The replacement of conventional gathering-arm loaders and shuttle cars with diesel-operated load–haul–dump units at Greenside Colliery

by E. L. ATKINSON*, B.Sc. Eng. (Min. & Metall.) (Fellow) and
G. W. LEACH*, Pr. Eng., M.S.A.I. Mech. E. (Visitor)

SYNOPSIS

The paper discusses the reasons for the introduction of load–haul–dump (LHD) units into Greenside Colliery, and the circumstances leading to the replacement of conventional mechanized equipment on a trial basis in the mining operations on No. 2, 4, and 5 seams. An outline is given of the factors governing the selection and introduction of these units into coal mining, and the associated mining and engineering aspects involved in the optimization of their use. Operating statistics comparing the performance of conventional and LHD equipment are included.

SAMEVATTING

Die referaat behandel die redes vir die invoering van laai–vervoer–storteenhede by die Greenside-steenkoolmyn en die omstandighede wat gelei het tot die vervanging van konvensionele gemeganiseerde toerusting op 'n proefbasis in die mynboubedrywighede by die lae nr. 2, 4 en 5. Die faktore wat die keuse en invoering van hierdie eenhede in steenkoolontginning bepaal, asook die verwante mynbou- en ingenieursaspekte betrokke by die optimalisering van die gebruik daarvan, word in hooftrekke bespreek. Daar word ook bedryfstatistiek verstrek wat die prestasie van die konvensionele en die laai–vervoer–storttoerusting vergelyk.

Introduction

At Greenside Colliery, the mining operations on the No. 2, 4, and 5 seams are fully mechanized except for the drilling, and are based on the standard bord-and-pillar method using conventional coal cutters, gathering-arm loaders, and shuttle cars. Conventional equipment operates best when the mining floor is competent, the gradient does not exceed 5°, and there is a minimum of stone in the coal seam.

Because of the increasing number of stone rolls and stone inclusions encountered in the operations on No. 2 seam, often resulting in abrupt changes in gradient to a normally uniform and gently dipping floor, the first load–haul–dump (LHD) unit was introduced on a trial basis in August 1974 to supplement the conventional equipment in use by separately loading and dumping stone into the old workings. Such stone was derived, either from the blasting of the footwall humps or rolls in order to retain an acceptably uniform gradient and follow the true plane of the coal seam, or from stone inclusions within the seam. At a later stage, the LHD application was extended into No. 4 and 5 seams.

An expansion in the mining operations on No. 2 seam had been scheduled for May 1975 as a result of a contract to produce low-ash coal for export to Japan. Unfortunately, conventional mining equipment had been ordered for this purpose at the beginning of 1974, which was long before the full significance of the stone problem in No. 2 seam was realized.

The next application of the LHD was to replace conventional loaders and shuttle cars and so improve efficiency by overcoming the following problems inherent in the use of this equipment.

(a) One-fifth of the downtime on the shuttle cars was associated with damage to electric cables; flexibility was limited by fixed tramming routes, and skilled artisans were required to maintain the complicated hydraulic circuits.

(b) The shuttle cars, spades, and gathering arms of the loaders suffered excessive wear when handling the abrasive sandstone that was associated with the operations on both No. 2 and 4 seams. This wear would now be limited to the bucket of one LHD and could be countered more effectively by the replaceable lips of the bucket and the hard-facing techniques used.

(c) As one LHD would replace one loader and its complement of shuttle cars, it was considered that there might be savings in the work load of artisans, the capital outlay, and the operating costs.

The expansion of the mining operations on No. 2 seam took place as planned in May 1975. A year later, abnormal geological conditions were experienced in the south-western portion of No. 2 seam reserve, where the frequency of large stone rolls, coupled with a floor gradient of up to 15° (Figs. 1 and 2), presented serious problems for conventional equipment. Shuttle-car load factors were more than halved when uphill trams were negotiated. Excessive wear resulted from the handling of the abrasive stone that had to be blasted. As a result, operating costs and the frequency of major overhauls increased to such an extent that it was decided to phase out conventional equipment in favour of LHDs in areas where conditions became abnormal (floor gradients of more than 5°). The experience gained in the LHD experimental phase was used in defining the selection parameters for the purchase of the additional units required.

The following two uses for LHDs had been identified at that stage:

(1) for handling coal and the associated stone in situations where the floor gradient was more than 5° and conventional equipment could not operate;

(2) as an auxiliary stone-handling unit in the operations where conditions were sufficiently reasonable to

*Gold Fields S.A. Limited, Johannesburg.

