targeted producer goods and environmental load resources

- Producer goods: labor (labor cost)
- Environmental load resources: Electricity (electricity rate), CO_2 (emissions trading cost)

CO_2 emissions were converted from electricity consumption, and CO_2 emissions trading costs used in some provinces in China were used for CO_2-related costs (transaction rate: approximately 1,000 yen/t-CO_2).

(5) Improvement plan

If the constraint is set to prevent deterioration in productivity, such as product quality and delivery time, the following three improvement plans are possible in this case.

- Improvement plan 1: Changing the production sequence
- Improvement plan 2: Shortening the facility startup time (before starting production)
- Improvement plan 3: Shortening the facility shutdown time (after the end of production)

4.2 Experimental results and discussion

Table 2 shows an example of calculating the baseline and optimal value of electricity consumption for each operating state (startup, shutdown, changeover, in production) of facilities when producing the product model A by implementing Step 1 of the framework. Table 3 shows three types of costs (annualized) for producer goods and environmental load: improvement-unapplied values, applied values, and actual values, when one cycle (Step 1 to Step 6) of the framework is performed using the baseline and optimal value for each facility operating state of all product models, including the results shown in Table 2. In this experiment, we were able to reduce the environmental load and cost by 1.5% without reducing productivity (2.3% improvement in this case), mainly due to the effect of implementing improvement plan 3.

Table 2 Example of calculation of baseline and optimal values for electricity consumption

Product Model	Facility Operating State	Baseline	Optimal value
Model A	Startup	5.1 [kWh] (3 hours)	1.0 [kWh] (1 hour)
	Shutdown	3.2 [kWh] (2 hours)	1.0 [kWh] (1 hour)
	In prduction	2.3 × 10-3 [kWh/piece]	2.0 × 10-3 [kWh/piece]
Model A → Model B	Changeover	2.0 [kWh] (2 hours)	1.0 [kWh] (1 hour)

Table 3 Producer goods and environmental load costs in the first cycle of improvement

	Producer Goods	Environmental Load	
	Labor cost (ten thousand yen/year)	Electricity (ten thousand yen/year)	CO_2 (ten thousand yen/year)
Unapplied Value	555	322	18
Applied Value	453	272	15
Actual Value	542	318	17

Table 4 Improvement plans and effects after the second cycle

Problems	Improvement Plans	Electricity (ten thousand yen/year)	CO_2 (ten thousand yen/year)
The cycle time setting value in production is lower than the facility specifications.	Operating the cycle time setting value at the minimum value in the facility specifications	25.2	1.4
Due to concerns about equipment failure (controller board), the (facility) shutdown has not been implemented after the end of production.	Improvement of the heat environment inside the control panel (addition/replacement of heat exchangers)	8	0.4
	Isolation of problem areas (division of power circuits in the control panel)		
It takes a long time to replace materials each time.	Work standardization (Educate beginners on the efforts of experts)	1.8	0.1
	Improving the work environment (effective use of lighting such as headlights)		
	Improving jigs (for inserting material only)		

In particular, there was a 14% difference between the (improvement) applied values and the actual values regarding the environmental load cost. Therefore, we analyzed the factors through interviews with users and data confirmation, and identified the problems shown in Table 4. In order to solve these problems, we extracted the improvement plans after the second cycle and calculated the amount of effect, and found that the environmental load cost can be reduced by 420,000 yen/year including the cost reduction in the first cycle (Table 4).

This demonstration experiment showed that it is possible to reduce the amount of environmental load and cost without reducing productivity, but this did not lead to the implementation of production improvement considering environmental laws and regulations.

In addition, using data from a period different from that of this experiment, we have confirmed, in previous evaluations, that the differences between the unapplied values calculated by simulation and the actual values when improvement was not implemented were sufficiently small, that is, the differences were not large enough to misjudge the amount of improvement effect presented in this study.

5. Conclusion

This paper proposed the Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity to help determine the optimal balance between productivity and environmental load.

The results of the demonstration experiment showed that the first cycle for improvement using the framework can reduce the environmental load by 1.5% without reducing productivity. The results also showed that improvements after the second cycle can reduce environmental load and cost by 420,000 yen per year including the cost reduction in the first cycle. In the future, we will continue to conduct demonstration experiments at our factory with the aim of providing solutions using this framework.

References

(1) Agency for Natural Resources and Energy, METI: Part 1 Energy Situation and Major Measures, FY2020 Annual Report on Energy (Energy White Paper 2021), 29–52 (2021)

(2) Mitsubishi Electric Corporation: Mitsubishi Electric Corporate Strategy, FY2021 Corporate Strategy Briefing [June 3, 2021], 20 (2021)

(3) Simulator for Deciding Optimal Balance between Productivity and Environmental Load, Mitsubishi Denki Giho, 95, No.1, 34 (2021)