Trackless mining at LKAB, Sweden

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SYNOPSIS

Because the usual means of transporting men and material to the working sites was time-wasting and uneconomical, inclined subways were installed in the Kiirunavaara Mine that permitted the access of rubber-wheeled vehicles to all underground working sites. Men and material could now be transported direct to the working site with no reloading. An increase of 8 to 12 per cent in underground productivity has been obtained by the use of this new transportation system. Rubber-wheeled vehicles are also used in development, production drilling, and loading. In December 1958, the management of the Luossavaara Mine decided to cut the costs of waste-rock haulage. The system of waste transport was the conventional one of shuttle car, rail haulage, and skip hoisting. After consideration of other methods, it was decided to re-equip the mine completely for a system of trackless transport. Results show that mining costs per ton of ore were reduced by 27 per cent, and mining costs per ton of waste were reduced by a spectacular 80 per cent. The new system has proved to be more flexible, and ore grading has been simplified since there is no longer any mixing in ore passes and chutes.

SAMEVATTING

Omrede die gewone manier om personeel en materiaal na die werkfront te vervoer baie tydrowend was, is skuinsvervoerweë in die Kiirunavaara Myn ge-open wat die toegang van voertuie met rubberwiele na alle ondergrondse werksfronte moontlik gemaak het. Personeel en materiaal kon nou sonder oorlaai na die werksfronte vervoer word. Hierdie nuwe vervoerstelsel het 'n verhoging in ondergrondse produktiwiteit van tussen 8 en 12 persent teweeg gebring. Voertuie met rubberwiele word ook gebruik in ontsluiting, boor- en laaiwerk. Die bestuur van die Luossavaara Myn het in Desember 1958 besluit om die koste van afvalrotsvervoer te besnoei. Die afvalrotsvervoer was voorheen behartig deur wisselkarre, spoorvervoer en hysbakke. Nadat ander metodes oorweeg is, is daar besluit om die hele myn toe te rus vir spoorlose vervoer. Resultate het bewys dat mynboukoste per ton erts met 27 persent gedaal het en mynboukoste per ton afvalrots met 'n ongelooflike 80 persent. Die nuwe stelsel is baie meer soepel en die gradering van erts is vergemaklik omdat vermenging in die ertsstortbaan uitgeskakel is.

INTRODUCTION

The most important exporters of iron ore in Scandinavia are the mines in Northern and Central Sweden, as well as in Sydvaranger and other places in Norway. By far the biggest quantities are mined at the LKAB mines in Northern Sweden. The present production of these mines is about 28 million tons per annum, with an expected initial increase to 32 and thence to 35, or even to 40, million tons per annum.

Formerly, the rate at which the mine was deepened was 5 to 8 m (15 to 25 ft) per annum, but this has now been increased considerably and will soon be 10 to 20 m (30 to 60 ft) per annum and more. This means that, simultaneously with the increase in output, problems arise from the increasing hoisting depth, the development of new haulage levels, and the sinking of shafts. In addition, newly opened, well-situated opencast mines present a growing competition to the iron ore mines in Northern Sweden.

IMPORTANT FACTORS FOR HIGH OUTPUTS

When an increase in output from underground mines is considered, shaft capacity is of prime importance. It is evident that the shafts, whether they are vertical skip shafts or inclined shafts with conveyor belts or rails, are one of the most costly investments in the exploitation of a deposit. The desired increase in capacity is generally attained either by means of several parallel shafts or by means of larger skips and a higher hoisting speed in existing installations. However, it may be equally important to increase the utilization of available time for haulage of ore in shafts in operation and to decrease the number of delays by well-planned personnel and material transport or by an alternative use of special shafts or ramps for this traffic.

In order to ensure an equal and uninterrupted supply of ore to the shafts, a high-capacity horizontal transport system is needed. This system must be backed by well-planned mining, including a sufficient number of highly productive loading points that can be combined in such a way that the optimum use of the transport system is obtained. In a well-planned transport system and in the subsequent ore-treatment phases, the use of automation often results in good economy.

High efficiency and low costs will be obtained from a mining method involving highly advanced mechanization and moderate development shortly before the actual mining. The method must also provide for the possibility, if necessary, of the selective and balanced mining of ore of various grades, depending on whether the ore is shipped as mined or is beneficiated.

Another important factor is the overall lay-out of the mine. The location of shafts, the shaping of main levels, the distances between levels, and the pattern of communications require a system of planning and projection, which nowadays can be examined by operational-research techniques. At the same time, installation and construction work can be planned with the help of some of the modern network methods, such as PERT or CPM.

Furthermore, it has proved fruitful to plan the integrated production flow by means of well-founded programmes based on mathematical analyses of the process. This planning is now achieved in one of Sweden's largest iron ore mines by means of an on-line computer.