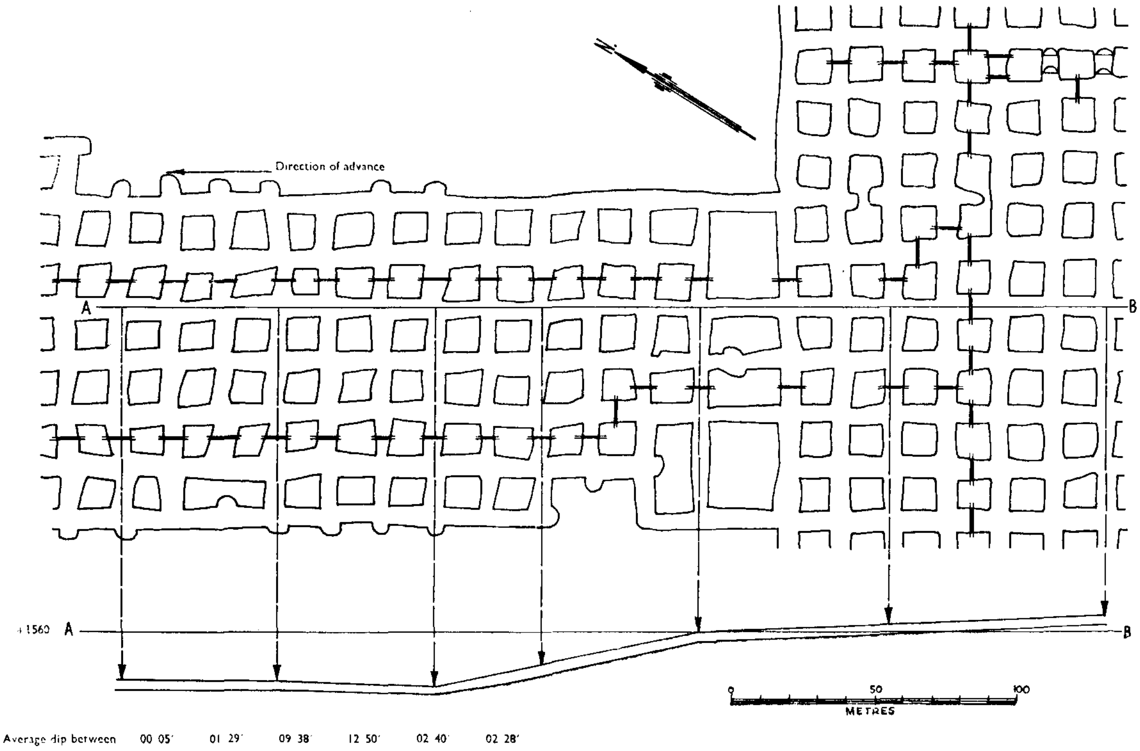

Fig. 1—Plan and section of Section 5/6 on No. 2 seam, Greenside Colliery

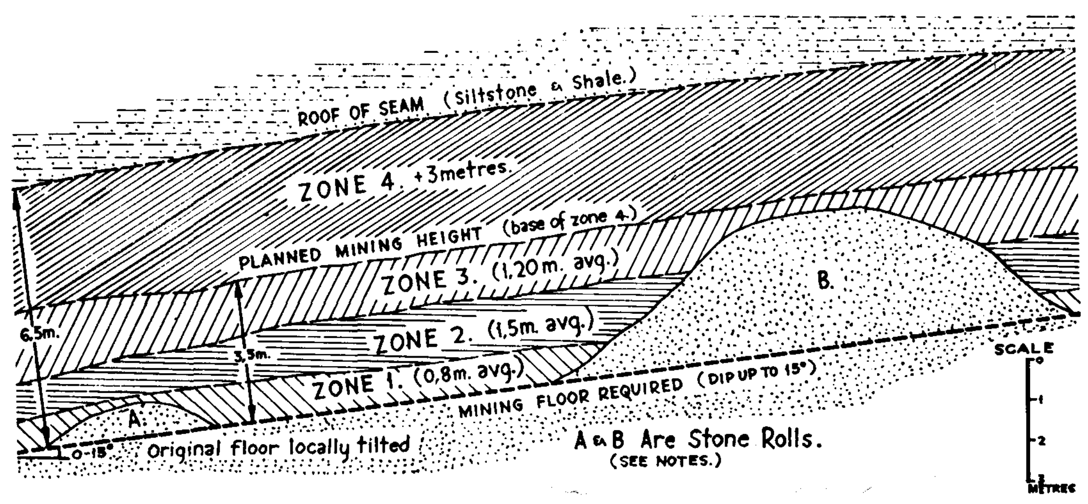

Fig. 2—Details of No. 2 seam, showing the mining height and the variations in floor dip and size of stone rolls

Notes:

1. **The mining floor is normally flat or inclined at a few degrees, but may dip at up to 15°, owing partly to original palaeoslope and partly to subsequent tectonic tilting. Such steepening is sometimes apparent in the vicinity of stone rolls.**
2. **The No. 2 seam is, ideally, made up of the following four zones varying in thickness and in low-ash coal (LAC) content:**

Zone	Width limits	Average width	Average LAC content
4	3,0-4,0 m	+3,0 m	8%
3	0-1,4	1,2	32
2	0,3-2,1	1,5	5
1	0,5-1,5	0,8	55

