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Application of Artificial Intelligence and Genetic Algorithm in Physical Distribution

Takehiko Iwaya*1　Toshiaki Sega*1
Shinichi Ohtsuka*1　Mamoru Kunimoto*1

Abstract

In the distribution field, artificial intelligence (AI) and genetic algorithms (GAs) can be effectively applied to achieve excellent results from a logistic point of view. Described here are a storage system for steel sheets at Nippon Steel's Kimitsu Works introduced as an application example of AI, and a vehicle allocation planning system implemented at another company as a test application of GAs.

1. Introduction

Many of the tasks (such as carry-in and carry-out, storage, and delivery) associated with distribution in the manufacturing and transporting industries are not automated nor computer integrated as is the case with manufacturing lines. The costs of these tasks are rising and must be urgently reduced from a logistics point of view.

When AI, for example, is used in distribution, optimum transfer sequences to move products into and out of a warehouse are determined according to a rule base, and transfer equipment is automatically operated. The resultant shortening of the transfer time can improve operating efficiency and reduce the number of operating personnel, providing a sizable cost savings. GAs can also be used to build an expert system and obtain nearly optimum solutions in a short time without the help of experienced engineers.

Based on actual application examples, this paper describes the ideas involved with the introduction of AI and GAs in the distribution field, and outlines the results achieved.

2. Storage System for Steel Sheets at Kimitsu Works

2.1 Equipment of outline

As part of its distribution infrastructure improvements, Nippon Steel's Kimitsu Works built strage system for steel sheets to streamline the distribution and transportation efficiency of coils.

The overall configuration and main specifications of the warehouse equipment are shown in **Fig. 1**, and the storage of coils at the warehouse is shown in **Photo 1**.

The warehouse is a single-story, three-bay building. Each bay is equipped with an automatic crane. An automatic inter bay car carries coils from one bay to another, and receives coils from the hot strip mill.

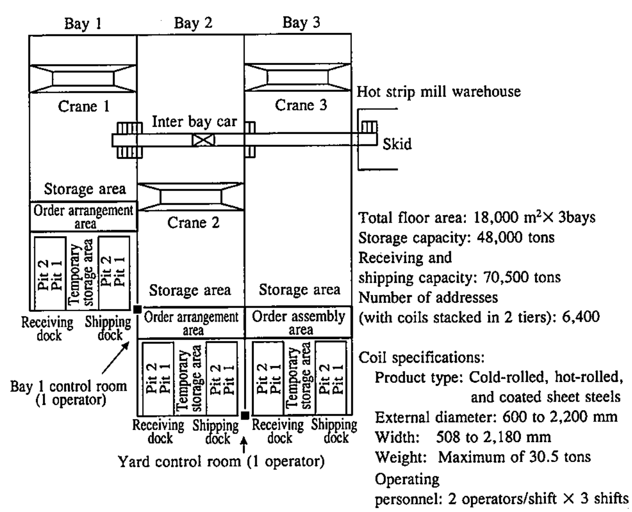


Fig. 1 Overall equipment configuration of warehouse

*1 Electronics & Information Systems Division

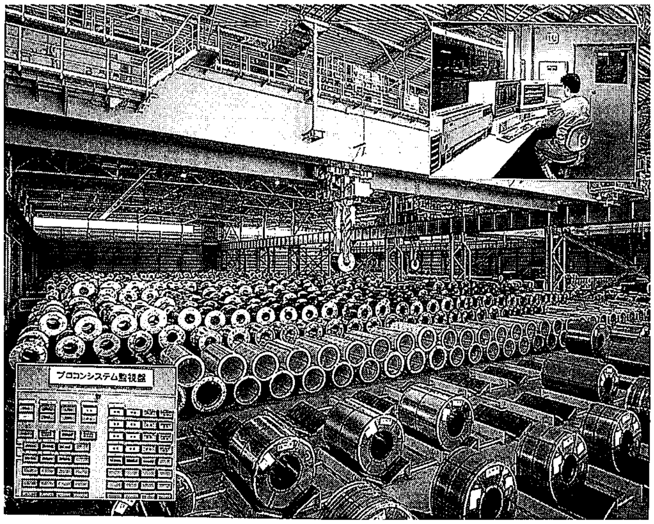


Photo 1 Coils stored in warehouse

Table 1 Distribution of system functions

Level	Distribution	Detailed function
Business computer	Preparation of transportation plan	• Transportation lot preparation • Vehicle operation plan preparation • Storage area plan preparation
Process computer	Optimization of work schedule in warehouse (AI)	• Automatic equipment operation control • Coil tracking • Equipment/operation control
Electrical equipment	Optimization of equipment operation	• Automatic operation

