NIPPON STEEL TECHNICAL REPORT No. 68 JANUARY 1996

UDC658.784:669.14-422

# Development of Directly Linked Bar Rolling-Finishing Technology (Automatic Bar Buffer Warehouse System)

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**Abstract:**

*In recent years, needs have increased for the full direct linkage of the rolling, finishing, and shipping processes at bar mills to reinforce quality control, enhance delivery efficiency, reduce manufacturing costs, and improve the working environment. To meet these needs, Nippon Steel developed directly linked bar rolling-finishing technology (automatic bar buffer warehouse system) by utilizing a multifunction automated high-rise warehouse. The automatic bar buffer warehouse system, adopted at the bar mill of Nippon Steel's Muroran Works, was put into commercial operation in December 1992, and has since performed as originally expected. The directly linked bar rolling-finishing technology is outlined here.*

## 1. Introduction

In recent years, needs have increased for directly connecting manufacturing processes to strengthen quality control, enhance delivery effeciency, reduce manufacturing costs, and improving the working environment. This is also true of special steel bar production processes. The special steel bar rolling and finishing processes were especially difficult to directly link due to such problems as processing speed differences and therefore were left separate despite the strong need for direct linkage.

In December 1992, Nippon Steel developed and introduced the Japanese steel industry's first directly linked bar rolling-finishing system (hereinafter referred to as the automatic bar buffer warehouse system) at the bar mill of its Muroran Works. The automatic bar buffer warehouse system features a multifunction automated warehouse with such control functions as artificial intelligence (AI)-based high-efficiency optimum receipt and retrieval control installed between the rolling and finishing processes. The rolling and finishing processes are fully automated and are connected through a convention, flexible shipping system to accomplish the direct linkage of all bar mill operations from billet reheating to product shipping.

As a result, the processing speed difference between the rolling process and the downstream finishing and shipping processes that vary from time to time can be accommodated, bars can be finished to customer requirements according to destination to shorten the delivery lead time, and bars can be manufactured to fill customer orders in a smooth and flexible manner. An overview of the automatic bar buffer warehouse system is presented below.

## 2. Special Steel Bar Manufacturing Process

Special steel bars are used in the critical safety components of automobiles, among other applications. To meet demanding quality specifications, special steel bars intended for automotive use must be inspected and finished in a cold state after hot rolling.

