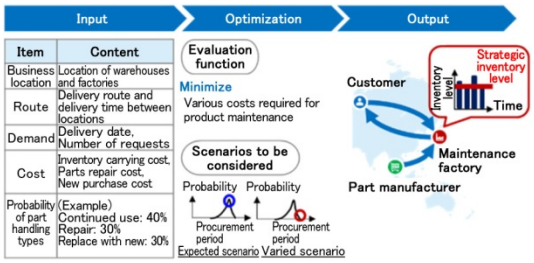
Inventory Strategy Planning Technology Supporting Expansion of MRO Business



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One of the important issues to be considered of MRO (Maintenance, Repair and Overhaul) business, which provides inspections and maintenance of products including repair and overhaul, is how much inventory should be held for operating the business. It is necessary to conduct many case studies based on market and supplier trends and shorten the maintenance period under constraints for minimizing costs. In general, the maintenance period and cost are often affected by the inventory level and the determination of how much the inventory level should be (inventory strategy) is the key to the operation of this service. In the past, this strategy was determined based on experience and intuition and there was room for improvement. Therefore, Mitsubishi Heavy Industries, Ltd. (MHI) has developed a technology for calculating the optimum inventory level based on a theoretical planning technology centered on mathematical optimization and have been using the technology to expand our MRO business.

This report presents an overview of this technology, our original inventory strategy planning technology and application examples.

1. Introduction

For large scale products that MHI manufactures and for the large scale facilities in which our products are incorporated, the operating rate is set by legal requirements, etc. The operating rate needs to be kept by services that supply the parts used for the maintenance of the product and performs maintenance on consignment. The service level, such as the immediate part delivery rate, the service type such as part supply, overhaul, etc. and the period required for part supply and maintenance vary depending on the product. In all cases, however, it is important to shorten the period from receiving a request for product repair or part supply from a customer to delivering the product or parts to the customer, as well as to reduce costs. On the other hand, the structure of products has become more complicated in recent years due to the advancement of technology and it has become difficult to shorten the period required for product maintenance and to reduce maintenance costs such as inventory carrying cost.

We also provide a service to perform maintenance on consignment and are examining the possibility of carrying the minimum inventory level that can ensure a stable supply of products as the strategic inventory level (**Figure 1**) as one of the measures to reduce the cost of the service and shorten the maintenance period. The strategic inventory level should be determined by conducting many case studies based on the trends of the market and suppliers and performing evaluation in terms of various lead times (the number of days for part procurement, repair, etc.) and costs (costs for carrying inventory and repairing defective parts). In the past, this strategy was decided based on experience and intuition and there was room for improvement. Therefore, we have developed a technology for calculating the strategic inventory level based on a theoretical planning technology centered on mathematical optimization. This report outlines the MRO business to which the developed technology is applied and then explains the original inventory strategy planning technology and application examples.

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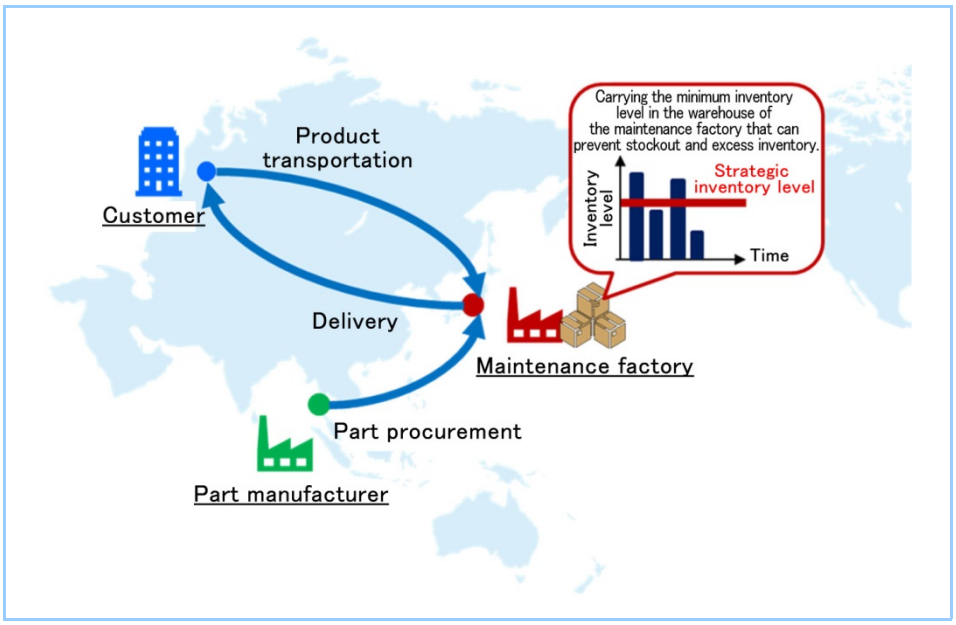