TRANSPORTATION SYSTEM IN THE MINE

In consideration of the principles on which an economic mine lay out can be established, methods will be found that permit the calculation of an optimum siting of the shafts in

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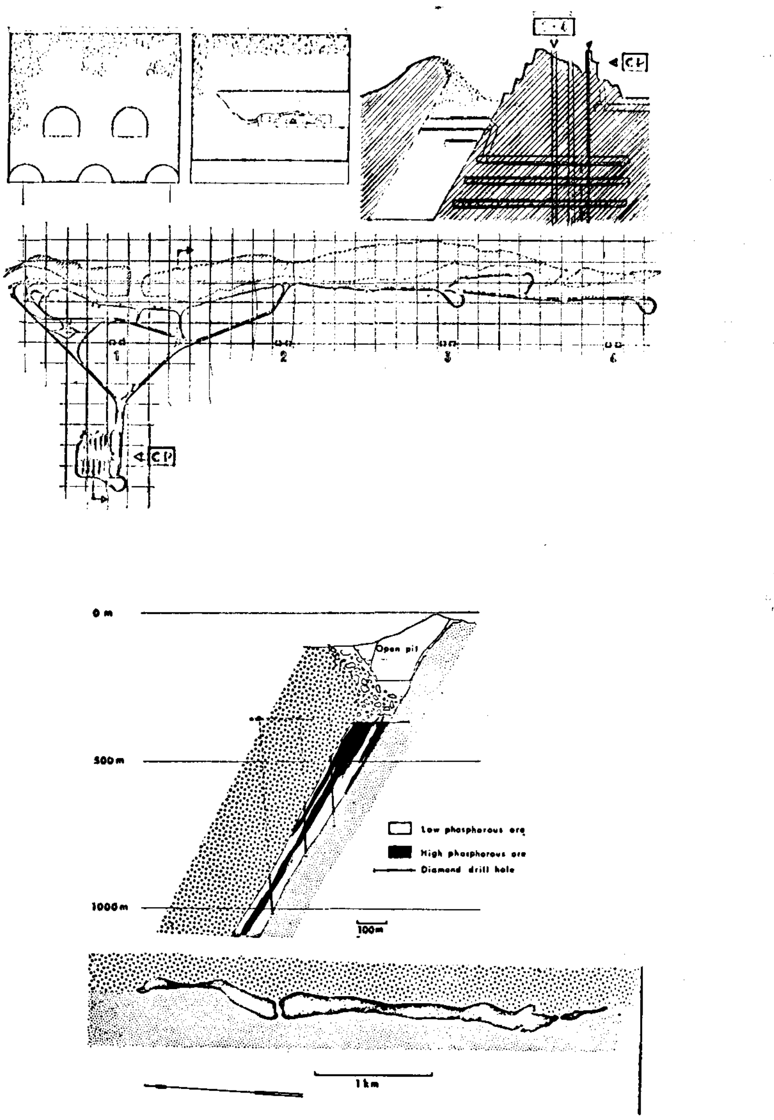


Fig. 1—The first lay out principle consisting of one to four shaft-groups in the footwall was replaced by a central hoisting plant with eight shafts designed for single hoisting and two shafts for double hoisting

relation to the orebody. An interesting example of a solution to the haulage problem where output is high and where there are many grades of ore is the Central Hoisting Plant in Kiruna (Fig. 1).

Here the choice had to be made between the siting of four shaft-groups at equal distances over the 4 km-long orebody, and the siting of all shafts centrally. The system of four shaft-groups would have limited the transport capacity underground. The system with a central hoisting plant offered the better solution to the ore treatment above ground. Because central haulage also had considerable advantages, in that the ore could be separated into various grades, it was adopted. Today, the hauling installation comprises eight shafts for single-skip hoisting with counterweights and two shafts with double skips, which together represent an annual capacity of 23 to 25 million tons of ore.

Moreover, it is possible to calculate the optimum distance between levels, especially because of the new and safe methods for the driving of raises. Formerly, a distance of 40 to 60 m (120 to 200 ft) between the main levels in a mine with a steep dip was often chosen. Nowadays the economic distance is greater and is often as much as 120 to 240 m.

Sometimes, in order to obtain the greatest possible utilization of the ore shafts, a special shaft for personnel and material transport is provided to relieve the main haulage shafts of this traffic. In the Kiirunavaara Mine, this problem—involving personnel and material transport—has been solved in a somewhat unusual, but nevertheless extremely rational, way.