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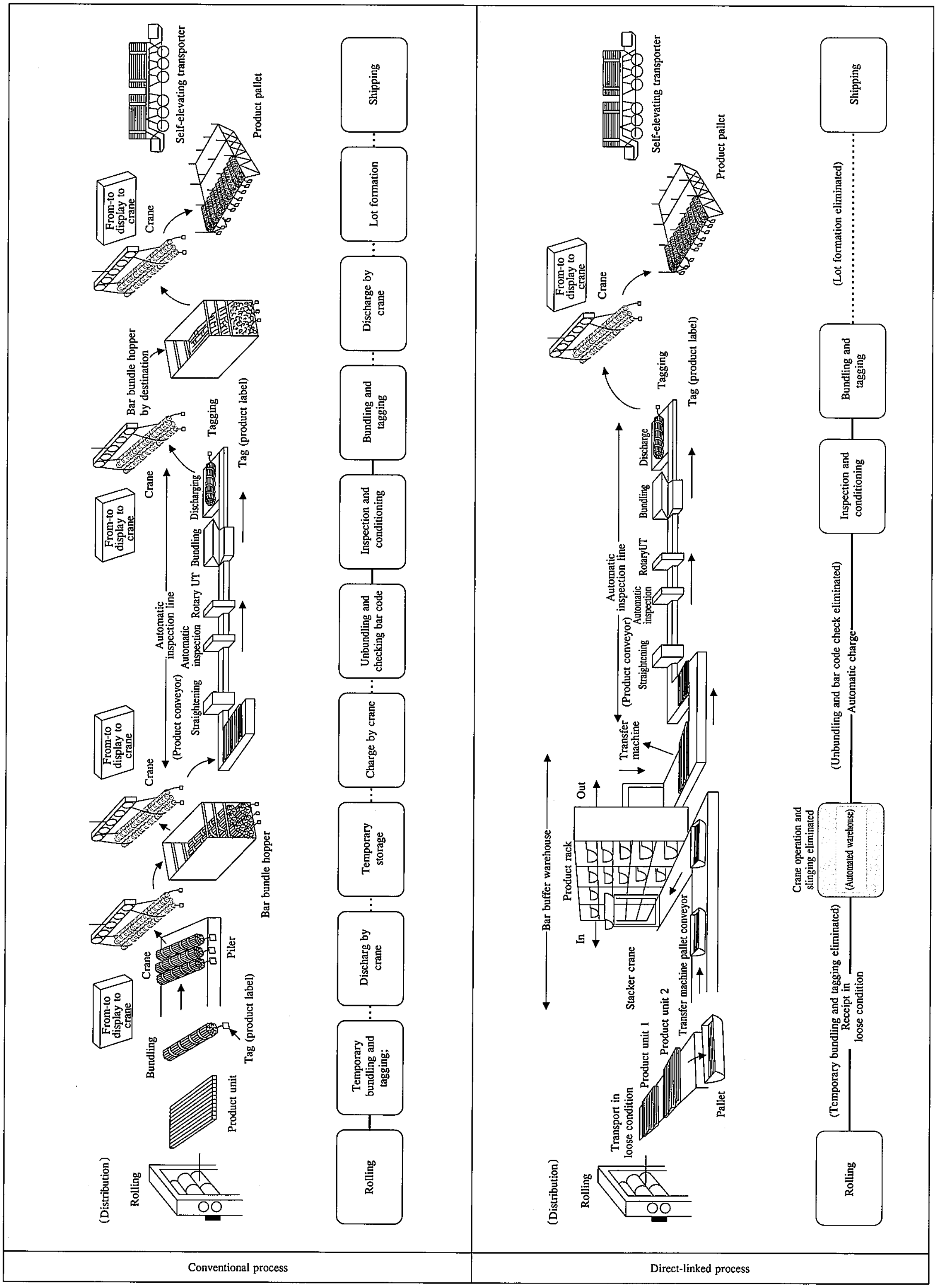


**Fig. 1** Special steel bar production processes

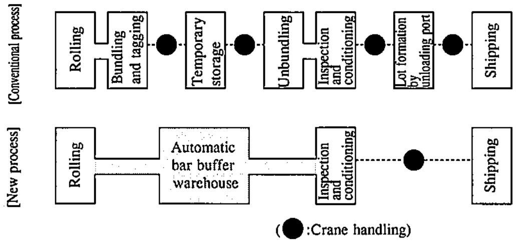


**Fig. 2** Special steel bar production process flow

The rolling process greatly differs in processing speed compared with the downstream finishing and shipping processes already described. Formerly, rolled and cut bars were temporarily bundled, tagged, and stored in a hopper as shown in **Figs. 1** and **2**. The bundled bars were then removed from the hopper and carried by crane to the finishing line where they were sequentially taken from the top of each bundle and finished. The finished bars were then assembled into lots for specific destinations.

The direct linkage of the processes from rolling to shipping is effective in: strengthening quality control by reducing handling defects; improving delivery efficiency by reducing the inventory and shortening the delivery lead time; reducing manufacturing costs by accomplishing labor and resource savings; and in improving the working environment. In particular, nonprice competitiveness can be further enhanced.

## 3. Directly Linked Bar Rolling-Finishing System

### 3.1 Problems with direct linkage from rolling through finishing to shipping, and direct-linkage technology

Of the problems with the full direct linkage of the rolling to finishing processes shown in **Fig. 3**, the most difficult one is compensating for processing speed differences between rolling and finishing. During finishing, one bar is handled at a time, so that its processing speed is lower than that of rolling. The simple, direct linkage of the finishing process with the rolling process would require installing many finishing lines at enormous equipment and labor costs. This method was considered actually impossible to achieve.