Figure 1 Strategic inventory in service business

2. Inventory strategy planning technology in MRO business

2.1 Outline and characteristics of MRO business

The MRO business referred to in this report is a business that provides inspections and maintenance of large scale products that require regular maintenance. This business has logistics characteristics including the following: (1) target products and parts go back and forth between locations such as maintenance and repair factories shown in **Table 1** multiple times and (2) the degree of damage to parts is determined only after the product is disassembled and inspected at a maintenance factory, while the number of parts to be repaired and the number of parts to be discarded and replaced are determined each time, etc. These characteristics are the main factors that cause various lead times (the number of days for part procurement, repair, etc.) and the total cost of the inventory carrying cost, the cost for repairing defective parts and purchasing new ones—as well customer damage due to late delivery—to vary in the logistics form of the MRO business. Therefore, the calculation of the strategic inventory level requires many case studies in consideration of the varying elements shown in Table 1 and then the comparison of the maintenance period and the total cost of multiple cases. Methods to optimize the inventory level include commercially available supply chain planning tools and inventory level optimization tools[(1)], which can optimize the inventory level according to demand scenarios and delivery methods. However, these are not suitable for the MRO business, which has the logistic characteristics described above, so we have independently developed an inventory strategy planning technology for the MRO business by combining logistics optimization technology and logistics simulation technology. The logistics optimization technology calculates the strategic inventory level and the logistics simulation technology evaluates the validity of an inventory strategy by, for example, analyzing the behavior of inventory changes when a warehouse is operated with the strategic inventory level.

Table 1 Types of locations constituting logistics network of our MRO business and varying elements in each location

No.	Location name	Explanation*	Varying element
1	Customer	Sends products to undergo maintenance to the maintenance factory (2) and receives the maintained products from the maintenance factory after maintenance is completed.	Number of products to undergo maintenance
2	Maintenance factory	Disassembles and inspects the received products and purchases replacements for the parts to be discarded from the part manufacturer (5). Arranges for repair of parts to be repaired at the repair factory (4) and reassembles the repaired parts after the repair.	Number of parts to be repaired and number of parts to be discarded
3	Dealer	Has the repair factory (4) repair the parts to be repaired that the maintenance factory requested for repair or procures replacements from the part manufacturer (5) and sends them to the maintenance factory (2). *No dealer intermediary in some business cases.	Repairer or seller - Repair or purchase lead time - Repair or purchase cost
4	Repair factory	Repairs the parts to undergo maintenance sent from the maintenance factory (2) or the dealer (3) and returns the repaired parts to the maintenance factory (2) or the dealer (3) after the repair is completed.	Maintenance lead time
5	Part manufacturer	Sends the parts requested by the maintenance factory (2) or the dealer (3) to the maintenance factory (2) or the dealer (3).	Part supply lead time

*Definition of terms related to MRO business
Maintenance : Work to maintain and improve reliability such as inspection and repair
Disassembly : Work to remove parts from products to undergo maintenance for inspection and testing
Replacement : Work to replace defective parts with new ones
Repair : Work to fix defective parts
Assembly : Work to attach disassembled parts to the product

2.2 Logistics optimization technology

Logistics optimization technology is a general term for methods in a certain logistics network to obtain a plan of location, inventory and delivery that minimizes the aforementioned total cost of production, delivery and inventory carrying and complies with constraints such as the upper limit of the number of inventory items and the delivery date. We realized optimization technology that can calculate a plan that minimizes the total cost for the logistics network of the MRO business, taking into account the variability of the part handling method (replacement, repair or use of another compatible part) after product disassembly, which is a characteristic of the MRO business.