3. **Stone rolls are protuberances of floor-rocks, usually rather gritty, upward-fining sandstone, into the coal-seam. They vary in height from 0,5 m or less to over 3,5 m, and cover areas of up to 100 m² or more. As the section shows, they may significantly affect the high-grade No. 1 zone at the base of the seam. Their origin, and thus their prediction, is still under investigation. It appears that they may have formed in three possible ways and may, in fact, be of different types.**
   (a) **They may in some cases be point-bars formed in distributary channels braiding or meandering over the original swamp-floor. In certain cases the sandstone is distinctly fluvial in nature.**
   (b) **They may in other cases be fossil sand-dunes formed by wind action. The internal structure of some of the larger rolls suggests this.**
   (c) **They may also be due to lateral compression, forcing semi-consolidated sand up into the incompetent semi-lithified coal. This mechanism is indicated by local slickensiding of the coal near certain rolls and by its fracturing in their vicinity.**
4. **It will be noted that the planned mining height for this seam is 3,5 m. Normally this is to the base of the low-grade zone 4. To maintain the grade of low-ash coal, it is essential to extract all the high-grade basal No. 1 zone. Thus, floor irregularities have to be followed as faithfully as possible.**

permit the use of conventional equipment except for the presence of stone rolls and/or inclusions.

Selection of LHD Equipment

A market survey was undertaken to ascertain the number and types of suitable LHD equipment available on local and overseas markets. The following requirements were taken into account in the survey.

(a) *Size and Capacity of LHD*
Machines of 4 to 5 m^3 capacity were required for the handling of coal on a production basis, and machines with a capacity of 2 to 2,5 m^3 capacity were required for the handling of stone.

(b) *Type of Bucket*
Coal-production machines were to be fitted with an ejector type of bucket, which allows the coal to be discharged at a controlled rate onto the tail end of the panel conveyor. (The ejector type of bucket requires the minimum of head room for tipping purposes, which is an additional advantage in narrow seams.) Machines for the handling of stones were to be fitted with conventional rock buckets of the earth-moving type.

(c) *Availability of Spares and Service*
The agents or companies offering equipment were scrutinized carefully with regard to the availability of spares and their past performance in providing service.

(d) *Compliance with Regulations Regarding Flameproofing*
Following investigation, it was decided that all the equipment purchased should comply with the requirements of the South African Bureau of Standards 'Specification for Diesel Engines for Use in Fiery Mines S.A.B.S. 868 — 1967', which automatically qualifies the equipment for approval by the Government Mining Engineer (G.M.E.).

The investigation into the requirements for the flameproofing of diesel engines proved to be both interesting and enlightening.

It was found that, during 1960, the Department of Mines decided to permit the use of mobile diesel-powered equipment in fiery mines in South Africa, provided that such equipment complied with the requirements of the U.S. Bureau of Mines Schedule 31 'Mobile diesel powered transportation equipment for gassy non-coal mines and tunnels'. However, experience with such equipment showed that the American requirements were not directly applicable to South African conditions. This resulted in the preparation of the S.A.B.S. standard specification already mentioned (868 — 1967). The present situation regarding the use of diesel engines in South African fiery mines is that any imported equipment having a certificate of compliance with U.S. Bureau of Mines Schedule 31 can be given a G.M.E. approval for use (without test), but any equipment that is assembled and manufactured locally must comply with S.A.B.S. 868 prior to the issue of a certificate by the G.M.E.

These investigations high-lighted other anomalies. One is that a diesel engine installed in a unit complying with U.S. Bureau of Mines Schedule 31 and imported into this country automatically receives a G.M.E. certificate, whereas, depending on the make and design, the same engine installed in a locally assembled unit may not necessarily comply with S.A.B.S. 868 and therefore cannot receive G.M.E. approval.

Table I details the conditions for the use of diesels underground in fiery mines as stipulated by the G.M.E.

TABLE I

CONDITIONS OF G.M.E. APPROVAL STIPULATED FOR DIESEL ENGINES THAT ARE TO BE USED UNDERGROUND IN A FIERY MINE

In terms of Mines and Works Regulation 10.25.2(B), the engine whose design and construction were approved by me by certificate no. D and as fitted to a loader may be used underground in your mine, provided the following conditions are observed:

1. The loader shall be used only in workings where the amount of moving fresh air for ventilation for each such machine is 5,75 m^3/sec. or more. This volume of air for ventilation is in addition to that required for other diesel engined machines and other requirements.
2. The loader shall not be used in any working place if there is sufficient firedamp present to be recognisable on the reduced flame of a safety lamp.
3. The engine shall be governed at a speed not exceeding 36,7 rev/sec. at full engine load and shall be kept clean and all fuel and oil leaks shall be rectified promptly.
4. A qualified mechanic shall be appointed in writing to examine the engines carefully on each working day, and to maintain it and all parts affecting its flameproofness in a safe working condition.
5. The temperature control devices shall be tested each week, at intervals not exceeding ten days to ensure effectiveness. In the case of the exhaust gas system, the calibration setting shall provide for operation of the tripping mechanism of the engine, at a temperature not exceeding 65 degrees celsius, and in the case of the cooling water system, at a temperature not exceeding 100 degrees celsius. The calibration setting shall be checked once yearly by actual temperature test.
6. The exhaust gas scrubbers shall be drained, refilled and checked not only at the commencement of each working shift, but also when there is a change of operators.
7. A loader maintenance record book shall be kept, wherein shall be recorded the date and details of the daily examination, services, repairs and the results of the prescribed tests. Such records shall be signed by the person who conducted the examination or tests or who did the repairs or adjustments.
8. No person shall operate, or authorise a person to operate the loader unless such operator carries a distinct authorisation which has been issued to him by the engineer appointed in terms of regulation 2.13.1.
9. The engineer appointed in terms of regulation 2.13.1. shall not issue such an authorisation until he is personally satisfied that the person concerned is competent to operate the loader, understands the flameproof and safety features of the engine and the requirements of servicing the scrubber. Such person shall be issued with and shall carry at all times when operating the loader, the distinctive authorisation badge or token.
A legible copy of the approval shall be maintained in the maintenance record book, and the requirements thereof shall be made known to all persons concerned.
The approval may be amended or withdrawn at any time.

Features Required of the LHDs

Based on the specification requirements, enquiries were issued for the following diesel-driven LHDs:

(a) machines of 5,0 m^3 approximate bucket capacity for handling stone in the conventional sections of No. 2 seam,
(b) machines of 5,0 m^3 approximate bucket capacity fitted with ejector-type buckets for the production of coal in severe conditions,
(c) machines of 2,0 m^3 approximate bucket capacity for possible operations in No. 5 seam and clean-up operations in the conventional sections of No. 2 seam.

The tenders received were duly analysed, and the final selection was made, not on the lowest price, but on the following basis.

(i) The design had to offer robustness and compactness.
(ii) The design had to lend itself to easy maintenance and location of faults, particularly in the hydraulic circuits.
(iii) The filters, flame-proofing components, and fuel- and water-filling points had to be easily accessible.
(iv) The diesel engines had to comply with G.M.E. and S.A.B.S. 868 requirements.
(v) The emission limit of the exhaust gas had to be well within the pollutant limit as scheduled by the G.M.E.
(vi) The spares and various facilities offered by the suppliers had to be of a high standard.
(vii) The delivery time offered had to meet the requirements of the mine.

TABLE II

SALIENT FEATURES OF THE LHD UNITS PURCHASED

Feature	LHD with 4,8 m^3 rock bucket or 4,0 m^3 ejector bucket	LHD with 2,0 m^3 rock bucket
Tramming capacity	7300 kg	3620 kg
Break-out force	15 000 kg	11 200 kg
Gradability	19,7°	20°
Mass (empty)	22 300 kg	12 400 kg
Maximum speed	23,9 km/h	19,0 km/h
Drive	Four-wheel	Four-wheel
Height	1,80 m	1,66 m
Width	2,45 m	1,70 m
Length	9,86 m	7,32 m
Type of engine	Diesel (indirect injection)	Diesel (indirect injection)
Power	107 kW at 2200 r/min	69 kW at 1500 r/min
Torque	580 N.m at 1200 r/min	310 N.m at 1500 r/min
Torque convertor	3,00/1 ratio	2,91/1 ratio
Transmission	Power shift	Power shift
Speeds	4 forward, 4 reverse	4 forward, 4 reverse
Axles	Rigid differential and planetary hubs, ±10° oscillation	Rigid differential and planetary hubs, ±10° oscillation
Brakes	Disc — self-adjusting pneumatic hydraulic—twin system	Disc — self-adjusting pneumatic hydraulic—twin system
Tyres	1800×25	1200×24
Capacities		
Fuel tank	350 litre	150 litre
Hydraulic oil	360 litre	190 litre
Water	300 litre	200 litre

Units Purchased

Table II gives the salient features of the two types of unit purchased. The total numbers of units in service to date, together with their working situations, are listed in Table III.

Requirements for Best LHD Operation

The following aspects were carefully considered before the LHD units were introduced, and standards were drawn up to meet the requirements.

Selection and Training of LHD Drivers

It is imperative that only individuals who are mechanically apt, responsible, and mature should become drivers of the large, powerful, expensive, modern LHD units, which, in the wrong hands, would constitute a danger to life and property underground. Eyesight is also a vital selection parameter.

Training of Artisans and Artisan-aides

On joining the underground maintenance crew, fitters and electricians, before being allocated to the section where they are to work, spend an initial 3 weeks in the underground workshops to become familiar with the various types of equipment used on the mine, and with the daily, weekly, and monthly service checks. This initiation is done under the supervision of the Engineering Training Officer. When a section machine is called into the underground workshop for planned preventative maintenance (PPM), the artisan concerned submits a report on the condition of the machine and returns to the workshop to assist with the work.

