Chapter One

Introduction

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Introduction

1.1 Background

We have been encouraged by some colleagues, who graduated before us, that we seek to conduct our graduation project with a supervisor from the industry, they praised the experience in all its aspects. Due to this we dived into this project with high hopes .

The projects specified & executed by our supervisor up to now (2009-2016) can all come under a general title which is the title of our project shown above. But every specific project specifies certain engineering problems, study & analysis them to contribute by presenting the possible solutions to them to enhance Sudan railways corporation (S R C) business requirements standards

1.2 The problem statement

The railway industry , like most of the industries lived its short infantile life , passed its teething problems to live as a new being , but like the human being in life , it passed many stages of developments and still has a lot to cope with .

The manufacturer & the user of railway products work in collaboration to achieve five basic requirements of the users (railways) namely, the maximum capacity of transportation, the best of maintainability & overhaul periodicity, reliability, performance , stability & safety.

The manufacturer through research & development (R&D) upgrade his products . The user is an important source of information to the manufacturer because he conveys the problems which happen in the manufacturers products .

The users also has an important role to play in the development of products , which he purchases in a certain stage , but new developments have superseded some of the systems , unites , components fitted in his old serving ownerships .

Although any railway built to serve a certain specified purpose , undergo some problems which necessitate solutions to let it live , there comes a time when the railway needs to be revised to cope with new market requirements .

At this stage , unconcerned persons , may jump to suggest that new railway track has to be built or it has to be standard gauge rather than the existing narrow gauge , or , or , or …..

SRC passed bad times in the two dicads passed.

It is high time to study the case of SRC and see what major schemes are needed to put SRC in the right track

1.3 specific objectives of the project

After through investigation of what has been accomplished by the previous SRC projects , which are considered as a series , it is clear that there is a lot to choose from

The importance of the project is that it is a link in a chain of knowledge in the railway industry as a whole and specially that of Sudan railway corporation . The information reached to is supported by actual experiences , & practical outcomes which have been presented in lectures in railway mechanical & civil engineering courses by British Railways (BR), the Railway Industry Association (RIA) & the Institution of Mechanical Engineer (I,Mech,E) of Britain for railway engineers at home & from abroad .

The results reached to by the project shall be firm & accurate supported by references which shall be accepted with appreciation .

We assume they would be of value to SRC .

The specific objective of the project shall be the upgrading of SRC business to cater for the transportation by mixed traffic of freight & passengers trains up to first half of the 22nd century .

1.4 Study areas

To achieve the specific objectives specified the study areas shall include and see what could be done. The legal status, the top management, the training institutions. The care and keenness on railway staff training are the guarantees for success. The basic branches to be rationalized and upgraded are the track, the signaling and telecommunications, operations, motive power, electrification, rolling stock workshops and depots. The processes of rationalization and upgrading are ment to achieve targets of annual tonnage transportation of freight. An account in this matter shall be presented in details.

1.5 Project layout

To achieve what has been planned and presented here in the introductory chapter it is important that we qualify ourselves in railway engineering.

We studied railway engineering courses for the whole year , six hours in the week. We had practical training in the central region of SRC. The project layout is shown in the next page.

Table (1/1) : Project Layout

July 2015 - October 2016

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	a) Track Sector Course b) Motive power Course c) Diesel Engines for rail traction course																						
2	Track & Signaling Training Course																						
3	Diesel Works shops Training Course																						
	Carrages & wagons shops training course																						
4	The Chinese concrete sleepers factory training course																						
5	Report writing																						
6	Report cretinism & correction																						
7	Handing over of report																						

Chapter Two

Development, Upgrading and Rationalization of SRC

(Literature Review)

Chapter Two

2.1 Introduction

This project is part of a series of Sudan Railways Corporation (SRC) history of developments, upgrading and rationalization of all components of its business and managements.

This way it is objectives to start with the review of projects already executed in the series to make use of it as it contain information which shall pave the way for execution of our project, but, most import, to avoide repetition of studying problems already been studied.

As stated in the specific objectives of the project in chapter one, this project shall prove that the existing track with its narrow gauge and its singleness are valid ownership after upgrading and rationalization to serve Sudan needs for goods transportation for more than hundred years to come.

The backbone for the prove of this claim is by thorough study and presentation of literature on:

A) Motive power (diesel electric / electric locomotives) Electrification is the future of all railways round the world. Therefore electrification literature review shall be dense.

B) The track speed and axle load are the main factors for raising the transportation capacity of a railway line . Literature this component of the railway shall be reviewed and presented here .

C) Signaling and operation is the third member of triangle

The outcome of all suggestions in this study are contribution to help in reaching to best solutions .

2.2 Previous projects review

Nine projects of similar main objectives, but different field areas have been prepared from 2009-2015.

The abstracts of these projects and their titles shall be presented together with one main important finding reached to.

2.2.1 evolution and upgrading in Sudan Railways Corporation

Presented by:

-Omer Al Fatih Babiker mohammed – Mohammed Tag Alsir – Mohammed Husain Dafa Allah

(August 2009)

Abstract

The evolution and development in the railway industry lead to replacement of products to products which become obsolete.

The railways, specially those of the third world, are bound to follow this trend of upgrading.

SRC, in the motive power use (Locomotives), started by steam locomotives for traction of it's trans. But it become clear that if the STEAM LOCOMOTIVES have been replaced by suitable DIESEL ELECTRIC (DE) LOCOMOTIVES fleet, there shall be two usefull benefites:

1) An appreciable rise of transportation capacity of the railway lines without much cost of upgrading them or the signaling system.

2) An appreciable reduction in the cost of operation specially in the fuel consumption.

For these reasons and others, the DE locomotive started to replace the steam locomotive.

Even though it seems remote, the ELECTRIC LOCOMOTIVE shall soon replace the diesel electric locomotive for more reasons than in the case of the steam and diesel electric.

From the findings of the project

The main objective of this project is to trace the development in technology application in the field of railway industry and conditions acting as incentives.

Also one of the objectives is to document the role played by SRC engineers in the engineering development of SRC for the promotion of the engineering profession.

It is clear from the study, what is considered as a development for a product in a certain stage, may render this product of second grade or even obsolete.

The steam locomotives became obsolete, replaced by DE locomotives and the replacement of the electric locomotives to the DE is jogging in the industrialized countries.

There is limited future for the DE locomotive due to the limited future of the fosel fuels

The diesel engine, specially the well proven traction diesel engine, is a unique piece of engineering work. The engines themselves and their spares are difficult to produce in the third world countries. On the other hand for the electric locomotive equipment such as transformers, motors, resistances ,etc are produced in some developing countries .

Some facts on diesel electric and straight electric can be presented here under:

1. The diesel electric traction suits the light traffic .The straight electric traction suits the dense traffic .

The performance of one traction means to the other depends on a feasibility study.

The DE locos. In use in SRC now, use DC traction .

The AC traction worth trying.

2. The lines with continues future traffic are suitable for electrification. The electric locos, serve only in electrified lines while the DE locos, Serve in both electrified and non-electrified lines .
3. The electrification of SRC depends on high production of electricity and wide distribution by the national electricity corporation (NEC) . The alternative may be a joint venture between NEC & SRC .
4. The DE locomotives when detained in station for rains, derailments , washouts , accidents ,etc , they have their engines working for long hours at idling speed . This leads to engine deterioration and lubricating oil dilution.
5. In case of electrification, the dynamic brake of the electric locomotive generated by the traction motors when used as generators can be fed back to the supply line in regenerative dynamic braking.
6. SRC is a producer of electric power using an electric transmition system in its DE locos.

In 1983 SRC owned 160 main lines locomotives producing round 230 megawatts.

The power produced by both Khartoum North and Borri thermal power stations in 1988 was 315 megawatts.

2.2.2 Technical Specifications and Design to be Considered When Choosing a Locomotive for SRC

Presented by;

- Anas Hamdan Ibrahim – Reem Ali Mohammed – Smoal Salih Aldaw

August (2009)

Abstract:

The object of this project is the specifications of the diesel electric locomotive (DE) the response of the designers /manufacturers to these specifications and the careful study and analysis of manufacturers offers by the user.

The technical study for the offers by the users is for the right choice of locomotives of proven performance with no deviation from SRC specifications to give the best reliability, availability, maintainability and overhaul periodicity.

SRC DE locomotive specifications consist of sixty five (65) items. The study concentrated on two important items, namely the required performance from the locomotive. The automatic load control of the locomotive.

Theoretically an offer may be studied to find that it is typical to the specifications . But this is not the end of it. Practical experience in this area is very important.

Lack of experience, when the steam locomotives were replaced by DE locomotives, led to costly faults in the air filtration system of the British locomotives, the cooling system of the Belgian and the design fault in the calculation of vibration and tortional critical speeds of the crankshaft system of the Japanese locomotives.

