IMPROVING THE COMPETITIVENESS OF
IRON ORE COMPANY OF CANADA
IN THE WORLD MARKET*

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THE CAROL PROJECT

Currently all of Iron Ore Company of Canada's (IOC) iron ore products are produced at the company's Carol Lake operations, located at Labrador City in the southwestern portion of Newfoundland-Labrador. The area, approximately 965 km NE of Montreal, is 535 meters above sea level in a climatic region characterized by cold winters and short, cool summers. The temperature ranges from $-50^\circ C$ to $25^\circ C$.

IOC began working in the area in 1949, however, it was not until 1958 that the decision was made to proceed with mining operations. The ore body consists of Specular Hematite ($Fe_2O_3$) and Magnetite ($Fe_3O_4$) with small quantities of Limonite and Geothite. The average grade of the ore bodies is 39% iron.

The mining facilities, crushing plant, and concentrator were in operation by the early part of 1962. In the summer of 1961, a decision was made to build a pelletizing plant adjacent to the concentrator. This plant was designed, erected and placed in operation during 1962 and the first half of 1963. Since the completion of the pelletizing plant, additional expansions to both the pellet plant and concentrator have taken place in 1967 and 1973. Today, the Carol Project has the capacity to produce 20 million tonnes of concentrate and, using part of this concentrate, 10.5 million tonnes of pellets.

A general flowsheet of the operation is shown in Figure No. 1.

The period 1980–85 spans a period of energy crisis, world-wide recession, and a consequent re-structuring of the worldwide steel industry as many producers struggle to survive in an arena of excess world capacity, and increasing competition from substitute materials.

Media headlines over the past few years echo the woes of the industry and the strategy plans for survival of the fittest.

In North America alone:

There have been over 600 facility closings.
Over 200,000 steelworkers have lost their jobs.
Major steel companies have lost over $7 billion since 1982.
The 7th largest producer went bankrupt.

This paper reviews the progress made by Iron Ore Company of Canada, Canada's largest iron ore producer, in its efforts to increase labor productivity, improve product quality and lower production costs at the Carol Project in an effort to survive in an increasingly competitive world iron ore market.

* 昭和61年6月10日本会第76回例会において発表
** Iron Ore Company of Canada
*** M.A. Hanna Company
Presented to the Mineral Beneficiation Conference The Research Society of Resource's Processing, Japan June 1986

Vol. 33. No. 2 (86-夏)
Because of variable market conditions in the early 1980s, a revised ten year mining plan was developed to accommodate scaled down operations while providing the flexibility for increased production modes as required. As a result, a significant reduction in the stripping program was achieved. During the period of 1980 through 1985, a better than 50% reduction in stripping costs was realized.

The Revised Ten Year Program: Figure No. 2 shows four pits which have produced approximately 630 million tonnes of crude ore since 1962. The ore is hauled by 150 tonne trucks to loading pockets or ore passes. Here the ore, maximum chunk size approximately 1.5 meters diameter, is transferred by pan feeders onto an automatic railroad system which feeds the primary crushing plant after a haul of approximately 14 kilometers. In the scaled-down operation the Smallwood Mine, which feeds #2 pocket, has been shut down since the remaining two pockets can handle the present ore volume requirements.

The #4 pocket is presently fed from Humphrey North and the #3 pocket is fed from the Humphrey Main and Humphrey South mines. The Humphrey South mine was expanded in 1983 to open up a large ore body that will increase in production as the Humphrey North and Humphrey...
Main ore bodies are depleted and as their increasing depth incurs additional haulage costs.

The major change in the mining plan was a decision to join the Humphrey North and Humphrey Main pits and eventually haul Humphrey Main ore to the #4 pocket instead of to the #3 pocket.
(Figure 3) This decision eliminated the need to remove some 14 million cubic meters of stripping at the south end of the Humphrey Main pit over the next ten year period. The disadvantage in this scheme is the longer uphill haul to #4 pocket, but this will be compensated by utilizing trolley assist, or in-pit crushing and conveying concepts as the pits get deeper.