Assistants to help the artisans on engineering maintenance are selected from the new recruits. Before being allocated to the various section artisans, the recruits undergo aptitude testing during their term at the induction school, where mechanical aptitude is the main selection criterion. After a period of three months as an artisan labourer, the recruit could be promoted to the

TABLE III

LHD UNITS IN SERVICE

No.	Type	Working place	Type of operation
1	1,8 m^3 (rock)	Being overhauled	Clean-up
2	3,8 m^3 (rock)	No. 2 seam, Section 28/29	Stand-by
3	4,0 m^3 (ejector)	No. 2 seam, Section 28/29	Coal production
4	4,0 m^3 (ejector)	No. 2 seam, Section 28/29	Coal production
5	4,0 m^3 (rock)	No. 2 seam, Section 28/29	Clean-up
6	4,8 m^3 (rock)	No. 2 seam, Section 24/25	Stone handling
7	4,8 m^3 (rock)	No. 2 seam, Section 26/27	Stone handling
8	4,8 m^3 (rock)	No. 2 seam, Section 20/21	Stone handling
9	4,8 m^3 (rock)	No. 2 seam, PPM	Stone handling
10	2,0 m^3 (rock)	No. 2 seam, Section 22/23	Stone handling
11	2,0 m^3 (rock)	No. 2 seam, Section 32/33	Stone handling
12	2,0 m^3 (rock)	No. 5 seam	Clean-up
13	2,0 m^3 (rock)	No. 5 seam	Clean-up

position of artisan helper if he has the qualities to become an artisan-aide. After 6 months, the artisan helper could be selected for training as an artisan-aide, depending on his job performance and initial Dudec rating. The training school forms part of the underground workshops. The first week of the five-week training period is devoted to basic induction, tools, lubrication, and safety, while the last four weeks consists of instruction on a specific type of machine under the direction of artisan-aide instructors. After completing the course, the trainee is returned to the artisan as an artisan-aide-in-training on one month's probation, following which, depending on the artisan's reports, he is appointed as an artisan-aide. The artisan-aide returns to the school at regular intervals for further training and short refresher courses. Each stage of promotion carries a higher rate of pay.

Maintenance Procedures

Each seam on the mine has a fully equipped underground workshop, in which there are facilities for breakdown repairs and PPM on coal cutter, loaders, shuttle cars, and LHD units.

A complete record of the machinery is kept in the planning office on surface. The records comprise machine number, working place, number of cuts, and loads or tons (as the case may be), together with case histories of the major repairs and overhauls, scheduled PPM checks, etc.

Scheduled daily, weekly, monthly, and annual checks, as laid down, are made on all the machinery by artisans and artisan-aides. When a machine is called into the underground workshop for PPM, it is cleaned by a high-pressure chemical-cleaning unit, examined, stripped and parts replaced where necessary, settings checked, tested, lubricated, and then returned to its working location.

Certain sub-assemblies, e.g. gearboxes, hydraulic pumps, motors, wheel units, electric motors, transmissions, and diesel engines, are not repaired (other than minor repairs) in the underground workshops, but are replaced on a service-exchange basis in the surface loss-control* workshop. Service-exchange units that cannot be repaired on the mine are sent to the suppliers for repair.

Each underground workshop is equipped with a store from which items are drawn on requisition. The stock levels of the store are maintained from the store consignment stocks on surface.

A comparison of the maintenance required by the conventional units and that by the LHDs indicates that daily and weekly checks on the LHDs are simpler than on the shuttle cars and gathering-arm loaders, and, on a workshop PPM examination, LHDs require 50 per cent less time to maintain.

In general, the artisan work-load on an LHD section is considered to be less than that on a conventional section, and the electrician could be shared between two sections, or even three sections if they are in close proximity.

*The term *loss control* is applied to the management principle of controlling losses. The surface loss-control workshop has been established for examining all machine parts to determine whether they are worth repairing or whether they should be discarded.

There is additional downtime on the diesel engines because the maintenance required is more than that on the electric motors and hydraulics of shuttle cars and loaders, and the flame-proofing requires regular physical checks, the exhaust flame arresters needing to be changed twice per shift on this type of LHD.

The underground workshops are equipped with injector testing equipment, and spare sets of injectors are carried. Injectors are replaced at intervals of approximately 1000 hours. From present experience, it appears that diesel engines and transmissions will run for approximately 8000 hours before they need to be replaced with service-exchange units, which are carried by the suppliers.

However, this additional down-time on the diesel engines is well compensated for by the down-time on electric cables in a conventional section. In the operation of LHDs, it has been found essential to maintain a clean water supply close to the operation in the form of a steady-head tank with a ball float valve. Clean water is fed from surface, and the discharge valve is capable of re-filling the scrubber and radiator tanks rapidly. Tractors tow in the fuel in 1000-litre tank trailers, from which it is pumped direct into the LHD fuel tanks.