Each bay in the warehouse is divided into storage, order arrangement, and temporary storage areas for the following purposes:

Storage area: Coils are stored in two tiers as classified by width and external diameter.

Order arrangement area: Coils to be shipped for specific orders are stored in a single tier before transfer vehicles enter the bay to transport them to customers.

Temporary storage area: When an address to store a coil to be received from a truck or an address to load a coil to ship by a truck is not known, such coils cannot be automatically handled and are temporarily stored in a single tier for semiautomatic handling.

2.2 System rationale

Warehouses and other auxiliary facilities traditionally have lagged behind production lines in automation (computerization) and have been operated by many workers.

In recent years, societal changes represented by demands for better working environments, have compounded the difficulty of employing warehouse workers, making it necessary to operate new warehouses with a minimum of labor.

Given these circumstances, the Kimitsu coil warehouse was designed with top priority given to full automation, except for some nonroutine operations, to achieve an overall improvement in oprating efficiency. The warehouse system was divided into three levels based on function.

The distribution of the system's functions is shown in **Table 1.**

2.3 Reasons for introducing AI

Warehouse operations have the following characteristics:

(1) Receiving and shipping tasks are constrained by traffic and weather conditions, and other factors.
(2) Although transport plans are prepared, the high volume of urgent orders hampers the early scheduling of tasks.
(3) Work methods themselves involve uncertain factors and are frequently changed.

In this way, warehousing work schedules and methods are difficult to determine rigidly. If all functions required of an automatic warehouse control system to be built on a process computer are described in a procedural language as done for ordinary production lines, it may detract from the operational flexibility of the system after start-up. In terms of engineering, the inability to determine functional specifications early is one factor responsible for delaying the system's overall schedule for system construction.

As a result, it was decided to divide system functions into two groups, and to apply AI to one group of functions that contain uncertain factors and are concerned with work schedules and methods of high maintenance frequency.

Application of AI with high maintainability ensures operational flexibility and allows continuing maintenance for better system performance after start-up. In addition, functional design can be carried out by separating rigid functions from ambiguous functions for higher engineering efficiency.

2.4 Overall functions of system

The warehouse undertakes receiving and shipping tasks based on a vehicle operation plan made with a business computer.

The process computer develops receiving and shipping instructions into transfer instructions in the sequence specified by the business computer and issues the instructions for low-level equipment. Since the planned and actual work sequences (or arrival sequences of receiving and shipping vehicles) are greatly different as described in the previous section, however, the process computer must judge which tasks should be given top priority when they are performed.

The following considerations must also be taken into account:

(1) The coils are stored in two tiers. Is the coil to be transferred located on the second tier? If the coil to be transferred is on the first tier, does it have another coil stored above it ?
(2) If the coil to be transferred is in a bay different from the bay where a vehicle enters to load it, when should it be carried by the inter bay car to the bay where the vehicle will enter ?
(3) Is it possible to receive and ship coils at the same time ?
(4) When should coils scheduled for shipping be transferred to the order arrangement area ?
(5) When should auxiliary tasks like rearrangement be carried out ?

Given the above considerations, it was decided to divide the functions into one rule base for determining the optimum work lot and another rule base for determining the optimum transfer sequence within the work lot.

In particular, the optimum transfer sequence determining rule base must decide the transfer of the next coil when the transfer of the first coil is completed (within the target time of six seconds or less as dictated by the mechanical equipment specifications). This real-time action requirement is higher than specified for conventional AI systems. To establish the optimum transfer destination and transport of coil in a short time, a storage area map is introduced into the process computer where it is formulated as a relational data base and managed on a real-time basis. This design eliminated tracking mistakes and improved the overall performance of the system, including the rule bases.