First, as shown in **Figure 2**, we formulated the logistics network of the MRO business as a mathematical model in the form of a time-space network[(2)] in which the locations at a certain discrete time are treated as points and the flow of products and parts are treated as branches, in order to take the flow of products and parts with the passage of time (assembly, repair, disassembly, delivery and inventory carrying) into account. We then defined the upper limit of the number of inventory items held, delivery date and other constraints shown in **Table 2** for this model to use it as an optimization problem for calculating a plan that minimizes the costs using mixed integer programming.

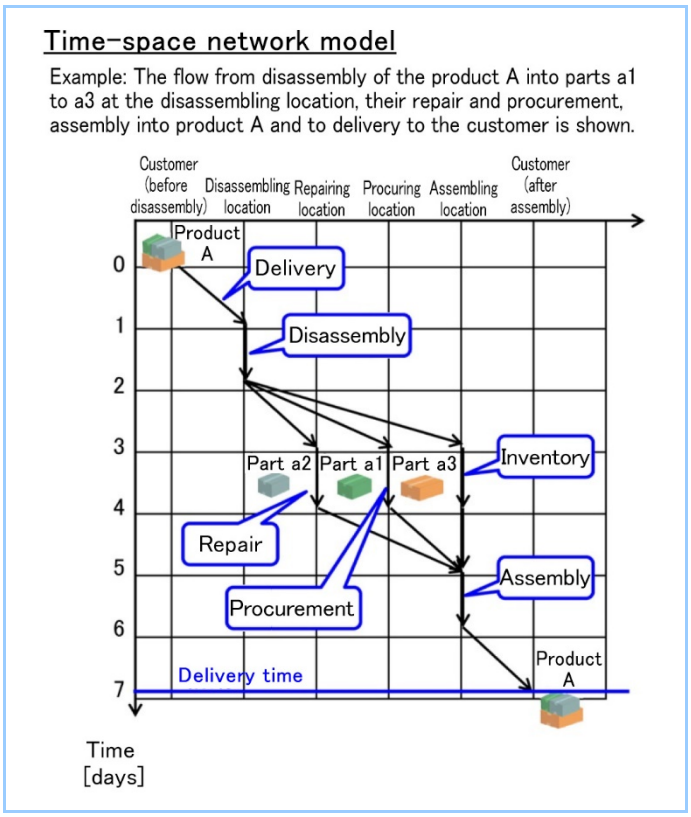

Figure 2 Time-space network model

Table 2 Main constraints in logistics optimization

No.	Classification	Constraint
1	Demand	Startable date and time
2		Delivery date
3	Inventory	Initial inventory level
4		Inventory level upper limit
5	Delivery	Delivery amount upper limit
6		Delivery route usable period
7		Delivery method
8		Delivery period
9	Disassembly/repair/assembly	Disassembly/repair/assembly amount upper limit
10		Disassembly/repair/assembly period

Next, as shown in **Figure 3**, we defined a cost calculation method according to the occurrence rate of parts repaired and parts replaced with new ones in the past results. Specifically, this calculation method calculates the cost for each of the scenarios in which the number of repaired parts and the number of replacement parts handled in the logistics network are changed, and then total the costs weighted by the probability of the occurrence of each scenario are calculated, to find the cost of an inventory strategy plan. By selecting the inventory strategy plan with the lowest cost as the optimal plan, the creation of a plan that reduces the cost when a scenario with a high occurrence probability occurs is made possible.