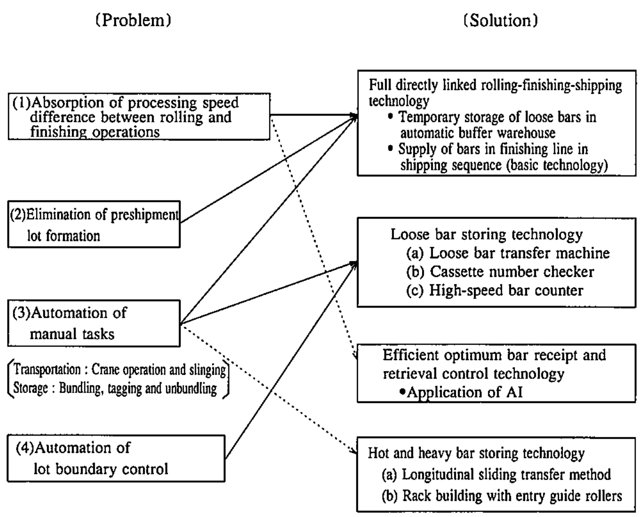


**Fig. 3** Problems with full direct linkage of rolling, finishing and shipping operations, and solutions

To solve this problem, Nippon Steel developed a full directly linked rolling-finishing-shipping system. An automatic bar buffer warehouse is installed between the rolling and finishing processes. Loose bars are automatically moved into and out of the warehouse and stored in the warehouse. The processing speed difference between the rolling and finishing processes that changes every moment is compensated for by the warehouse's buffer function.

In addition, the flexible receiving and retrieving functions of the automatic bar buffer warehouse allow the bars to be retrieved and finished in the sequence suited for shipping by destination, eliminating the need for preshipment order formation. The basic technologies of the automatic bar buffer warehouse system include: 1) full directly linked rolling-finishing-shipping technology; 2) loose bar storage technology; 3) high-efficiency optimum receipt and retrival control technology; and 4) hot and heavy bar storage technology.

### 3.2 Outline of automatic bar buffer warehouse system

The automatic bar buffer warehouse system installed at the Muroran Works bar mill achieved full direct linkage of the rolling line with multiple finishing lines through automatic transfer of loose bars and eliminated the need for preshipment order formation.

The automatic bar buffer warehouse system features large unit weight and storage capacity for an automated warehouse as detailed in **Table 1**.

The bar flow in the new system as described below appears in **Fig. 1**.

(1) The rolled and cut bars are automatically loaded loose into a cassette by a receiving transfer machine and are stored in the rack building.

(2) The cassettes containing bars are automatically retrieved from the rack building as requested by the finishing line for specific destinations.

(3) The desired bars are automatically supplied by an transfer machine to the finishing line.

Some of the technologies developed and implemented for the automatic bar buffer warehouse system will be described in the next chapter.

## 4. Outline of Technologies Developed

The four main technologies developed for the automatic bar buffer warehouse system are briefly described below (see **Fig. 3**).

(1) Technology for full direct linkage of the rolling, finishing, and shipping processes

(2) Technology for storing bars in a loose condition

(3) Technology for controlling the receipt and retrieval of

**Table 1** Main specifications of automatic bar buffer warehouse

| Item | | Specification |
|---|---|---|
| Product | Size | Round bars : 19 - 120mm$\phi$<br>Square bars : 42 - 90mm |
| | Length | 3.5 - 8.0m |
| Number of racks | | 1,800 |
| Unit weight | | Maximum of 4.0 t and average of 3.2 t |
| Storage capacity | | 5,760t |
| Receiving and retrieving rate (t/h) | | Receiving rate of 150 t/h and retrieving rate of 110 t/h |
| Receipt and retrieval control | | AI applied |

bars in a highly efficient and optimum manner

(4) Technology for storing hot and heavy bars

### 4.1 Full directly linked rolling-finishing-shipping technology

Described below, this is the basic technology of the automatic bar buffer warehouse system.