Formerly, personnel and material were taken by rail through horizontal galleries to the various underground shafts, where they were transferred and transported vertically to the underlying levels (Fig. 2a). After a further transfer and another horizontal passage along the main levels, personnel and material were transported down an inclined subway to the site where either the material or the personnel were required. This personnel and material transportation system resulted in considerable time-wasting and uneconomical rehandling, all of which disturbed the efficient transport of ore.

An entirely new and radical solution to the transportation problems was achieved by the installation of inclined subways that permitted the access of rubber-wheeled vehicles to all underground working sites. This form of communication has made it possible to transport both material and personnel direct to the working sites with no reloading (Fig. 2b). This, in turn, has resulted in considerably cheaper handling of material, as well as in a reduction of travelling time and in a corresponding increase in the productive labour time available underground. An increase of 8 to 12 per cent in underground productivity has been obtained by the use of this new transportation system. Also, the shafts have been relieved of the disruptions caused by waste-rock handling.

PRACTICE IN SUB-LEVEL CAVING IN KIIRUNAVAARA

Extraction

Sub-level caving can be divided easily into the following independent operations:

(1) development (drifting),

(2) production drilling (fan drilling), and

(3) loading (caving) (Fig. 3).

The old transport system

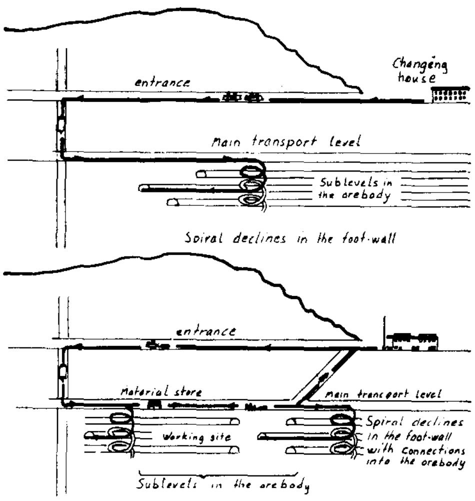


Fig. 2a

The new transport system

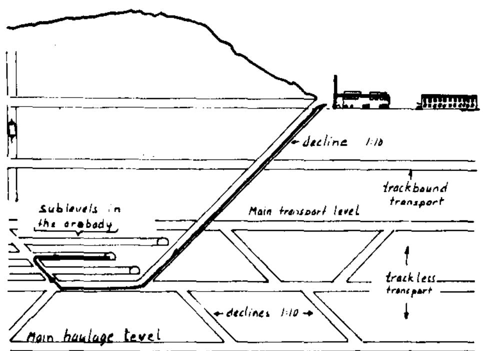


Fig. 2b

A strict application of this division and a geographical separation of the operations ease the optimization of the use of the machine units involved, facilitate planning, and minimize the number of interruptions. In addition, production flexibility is increased.

Development for Sub-level Caving

Each incline has connections driven towards the orebody on each sub-level. When the development of a sub-level is started, this drift is driven further into the orebody to the main transport drift. In order to obtain numerous points of attack, drifting is then concentrated on the main transport drifts, and cross-drifts are collared at every 11 m. The cross-drifts are then driven from the main transport drift in both directions up to the hanging-wall and footwall.

At the footwall, short stretches of drift are opened between the cross-drifts so that a longitudinal footwall drift is created. This is necessary when the last portion of the sub-level is caved. In the near future, the layout of the sub-level will be