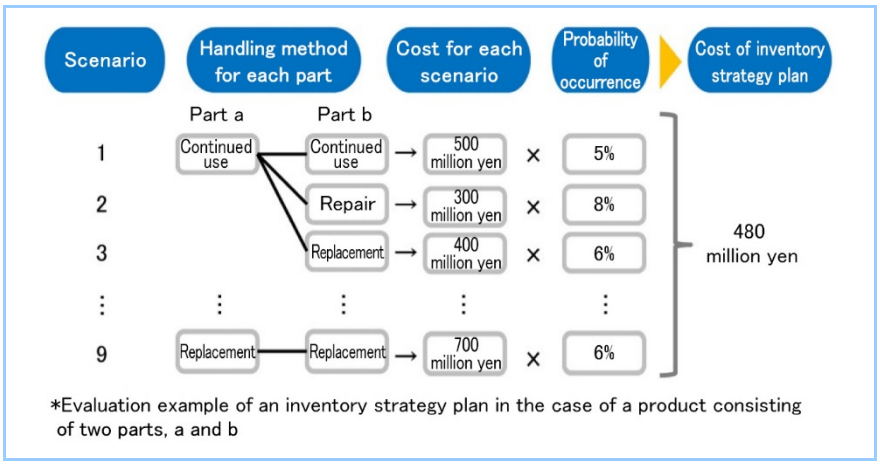

Figure 3 Inventory strategy plan cost evaluation model

2.3 Logistics simulation technology

This section introduces a technology that simulates the inventory transition in cases where the warehouse is actually operated with an inventory strategy planned using the logistics optimization technology described in section 2.2. First, the subsequent description explains the simulation model designed to realize this technology for the quantitative evaluation of the distribution network of the MRO business with the characteristics described in section 2.1 (**Figure 4**). The simulation model represents the configuration of logistics with the locational objects of the warehouse, maintenance factory, etc. and expresses the handling (repair/disassembly) of the part to undergo maintenance that is stochastically determined in these objects. In this model, in order to distinguish the opposing item flows at the maintenance location that occur in the steps of product disassembly (from customer to maintenance location, then to repair/disassembly location) and product assembly (from repair/disassembly location to maintenance location, then to customer), the maintenance location is defined as two divided objects. Based on this model, we developed a simulator with a function to discretely simulate the item flow from the time the product to undergo maintenance is shipped from the customer, to the time the product that underwent maintenance is received by the customer. When the number of inventory items held in the warehouse, the probability of maintenance request occurrence, the maintenance cost and the maintenance period for each location that requests repair or disassembly of component parts are input, the simulator determines probabilistically the part maintenance request destination, the number of parts for which maintenance is to be requested, the maintenance cost and the maintenance period and outputs the inventory level, maintenance period and distribution of various costs such as inventory carrying cost, repair cost and replacement cost. This made it possible to evaluate the total cost and analyze the inventory transition of the warehouse operated with the planned inventory level based on the past maintenance results.