**Computerized Truck Dispatching System:** The purchase price of a 150 tonne haulage truck is over 1 million dollars. Loading and hauling accounted for 37% of the Carol mining costs in 1984. As the pits get deeper the haulage costs increase each year. Increasing the efficiency of the shovel and truck fleet is, therefore, an important priority. A computerized truck dispatching system has been in operation since May 1985. A central computer is located in the mine office, 5 kilometers from the mining area. A dispatcher is stationed at the central control 24 hours per day. The trucks are automatically assigned to shovels on a priority basis. The purpose of the system is to reduce the lost time associated with trucks queuing up at shovels, or shovels waiting for trucks. The object is to optimize the truck/shovel operation, reduce lost time, increase the productivity of the shovel/truck fleet and thereby reduce the number of pieces of equipment and manpower required for loading and hauling.

Each truck and shovel has a transmitter and console on board. Location sensors are located along the haul roads on the waste and ore dumps and at strategic points around the mine. Signals are relayed by way of a transmission tower to and from the computer so that the movement and activities of the shovel/truck fleet are monitored on a minute to minute basis.

The dispatcher watches the operation by means of screens and reacts to exception messages, out-of-line conditions, and inserts details on reasons for delays, changes in the operating parameters for the day, etc. The benefits of the system are:
- Improved truck and shovel productivity.
- Reduced cost due to less idling, less fuel waste, reduced fleet and associated manpower and maintenance savings.
- Reduced supervision required in the pit.
- Reduced clerical staff required for production recording, report typing, manual data analysis etc.,
- Improved quality control of the blending operation.

The system also provides data required to further analyze the reasons for lost time and the areas to concentrate on for additional improvements, shovel clean-up delays, repeated maintenance problems, etc.

**Improvement in Blasting Methods:** Drilling and blasting amounts to about 40% of the mining costs and is therefore an area where cost reduction methods are continually being initiated. Following are four projects that have been completed or are in progress:
- Deep Well Dewatering
- Conversion to Gelmaster Trucks
- Testing of different explosives
- Final Wall Drilling

**The Deep Well Dewatering Program:** Consists of installing wells approximately 200 to 300 meters deep around the perimeter of the pits in area where the ground formation is water bearing. The objective is to lower the water table in the vicinity of the well and provide drier conditions for blast site drilling and loading. Dry ground conditions reduce drilling costs and enable cheaper
Improving the Competitiveness of Iron Ore Company of Canada in the World Market

Explosives to be used.

The wells are drilled with a conventional Gardner Denver GD120 drill with a 38 cm drill bit with various modifications added for the annual well drilling program.

Conversion to Gelmaster Explosive Trucks: Prior to September 1982, bulk explosive slurries were mixed in batches and stored in holding tanks at the explosives plant. From the holding tanks the slurry was pumped into three slurry bulk trucks that transported the material some 10 kilometers to the mine site. Each truck at that time averaged $2\frac{1}{2}$ round trips in an eight hour day, seven days per week.

The three trucks were replaced with three Gelmaster trucks, which operate in the same manner as a concrete truck with a revolving drum action. The Gelmaster truck mixes the slurry while it is enroute to the mine facility and reduces the manpower required for operation of plant facilities and also the blast site loading application. The improvement in productivity in terms of tonnes of explosives per manhour was $+22\%$.

Blasting Tests: The economics of blasting includes the overall cost of drilling, blasting and the effect of good muck pile fragmentation on the productivity of the mining operation. The status of present blasting technology on the Carol Project is that we appear to have reached a system plateau where we have optimized the use of our present system. Further attempts to increase the drilling pattern to reduce explosives costs are offset by increased costs of secondary blasting of oversize material, decreased shovel and truck productivity from difficult digging conditions, and the associated higher maintenance cost of the mining equipment.

To achieve a major reduction in the cost of explosives, without adversely affecting blast pile fragmentation, requires an analysis of the cost of the various blasting ingredients and a chance in the 'blasting system' to reduce or replace the quantity of the high cost explosives with a lower priced product.

The dominant ingredient in the product where cost reduction would be most effective would be finding a cheaper substitute for T.N.T.

From November 1984 to July 1985, approximately 3.3 million tonnes of ore have been blasted with either a slurry type or a heavy ANFO explosive. At this time, the test work is not completed but illustrates the magnitude of our commitment to reduce our blasting costs.