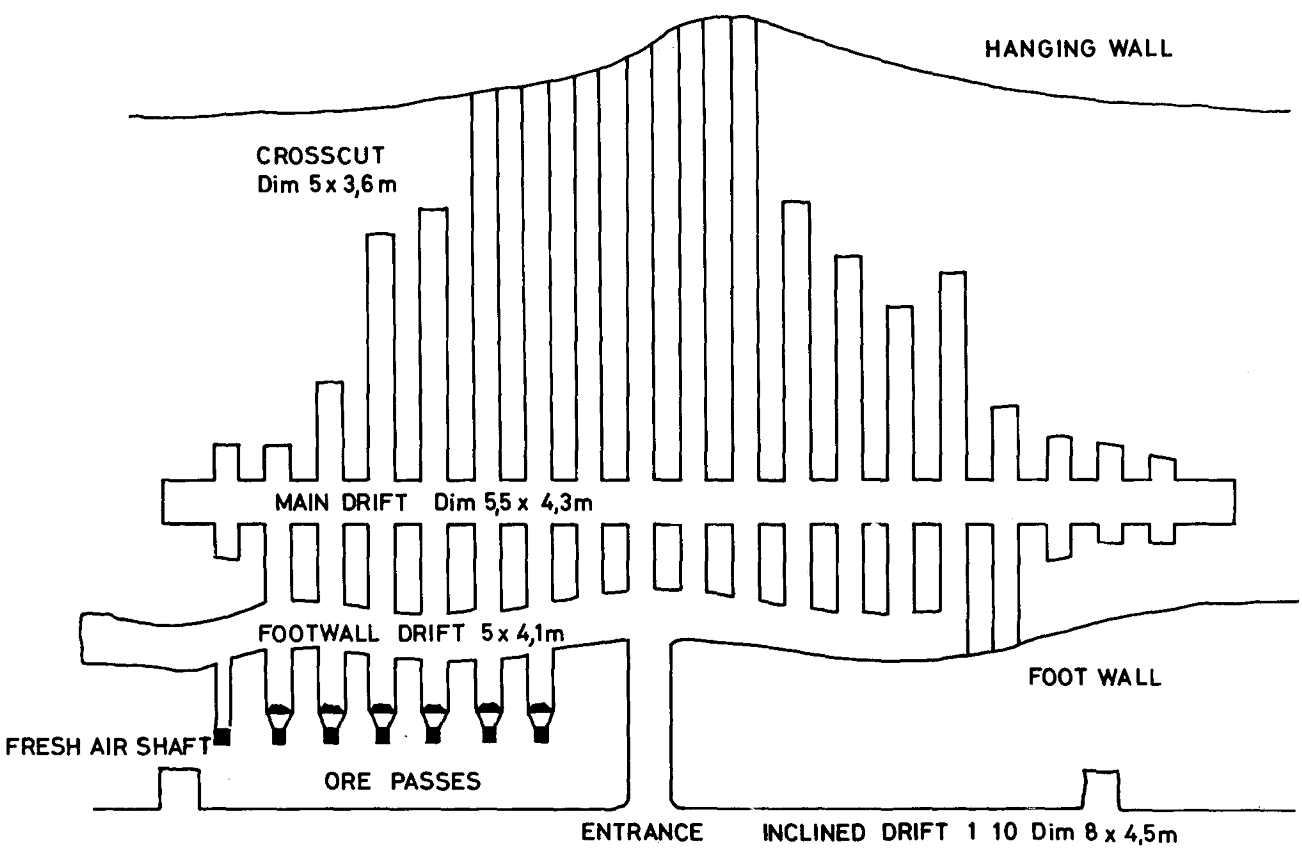


Fig. 3

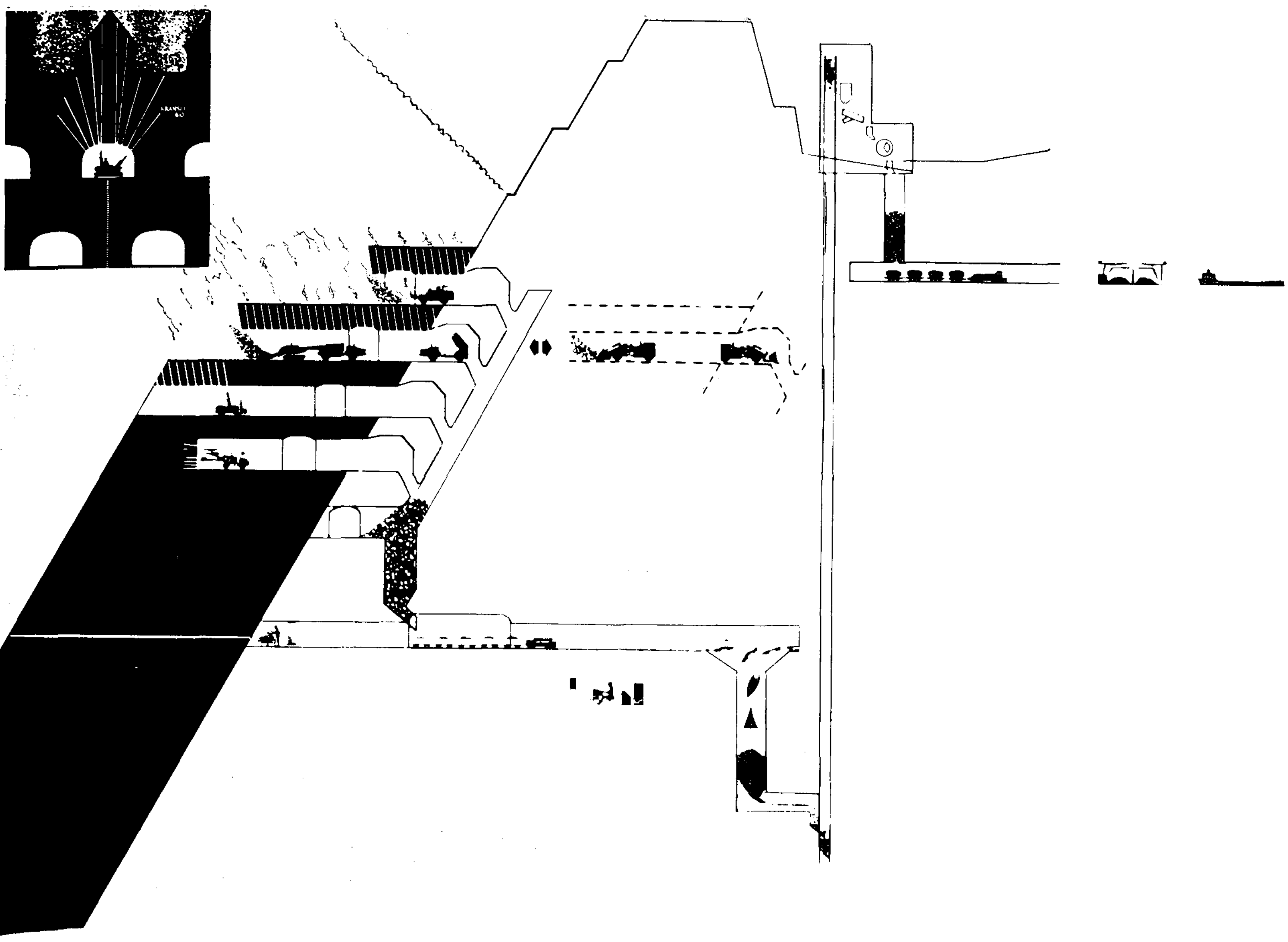


Fig. 4

changed. The main transport drift will be situated about 15 m from the point of contact with the footwall. From it, cross-drifts will be driven towards the hangingwall. This modification is primarily due to problems of rock mechanics and, secondarily, offers the possibility of an appreciable lowering of ore losses (footwall losses and losses where drifts cross). This layout also offers the advantage of increased flexibility during extraction.

Development drifting is carried out by one man operating drilling rigs on rubber tyres with three hydraulic booms. Holes with a diameter of 43 mm are drilled parallel to a depth of 3,2 or 3,8 m. The drilling pattern comprises 45 to 50 holes, of which a 100 mm hole serves as a cut hole. Plans are being considered for drilling even longer rounds of up to 5 m, which would then require 100 to 150 mm cut holes. The capacity of the present units is two to three rounds per shift and rig.

Loading and transport of ore resulting from development to ore passes in the footwall are carried out with wheeled loaders (Cat 980 B) or combinations of Joy loader and Kiruna truck (K-162, 25 ton).

Drilling for Caving

Rock conditions permit the drilling for caving long in advance. Generally, there are at least two ready-drilled sub-levels between drifting and caving. The sub-level nearest that being caved is always ready-drilled, and drilling is in progress on the next sub-level. The fan holes are drilled by rigs either of type SIMBA 22 (about 16 units in 1973) or of type SIMBA 323 (about 8 units in 1973). Both these units are operated by a single operation (Fig. 4). SIMBA 22 has been used in the Kiruna operations for about 10 years and is being replaced gradually by drilling rigs suited to parallel-hole drilling. Both the above units have rubber tyres and are air-powered. SIMBA 323 has three powerful rock drills and feeds, and has separate rotation, which gives it a greater outputs than that of SIMBA 22. It is also designed specifically for parallel-hole drilling. The machine outputs for SIMBA 22 and SIMBA 323 are 220 and 360 drill metres respectively.