System flow, including the high and low levels, is shown in **Fig. 2.**

2.5 System configuration

The system must meet the following requirements:

(1) Perform AI processing and general-purpose processing such as data editing in a closely coupled manner.

(2) Have real-time and multi-task control functions at the OS level.

(3) Be reliable enough to serve as the core of operational support.

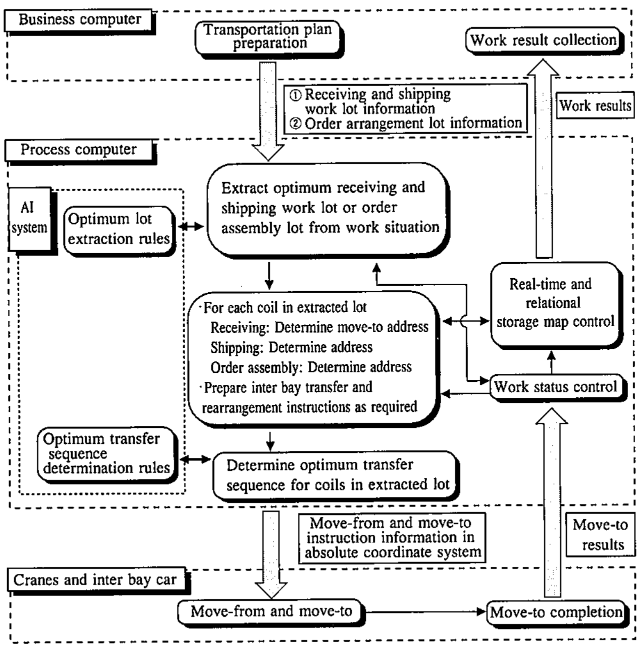


Fig. 2 System flow

(4) Excel in cost performance.

To meet these requirements, the desktop-type process computer MC20, made by Nippon Steel's Electronics & Information Systems Division, was selected as the hardware.

The hardware and software configurations of the system are shown in **Figs. 3** and **4**, respectively.

2.6 System performance

The system was put into on-line operations in June 1993 and has been performing as initially planned.

(1) Reduction in personnel

Three operators were formerly required per crane. Except for some irregular tasks, full automation now allows the three cranes to be operated by two operators.

(2) Reduction in vehicle waiting time and ship waiting time by shortening of working time

Selection of an optimum work lot and determination of an optimum transfer sequence are achieved by the rule base on a real-time basis. As a result, the variations in required time caused by personal differences (differences in time required for selecting tasks and in task efficiency with task sequence) can be eliminated. Coupled with the synergistic effect of automatic operation, the tasks can be completed in about a half of the time conventionally required. As a result, transportation costs have been reduced by shortening vehicle waiting time, and demurrage has been reduced by shortening lay days.