Final Wall Drilling: In the review of the mining plan the necessity to include a detailed final wall drilling program was considered critical for two reasons:

1. To address the potential safety hazard of rock slides with our present final wall design. This hazard increases with depth.
2. To achieve further reductions in stripping by increasing the final wall slope from the present design of $55^\circ$ by at least $2^\circ$.

Figure No. 4 shows the effect of uncontrolled blasting on final pit walls. Three benches are stacked as shown with a 18.3 M berm every third bench. The location of the 38 cm drill holes are shown using conventional drilling equipment.

To attain the $55^\circ$ final pit slope requires that the last drill hole be located as shown. The planned final wall location and slope is $76^\circ$.

Figure No. 5 shows the concept of final wall blasting using preshearing and buffer control blast layout. One row of small diameter closely spaced holes, located at or as close as possible to the desired final wall face, is drilled off and lightly loaded. When detonated prior to the main portion of
the blast, a crack is created providing the mechanism by which the large forces generated during the main blast can be dissipated so no damage occurs at the final wall.

At the present design of 55° or a future design of 57° this method is an improvement to leave the required safety berms intact and provide competent pit walls.

Figure No. 6 demonstrates how the increased slope angle can produce cost benefits.

The example shows a typical cross section of a pit final wall. The section is 10 benches deep. The length of wall is 1,340 meters. With a slope increase of 2° a reduction of 650,000 cubic meters of stripping would be achieved. The proposed program over the next three years totals some 10,000 meters of final wall length.
CONCENTRATING

With the addition of two mills in 1967, the grinding section of the Carol concentrator consisted of 8, 6.4 meter diameter dry Aerofall mills. In 1973, a major plant expansion resulted in the installation of two, 10.52 meter diameter dry Aerofall mills. At the same time, new mining areas were developed that produced ore of a more difficult grinding type. Combined with a number of startup difficulties encountered with the 10.52 m mills, the result was a net decrease in the anticipated productive
According to the manufacturer, a distinctive feature of the Aerofall mill, as compared to the conventional mill, is the special feature of its wedge shape “deflector” liner design (Figures 7 and 8) which was claimed to provide “keying” action in the mill that produces an important part of the crushing and grinding action in the mill.

Test work conducted in the 6.4 and 10.52 m Aerofall Mills showed that the conventionally used “deflector” type liners which form the basic principle of Aerofall Mill grinding did not necessarily provide the best grinding performance. A new design, as shown in Figures 9 and 10, using low profile liners incorporating radial ribs of proper height, actually improved the mill throughput in the order of 9 to 20% without sacrificing grinding efficiency. In addition, the new design reduced liner weight and scrap losses, which resulted in reduction of liner consumption by 25%. It provided better protection to the mill shell and reduced the overall maintenance cost for the mills.

In mid 1985, the concept of using wet autogenous grinding to replace the old, small Aerofall mill was carefully re-evaluated. This study was prompted by the high fuel costs associated with dry grinding and in-plant environmental concerns relative to controlling dust levels. Additionally, the shells and heads of these mills had experienced substantial wear during their 20 years of operation and would require replacement in the near term.

The results of this study indicated that there was significant financial justification in replacing the six original small Aerofall mills with 2, 9.75 meter diameter wet autogenous mills. Of the total cost savings, fuel reduction was 2/3 and labor and maintenance was 1/3. The project was approved at a capital cost of $19.4 MM (Canadian) and construction is in progress. The first new mill will start up about September 10 this year and the second by the end of 1986.

Flowsheets of the old and new installations are shown in Figure No. 11.

With the present gravity concentration flowsheet followed by magnetic scavenging of the tails, the plant weight yield in 1985 was 44.2% with an overall iron recovery of 73.8%.
While some of the iron in the tails is in the form of unrecoverable silicates or carbonates, there is significant quantity of liberated and liberable iron mineral which is both too fine for efficient gravity concentration and is non-magnetic. A research program is currently underway to assess the potential of recovering the iron values using present day mineral processing technology.