Rolled and cut bars are transferred and received loose into the automatic bar buffer warehouse. Finishing lines where bars are inspected and conditioned are installed after the automatic bar buffer warehouse. This layout eliminates the temporary bundling and tagging of rolled bars and the temporary handling and storage with overhead traveling cranes; the supply of bars by an overhead traveling crane to the finishing line and the unbundling of bars at the finishing line; and the formation of finished bars into lots for specific destinations by supplying bars to the finishing line in the sequence to be shipped while making use of the flexible receiving and retrieval functions of the automatic bar buffer warehouse (see **Fig. 1**).

The processing speed difference between the rolling and finishing processes, the largest problem prohibiting the full direct linkage of the rolling and shipping processes, has been successfully accommodated with this technology.

### 4.2 Loose bar storing technology

Formerly, many long bars were handled as one lift, so that they had to be bundled, transported and stored as one lift at a time as shown in **Fig. 4**. This traditional procedure involved temporarily bundling, tagging and unbundling bars, requiring materials to bundle and tag the bars and raising the bar handling cost.

The loose bar storing technology was developed to counter this situation. As shown in **Fig. 5**, it consists of a loose bar transfer machine to protect bars from defects during conveyance and transfer and a cassette number checker and a high-speed bar counter to automate lot boundary control.

4.2.1 Loose bar transfer machine

As already described, many long bars are handled together as one lift at a time. A holding frame is required to convey and store bars unbundled. As illustrated in **Fig. 6**, bars are loaded into a cassette by a transfer machine, conveyed in the cassette, and stored in the cassette in the automatic bar buffer warehouse.

One problem with this method is that bars are scratched after contacting the transfer machine and cassette when they are loaded and unloaded from the cassette.

A loose bar transfer machine was developed to prevent the scratching of bars during handling and conveyance. As shown in **Fig. 7**, the arms are oval-shaped to change the internal arm width when the forks are opened and closed and to prevent the bars from coming into contact with the cassette support posts or finishing line bar receiving support posts when the transfer machine is raised and lowered. This technology made the scratch-free transfer of loose bars possible.

4.2.2 Cassette number checker

Another problem with the storage of loose bars is the complete automation of lot boundary control. Since loose bars cannot be individually tagged, the data about the cassettes containing loose bars must be controlled by computer tracking alone. A cassette number checker was developed to back up cassette data control, should a tracking error occur. As shown in **Fig. 8**, each cassette is fitted with a bar code plate bearing its number, and the bar code plate is automatically read by the cassette number checker as the cassette enters and leaves the automatic bar buffer warehouse.

During six months of continuous operation, the cassette number checker achieved a reading accuracy of 100%.

4.2.3 High-speed bar counter

Reliable lot boundary control of loose bars requires controlling the number of the bars as well as the cassette data mentioned