From the findings of the project :

This study made clear the interaction between the locomotive specification , the designer , manufacturer and user and the need of each to the other for the development of locomotives .

The problems in locomotives passed by SRC were very valiable as they led to the modification of the specification items of the :

The air filtration system of the locomotive.

The cooling system of diesel engine.

The tortional vibration of the crankshaft system calculation.

The specification are subdivided into sections such as :

- The climate.
- The loading and structural gauge .
- The track, its route, gauge, gradiets , curvature , the highest point , the highest speed , the axle load .
- The specification of motive power (locomotives).
- The resistance for the locomotive: rolling, curve and grade resistance to enable us to calculate equivalent horse power.
- The rolling stock (carriages & wagons) , their dimensions , weight capacities , etc .

2.2.3 ASIS Main Line Locomotives

(A Case history of such locos. offer for SRC for purchase)

Presented by:

- Mohammed Babiker Hussien – Mohammed Alamin Adam – Mohammed Alhaj Idriss Mohammed

(July 2010)

Abstract:

This project is about a unique piece of engineering work. It is about the railway Diesel Electric (DE) Locomotive. The major branches of engineering, mechanical, electrical, civil, electronic, hydraulic, control, safety, telecommunication are including in a DE locomotive design, manufacture and operation.

Locomotives are usually built to the specifications (specs) of the user to suit his requirements, e.g. horsepower, gauge, track, environmental and geographical conditions, etc. If there are major deviations from the specifications of the user , an offered locomotive with such drawbacks shall not be suitable for him.

In rare case some railways purchase used or new locomotives which have been built according to another user specs . Such locos are termed AS IS (as it is –as they are). For these IAS IS locos, to work in another railways, Their specs. MUST be very near to that of the purchasing user.

This study is an application of such a case which happened in Sudan Railway Corporation (SRC). There was a technical dispute on

some AS IS locomotives offered for SRC for purchase. The two teams who led the technical debate are ex and in service SRC engineers.

We studied this case history and made our contribution.

From the findings of the project:

The GR-12X Locomotive

Summary :-

SRC Management had an offer for the purchase of seven used diesel electric locomotives – 1200 h.p each of General Motors design manufactured in Canada. A team of senior SRC staff travelled to Nicaragua, inspected the locos and recommended their purchase.

The date of manufacture of the GR-12X locos is 1960 where rail traction technology stands modest in front of today's technology.

The loco engine is model 567-C, a naturally aspirated diesel engine, which is out of production since the late – fifties and has been superceded by so many models which made use of turbocharging and aftercooling to double their power output and minimize their fuel consumption .

The engine specific weight (weight/power) is high, its output is low and its fuel consumption is high. A combination of disadvantages which rendered it obsolete and out of production. The GR-12X loco, athough (very weak) in terms of hauling capacity (only 500 tons) compared with any SRC main line LIGHT locomotive hauling capacity (900 tons), it is too HEAVY in weight having an axle load of 16.92 long tons which makes its operation in SRC routes prohibited.

The GR-12X loco, performance is poor . A single loco, can haul 500 tons at 25 Km/hr on a one (1) percent grade . Two GR-12X locos, as multipule units can haul 900 tons at 35 Km/hr on a one (1) percent grade. This is which can haul the same 900 tons (hauled by two GRS) but at a 25 Km/hr speed on one (1) percent gradient . Multiple unit application is not valid in SRC for many reasons.

The GR12-X locomotive cooling and air filtration systems, which are very important systems and must be designed to SRC site conditions , are designed to the temperate climate of new found land . They can not operate in the tropical climate of the Sudan .

There is no compatibility between the AAR air brakes (fitted in the GR- 12X loco .) and the UIC air brake system which is adopted by SRC .

All SRC main line locomotives are equipped with dynamic brakes which are through to be an important part of SRC locomotives . SRC rejected any offered locomotives which did not include dynamic brakes

All SRC main line locomotives have tow driving positions . The GR-12Xloco has one driving position which makes it travel in ONE direction only creating a lot of traffic problems and costing a lot of money .

The GR-12X locomotives is out of dimensions and it is NOT FITTING SRC loading gauge .

The GR-12X locomotive axles , wheels, bearings and couplers are not to SRC specifications.

Spare – Parts , if ever made available , will be very expensive.

Locomotives cannot go on serving forever. They normally have an estimated life of 25-30 years. The GR-12X Locos, served their useful life and fracture of their material is imminent.

SRC have enough tractive stock to haul its available rolling stock. They need to invest in spare parts and components to maintain and rehabilitate locomotives and rolling stock out of service for lack of spares. Therefore it is recommended that SRC should not purchase additional old or new locomotives.

2.2.4 Deviation from SRC Specification for Diesel Electric Locomotives

Presented by:

- Ali Mustafa Ali Alatta – Al-mohanad Mobarak Attia – Al-Sayed Mohammed Alamin – Magdi Mohammed Gaily

(July 2013)

Abstract:

The diesel electric locomotive and its specification are a unique piece of engineering application . This include mechanical , electrical , electronic , civil engineering aspects .

Lately Sudan Railways Corporation (SRC) deviated from SRC specification for locomotives by purchasing Chinese locomotives powered by CAT series 3500B diesel engines which are of high speed (1800 rpm), contrary to the specified and used medium speed (1050 rpm max) proven traction engines specially developed for traction duties .

Three famous designers & manufactures of locomotives and their research and development works to produce TRACTION ENGINES is presented in this study .

A RAIL TRACTION ENGINE is an engine which has been developed SPECIALLY for this application .

The first cost is of secondary importance to technical assessments associated with maintenance and operating costs when taken over the twenty five years life of engine. The first cost is less than 5% of the full life operating & maintenance cost without conceding inflation .

Testimonies of users , manufactures , consultants ,etc . on medium speed versus high speed for main line locomotives have been presented .

To name two :

1) British railways (BR):

Traditional BR have specified medium speed engines for all main line locomotives and the few deviations to 1500 rpm engines have generally resulted in engines of poor reliability . Together with the higher fuel consumption of the 1500 rpm engine .

2) Nigerian Minster in his parliament (from the net):

Chinese trains … were 50 , none of them today is on our rail track . They are all bad for reason may be technology is not as good as the one we are buying is general electric (GE) … have been in locomotive business for eight decades .

Nigerian Railways corp. bought GE locos .30 to 40 years ago . They are still the ones we are using today.

The extent of damage happened by the introduction of a high speed engine is specified in the conclusion of this study .

From The Findings of The Project:

Medium and High Speed Diesel Engines in Rail Traction

Summary and Conclusion

Introduction:

Medium and high speed diesel engines are in rail traction with medium speed engines dominating the field specially the field of main line locomotives for freight traffic.

The high speed diesel engines are used shunting and switching locomotives. Also they are used in rail diesel cars (DMU) for suburban passenger trains and may be for inter-city passenger trains.

High speed in rail traffic, are in many cases, of grate commercial value and, therefore, the maximum power must be installed in the locomotive whilst still retaining light axle loads. To quote an example, the maximum permitted axle load on British Railways 25 tons, but for the high speed train (HST), (inter-city passenger train, which travel s at speeds of up 200 km/h), the maximum permitted axle load is restricted to 17.5 tons, in order to keep track stresses within acceptable limits.

The need to recognize the severity of the traction duty cycle cannot be over emphasized. The traction mode of operation involves many hours at idling which can produce oil carry over, carbon build up, low temperature corrosion, and the other problems with fuel injection equipment.

In assessing methods of acceptance testing of new designs of diesel engines for rail traction duties, both the mechanical (high cycle) and thermal (low cycle) fatigue regimes have to be considered. The cycle life of components depends upon the magnitude and type of strain and it seems that strain is the most significant factor in governing the cycle failure mechanism.

However, the behavior which dictates the actual magnitude and type of strain encountered is strongly influenced by the imposed temperature stress and engine cycling loads and hold times.

To this end, it is clear that A RAIL TRACTION ENGINE is an engine which has been developed SPECIALLY for this APPLICATION.

This project displayed, the effort made by three famous locomotives manufacturers to develop their engines for TRACTION.

For some reasons, to be shown, the three started by medium speed 2-stroke and 4-stroke and HIGH rotational speed engines. Each has his inherited problems linked to his choice of design.

They started developing these engines to suit the traction duties. Engines which had not undergone such research and development work are still with their inherited problems.

The reasons which dictated on the three manufacturers are shown under.

1. Historically, General Motors has pioneered the medium speed two-stroke cycle diesel engine, although they are not irrevocably committed to any specific type of design. In the early thirties research at EMD/GMC had led to an eight cylinder two-stroke cycle diesel engine design which could be built with a rating of 600 horsepower. The best 4-cycle, 8 cylinder Of the same bore and stroke as EMD's 2-cycle design was then rated 400 H.P., so it appeared that their 2-cycle engine had a fair edge over the 4-cycle and then they produced the 8 cylinder two- stroke cycle.