Blasting

Development rounds are charged with ANFO, except the toe holes, which are charged with dynamite. The fan-patterned rows are also charged with ANFO, and dynamite is used as primer.

ANFO is manufactured in LKAB's own factory. From the factory, it is transported in bulk to an underground silo. Diesel-powered charging trucks transport the explosive from the silo, and charging is carried out pneumatically from these trucks.

The charges are initiated once a day from central firing stations.

Loading

Loading of the caved rounds is carried out with Joy loaders plus Kiruna truck (K-162, 25-ton), or with front-end loaders (Cat 980 B). At present, the relative number of front-end loaders engaged in the loading of caved rounds is being increased gradually.

Ore Flow

The ore is transported from the caving faces on the sub-levels by way of ore passes in the footwall to tracked main levels at depths of 420 and 540 m. The ore is then transferred from draw points on the main level to central underground installations, where the ore is crushed in two stages to minus 100 mm, after which it is hoisted to the surface.

Ventilation

Primary ventilation. The distribution system for ventilation air in Kuj consists at present of 50 shafts with main fan stations.

Secondary ventilation. From the primary air passages (ventilation shafts), the air is distributed with fans and tubes to the working sites of the mine. These installations are not permanent but follow the continuous changes of the working faces, so that a great number of fans and ventilation tubes must be handled. Today, about 30 km of ventilation tubing and about 390 fans are used for this purpose.