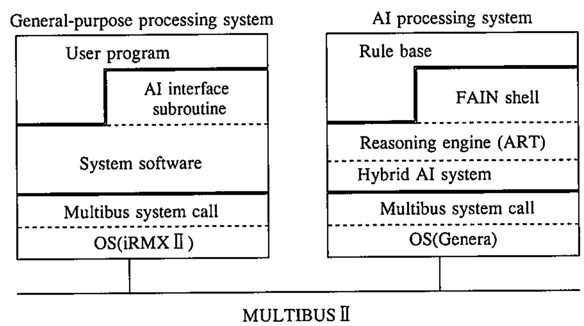


Fig. 4 Software configuration of system

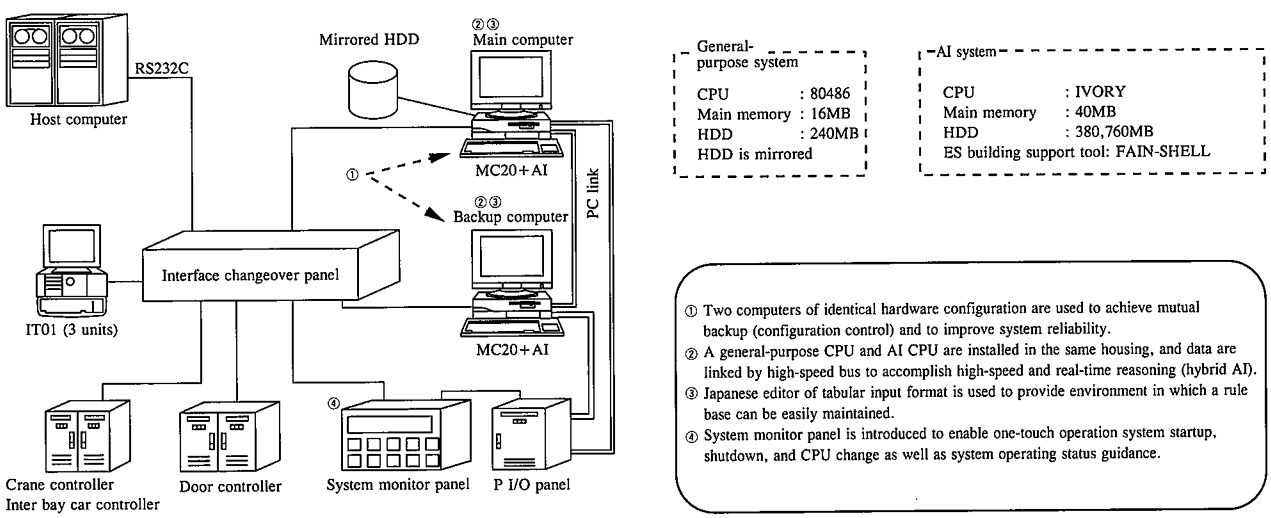


Fig. 3 Hardware configuration of system

(3) Operational flexibility

The maintenance of the rule base is frequently performed. Because of its case of maintenance, frequent maintenance has resulted in the system reaching initial targets on a qualitative basis without becoming obsolescent.

3. Vehicle Allocation Planning System

With distribution control, optimization of schedules to assign vehicles to loads involves many constraints such as customer requirements like delivery time specification, vehicle constraints, and traffic conditions. Vehicle allocation planning is difficult to achieve by conventional optimization techniques. Consequently, vehicles must be manually allocated for specific loads. As load weight and number of vehicles increase, vehicle allocation becomes more difficult, the improvement in efficiency of vehicle allocation becomes limited, and additional labor and time become neccessary to make and revise vehicle allocation schedule.

Nippon Steel has successfully applied GA technology to various optimization problems (see **Fig. 5**). The results of prototyping a vehicle allocation planning system are introduced here as an example of a GA application in the distribution field.

3.1 Genetic algorithm (GA)

The GA is an algorithm conceived from the principles of biological evolution and is known as an effective method to rapidly obtain practically optimum solutions to various optimization problems and rule learning problems difficult to solve by conventional techniques. The GA was introduced more than 20 years ago by J.H. Holland of the United States. Now that it is possible to process large amounts of iterative calculations within a realistic time range thanks to the marked progress of hardware processing capability, the GA is drawing increasing interest for engineering applications. Processing by the GA is outlined below (see **Fig. 6**).

(1) A group of virtual organisms with genes (first generation) is set in the computer. The genes represent solutions to specific problems.

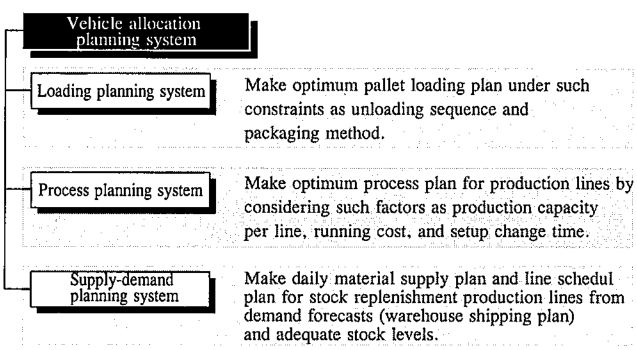


Fig. 5 Examples of applying genetic algorithms to optimize logistics

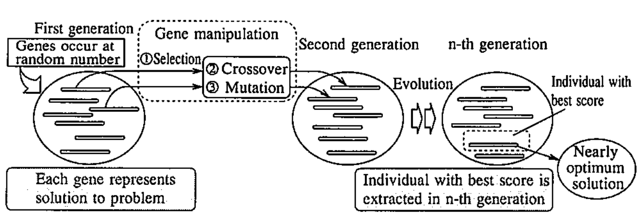


Fig. 6 Principle of genetic algorithm

(2) An alteration of generations in the group of organisms is simulated so that individuals adaptable to a predetermined environment (constraint) are highly likely to leave offspring, and the individuals and the group of organisms are sequentially evolved.