Design of Mine Layouts for Best LHD Output

During the LHD test period, the conveyor systems of No. 2 and 5 seams were being uprated in order to handle tonnages in excess of the previously planned requirements. This resulted from a lower yield than that forecast in No. 2 seam operations and an increased demand for No. 5 seam coal. Breakdowns and overloading of conveyor systems were factors militating against ideal application of the LHD units.

The following factors were taken into account in the design of the mine layout.

(1) Tramming distance between the face and the panel conveyor-tipping point was minimized. To achieve

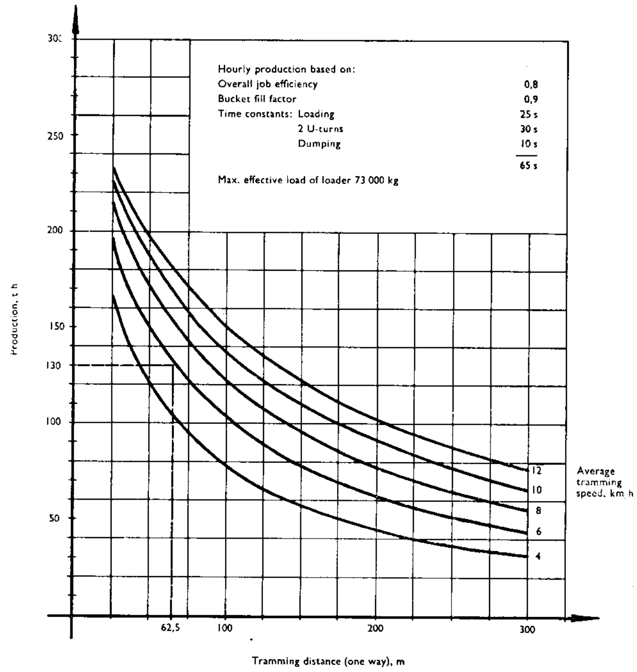

Fig. 3—Variation of output with tramming distance

this, the tail ends of the conveyor were kept not more than twice the pillar-centre distance from the face. As the pillar centres increase with increasing depth of workings, the number of roads was reduced accordingly to maintain the tramming distance from the face to the tipping point at a maximum of 62,5 m (Fig. 3 shows the variation of output with tramming distance).

(2) Since loading efficiency depends significantly on the size and shape of coal and stone in the blasted coal pile, as well as on the floor conditions, blasting rounds should be designed to give adequate fragmentation and so eliminate large lumps of coal and stone. Every effort must also be made to maintain an even floor gradient to expedite the tramming speed.

(3) Depending on whether the coal being loaded contains stone or not, feeder breakers or feeder conveyors should be provided at panel belt-tipping points to facilitate the rate of bucket discharge. In actual practice on No. 2 and 4 seam operations, grizzleys had to be installed over the tail end of the conveyor to prevent large stones and lumps of coal from causing bottlenecks at transfer points and washing plants. Despite the optimization of blasting rounds, large stones and lumps of coal occurred in the blast pile. They were not easily visible to the LHD operators and were easily accommodated in the large 4,8 m^3 bucket. The large fragments were easily visible to the operators of the gathering-arm loaders and were dealt with before being loaded into shuttle cars.

(4) There are two basic loading times for LHDs with large bucket capacities: loading from a 'pile' after the blast, and 'cleaning up' the final few loads towards the end of a cycle. Pile loading is three times faster than 'cleaning up' operations. To optimize the rate of loading, it has, in addition, become necessary to provide a smaller LHD of 2 m^3 capacity for cleaning up the last few face loads. This releases the large production units for high-capacity 'pile' loading elsewhere. It is pertinent to note that, for maximum efficiency, the rate at which blasted coal is made available for loading must exceed the optimum loading rate of the LHD.

Details of LHD Applications

The ideal set-up is to provide two production LHD units per section, one production LHD being provided as a back-up for two production sections (on account of its high manoeuvrability and tramming speed) and a smaller clean-up loader per section.

No. 2 Seam

Conditions vary so much in this seam with regard to the frequency of stone rolls and changes in floor gradient that performance statistics were much lower than elsewhere in the mine.

No. 5 Seam

Greenside was the first colliery to mechanize operations in a seam where the height varied from 1,5 to 2,0 m. Low-profile LHD units were used mainly to negotiate dykes, and to brush the floor and so gain adequate height in the travelling roads and clean-up operations. On one occasion, LHDs were used for a short period as production units in areas of black shale. Here, the roof conditions did not allow the use of conventional equipment because, in an attempt to stabilize the roof conditons in the area, mining bords had to be kept to a minimum while resin-bolting experiments were in progress. No performance figures were kept for this short period.