Cross-drift ventilation. To improve the effectiveness of the ventilation system, further 'cross-drift ventilation' was introduced at the turn of the year 1971/1972. About 230 fans and about 10 km of tubes are at present used for this purpose.

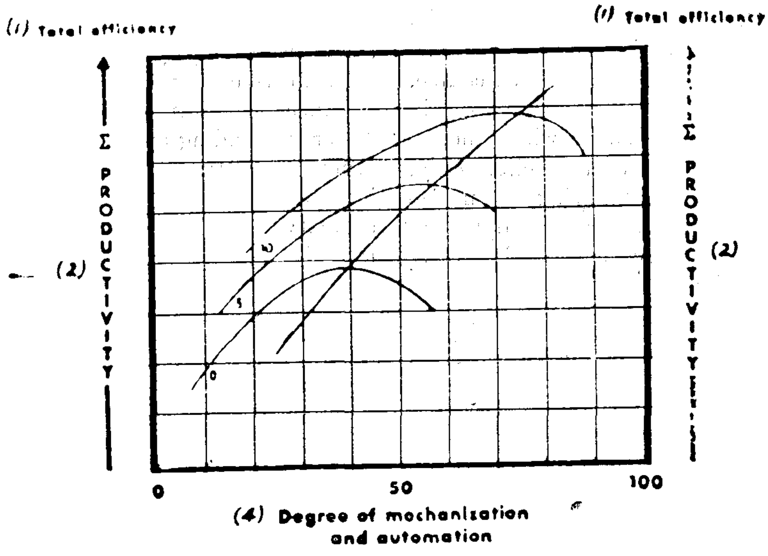
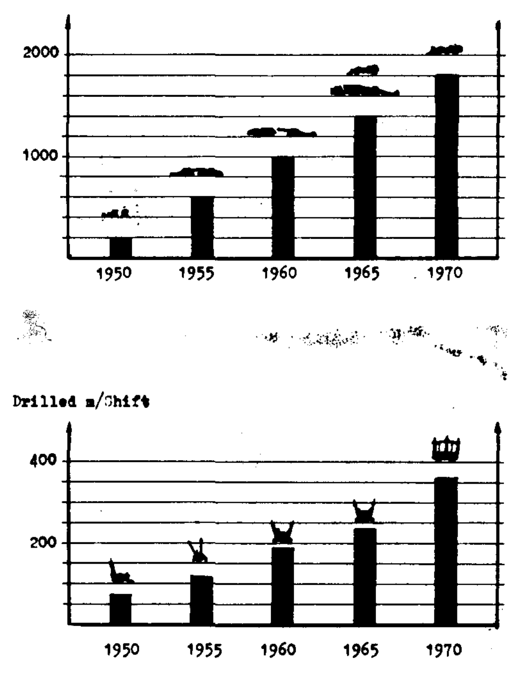


Fig. 5

MECHANIZATION

Effective production at a high level is hardly feasible without advanced mechanization and automation. However, this does not imply that every measure of mechanization is rational and economic. The development of mechanization has at least temporary limits, apart from being hindered by a possible lack of capital. It is possible that, at any given moment, the extent of mechanization cannot be increased indefinitely without jeopardizing both economy and efficiency.

Fig. 5 shows in principle how increased mechanization and automation in the beginning result in increased total productivity, measured here as total efficiency for



The development of new machines and methods has had a great influence on the rapid increase of the drilling and loading efficiency.

Fig. 6

personnel, capital, material, energy, etc. Beyond a certain point, the efficiency begins to decrease again when the investments in mechanization do not yield sufficient return to make them profitable. Of course, these limiting points do not remain stationary but change with time.

On the basis of this philosophy, LKAB is today trying to utilize machines lying around the optimum point for curve O, which represents today's technique. In the test mine and in the laboratory, machines are being developed for installation in five years' time (curve 5). The calculation and projection stages include those machines that are to be utilized in ten years' time.

As an example, mention is made here of the development of new and more efficient methods for drifting and production drilling, for charging and blasting, for loading and transporting, and, last but not least, for the maintenance and repair of the increasing number of electro-mechanical equipment.

The development in the field of *direct production drilling* is shown in Fig. 6.

Even *charging and blasting* have undergone rapid development, in particular by the introduction of ammonium nitrate-fuel oil explosives and powder-charging machines. The cost for explosives has decreased to a third, while the charging rate has been doubled.

The biggest cost item in direct mining is that of *loading and transportation*, and in this regard efforts to invent more effective machines have led to the development of the 'load-and-carry' and 'dig-and-carry' systems.