**PELLETIZING**

**Open Circuit Grinding:** After extensive inplant testing, two of the six pellet lines were converted to open circuit grinding (from closed circuit) in early 1981. With the elimination of classification, the heat generated during grinding is preserved in the product slurry. The net result is improved filtering efficiency, lower green ball moisture, reduced bentonite consumption by (7%) and a better
quality green ball fed to the induration machine.

Comparative plant evaluation indicated that the converted line produced a 19% better Tumble Index, a 1% increase in Q Index, a 11% higher compressive strength, and a 6–10% reduction in fuel oil consumption. The entire plant was subsequently converted to open circuit grinding.

**Grinding Media:** During the development work on open circuit grinding, it was found that grinding in open circuit resulted in a 15% reduction in mill throughput using 3.81 cm forged grinding balls. This negative factor, mainly because of a higher blaine target, made it impossible to consider a complete plant conversion to open circuit grinding at that time. To overcome this problem, five different grinding media were evaluated. The five grinding media were: 2.86 cm slugs, 3.81 cm Algoma forged balls, 3.81 cm Norforge forged balls, 3.81 cm high chrome balls, and 2.54 cm high
6.4 m Diameter Aerofall Mill
New Liner Assembly

Fig. 9

Table 1.

<table>
<thead>
<tr>
<th>Grinding Media</th>
<th>Consumption (kg/t)</th>
<th>Power (kwh/dlt)</th>
<th>Throughput (dthp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) 2.86 cm Slugs</td>
<td>1.91</td>
<td>27.3</td>
<td>70</td>
</tr>
<tr>
<td>2) 3.81 cm Algoma (Base Case)</td>
<td>2.11</td>
<td>23.6</td>
<td>81</td>
</tr>
<tr>
<td>3) 3.81 cm Norforge</td>
<td>2.04</td>
<td>20.8</td>
<td>84</td>
</tr>
<tr>
<td>4) 3.81 cm High Chrome</td>
<td>0.94</td>
<td>23.2</td>
<td>85</td>
</tr>
<tr>
<td>5) 2.54 High Chrome</td>
<td>0.86</td>
<td>19.0</td>
<td>94</td>
</tr>
</tbody>
</table>
The performance of these grinding media is shown in Table No. 1. The best performance was achieved with the 2.54 cm high chrome balls. This media provided the grinding capacity to handle 100% open circuit grinding without any loss in tonnage. It was also the most cost effective of all the grinding media evaluated. All mills were converted to 2.54 cm high chrome grinding balls in 1982.

**Product Size Control:** The control of product sizing in a pelletizing operation is accomplished in
Improving the Competitiveness of Iron Ore Company of Canada in the World Market

Fig. 11

the balling circuit. Carol Project employs balling drums, originally closed on vibrating screens for size control. In 1977, a test roller screen was installed to replace a Tyler vibrating screen.

A test program comparing the two screen types led to complete conversion of one line to roller screens. Substantial improvements were indicated compared to the vibrating screen. This led to the conversion of the entire plant to roller screens by the summer of 1980. The benefits of roller screens over vibrating screens are: Elimination of oversize with roller screen shredder system improvement of at least 20% on the 12.5 mm × 9.5 mm, and undersized fraction.

**Rubber Lined Balling Drums:** The elimination of balling drum cutter bars by the installation of a flexible rubber lining had proven successful in Sweden and Holland. The balling drums at the Carol Project were 20 years old, and major mechanical maintenance was becoming inevitable. The possibility of reduced maintenance cost and a better balling operating resulted in one drum lining being installed in 1982. Six drums have been converted subsequently and more will be installed this year. The drums operate at one half the speed of the cutter bar equipped drums. This has allowed drums with worn riding rings to operate without major maintenance. The slower speed also has resulted in an improved green ball size structure.

**Use of Coke Breeze:** The addition of coke breeze to the Pellet Plant feed has been a dominant factor in reduced fuel cost and improved pellet quality control.

Coke breeze was added to one machine as a test in June 1984. The addition rate was gradually increased to 0.4% (dry basis) as more experience and confidence was acquired. Despite some feeding and grinding problems, the benefits of coke breeze were evident in both pellet quality and energy consumption.