No. 4 Seam

Except for inclusions of sandstone in the coal seam, all the other conditions were ideal (mining height 2,8 m, competent floor, and gradient less than 5°). Tests in which the bucket contents were tipped direct onto 900 mm belts were never satisfactory because the LHD had to 'pour' out the contents instead of dumping in one operation. The result was an increase in the tipping time.

Experiments using a feeder unit ahead of the panel belt were brought to a halt when there was a sharp fall in the demand for domestic coal, resulting in LHD equipment having to be transferred to No. 2 seam. However, at that stage sufficient time-study data were available for the cycle times to be calculated, and these are shown in Table IV. The table indicates that, with standard layouts, proper maintenance, and uninter-

TABLE IV

COMPARISON OF THEORETICAL OUTPUT OF CONVENTIONAL AND LHD SECTIONS BASED ON TIME-STUDY VALUES IN NO. 4 SEAM

1. *Section Equipment*

Detail	Conventional	LHD
Operating	1 loader 2 shuttle cars 1 coal cutter	2 4,8 m^3 LHDs 1 coal cutter 1 2 m^3 LHD

2. *Operational Parameters*
Pillar centre: 13,5 m Bord width: 6,5 m Seam height: 2,8 m
Tons per blast: 63
No. of roadways: 9
Load factor: Shuttle car 7,0 t LHD 3,0 t
Tramming speed: Shuttle car 4,7 km/h LHD 5,6 km/h
Availability: Conventional 90% overall utilization
LHD 95% machine availability 90% utilization
Shift time at face: 510 min

3. *Conditions* (both LHD and conventional)
Slow tipping over grizzley onto 900 mm panel conveyor
No conveyor delays
Always coal available to load
Good road conditions (flat)
Average tramming distance both ways: 125 m

4. *Cycle Times*

Shuttle Cars		LHD	
Element	Time min	Element	Time min
Loader moves into face	2,00	Av. loading time per load (pile and clean-up)	0,61
Loader waits for shuttle car change-out time	4,50	Travelling time	1,34
Load shuttle cars	25,77	Tipping time	0,71
Loader waits for shuttle car	2,80		
Total time per face loaded	35,07	Total time per load	2,66

5. *Output*

Conventional		LHD	
Faces loaded	13,1	Faces loaded	15,6
Tons per face	63	No. of loads per shift	328
Tons loaded per shift	825	Tons per shift for 3 loaders	983
Shuttle cars per shift	118		

rupted availability of coal for loading, the LHD units can outperform conventional equipment.

Costs

A comparison of the capital and operating costs for conventional and LHD sections is given in Tables V and VI respectively.

Uses of LHD Units

(1) Experience gained over a four-year period confirms that the diesel-operated LHD is a highly manoeuvrable, multi-purpose unit that can load stone and coal with equal facility. It is the only production unit that can function effectively in abnormal geological conditions where the gradient of the floor exceeds 5°. The efficiency of conventional equipment is reduced at such gradients, and the maximum gradient tolerable, at further reduced efficiency, is about 7°.

(2) Feeder conveyors when there are no inclusions of stone in the coal, or feeder breakers when stone is mixed with the coal, of adequate capacity are required at panel conveyor-tipping points to optimize LHD unloading rates.

TABLE V

A COMPARISON OF THE CAPITAL COSTS OF CONVENTIONAL AND LHD SECTIONS

Conventional section			LHD section		
Item	Price each $R \times 10^3$	Total $R \times 10^3$	Item	Price each $R \times 10^3$	Total $R \times 10^2$
1 coal cutter	95	95	1 coal cutter	95	95
2 gathering-arm loaders	92	184	2 4,8 m^3 LHDs	168	336
3 shuttle cars	76	228	Use of 50 % of 1 LHD*		84
1 clean-up LHD	114	114	1 clean-up LHD	114	114
Electrical reticulation above that required by LHD section		35			
Total		656	Total		629

*One 4,8 m^3 LHD can be shared as a spare unit owing to the mobility of the unit.

TABLE VI

A COMPARISON OF THE OPERATING COSTS[1] OF CONVENTIONAL AND LHD SECTIONS

Item	Conventional section		LHD section
	Loader	Shuttle car	4,8 m^3 LHD
Prime cost, R	92 000	76 000	168 000
Tyres, R	—	1 100	7 860
Price less tyres, R	92 000	74 900	160 140
Average operating time per year, h	1 200	1 800	3 600
Depreciation period, y	7	10	2,78
Depreciation period, h	8 400	18 000	10 000
Cost per hour, R			
Depreciation	10,95	4,16	16,80
Spares — Overhaul	4,17	1,94	7,31
— PPM	6,25	4,17	—
— Miscellaneous (cables, etc.)	0,63	0,83	—
Tyres (retreads — 2500 h for shuttle car)	—	0,27	2,09
Lubricants	0,14	0,14	0,28
Filters	0,12	0,12	0,12
Electricity (conventional)/Fuel (LHD)	0,13	0,17	3,61
Operators (conventional)/Operator (LHD)	2,25[2]	1,00[3]	0,98
Workshop overheads	2,97	2,97	3,66
Total	27,61	15,77	34,85
Cost[4] per ton			
No. of units per section	1,5	2,5	2,5[5]
Effective shift time, min	459[6]		436,05[7]
Output per shift, t	825		983[8]
Output per hour, t	107,84		135,21
Cost per hour, R	80,84[9]		87,13[10]
Cost per ton, R	0,75		0,64