   The general philosophy of EMD/GMC is to solve the problems related to 2-stroke cycle design. The development work is for the enhancement of reliability, durability and engine performance. Lately a conservative attempt to uprate Series 645 engines was made (645FB).

2. The Ruston philosphy is a philosophy of uprating. Development work is for solving the problems related to higher thermal and mechanical loading due to uprating and to enhance reliability and durability. Redesigning for ease of maintenance was also looked at. The horsepower which had been available from a 16 cylinder version (RK3) was extracted from a 12 cylinder version with the same bore and stroke (RKC). It is now possible to see an 8 cylinder version replacing the 12 cylinder at the same horsepower.

3. Maybach Motorenbau of Germany pioneered the design & manufacture of high speed, light weight and small size gasoline and diesel engine for airships. They found themselves bound to move continuously, extensively & expensively into research and development work to introduce their HIGH SPEED ENGINE in RAIL TRACTION.

4. Cat. Series 3500B engine history shows:

   1) 1980s start electronic engine design.

   2) later 1980s start 3500B electronic engine production including 8, 12, 16 cylinders.

   3) since 1995 3500B engine start volume manufacturing.

   4) in 1998 first 3508B locomotives engine sold in China.

6.2 Some users, consultants & manufacturers viewpoints:

6.2.1 British Rail:

First cost:

First cost has to be seriously considered at the purchasing stage, but it is of secondary importance to technical assessments associated with maintenance and operating costs when taken over the twenty-five year life of the engine. The first cost is less than 5% of the full life operating and maintenance costs, and if inflation and the increase in fuel costs are taken into account, it becomes almost insignificant. In practice however, first cost can be decisive if engines of similar design and operating performance are offered at a significant difference in price.

Overhaul periodicity:

In citing improved reliability as a major users requirement, it is essential that this leads to an increase in the time between workshop overhaul periods, and hence reduced maintenance costs.

Consider the existing 2984 DMU engines which at the present time do not operate on a preventative maintenance basis, but are overhauled when they fail. The average life of these engines is appalling, at approximately 161 000 km (100 000 miles), 4000 engine hours. The major failures being pistons and bearings, which account for roughly 60% of total failures. The causes of these failures are generally inadequate cooling, poor air filtration, poor lubricating oil filtration and low lubricating oil pressure. In specifying new engines, a minimum overhaul period of 450 000 km (280 000 miles) will be required and a preventative maintenance schedule will be introduced to. further reduce costs of expensive engine failures.

Locomotive maintenance costs are approximately ten fold those of the DMU engines and a carefully specified maintenance and overhaul schedule is laid down. Depot maintenance procedures are fairly common between the various types of engine, but the overhaul periods are dictated by the first component to reach its life or wear limit. This could be piston ring wear, piston ring groove wear, bearings etc. A further factor is the duty cycle. Passenger train cycles for instance, are more severe than freight. Overhaul periods are therefore, determined by experience in service and the current periods are shown in Table 4-3 British Rail operate both medium speed and high speed engines and experience has shown that the medium speed engines can achieve an overhaul period of approximately 15000 hours.

The HST however, has to be considered in a different light, as it undergoes a much more arduous service duty cycle, as shown in Fig 4-3. The figure illustrates a typical locomotive hauled passenger train and an HST from which it can be. seen that the HST engine experiences 8.2 full load to idling thermal cycles per hour compared to 4.9 of a typical passenger train. The present overhaul cycle on the HST engine is 7000 hours.

The user, in looking to the future, must aim at a significant improvement in these figures and on a medium speed engine it should be possible to extend the overhaul period to 20000 hours to a top overhaul, that is piston removal, and 40000 hours to a major overhaul, that is crankshaft removal. A better alternative would be 30000 hours to a major overhaul with no intermediate repair.

The second alternative is favoured, as the first option can lead to dirt ingress to the main bearing system during a top overhaul. If a 30000 hour overhaul period is achieved, it would reduce the annual engine maintenance cost by 25 to 30%.

A similar argument should apply to the HST engine and a 15 000 hour period should be possible, which will give a similar reduction in costs.

In looking to these extended periods, it will be necessary to introduce Depot schedules for the changing of fuel injection equipment and turbochargers at intermediate periods.

It is worth noting that the French Railways have already achieved the above overhaul periods with their 67000 type locomotive and are overhauling the 1500 rpm engine after 775,000 km (481 000 miles) which is equivalent to 24000 hours.

The engine of course, cannot be treated in isolation and cooler groups, transmission systems and all other equipment has to be carefully matched to ensure it gives the same performance.

Reliability & fuel consumption:

Traditionally BR have specified medium speed engines for all main line locomotives and the few deviations to 1500 rpm engines have generally resulted in engines of poor reliability. Together with the higher fuel consumption of the 1500 rpm engine.

6.2.2 Maybach motorenbau (High Speed engine):

Opinion at that time - which many still hold today - was that the high-speed engines despite their obvious advantages with respect to weight and reduced space requirements would have a shorter service life, have less favorable consumption figures, and be more prone to trouble. This opinion chiefly resulted from the fact that many firms tried to increase the output of their existent low-speed engines merely by increasing the engine speed and neglecting any improvements in design. Naturally, this led to setbacks which in turn gave rise to such widespread opinion. The Maybach Motorenbau, which even then had many years of experience in the field of high-speed Otto engines, adopted new methods by designing a diesel engine especially for high speed and by aiming simultaneously at a corresponding increase of operating reliability and service life, two requirements obviously necessary for airship engines.

6.2.3 The Henderson Partnership (Consulting Engineers):

In the past many third world countries have purchased locomotives, which have proved less satisfactory than when running in developed countries, and which have shown their poor reliability when maintenance has not reached a sufficiently high standard.

For third world countries for many years in the future, there are advantages in having engines less sophisticated and less sensitive, but with a high degree of reliability.

6.2.4 Cat. Electro-Motive Diesel (EMD):

Idling Speed:

The idle speed of the Model F3A engine is 200 rev/min the lowest idle speed of any modle 645 engine to date. this 200 rev/mm idle speed reduces the engine fuel consumption at approximately 15 per cent when compared with the 235 rev/min idle speed of the model F engine.

Prior to adoption of the 200 rev/min idle speed studies had indicated the engine performance at this very low idle speed is characterised by satisfactory combustion, invisible exhaust, and freedom from lubricating oil dilution.

N B the idle speed of Cat. 3516 B engine is 600 rev/min.

6.2.4 Ganz Mavag – Budapest:

Diesel engines:

Type Ganz-Mavag S.E.M.T.-pielslich PAV-185.

Maintenance & repair instruction:

The schedules of maintenance in this instruction are given in engine revs. Which indicates that a high speed engine has a shorter period between overhauls than a medium speed engine.

From all testimonies above and the content of the project we conclude the Chinese locomotives with their undeveloped engines for locomotives are inferior than any of SRC locomotives purchased to SRC specs.

There are no technical or economical grounds for the introduction of locomotives with high speed engines in SRC because:

Reliability

Durability

Fuel economy

Overhaul periodicity

Shall be inferior to that of locomotives with medium speed traction engines purchased by SRC according to rules & regulations.

2.2.5 Water Cooling Versus Air Cooling For Diesel Engines

- Abu Bakr Al-Fatih Babiker Mohammad – Maay Alhag Ali – Fawaz Abd al monim – Mohammed Kamal – Taha – Al sadig - Hosam

(July 2013)

Abstract:

The main fields of application of diesel engines in Sudan are: agricultural vehicles, construction equipment, trucks, electricity generation, automotive, industrial, rail traction, etc

Sudan climate is temperate & dusty which puts more load on the engine demanding efficient cooling to release its heat.

This project is a study on the diesel engine with emphases on its cooling system. Water cooling & air cooling are the two modes dominating the field. Thorough study of the two systems & their comparison is presented.

It is difficult to make generalization about air-cooled & liquid cooled engines. Research & development succeeded in reversing disadvantages to advantages.

From The Findings of The Project:

Conclusions

Air cooling uses airflow directed at fins on the cylinders and heads is the cooling medium: heat is transferred directly to the air. The air comes either by natural convection (e.g., a motorcycle) or by forced air (e.g., air-cooled VW or Porsche engine.)

Water cooled engines circulate coolant around the heads + cylinders though a surrounding water jacket, and use a separate high-efficiency radiator for the final heat exchange to the air. (Marine engines are a bit different – they use the surrounding water instead, either directly or through a water-to-water heat exchanger.)

Air-cooled engines are simpler, lighter and easier to maintain as they don't have the 'wet' cooling system elements. They excel in cold climates where coolant freezing can be a problem. However , air cooling is less efficient due to the low heat capacity of air so these engines suffer from hot spots which reduces power, increases emissions and shortens their life.