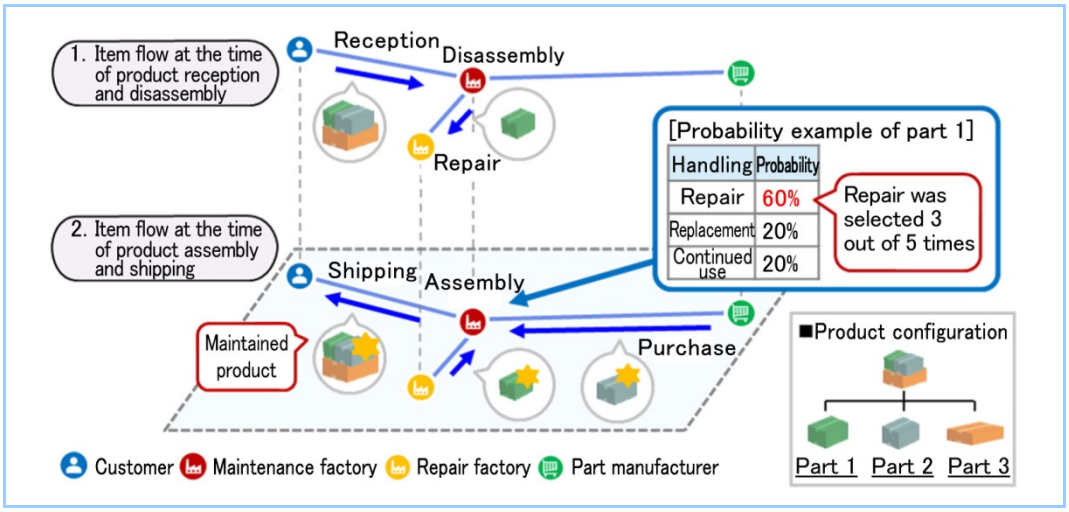

Figure 4 Simulation model

2.4 Inventory strategy planning and quantitative evaluation

Figure 5 shows the series of flows from planning an inventory strategy in the MRO business by combining the logistics optimization technology described in section 2.2 and the logistics simulation technology described in section 2.3, to evaluating the inventory transition operated based on that strategy. First, the strategic inventory level is calculated in consideration of the actual replacement results of the product components (disassembling, inspecting and determining repair or replacement) and the variability of various lead times (the number of part procuring days, the number of part repairing days, etc.) using the logistics optimization technology. Next, the calculated inventory level is input into the simulator described above to probabilistically determine the maintenance request destination for defective parts found after product disassembly and the number of those defective parts for which maintenance is to be requested, calculating the maintenance cost and inventory level during the simulation period. After repeating this calculation and obtaining the results of multiple scenarios with different types of defective parts, different maintenance request destinations and different numbers of defective parts for which maintenance is to be requested, the validity of the strategic inventory level is evaluated by checking whether stockout or excess inventory occurs based on the average values of the maintenance period and maintenance cost and the behavior of the inventory transition along the time series.

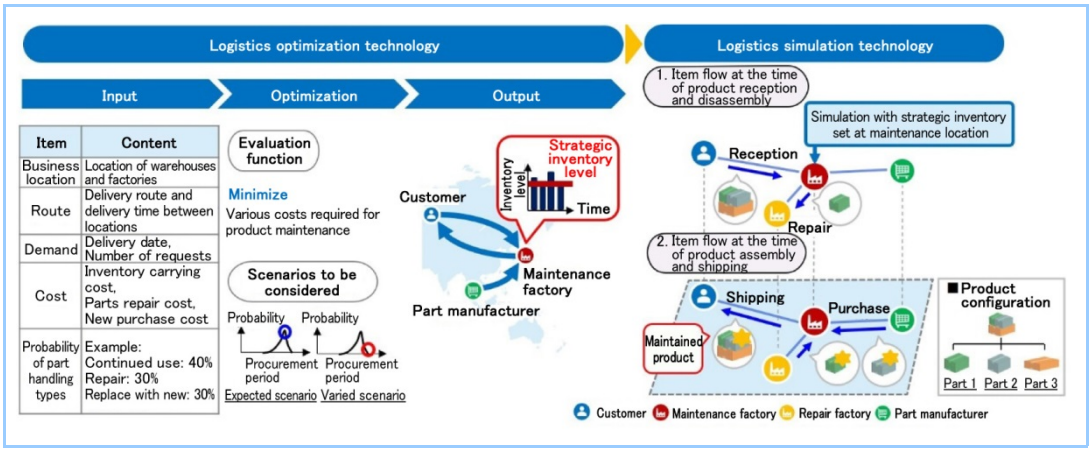

Figure 5 Flow from inventory strategy planning to quantitative evaluation

3. Example of quantitative evaluation of MRO business

This chapter verifies the effectiveness of the developed logistics optimization and logistics simulation technologies by evaluating the simulation results for one year that is assumed to annually maintain about 30 products consisting of about 400 different parts for our representative MRO business.

Five hundred calculation results with a simulator incorporating the technology described in section 2.3 when the strategic inventory level (1-4 pieces) for 9 parts, which were calculated using the logistics optimization technology, was input were compared between the case with strategic inventory and the case without, in terms of the maintenance period, total cost and inventory carrying cost, which was the sum of the carrying cost for strategic inventory and the carrying cost for parts stored in the warehouse until the arrival of other parts after disassembly (**Figure 6** and **Figure 7**).