(3) As a final result of repeated evolution, individuals perfectly adapted to the desired environment (or genes representing nearly optimal solutions) are produced.

The GA can obtain nearly optimal solutions at high speed. As an optimization algorithm, the GA also has the following characteristics:

(1) It has a wide search range and is not subject to local solutions, as compared with other optimization techniques.

(2) It can also be applied to search for discontinuous evaluation functions.

(3) Since it yields solutions through probability and selection, it does not require components equivalent to program logic or AI rule bases, for example, and is easy to maintain after implementation.

(4) It is not as good at a local search as other search techniques and is sometimes implemented in combination with other local search techniques.

3.2 Benefits of vehicle allocation planning system

The benefits of a vehicle allocation planning system based on the GA are described below.

(1) Reduction in distribution costs

Vehicle allocation plans can be made for wider areas than traditionally done manually (see **Fig. 7**). For example, it is possible to create a distribution system aimed at an overall optimal solution rather than a local optimal solution in each area. As a result, transportation efficiency (such as loading ratio, turnover ratio, or empty travel distance) is expected to improve, resulting in lower distribution costs.

(2) Improvement in level of distribution service

Because the time required for making a vehicle allocation plan can be shortened, the lead time can be reduced and the order acceptance time can be extended. Systematization allows distribution data to be controlled in an integrated manner and urgent orders and inquires to be quickly met. The resultant improvement in the level of distribution service is expected to expand demand.

3.3 Prototyping preconditions

To evaluate its functions, the vehicle allocation planning system was prototyped for a carrier that covers a certain distribution area. The carrier's distribution pattern is described below.

(1) The basic delivery pattern is a shuttle service between

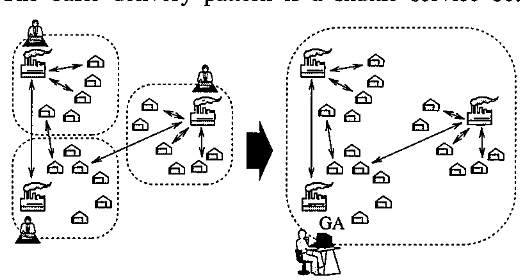


Fig. 7 Expansion of scope of object to be optimized

factories and distribution centers/large-lot customers. There are also irregular deliveries between the factories and between the distribution centers.

(2) Goods may be loaded in the morning and delivered to customers within the same day, or may be loaded in the evening and delivered to customers in the morning of the next day.

(3) A few hundred orders (loads) are delivered per day.

(4) Scattered over a wide area, there are about two hundred distribution centers/large-lot customers with varying load acceptance times and vehicle entry limitations.

(5) The carrier owns about 100 trucks, tractors, and trailers, and hires vehicles to alleviate shortages. Any reduction in hiring costs can thus directly lead to a gain in the carrier's profitability.

The following conditions contribute to vehicle allocation efficiency:

(1) Increasing the loading ratio of the vehicles as much as possible.

(2) Shortening the loading and unloading waiting time improves the turnover ratio of the vehicles.

(3) Assigning loads to vehicles on return trips reduces the empty travel distance.

(4) Transporting on a single vehicle loads for adjacent destinations or for customers on the same route increases delivery efficiency.

(5) Stabilizing driver workloads.

The vehicle allocation system prototype is aimed at reducing the number and cost of vehicles on hire by increasing the operating ratio of the carrier's vehicles while meeting the above conditions.

3.4 Configuration of system

The prototype consisted of master control, order entry, operating vehicle entry, vehicle allocation planning, vehicle operation control, and document output (see **Fig. 8**). The hardware and software configuration of the system are shown in **Figs.9** and **10**, respectively. The system is built as a personal computer server/client network. The data base is managed by the server, and the vehicle allocation plan (genetic algorithm computation) is made by the client. This distributed processing configuration increases the speed of planning the vehicle allocation.