Air-cooled engines are also considerably noisier – both from the engine directly and also from the air blower cooling fan if used.

Water-cooled engines take advantage of water's high heat capacity to efficiently carry away the heat. So they offer the best control over temperature allowing for more aggressive / efficient tuning and optimal head design. While they have increased near-term maintenance costs (coolant, water pump, hoses, etc.) they make up for it in a longer-lived engine core (longer time between overhaul.)

Water-cooled engines are also quieter due to the insulating properties of the water jacket and the lessened airflow requirement.

Water cooling also permits more flexibility in engine architecture and installation since there isn't a need to duct cooling air directly to the cylinders.

It is difficult to make generalization about air-cooling and liquid cooling engines.

Air-cooling (Volkswagen kombis) are known for rapid wear in normal use and sometimes sudden failure when driven in hot weather, alternatively, air-cooled deutz diesel engines are known for reliability even in extreme heat , and often used in situations where the engine runs unattended for months at a time .

From the para above we conclude that within the range of air-cooled engines there is a role for research and development to play to remove the inherited disadvantages of air-cooled engines.

2.2.6 The Role of Engineer in Lubricants Condition Monitoring and Conservation

Presented by:

- Mohammed Fakhr Eldeen Altaher – Aamer Alameen Musmar

(2013-2014)

Abstract:

- The mechanical engineer, whether a production engineer or power engineer, needs a prime mover to turn his machines if they are stationary or move them if mobile. In all cases machines and prime movers need to be lubricated or else they will paralyzed and useless.
- Therefore lubricants are vital for machine operation and the engineer's theoretical and practical know how in the field of lubricants is a corner-stone for him to enable him to fulfill his duties properly.
- Four chapters, (2, 3, 4, and 5), have studied, investigated displayed a dense and rich information on lubricants including types and sources, purposes and formulation, degradation and the Root Cause Analysis (RCA) to know the reasons of degradation and the steps followed for protection and rectification, the analytical tools which assess lubricants degradation, condition monitoring while lubricants are in use during service, and the laboratory services, etc.
- Since lubricants are scarce and non-renewable, the users are bound to re-refine them for re-use. Re-refiners are active in this field developing means of processing used oil to its virgin condition once again.

From The Findings of The Project:

Conclusions and Recommendation:

Introduction

Lubrication and lubricants are vital for machine operation and life. Without it machines shall be paralyzed and useless.

The engineer`s theoretical and practical know-how in the field of lubrication and lubricants is a corner-stone for him to fulfill his duties properly.

This study have investigated and displayed practical experiences in the fields of petroleum industry, petrochemicals, use of lubricants and the re-refiners who recover the base oil from the used oil again.

Dense and information on lubricants, their sources & types, refining of base oil, purposes and formulation, degradation by use, condition monitory in service, Root Cause Analysis (RCA) for degradation, analytical tools for assessing lubricants` degradation and laboratory services have presented.

Since lubricants are scarce and non-renewable, the users are bound to re-refine them for re-use. Re-refiners are active in this field developing means of processing used oil to its virgin condition once again.

Base Oil:

Base oils are the primary ingredient in oils and greases. Most oils are formulated with 70% to 99% base oil and the rest being additives. Greases typically have 70% to 94% base oil.

These base oils come from three primary sources:

1.Crude oil.

2. Chemical syntheses.

3. Natural resources other than crude oil (fats, waxes, vegetables, etc.).

Contrary to popular belief, there is no doubt that the type of base oil and the refining method must be considered when selecting lubricants, particularly for unique or unusual applications. In order to understand why base oils exhibit different qualities, it is necessary to briefly describe the various refining processes.

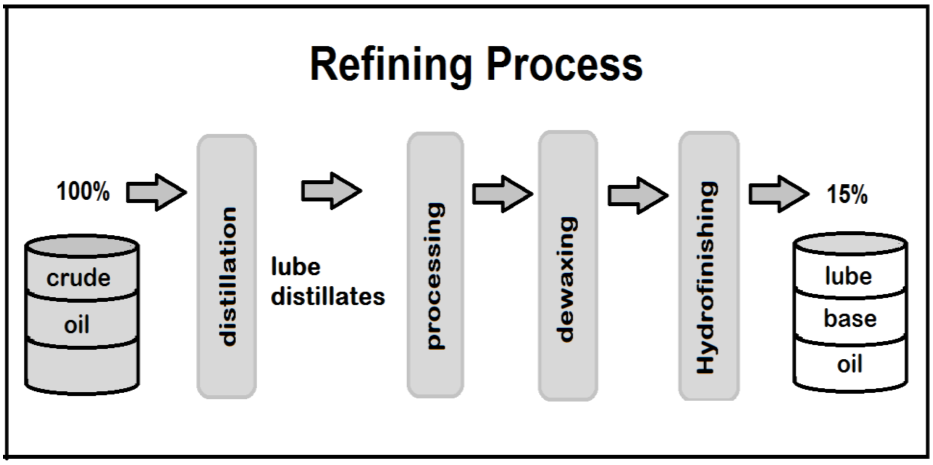


Figure (2/1): The Refining Process

Base Oil Groups

Mineral oil term is used to encompass lubricating base oil derived from crude oil. The American Petroleum Institute (API) designates several types of lubricant base oil:

- Group I – Saturates <90% and/or sulfur >0.03%, and Society of Automotive Engineers (SAE) viscosity index (VI) of 80 to 120

  Manufactured by solvent extraction, solvent or catalytic dewaxing, and hydro-finishing processes. Common Group I base oil are 150SN (solvent neutral), 500SN, and 150BS (bright stock)

- Group II – Saturates over 90% and sulfur under 0.03%, and SAE viscosity index of 80 to 120

  Manufactured by hydrocracking and solvent or catalytic dewaxing processes. Group II base oil has superior anti-oxidation properties since virtually all hydrocarbon molecules are saturated. It has water-white color.

- Group III – Saturates > 90%, sulfur <0.03%, and SAE viscosity index over 120

  Manufactured by special processes such as isohydromerization. Can be manufactured from base oil or slax wax from dewaxing process.

- Group IV – Polyalphaolefins (PAO)
- Group V – All others not included above such as naphthenics, PAG, esters.

The lubricant industry commonly extends this group terminology to include:

- Group I+ with a Viscosity Index of 103–108
- Group II+ with a Viscosity Index of 113–119
- Group III+ with a Viscosity Index of at least 140

Synthetic Oils:

The use of synthetic lubricants in various industrial and automotive applications is becoming more and more common, due in part to heavy marketing of synthetics. The word synthetic has nearly become synonymous with high quality or high performance. However, it should not be a given that a synthetic formulation is always the right choice. Those responsible for choosing lubricants have to decide between synthetic and mineral oil based lubricants and - if a synthetic is the right choice – they have to decide what type of synthetic lubricant to use. This decision can impact the health and longevity of the machinery, as well as an organization`s, operational costs and eventually the bottom line. Base fluid type should not be the only consideration. Additional factors that should be considered in the lubricant decision-making process include environment, equipment type, application technique, speed, load, temperature, and OEM recommendations.

- Polyalpha-olefin (PAO)
- Synthetic esters
- Polyalkylene glycols (PAG)
- Phosphate esters
- Alkylated naphthalenes (AN)
- Silicate esters
- Ionic fluids

Additives (oil additives)

A large number of additives are used to impart performance characteristics to the lubricants. The main families of additives are:

- Antioxidants
- Detergents
- Anti-wear
- Metal deactivators
- Corrosion inhibitors, Rust inhibitors

- Friction modifiers
- Extreme Pressure
- Anti-foaming agents
- Viscosity index improvers
- Demulsifying/Emulsifying
- Stickiness improver, provide adhesive property towards tool surface (in metalworking)
- Complexing agent (in case of greases)

Note that many of the basic chemical compounds used as detergents (example: calcium sulfonate) serve the purpose of the first seven items in the list as well. Usually it is not economically or technically feasible to use a single do-it-all additive compound. Oils for hypoid gear lubrication will contain high content of EP additives. Grease lubricants may contain large amount of solid particle friction modifiers, such as graphite, molybdenum sulfide.

Greases

A grease is defined by the ASTM (American Society of Testing Materials) as: a solid to semi-fluid product of a dispersion of a thickening agent in a liquid lubricant.

A grease typically consists of the following three main components, base oil, thickener and performance enhancing additives.

Both grease and oil lubrication serve the same purpose, that of minimising friction and wear between moving surfaces. Because of their essentially solid nature, greases do not perform the cooling and cleaning functions associated with the use of a fluid lubricant. However, greases are able to provide many functions that cannot be provided by oils, and under many

Situations encountered in service the properties of grease can be superior thus making grease the lubricant to choose.

Most grease is used in rolling element bearings with lesser quantities used in plain bearings, gearboxes and on open gears.