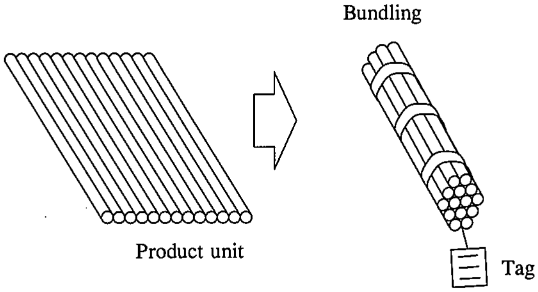


**Fig. 4** Conventional bar storing method

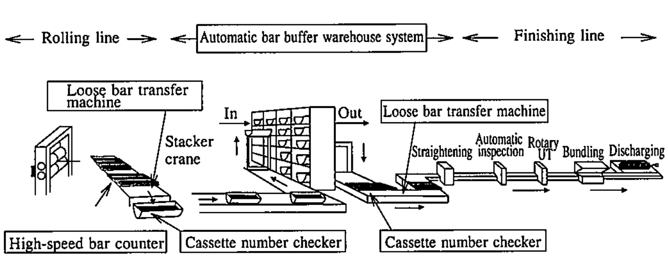


**Fig. 5** Loose bar storing technology

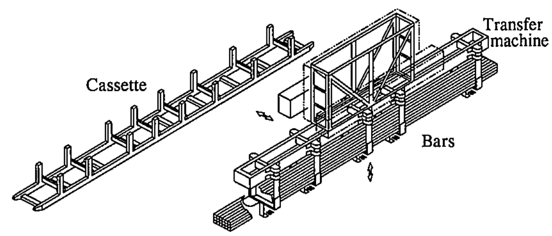


**Fig. 6** Loose bar transfer method

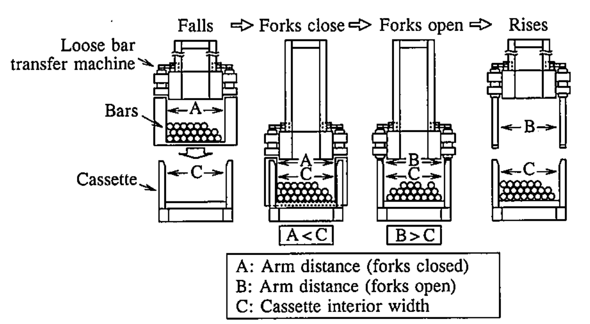


**Fig. 7** Loose bar transfer machine

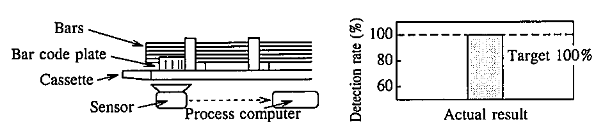


**Fig. 8** Equipment outline and detection rate of cassette number checker

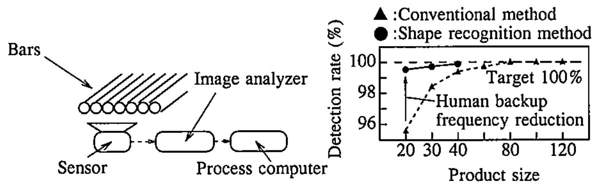


**Fig. 9** Equipment outline and detection rate of high-speed bar counter

above. Bar counters that automatically analyze the image of the end of each bar and count the bars were used but these conventional bar counters were unreliable and incorrectly counted bars due to such problems as deformed bar ends.

The shape recognition method shown in **Fig. 9** was adopted instead to improve the detection rate and to reduce the frequency of human backup.

### 4.3 High-efficiency optimum bar receipt and retrieval control technology

Advanced control functions, such as AI-based optimum bar receipt and retrieval control were introduced into the automatic bar buffer warehouse system to achieve efficient receipt and retrieval of bars within a compact warehouse.

The functions of the high-efficiency optimum bar receipt and retrieval control technology are as follows:

(1) Optimizing operating performance of receiving and retrieving cranes;

(2) Automatic selection of receiving rack positions according to receiving rate;

(3) Automatic relocation of cassettes by prediction of future inventory;

(4) Selection of bars to be retrieved in anticipation of overall material flow from order receipt to shipment;

(5) Selection of bars to be retrieved to maximize finishing line efficiency.

Optimizing the operating performance of the receiving and retrieving cranes noted in item (1) above is shown in **Fig. 10** as an example of applying AI.

### 4.4 Hot and heavy bar storing technology

Conventional automated warehouses mostly handled room-temperature and light materials as shown in **Table 2**. The bars to be stored in the automatic bar buffer warehouse are still at a temperature of about 300°C approximately one hour after rolling and their weight is limited to four tons so that they can be received and stored efficiently.

The following technologies were developed to achive a automatic bar buffer warehouse that can store hot and heavy bars efficiently and inexpensively:

(1) Longitudinal sliding transfer method;

(2) Rack building with entry guide rollers.