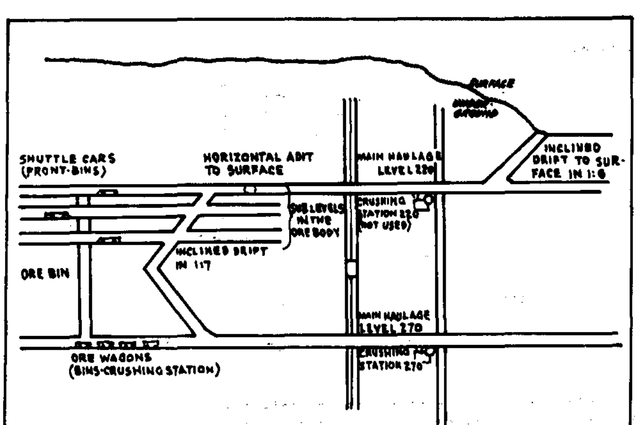
Analyses of the haulage conditions in direct mining indicated that the old system in which one loading machine and one or two trucks were employed could not be used effectively for short and variable distances. It is impossible to prevent either the loading machine or one or other of the trucks from remaining idle when one has a transport capacity that cannot be adjusted to the changes in haulage distances. Perfect utilization occurs only at specific distances.

The most interesting ideas to materialize in this search for an effective use of loading machines and transportation vehicles were the systems 'dig-and-carry' and 'load-and-carry'. The first system consists, in its simplest form, in the use of a rubber-wheeled diesel-powered front-end loader that takes the load in the bucket and carries it to the ore passes. The capacity and economy of this system are surprisingly good at a haulage distance of up to 200 m (600 ft) one way. To increase the economic radius of action, the system 'load-and-carry' was added; this consists principally in the use of a front-end loader with increased carrying capacity obtained by means of a self-loading ore container behind the bucket. This self-loading vehicle takes a load of 15 to 40 tons. The economic radius of action of this vehicle can be increased to about 1000 m (3000 ft) and eventually more. The development of loading and transport capacities is shown in Fig. 6.

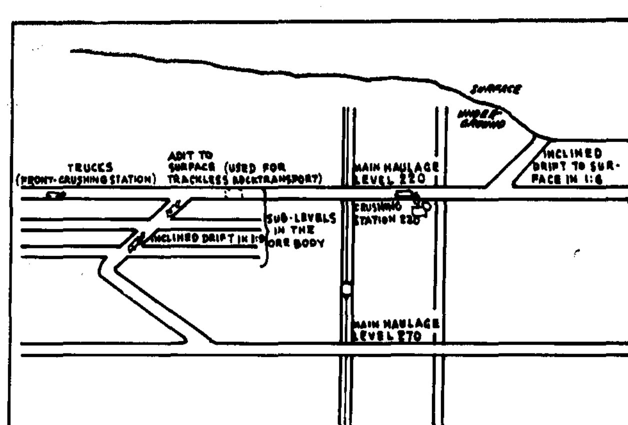
In order to co-ordinate the drifting, drilling, charging, blasting, loading, and transporting of ore, production groups have been formed. Each group is composed of adaptable personnel who, equipped with a sufficient number of productive machines including reserves, are responsible for the production within a limited field of the mining process. The production group has to a great extent been found to be self-supporting as far as machines, *maintenance service*, and transport are concerned, and is made up of chargers, loaders, truck drivers, and repair men. It numbers about 25 men, spread over two shifts. Every man in the group is able to manage several working phases and works alternately as repair-man, loader, or charger, etc. This form of organization, which is highly stimulating for the personnel, has resulted in a considerable increase in productivity. Each such group loads about 2 million tons per annum.

Another important contribution to productivity is an extensive development in ergonomic work; this concerns the adaptation of machines to the human being. This development has aroused a greater interest in the working conditions of the individual worker, contributing not only to better-designed machines but also to a more positive attitude on the part of the employees towards changes and evolution.

As one example of the benefits of this research, the large drilling unit has now begun to be modelled with noise-moderating cabins, ergonomically designed, from which the drilling operator, by remote control, performs the complete processes of drilling and readjustment of collaring. Furthermore, ergonometric measurements permit determination of the strain to which the operator is



Shuttle car-rail haulage system prior to conversion



New trackless transport system now in use.

Fig. 7

exposed by machines of different designs.

ECONOMIES OF TRACKLESS MINING

The modernization of Luossavaara Mine in 1961 is briefly described here as an illustration of the economies that can be achieved by trackless mining.

In December 1958, the management of the Luossavaara Mine decided that definite steps should be taken to reduce the costs of waste-rock haulage. The system of waste transport was the conventional one of shuttle car, rail haulage, and skip hoisting. However, capacity was decreasing and costs were increasing in proportion to depth of mining.