Degradation

A lubricant in service is subjected to a wide range of conditions which can degrade its base oil and additive system. such factors include heat, entrained air, incompatible gases, moisture, internal or external contamination, process constituents, radiation and inadvertent mixing of different fluid.

Fluid degradation can be responsible for many kinds of equipment failures.

To find the root cause of oil degradation a root cause analysis (RCA) has to be conducted.

The objective of a root cause analysis (RCA) is to identify what happened, why it happened, and what can be done to prevent it from happening again. It involves examining the problem and considering evidence from several diverse perspectives.

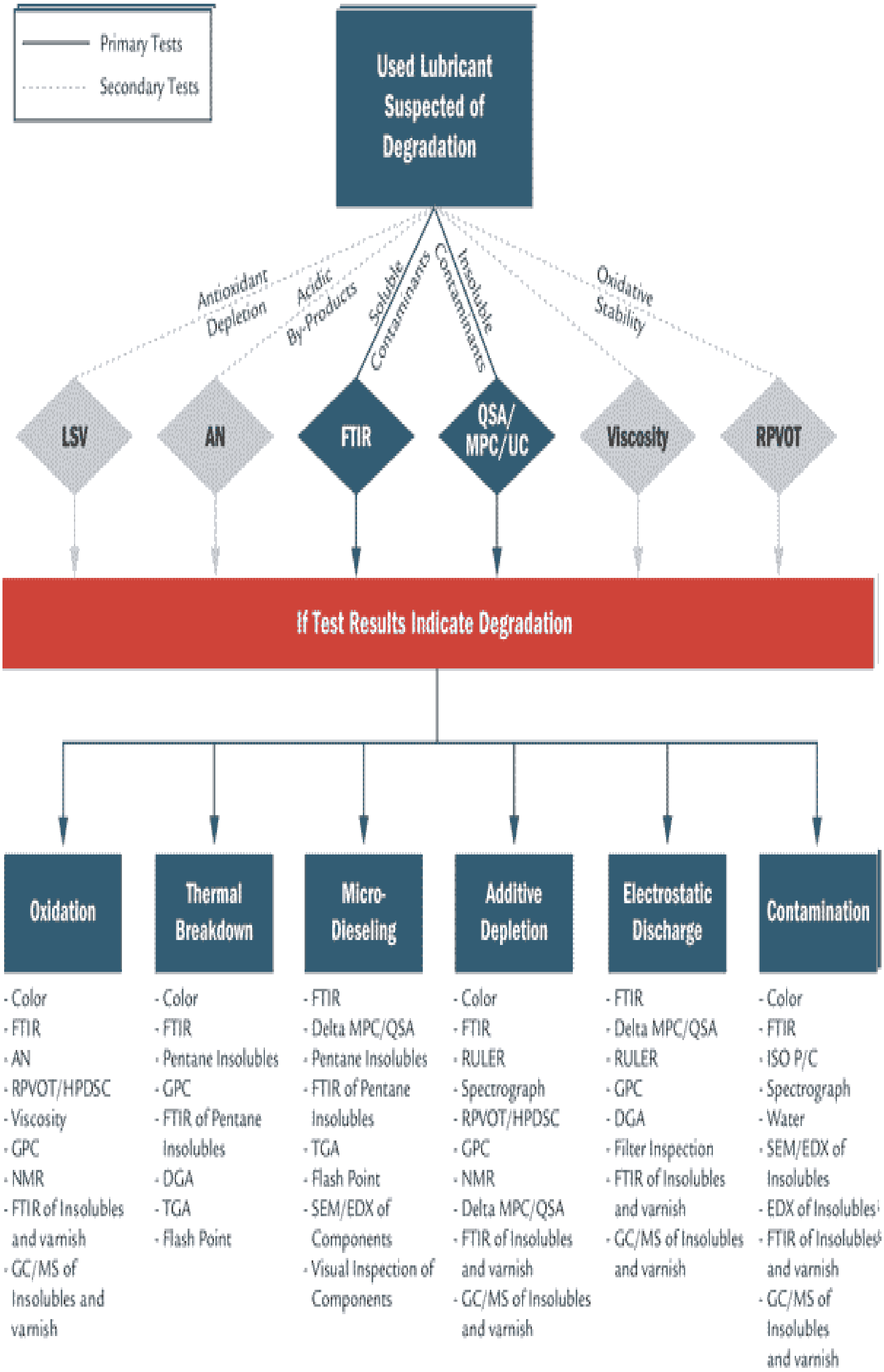


Figure (2/2) Analytical Tools Assess Lubricant degradation

Laboratory Services

British Rail (BR) and its associated companies are major users of product derived wholly or mainly from petroleum feedstock. Present usage is in excess of 900 million liters per annum at a cost in excess £ 100 million. Most of this volume and cost in excess of with provision of diesel fuel oil for our fleet of approximately 2100 main line locomotives and 4000 or so diesel multiple unit (DMU) engines. BR also uses 16 million liters per annum of lubricating oil.

By using laboratory services it is possible for a major user to minimize expenditure on petroleum products and to reduce the volume of virgin oils used. This has to be a clear objective for all industry in the UK and other countries dependent on the comparatively limited world resources of petroleum product. The way in which this achieved can be divided into four headings as follows:

- Oil formulations
- Quality control of oils in service
- Conservation and recovery for re-use
- Good housekeeping and practice

Spectrographic Analysis

The concept of being able to monitor the wear levels and component condition in the diesel engine without recourse to stripping the engine is very attractive, particularly where a large fleet of engines is concerned. Mechanical wear is an inherent part of diesel engine operation resulting in the generation of metallic particulate matter. In a lubricated system these particles can be suspended in the oil and analytical methods designed to quantity such particles offer a means of monitoring the wear process.

Spectrographic analysis is applied as a matter of policy to engines of a new type to BR service. This enables wear rates and overhauls periods to be established and highlights specific problem areas allowing corrective measures to be taken. In the short term, failures in service and cost of remedial action are minimized. In the longer term design changes are introduced to overcome the problems. This can lead a termination of the use of spectrographic analysis as is the case with the majority of the main line locomotive fleet.

Probable source of wear elements (etc.):

Al	Speed switch bob weights contacting aluminum casing.
	Main bearing and fork rod end shells.
	Pistons
Cr and Fe	Cylinder thrust bearing locating washer.
	Blade rod bearing and small end bushes
	Turbocharger bearings
Cu, Fe and Si	piston rings
Si	damper leak
Na	coolant leak

The spectrographic analysis procedure has proved to be very successful in diagnosing several engine faults and at the same time prevented many serious engine failures.

Re-refining of Used lubricating Oils

Re-refined lubricants have been produced for over 50 years. However, their acceptance as a high quality lubricant has been a gradual process. Largely because of the scepticism of the public that the product can be re-refined to its original condition.

Most of the sceptics regard the process as some sort of simple filtration. In fact the re-refining process used is a highly sophisticated operation using the most modern plant available in the world today. The process used is in many ways similar to that used to refine crude petroleum. Consideration of the composition and refining of crude will give a better understanding of the re-refining process and highlight the similarities.

The composition of crudes from different sources varies tremendously, but a typical make-up is as follows:

Gases: 5%

Gasoline: 35%

Kerosene 10%

Diesel 20%

Lube oil: 2%

Tar, Bitumen: 28%

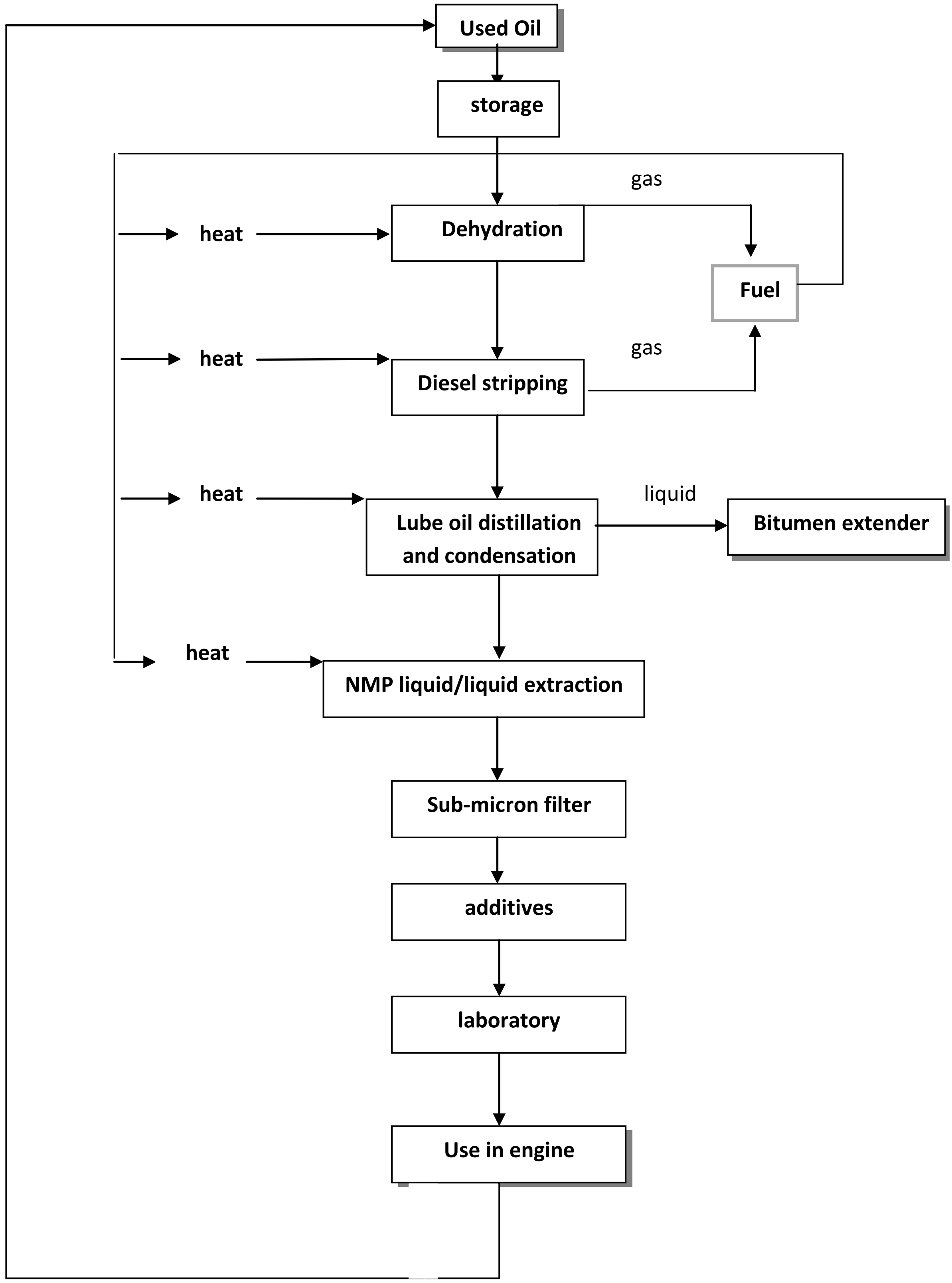

Used Oil
storage
gas
heat
Dehydration
Fuel
heat
gas
Diesel stripping
heat
liquid
Lube oil distillation
and condensation
Bitumen extender
heat
NMP liquid/liquid extraction
Sub-micron filter
additives
laboratory
Use in engine

Figure (2/3) Schematic of Dominion Oil Refining Process

Recommendations

There are, in practice up to date, four practices for conservation and recovery of oils for re-use lubricating oils are scarce and have very high demand. Above all, Lubricating oils from mineral and synthetic sources are non-renewable. Therefore used oil recovery is an issue of great importance.

In places like Europe and North American simple treatment or total re-refining are used to make use of the used oils to the greatest extent.

In third world countries, like Sudan, this technology is not yet adopted. Due to this, a great wealth is lost, even contributing in creating environmental hazards.

Conservation and recovery of oils for Re-Use

Again the severe petroleum shortage of 1973/74 provided the impetus which BR and other industry needed to seriously consider conservation and recovery of oil for re-use. Prior to 1974 very little recovery of petroleum product was undertaken on BR since oil was readily available and comparatively cheap. We suspect at that time that other industries, like ourselves, were quite happy to sell it as a waste product.

1/ Re-Use without treatment for same duty

Firstly by using the oil for as long as possible without changing it. In this category comes the lubricating oil change procedure adopted by BR for its main line fleet of locomotives. A second example is to increase any mixed mileage oil changes. Laboratory controlled oil changes are not economic for the 25 liter sumps of the DMU engines. By examining a lot of samples taken at the 20,000km oil change period we concluded that this could be doubled to 40,000km. The expensive phosphate ester fluid used in DMU fluid couplings when removed in works is analyzed and much of it is re-used without treatment.

2/ Re-Use without treatment for secondary or downgrade duty

Examples of this category are:

1- Certain waste crankcase oils are used as point and fishplate lubricants.
2- Grease removed from roller bearing axle boxes in Works is used as a switch plate lubricant at a rate of 50,000kg per annum saving £12,000
3- Burning, the ultimate downgrading when all else fails.

3/ Re-Use with simple treatment (lubricating) for the same duty either in house or by Private Contractor

In house a BR-developed process for the removal of particulate matter, including sub-micron carbon, from diesel engine oil leaving the up-spent additives in the oil, has been in use at Immingham depot since 1975. The process was developed in order to improve the efficiency of filters. By combining the use of a centrifuge with a coagulant mixture we were able to achieve a 100% efficient filter.

Since the process will not remove fuel or soluble oxidation products careful selection and segregation of those waste oil arising suitable for laundering by this process are required. Nonetheless, since 1975 over one million liters of oil have been treated for re-use saving some £100,000.

Several waste hydraulic oil arising are sent to a private contractor to remove water and particulate matter. These include oil from the hydraulically operated automatic marshalling yard at Sheffield Tinsley and hydraulic oil from dampers.

4/ Total Re-Refining

In this process, which is carried out by specialist contractor, all additives and contaminants in used oil are removed to yield the base oils to which the appropriate additives can then be blended to give a product which has properties equivalent to the virgin product. We insist on:

a- Approving the re-refiner at the outset.

b- Segregation of our waste oil from other wastes being handled by the re-refiner to ensure we get our base oil back again.

c- Re-spiking it with the same additive package as used for the virgin oil.

Examining samples of the re-refined oil against the same quality criteria as the virgin oils before it is cleared for delivery back to BR.

Recommendations

We recommend that Sudan should consider the conservation and recovery of oils for re-use seriously.

2.2.7 Study of How Basic Diesel Engines Are Developed for Different Applications:

Presented by:-

- Abd Al Rahman Al-Siddig Salih – Hassan Mutwakil Hassan

(2013-2014)

Abstract:

This project analyzed and displayed in three chapters, the efforts made by five famous diesel engine designers and manufacturers to develop their engines for rail cars, main line diesel electric locomotives and marine propulsion.

In a fourth chapter the experience of SRC, as a user, their feedback to a manufacturer (END-GM) to inform on faults and defects on their locomotives to be rectified, have been detailed.

In chapter six the findings and results of all efforts detailed in the four chapters mentioned above have been summarized and conclusions reached to have been documented.

A recommendation has been drawn for engineers, who work in different fields of application of the diesel engine as prime mover, which may encourage them to study and analyse the developments in fields other than their fields of specialization.

This may lead to transfer of operational and technological knowhow which may help by adoption of means of reduction of SFC, CO_2 emissions;

Improve overhaul periodicity, reliability, durability, etc.

NB:

- Sudan Railways Corporation (SRC).
- Electro-Motive Division-General Motors (EMD-GM)-USA.

From the findings of the project:

Derating

Derating for example, is not adopted in railway application, but it worth trying since fuel consumption costs are over 40% of the operational costs.

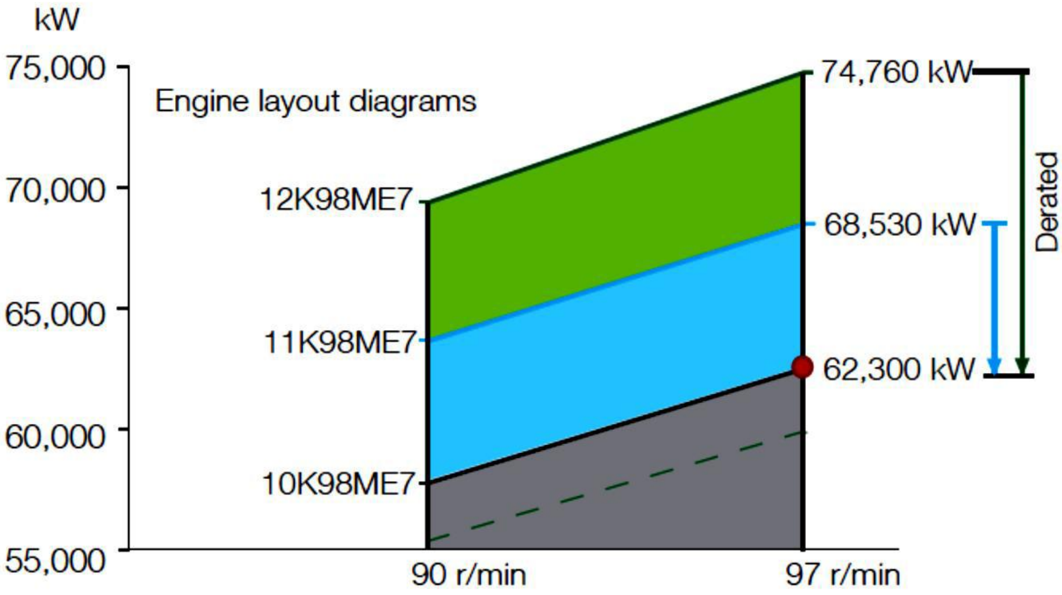
Derating is a traditional method of reducing fuel oil consumption, i.e.