As a result, it was confirmed that the maintenance period (average value) was reduced by about 37% by the strategic inventory case and the total cost (average value) after optimization was reduced by about 4% due to the resulting reduction in the number of deliveries after the deadline and the inventory carrying cost.

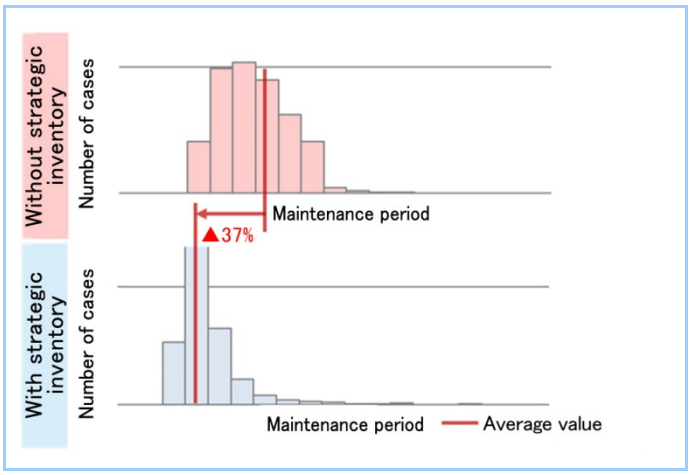

Figure 6 Maintenance period

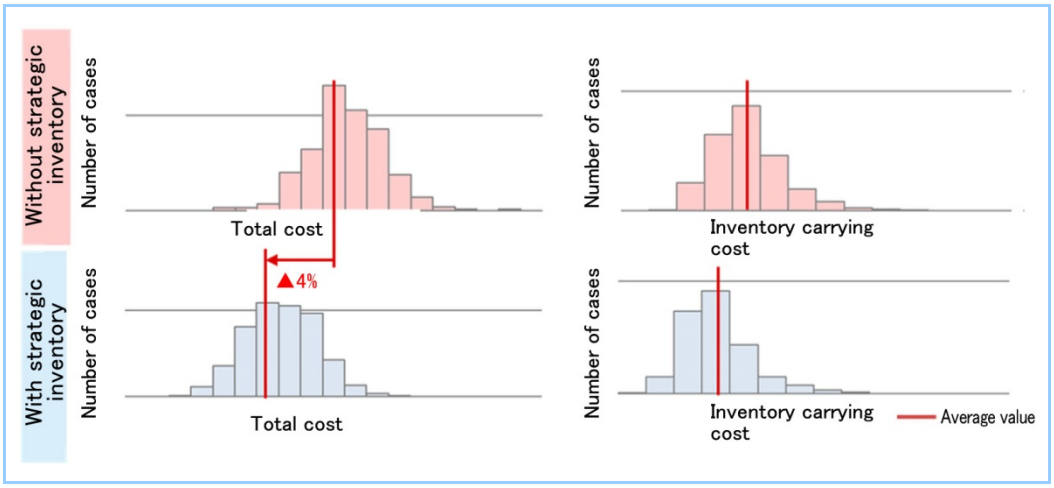

Figure 7 Maintenance cost

4. Conclusion

We are considering strategically carrying inventory as one of the measures to reduce the cost and shorten the period for product maintenance in our MRO business. This report introduces the application of strategic inventory level calculation technology based on mathematical optimization to our representative MRO business. It was confirmed from the result that the maintenance period could be significantly shortened, while also minimizing various costs required for product maintenance such as inventory carrying cost in consideration of the replacement record of product component parts (disassembling, inspecting and determining repair or replacement) and the variability of various lead times (the number of part procuring days, the number of part repairing days, etc.). This method makes it possible to reduce the number of occurrences of stockout and excess inventory in the MRO business and stably supply products with a lean operation while reducing the total cost. In the future, we will confirm the effect of this technology by conducting actual operation based on the strategic inventory level obtained and promote the development of this technology to other products.

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