#### 4.4.1 Longitudinal sliding transfer method

As shown in **Fig. 11**, cassettes containing bars may be either transferred into the racks of the automatic bar buffer warehouse by the longitudinal sliding transfer method, which involves sliding them into the racks, or by the walking beam transfer method whereby they are lifted and moved into the racks. The former method was adopted to reduce rack space in the vertical direction and to enhance storage efficiency.

As shown in **Fig. 12**, the racks may be installed in the automatic bar buffer warehouse by either the transverse method whereby the stacker crane travels at right angles to the longitudinal direction of the bars, or by the longitudinal method whereby the stacker crane travels in parallel with the longitudinal direction of the bars. The former method, which is suited for moving long bars into and out of the warehouse at a high rate, was adopted to reduce the number of stacker cranes and associated equipment costs.

Accordingly, the cassettes containing bars are longitudinally

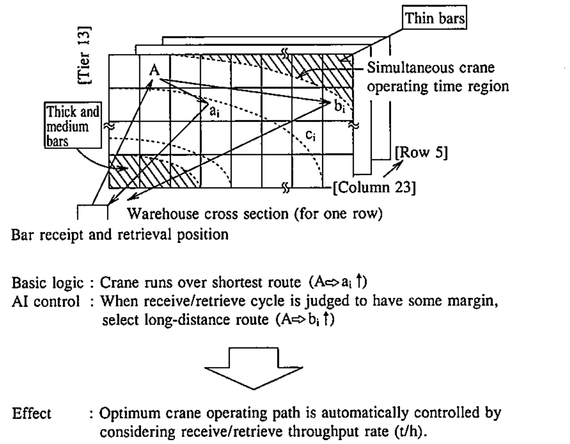


**Fig. 10** Optimization of receiving and retrieving crane operating efficiency as example of AI application in efficient optimum receipt and retrieval control

**Table 2** Needs for hot and heavy bar storing technology

| | | Conventional | New |
|---|---|---|---|
| Material | Temperature | Room temperature | 300°C |
| | Weight | ≦ 2t | 4t |
| Receiving and retrieving rate | | ≦ 100 t/h | 150 t/h |

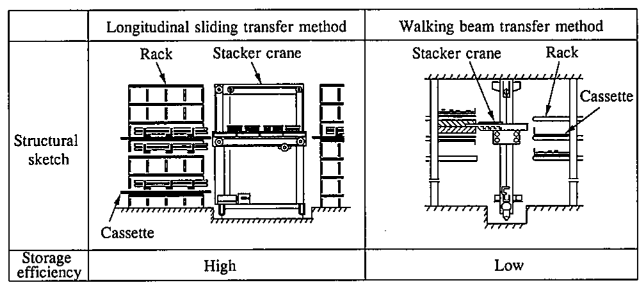


**Fig. 11** Comparison of automatic bar buffer warehouse transfer methods

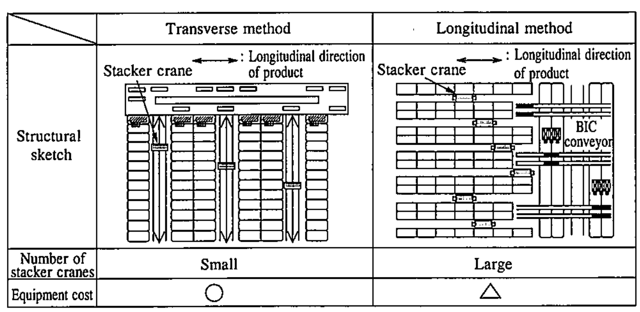


**Fig. 12** Comparison of automatic bar buffer warehouse rack installation methods

slid into the racks of the warehouse in a process known as rack building.

4.4.2 Rack building with entry guide rollers

The longitudinal sliding transfer method allows the cassettes containing bars to be longitudinally moved on the sliders into the racks.