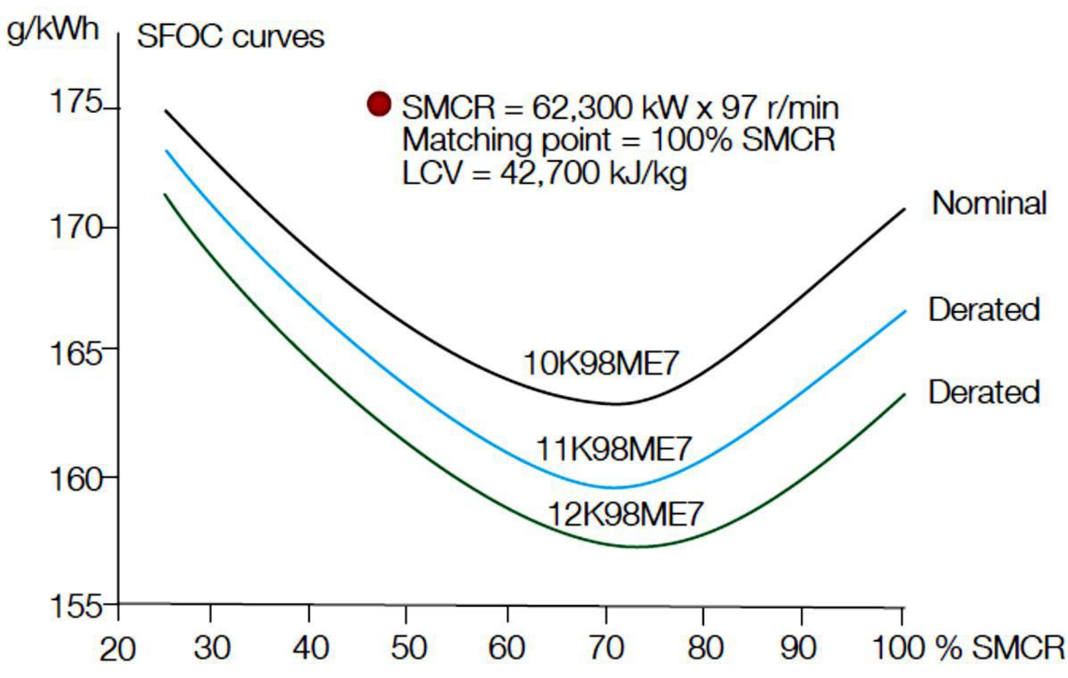
Choosing specified MCR point lower than the nominal MCR point along the vertical constant engine speed line in the layout diagram. See fig (6-4).270Previously, this layout philosophy was widely used, and most engines were derated. The advantage is that SFOC is significantly reduced, the disadvantage is that the engine generates less propulsion power.

Derating is possible for ME/ME-C as well as for MC/MC-C engines

For example, if the power of a 10K98ME engine is required, but a derated version of a 1198ME engine is chosen instead, SFOC is reduced as shown in Fig. 4-15. The extra cylinder obviously represents an extra expense, but with the current fuel oil prices, the expense is paid back in 3-4 years. Similarly, if a 12K98ME engine is chosen, the SFOC reduction is twice as big, as is the initial extra expense, however, the pay-back period remains 3-4 years.

Making such a choice also means that if fuel oil prices should go down in the future, calling for increased ship speeds again, the engine can be upgraded to the original full L1 power. Changing the rating of an engine in service may not be so simple, but if the possibility of changing the rating in the future is considered in the project phase, it may be relatively simple. The choice of turbochargers and air coolers should be considered.





SFOC reduction by derating a K98ME7 engine

2.2.8 Rolling Stock Different Design (Their effect on performance)

- Omer Mohammed Omer Eltinay – Amr Elnijomi Alattaya – Ahmed Hassan Al mubark

(September 2015)

Abstract:

The general objectives of this project are to trace and study the research and development (R&D) work done by the designers/manufacturers to develop particular railway industry products to solve problems encountered in service, reported by the users, to enhance the specifications of the products to upgrade their maintainability & overhaul periodicity, reliability, performance and safety.

Also SRC efforts to redesign and upgrade products of inferior designs to achieve the same targets of designers/manufacturers and to raise the transportation capacities of their trains.

The specific objective of the project is to highlight revise and prove by presentation of calculations, designs, comparisons, ….etc. that the efforts done by the designers and SRC were a **MUST** and they fulfilled their goals.

The developments and redesigns done to answer the requirements of railways are in.

- The evolution of freight wagon bogies design.
- Adoption of the air brakes.
- Adoption of the axle box journal rolling bearings.

- Adoption of the automatic couplers.

Each of the four evolution and adoptions have lead immediately to:

- Better maintainability and long intervals between overhauls.
- Better reliability.
- Better performance (better availability).
- Better safety (stability & derailments).
- Multiple transportation capacity.

From the findings of the project

The gain from conversion to air brake:

To show how the conversion to air brakes has raised the capacity of transportation of SRC trains we calculated an actual example here under.

The economic gain of air brakes as against vacuum brakes is illustrated by the following example:

SRC block trains for the transportation of cement from Atbara Cement Factory to Khartoum North railway station, a distance of 300 km. The train shall have three stops, each after 75 km (of course the route is single line). The three turnouts to be used by the block trains are suitable for train lengths of app. 400 meters. The terrain includes extended down-hill sections. The annual transportation capacity is approximately 840,000 t with round-the-clock operation on 350 days per year. Six trains consisting of 294-axle goods wagons each and equipped with vacuum brakes are in continuous operation.

The question to be asked is by how much the annual transportation capacity can be increased, if air brakes are used instead?

Table (2/1) SRC annual transportation of cement from Atbara Cement Factory to Khartoum North railway station

Parameter	**Vacuum brake**	**Air brake**
Train length	appr. 500 m	appr. 500 m
Number of wagons per train	29	29
Axle load	16.5 t	16.5 t
Gross weight of one train	1523 t	1523 t
Transportation capacity of one train	1000 t	1000 t
Maximum speed	60 km/h	60 km/h
Average speed	30 km/h	50 km/h
Headway time	5 h	3 h
Total turn-round time of train	60 h	36 h
Turn-round frequency of one train per year	140	233
Transportation capacity of one train per year	140.000 t	233.000 t
Total annual transportation capacity of 174 wagons	**840.000 t**	**1.388.000 t**

The headway time is determined by the distance between the individual turn-outs and the speeds practicable on these sections. Due to the higher average speed achieved with air brakes particularly on downhill sections, the headway time and therefore turn-round times of the trains can be reduced considerably in comparison with vacuum braked trains. The turn-round frequency is therefore considerably higher.

As can be seen from the calculations, the transportation capacity in the model case used can be increased by app. 66% after changing to air brakes and using the same number of vehicles, solely became the shorter turn-round time.

As mentioned above, the use of air brakes allows considerably longer trains. If the length of the turn-outs is increased, for instance for train lengths of 1000 m, an increase in the rolling stock by a factor pf about 2.5 could boost the transportation capacity by a factor of even better than 4. The last presentation on the conversion to air brake subject is the redesign of vacuum brake rigging to suit the newly introduced air brake which may be of slightly less leverage ratio .There are two parts of brake rigging; the center brake rigging & the axle brake rigging .When converting from vacuum brake to air brake, the center brake rigging level (c) is calculated & changed .The axle brake rigging is kept.

2.2.9 SRC Motive Power, Rolling stock & Track (Design, Specifications, Construction & Safty)

-Mohammed Abdalbaje M.Abbas – Taha Omer Fath Alrahman Mahmoud – Abdalhalim Ismael Babiker Mohammed

(September 2015)

Abstract:

The general objectives of this project is a comprehensive package of study & analysis of the main components of SRC business in order to draw conclusions & recommendations on deviations from specifications in motive power, development in rolling stock bogie design & the interaction between wheel/rail to analyze the stability and safety of trains on the track, this has been covered in chapter two & three.

The specific objective of this project shall be a preliminary technical feasibility study for some of the existing main line routes of SRC to be upgraded to a higher speed of 120 km/hr & a higher axel load of 20tones which is a redesigning work involving train track dynamics studies. This has been done as a research work which showed that the NARROW GAUGE of SRC track with upgrading can served Sudan freight transportation for more than hundred years.

This has been presented in the Research Work (Chapter four) with calculation supported by references.

Chapter five of the conclusions and recommendations recommends practical testing for the fuel consumptions to be conducted SRC to show that diesel engine in traction application have to be of medium speed.