As a result of this improved performance, it was decided to add coke to all machines. Coke addition to the plant began in September 1984 at a rate of 0.5%. The addition rate was increased and has been set at approximately 1% since November 1984. The indurating machines have been set up to run at approximately 80% magnetite equivalent.

The effect of the coke breeze addition at the 1% rate was been an improvement in pellet quality.
1) The abrasion index has improved by 20%.
2) Fired compression has been reduced by 3% but the standard deviation has improved by 25%.
3) The reducibility has improved by 13%.

The benefits on energy consumption has been:
1) A 15% reduction in total fuel energy.
2) A 60% reduction in the number of operating burners.

Coke breeze addition has become an integral part of the pellet plant operations. Modifications and adjustments to plant conditions such as furnace temperature profiles, air system changes, and improved operating procedures are being implemented.

Fluxed Pellets: Late in 1985, over 100,000 tonnes of fluxed pellets were produced in a special operation at the Carol Project. One pelletizing machine was isolated from the rest of the plant to produce fluxed pellets. Normal acid pellet production was maintained during the period. The pellets were fluxed with a mixture of 60% dolomite and 40% limestone. This trial run was successful. Over 1.0 mm tonnes of fluxed pellets have been booked for 1985. This new product has improved IOC's marketing capability.

LABOR PRODUCTIVITY

Manpower Re-organization: The labor cost for the Carol Project is in the order of 23% of the total operating cost. Improving manpower productivity and reducing the workforce was essential to offset the increasing cost of labor. The downsizing of the operation during the period of 1980 to 1984 required a re-organization of not only the plant and mine departments but also the service department such as warehousing, administration, financial departments, etc. A task force was set up with a mandate to review the Company organizational structure and, based on general production level guidelines, provide a detailed report outlining a revised and streamlined work force organization and manpower requirement. The task force completed a six-months review in November 1983 and major organizational changes were in place by year end. The Carol Project's total work force in 1980 averaged 2,760, in 1985 the force averaged 1,505, a decrease of 1,255 persons or 45.5%. The corresponding reduction in concentrate production was from 16.27 million tonnes to 15.3 million tonnes and pellet production from 9.15 million tonnes to 8.95 million tonnes. This was only a 6% and 2.2% reduction respectively.

The labor productivity improvement and associated force reduction were obtained by the following general programs:

By installing a project-wide system of planning and scheduling which analyzes manpower requirements and focuses on reasons for lost productivity.

By implementing job combinations and reducing the number of job classifications from 51 to 13.

By implementing equipment and plant improvements which results in manpower reductions.

Manpower Scheduling and Control: A part of the re-organization and scale-down of the work force included the installation of a new concept of manpower planning and control. This system was installed in all maintenance departments of the Carol Project, in Mine Operations and also in Warehousing. The system enforces the five basic management principles of planning, assignment, follow-up, reporting, and perpetuation. The system was installed over a period of approximately six months starting with the Mine Maintenance group, and continuing in a systematic manner with the other group. The new system played a major role in the analysis of the individual department's
Improving the Competitiveness of Iron Ore Company of Canada in the World Market

manpower levels for various production scenarios. This is an exercise which is now done much more frequently than in previous years, due to the uncertainty of the steel industry and the need to respond quickly to the change in market. The new system played an important role in the re-organization and streamlining of communication in the various departments.

Job Amalgamation: The inflexibility of the Carol work force due to the number of different job classification in the operating departments become more apparent with the scaled down operation.

The process of bumping following manpower layoffs under the labor agreement causes a major disruption to the operation. As an example, to replace one attendant could trigger 55 moves across the project.

In January 1984 a series of job combinations was initiated which reduced the number of operating job classifications from 51 to 13. While this amalgamation effectively reduced the work force by 42 persons, the implementation of the move coincided with a boost in production which cushioned the effect of the number who would have been layed off. The resulting improvement in flexibility for different levels of production, for vacation replacement, and for departmental organization is a major factor of improved productivity in recent months. The benefits of job amalgamation can be summarized as:

1) Reduced work force.
2) Improved flexibility.
3) Improved productivity.
4) Improved stability and reduction of bumping effect during layoff periods.
5) Reduction of temporary recalls for vacation replacements.
6) More variety in the employees’ job content.