After a consideration of other methods, it was decided to re-equip the mine completely for a system of trackless transport (Fig. 7). This method of haulage would be possible and practical since the underground workings were connected to the surface, not only by vertical shafts, but also by a series of inclined drifts leading to a horizontal adit suitable for trackless transport. The haulage trips would be from the waste passes, or the caving sub-levels, to the dumping station outside the mine.

Using a fleet of suitable trucks, an excellent haulage system could be operative within the mine in a short time. Waste would be hauled out of the mine, while ore would be carried from various caving sub-levels to the underground crushing station on the 220 level. With this trackless transport system, the 220-level crusher station could be used for another six years, since ore would be carried direct to the crusher on the main level, and also from the lower sub-levels connected by inclined drifts. The exclusive use of trucks would obviate the need for ore passes between caving levels and the haulage level. Thus, development work would be substantially reduced, as would the overall volume of waste rock handled.

By the end of 1959, all studies of the transportation problem had been completed, and work on the conversion to trackless transport was started in January 1960. This involved (1) driving an inclined shaft at 1:9 (11 per cent) between the 220 and 270 levels, (2) asphalt paving of level 220 and the above inclined shaft, (3) widening and adjustment of corners at several places in some of the existing inclined shafts, (4) conversion of the car-dumping station at the 220-level crusher to truck dumping, (5) cessation of all development work on haulage levels 270 and 320, since their use would not be required for several years, (6) purchase of seven Kiruna rear-dumping diesel-powered, trucks, and (7) removal from the mine of 11 000 yards of rail, 1 diesel locomotive, 9 electric locomotives, 10 battery locomotives, 300 ore cars, 3 Atlas Copco loading machines, 2 Joy loading machines, 11 Joy shuttle cars, and 1 internal hoist. The actual work of conversion took about six months.

The number of personnel in the mine was changed immediately to conform to the new system, being reduced to one operating crew of 28 men per shift. Each crew now consists of 6 truck drivers (only 6 trucks are in service at one time), 10 drillers, 6 blasting men, and 6 mucking-machine operators. In addition, there is a maintenance crew of 4 men per shift. The normal work schedule is two 8-hour shifts per day, and each operating crew produces about 90 tons per man-shift.

A comparison of the two systems of transportation in the Luossavaara Mine is possible from the operating results for the fourth quarter of 1958 and for the fourth quarter of 1961. By the end of 1958, no steps had been taken to convert to trackless transport. By the end of 1961, the new system was in complete operation. For both periods, the quantities of ore and rock drilled, blasted, loaded, and hauled were about equal—approximately 2500 tonnes per shift.

The results show that mining costs per tonne of ore were reduced by 27 per cent, and mining costs per tonne of waste were reduced by a spectacular 80 per cent. The total number of personnel employed was reduced by 138 employees. However, only about 40 of these were removed from the underground-transportation section. About 45 other jobs were eliminated from other sections of the mine, and the balance were eliminated from various surface departments.

The most impressive results are noted in actual ore production per man per shift, including all underground and surface workers. In 1958, before trackless transport was introduced, ore production was 9 tonnes per man-shift. In 1961, however, this ore production figure had risen to an impressive 19 tonnes per man shift.

The changeover to trackless transport was accomplished without any unexpected problems. The exhaust fumes from the diesel engines has caused no underground hazards, and the frequency of accidents has actually been cut by half to a low 3,5 accidents per 100 000 man-hours worked. The new system has proved to be more flexible, and ore grading has been simplified since there is no longer any mixing in ore passes and chutes.

CONTINUED DEVELOPMENT

The development towards a higher output, which is at present noticeable in Swedish iron ore mines, results from the higher demand for iron ore in Europe. This rise in production has occurred in the face of sharp competition from newly opened, often well-situated, opencast mines in the Atlantic and Pacific areas. The new metallurgical processes make different, and greater, demands on the chemical and physical properties of the shipped ores.

A more intensive utilization of scientific and engineering methods in the layout of mines now permits more efficient solution of mining, transportation, and haulage problems. Continual improvement in the components, and the development of systematic industrial engineering methods and of machinery, contribute to lower costs and to better utilization of present installations.

The very recent developments in mechanization and automation have led to improved control of underground traffic, of direct extraction, and of ore-grading, with the aid of an on-line computer.

The overall result of all these efforts has been a significant rise in production, while, at the same time, increasing the responsibilities of the individual miner in regard to his use of machinery and installations. A constant increase in productivity and efficiency is necessary in order to meet the sharp international competition, to compensate for the increased capital investment, and to allow for the constant improvements in salaries.