1. The costs of units common to the two sections have been omitted for convenience.
2. Includes the cost of 2 operators (driver and cable handler).
3. The cost of only 1 driver is included because the cable is reeled in automatically.
4. Based on theoretical output.
5. ½ unit standby.
6. Based on an operating time of 510 minutes per shift at 90 per cent overall availability.
7. Based on an operating time of 510 minutes per shift at 95 per cent mechanical availability and 90 per cent utilization.
8. 2 LHDs.
9. $1,5 \times 27,61 + 2,5 \times 15,77 = R80,84$.
10. $2,5 \times 34,85 = R87,13$.

(3) The capital cost of an LHD section is marginally lower than that of a conventional section.
(4) Under both ideal and difficult conditions, LHD sections can outperform conventional sections at lower cost.
(5) The artisan work load is lower in LHD than in conventional applications, and maintenance can be conducted by suitably trained artisans instead of skilled diesel mechanics. The electrical work is simplified because power has to be provided only for drilling and coal-cutting operations.
(6) The wear from the handling of abrasive stone is confined to the bucket, which is constructed of abrasion-resistant steel with replaceable lips of hardened alloy steel, and the wear is more easily controlled than in conventional sections, where it is spread over more units.
(7) The key to the successful use of diesel equipment is in the hands of the maintenance staff, who have to ensure that standard procedures are strictly observed so that emission standards are not exceeded.
(8) To provide environmental conditions acceptable to operators in LHD sections, ventilation standards should be better than those in conventional sections.
(9) To achieve high rates of face loading, LHD units should load only 'piled' coal, leaving the final clean-up to small (2 m^3) loaders.
(10) LHD production units in South Africa are limited to the mining of seams with abnormal floor gradients. Where conditions are reasonable and the associated stone presents no problem to continuous miner (CM) operations, both LHDs and conventional equipment will be phased out in favour of CMs. CMs appear to be the units of the future because of their high capacity to break coal non-explosively.

The future of both diesel- and battery-powered LHDs as multi-purpose auxiliary units is assured. The following operations can be carried out by auxiliary loaders:

(i) final face clean-up operations,
(ii) loading of coal-cutter duff,
(iii) handling of waste brushed in the roof or floor of seams to achieve adequate access height,
(iv) development of winzes, raises, etc., to negotiate faults,
(v) construction work (e.g. the development of underground storage silos), cleaning of air crossings blasted in old areas, etc., and
(vi) stone dusting of old areas, the stone duster being transported in the LHD bucket and driven off its hydraulics.

Advantages of LHD Units

(a) The use of LHD units simplifies power-cable installations in that these installations then need to meet only the cutting and drilling, making mining operations possible in areas where limited power is available.
(b) The opening up of new sections is speeded up owing to the high manoeuvrability of LHDs, e.g. breaking away through barrier pillars.
(c) LHDs can be used in areas where no power is available, e.g. in cleaning up operations and the re-establishment of old areas.
(d) The flexibility of LHD units, especially in the mining of stone rolls, floating stone, and dykes, means that the conventional loader, which is not designed for rock handling, need not be used in these tasks.
(e) LHDs can mine on a gradient of up to 20°, whereas a shuttle car is limited to a maximum of 7°.
(f) LHDs do not bottom out on rough roads.
(g) When LHDs are used, there is less risk of fires caused by faulty trailing cables. (There were two such occurrences at Greenside in 1976.)

Disadvantages of Diesel-powered LHDS

(1) Air pollution can be a major problem if proper ventilation and maintenance standards are not maintained.
(2) Large volumes of dieseline have to be transported underground.

Acknowledgement

The permission granted by the Technical Director of Gold Fields of South Africa to publish this paper, and the help received from the Manager and staff of Greenside Colliery, are gratefully acknowledged.

Gold-mining museum

The Chamber of Mines has decided to establish a gold-mining museum at No. 14 Shaft, Crown Mines, about four kilometres south of Johannesburg's city centre.

The existing 14 Shaft headgear and mine buildings will be the nucleus of the museum. Work will begin immediately on restoring the buildings and assembling exhibits for display, which will depict the historic aspects of mining from the time of the discovery of the Main Reef in 1886.

In due course it is hoped that old mine steam locomotives will be acquired to take visitors for rides round the perimeter of the site, and that a historic mine village will be recreated.

It is hoped that other interested bodies will provide the further financial assistance and support that will be required to complete a comprehensive museum complex on the 10-hectare site that has been provided by Rand Mines Properties.