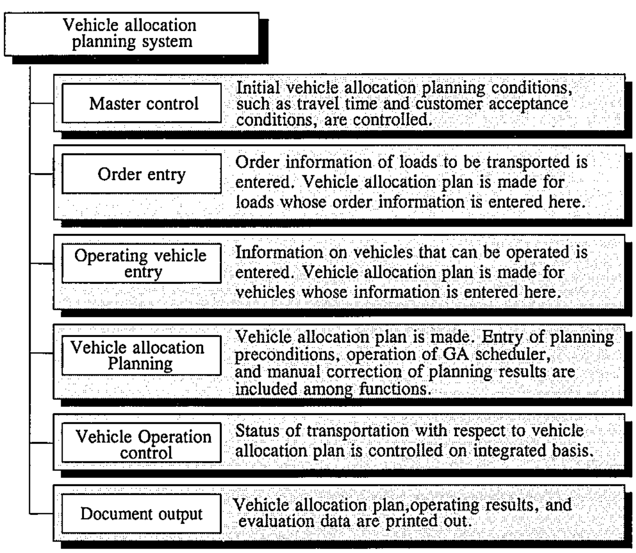


Fig. 8 Configuration of functions

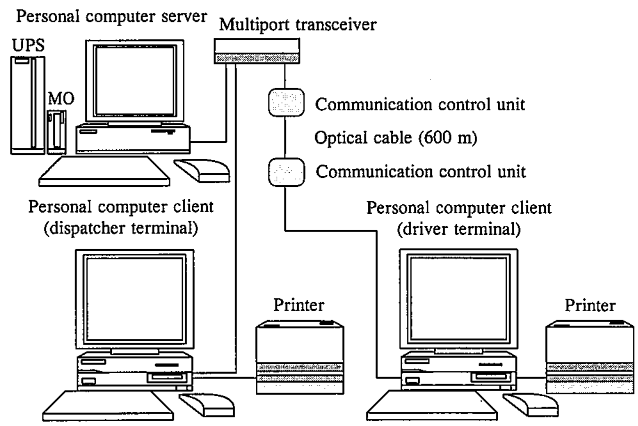


Fig. 9 Hardware configuration1

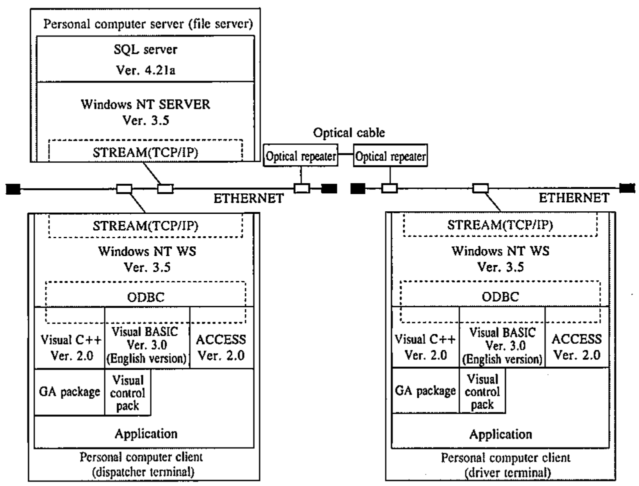


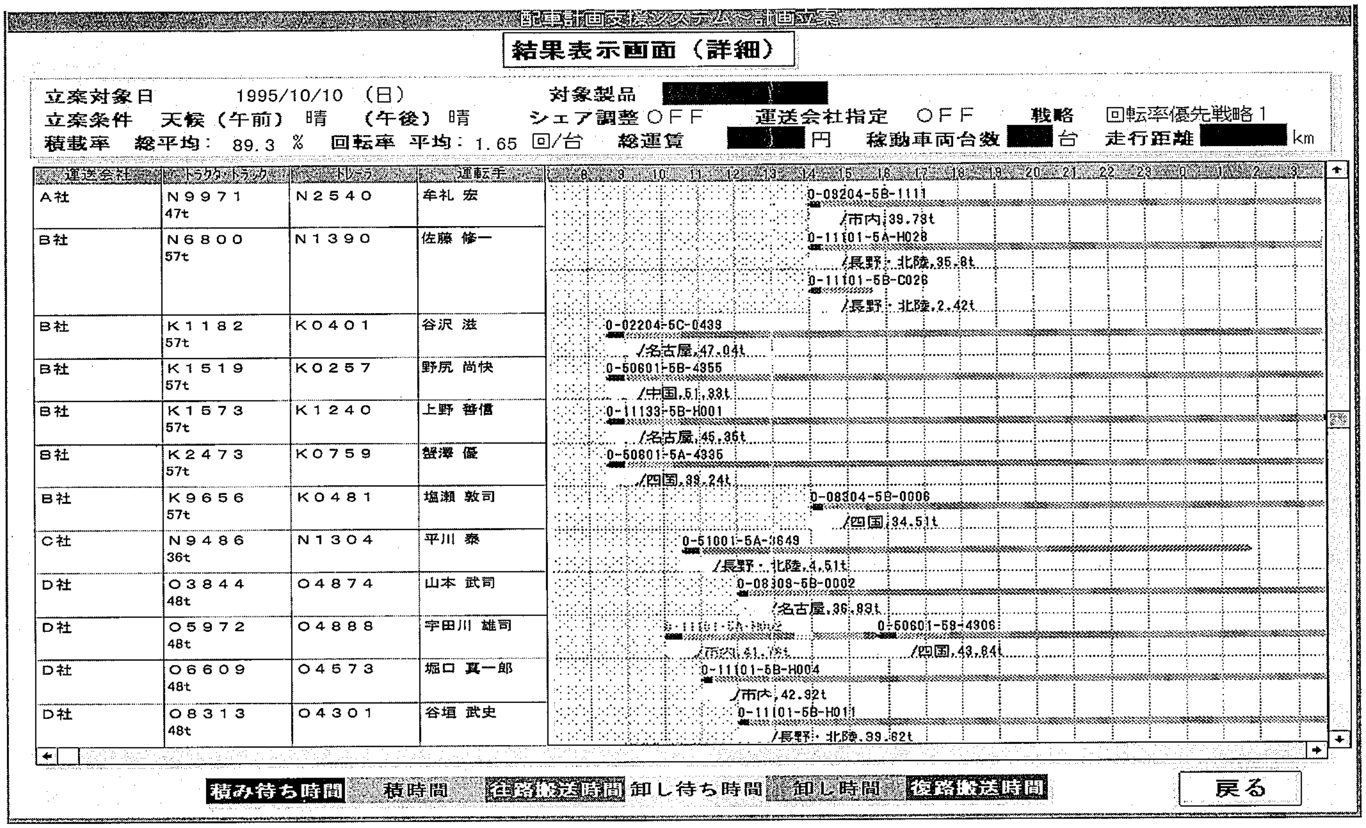
Fig. 10 Software configuration

3.5 System implementation

When the GA was implemented, a local search technique (hill climber) was incorporated into the planning algorithm to alleviate the local search deficiency of the GA, and individuals that underwent gene manipulation (or genes strong in some evaluation items) were added to the first generation to increase the speed of initial convergence. The search time was shortened by taking these measures. The GA was also implemented to allow the weighting of constraints to be dynamically changed in anticipation of the changes to be made to the planning strategy, such as priority being given to the turnover ratio of vehicles, loading ratio of vehicles, or stabilizing driver workloads.

3.6 Verification of system

The results of the system evaluation show that when the GA system cannot completely satisfy all of the constraints (i.e. cannot produce final solutions), it can still yield nearly optimum solutions according to the weight of the constraints. (If the delivery of a particular load cannot be completed within the usual working hours, the system does not indicate that there is no solution, but makes a vehicle allocation plan that allows for the overtime of the driver of the vehicle.) The system is expected to run with