The results of these efforts is best illustrated in Figure 12 and 13. Figure No. 12 compares the manpower productivity, the labor rates, and the unit costs over the period 1980–85. The labor
rate has increased by 36.8% over the period. The labor productivity has increased by 62.6% and has been a major influence in achieving a 6% reduction in the cost of the Carol Project's total saleable production.

Figure No. 13 compares total saleable product and associated manpower levels in 1980, 1984, and 1985 versus 1980. The trend shows that by 1985 while the production level has decreased by 4.6%, the hourly force has been reduced by 42%, the supervisory force by 54% and the clerical force by 76%.

ENERGY CONSERVATION

Energy Conservation Program: Fuel energy is the second largest component of the Carol Project's operating costs and in 1985 accounted for approximately 8.5% of the mining cost, 36.2% of the concentrating costs and 45.3% of the pelletizing costs. These statistics illustrate the challenge for energy conservation strategies on a continuing basis. Major improvements have been and are being implemented in this respect.

In 1980 a strong corporate commitment was made to address the high cost of fuel. Two major objectives established were:

I. To investigate appropriate means to ensure an adequate energy supply at an acceptable cost on a continuous basis.

II. To reduce the rate of energy consumption for each product by 10% within a two year period.

To carry out this task a director of energy management was assigned to work towards corporate energy objectives. In each Company division an energy co-ordinator was designated to monitor and report on all energy related projects. An extensive improvement program was initiated with an emphasis on the reduction of oil consumption.

Energy Cost Versus Consumption: Figures 14 and 15 illustrate some trends in increased
major consumables cost versus consumption rates. The graphs reflect the energy conservation program's success in offsetting inflation by reducing the consumption rates of the various products.

The Bunker 'C' cost for the dry grinding circuits in the concentrator has increased by 121%,
Figure No. 14 shows the reduced consumption of 18% over the period 1980–84. In product drying the price increase of 101% is offset by a 51% reduction in consumption by partially converting to electrical energy.

Fuel cost represents approximately 45% of the pelletizing cost and Bunker ‘C’ cost has increased by 126% (Figure No. 15). This has been offset by a reduction in consumption of 21%. Grinding ball price has increased by 73% partly due to a change in the specification. This has been offset by a 43% reduction in consumption.

The most significant modification in pelletizing was the addition of ‘coke breeze’ to the furnace feed. Coke breeze when mixed into the iron ore pellet prior to ‘indurating’ provides an internal source of energy which reduces the Bunker ‘C’ oil consumption during the indurating cycle. This internal heat release also improves productivity and the quality of the pellet.

QUALITY CONTROL

The 70’s was an era of expansion in the steel industry, witnessing an increase in both steel making capacity, iron ore mining, concentrating and pelletizing. The steel plants were anxious to ensure a continuing source of raw materials. The emphasis was on volume. Quality tended to be a secondary consideration.

The ’80s brought a continuation of the energy crisis, a world recession, a transformation to the small fuel efficient cars, a major reduction in steel requirement and a resulting surplus of steel making and support industries’ capacity. The recession required drastic cost cutting measures to be taken. Obsolete and high cost operations were shut down. In a buyer’s market the emphasis has moved to quality and cost.

Quality control is now the key word in the industry. In Japan you have demonstrated that quality control and productivity are synonymous to producing a high quality product at a low cost.

In early 1984 the Iron Ore Company embarked on a Company-wide training program on the use of statistical process control methods. Senior management endorsed the quality control concepts of S.P.C.

Training programs were implemented at each level in the organization outlining the concepts of statistical quality control, and their potential application in all phases of the operation, from purchasing of supplies to the quality of the iron ore concentrate and pellets produced. Consultants were used to train key personnel such as managers, superintendents and engineers on the technical application of statistical process control.

At the present time these concepts are being integrated into the day to day operation of the project. Training programs are being prepared for the total work force. To further emphasize the importance of the production of quality products, IOC has very recently created a new department which will control and coordinate all quality control functions in the company.

We believe that with these measures already made and our effort to make improvement a continuous process, IOC will remain a competitive producer in the market place.