The problems with this method are that the large sliding resistance accelerates slider wear and the large motor load requires increased motor capacity.

As shown in **Figs. 13** and **14**, the first slider at the entry side of each rack in the rack building was replaced by a roller to reduce slider wear. All sliders may be replaced by rollers, but this would lead to the cassettes being unsecured in the event of an earthquake. If a roller is installed at the first entry position of each rack, the cassette is not in contact with the roller when moved into the rack and will not move out of the rack when an earthquake occurs.

## 5. Performance of Automatic Bar Buffer Warehouse System

As shown in **Fig. 15**, the full direct linkage of rolling, finishing, and shipping operations enhanced nonprice competitiveness, reduced manufacturing costs, and improved the working environment.

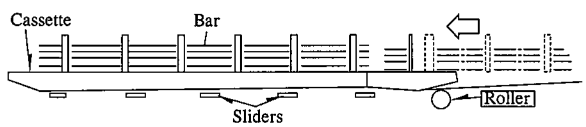


**Fig. 13** Equipment outline of rack building with entry guide rollers

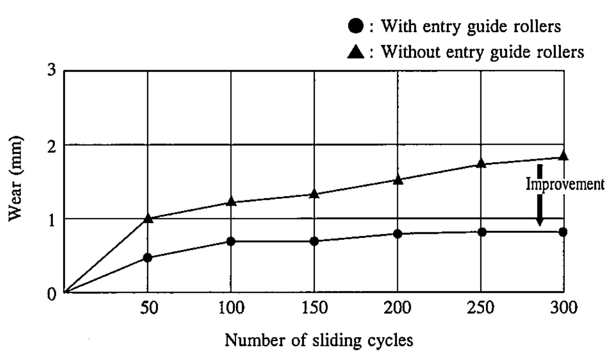


**Fig. 14** Effect of rack building with entry guide rollers

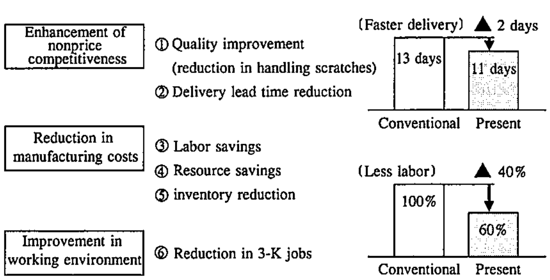


**Fig. 15** Benefits of development project

### 5.1 Enhancement of nonprice competitiveness

The full direct linkage of the rolling and shipping processes cut the number of times the bars are handled by crane by a factor of four, sharply reduced the handling scratches of bars, and strengthened bar quality control.

### 5.2 Reduction in manufacturing costs

The elimination of some process steps obviated the need for crane operation and slinging in the transportation phase and bundling, tagging, unbundling and yard control in the temporary storage phase. As a result, a labor saving of 40% was achieved, and the inventory was reduced.

The consumption of the materials associated with the above-mentioned operations such as bundling hoops and packing tags was also reduced to gain a large reduction in manufacturing costs.

### 5.3 Improvement in working environment

In Japan, the crane operating and slinging tasks are classified as 3-K jobs. Elimination of these Kitsui (demanding), Kitanai (dirty), and Kiken (dangerous) jobs markedly improved the working environment at the bar mill.

## 6. Conclusions

Nippon Steel's Muroran Works has long strove to build a comprehensive integrated distribution system and a flexible special bar and wire rod manufacturing system to supply customers with the products they need when they need them, and to augment its special bar and wire rod manufacturing base.

Under these circumstances, the Muroran Works has already implemented such control systems as a small-lot steel product manufacturing system, a flexible shipment tracking system, and Polestar, an integrated process control system.

The introduction of these closely linked systems has strengthened the flexible bar manufacturing system at Muroran. At the same time, the quality control was reinforced, inventory reduced, delivery efficiency was raised by improving distribution efficiency and shortening the delivery lead time, and nonprice competitiveness as represented by order status information service was improved markedly.