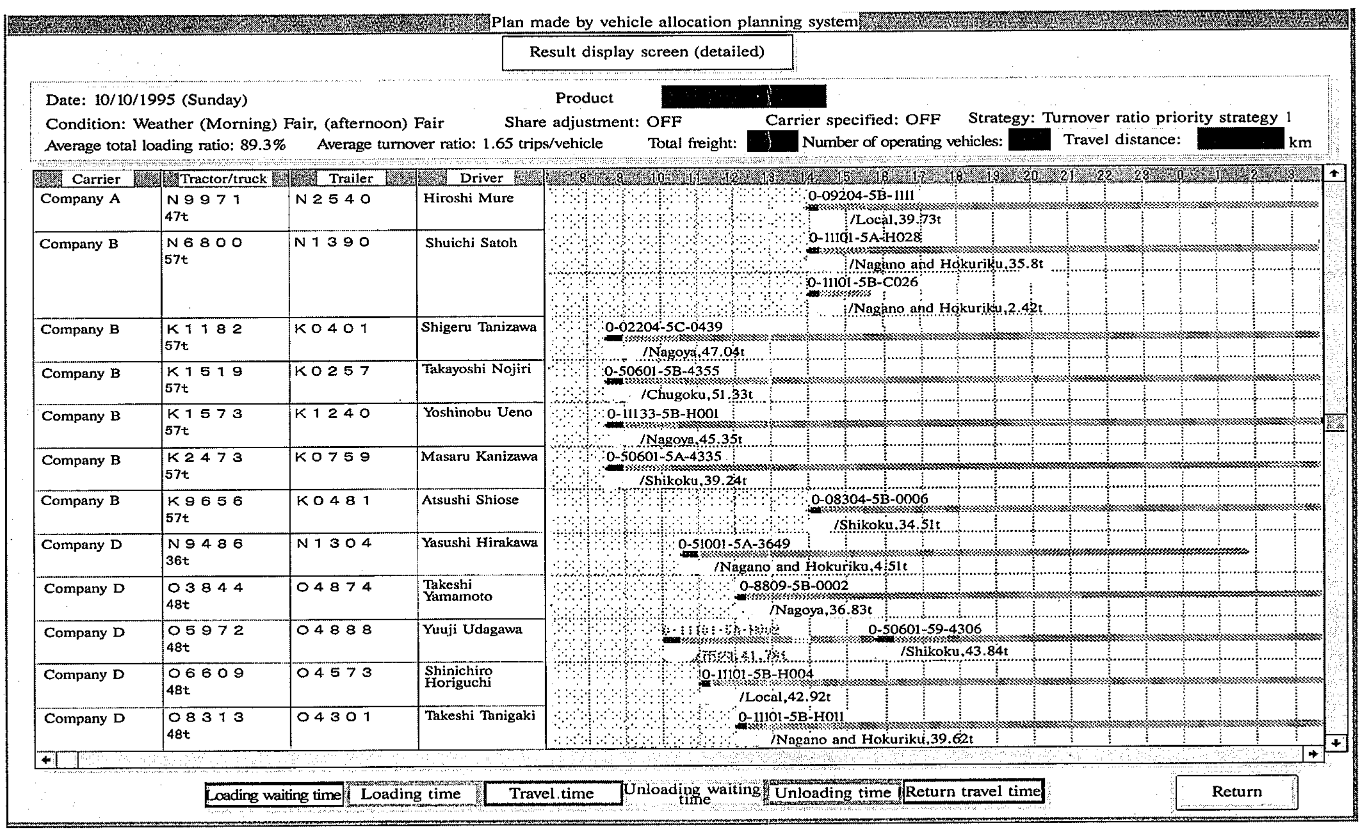


Fig 11 Example of plan made by vehicle allocation planning system

considerable flexibility after commercial application. The prototype system could make vehicle allocation plans with higher loading and turnover ratios in about one twenty-fourth of the time (15 min instead of 6 hours) required by the carrier's veteran dispatcher. It was ascertained that with the system vehicle hire costs could be reduced by about a half (see **Fig. 11**). These results are highly rated by carriers and customers, and the system is now being fine tuned for commercialization.

4. Conclusions

Two examples in which AI and GAs were applied to distribution were introduced.

The AI-based strage system for steel sheets has been already placed on line, has performed as originally planned, and is highly rated by users.

The technical evaluation for the GA-based vehicle allocation planning system has been completed in the prototype phase and is judged to have no problems concerning practical application.

The AI and GA technologies have specific characteristics but their applications are not limited to the distribution field. It is, however, necessary to study whether or not their characteristics can be fully used in their intended applications.

By expanding the application scope of AI and GAs and exploiting these leading-edge technologies, Nippon Steel will continue to improve management operations and working environments by developing practical solutions.

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