The results of these test shall be very useful to SRC.

From the Findings of The Project

Up-grading the same lines to 20 tones axle load

Introduction

This is a process of strengthening every component of the track. It involves introduction of new materials if the existing ones strength is not suitable, the addition of ballast to the appropriate depth, the treatment of the subsoil & the formation, strengthening of bridges, choice of the right materials, the drainage systems, much consideration for the maintenance works (manual, semi – mechanised or mechanised) etc. see fig.(4.5a) for the pressure distribution of the wheel force on the track components.

The target should not be engineering excellancy but the achievement of the job which will do its specified duties with minimum execution cost. For types of tracks &their characteristics see tables (4.2) &(4.3). Here under are annexes which cover the construction, histories, European& American view points on sleepers & their uses & the railway bridges.

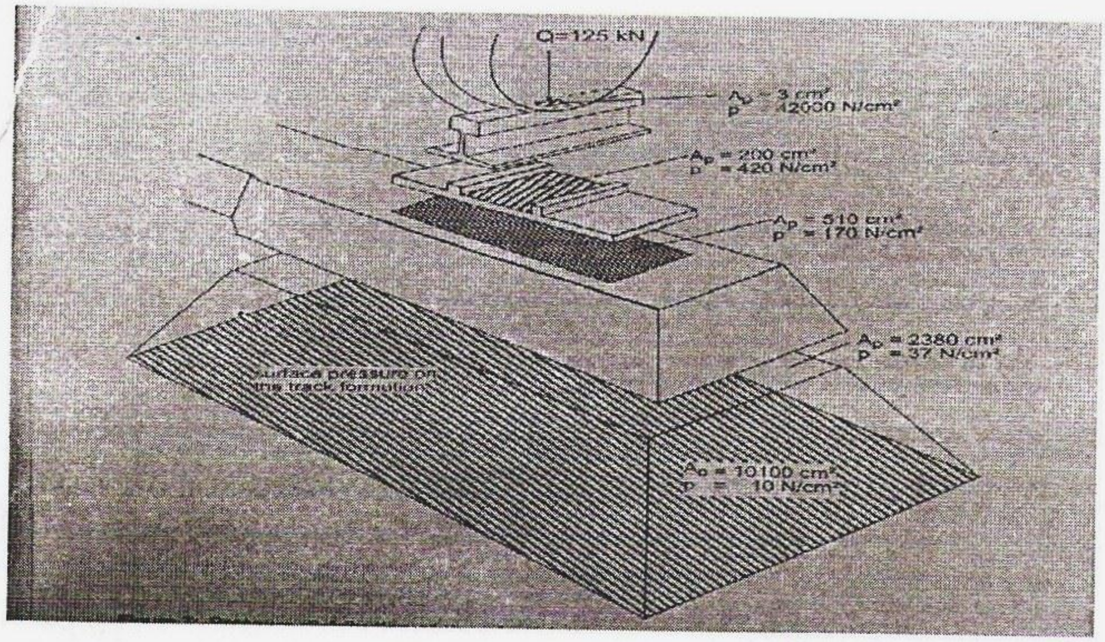


Fig (4.5a) pressure distribution of the wheel force Q

Annexe

Track structure

Historical Background Most of the mainline tracks in North America are now more than 100 years old and still remain on the original roadbed. It is important to consider the impact of initial construction and subsequent maintenance on the performance of current track structures.

Originally, the mainline tracks were constructed on a very compressed schedule using immediately adjacent soil sources, with the greatest emphasis placed on production rather than track quality. Furthermore, the initial construction was meant for trains that were much lighter and traveled much slower than today's vehicles.

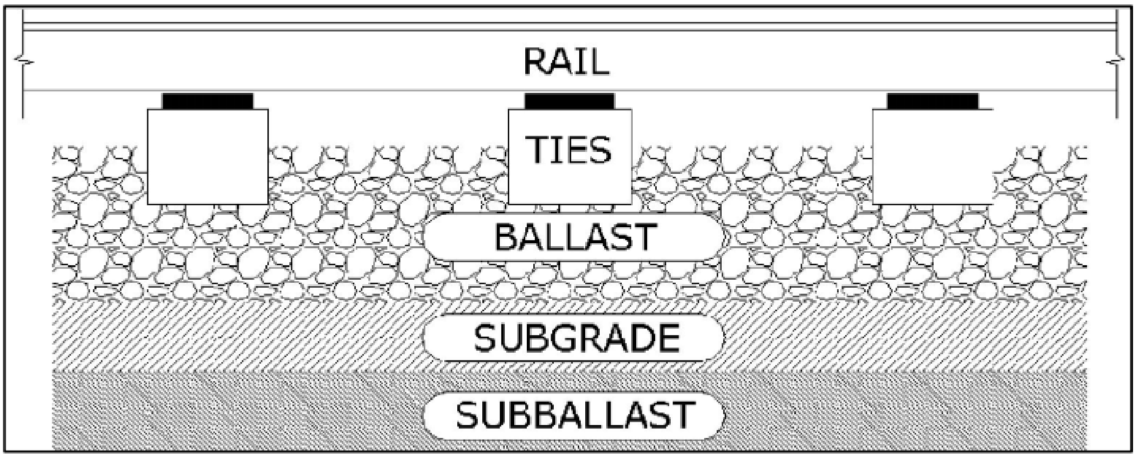
The historic construction methods used 150 years ago would not meet today's standards. For instance, it was common to lay a skeleton track (track structure laid immediately on top of the subgrade with the tie cribs and shoulders being devoid of ballast) directly on either the original ground surface or on a minimum amount of uncompacted fill. Ballast, then, was placed as required to sustain traffic. In the mountains and similar steep terrain, side hill cuts and fills were common, with a portion of the subgrade supported on rock foundations and the remainder on loosely placed fill.

Soft track, groundwater discharge, bearing capacity issues, slope failures and sinkholes are all commonplace problems. Remediation of these problems
must address not only what is apparent in the track structure today, but also the legacy of construction and maintenance over the past 100 years. For instance, it is not unusual for track that functioned very well for more than 50 years to suddenly develop severe geotechnical problems.

In solving problems today, the experiences and effects of the last 100 to 150 years ofrailway practice must be considered. Not only are the railways dealing with ever-increasing loads and ever-increasing traffic, but also a maintenance effort focused on rails and ties. Ballast, being less visible, receives less attention, and the subgrade, less still except when problems develop.

Nonetheless, knowing the history of a section of track is an important component of effective track maintenance.

Components and Functions



The Track Structure

The track structure is made up of subgrade, sub-ballast, ballast, ties and rail as illustrated in Fig. (4.5) each of these contributes to the primary function of the track structure, which is to conduct the applied loads from train traffic across the subgrade safely. The magnitudes of typical stresses under a 50,000 lb axle load are shown in Fig. (4.6) these stresses are applied repeatedly, and each repetition causes a small amount of deformation in the subgrade. In theory, the track structure should be designed and constructed to limit rail deflections to values which do not produce excessive rail wear or rates of rail failure. In reality, cumulative deformation of the subgrade causes distortion of the subgrade, leading to formation of .ballast pockets" (Fig. (4.6)) or outright shear failure.

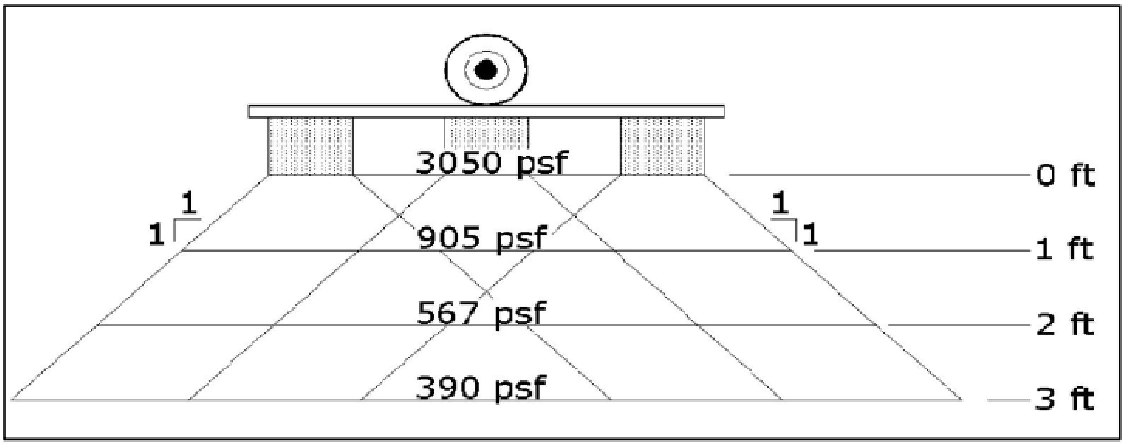


Fig. (4.6) Stresses Imposed by Train Axle Load

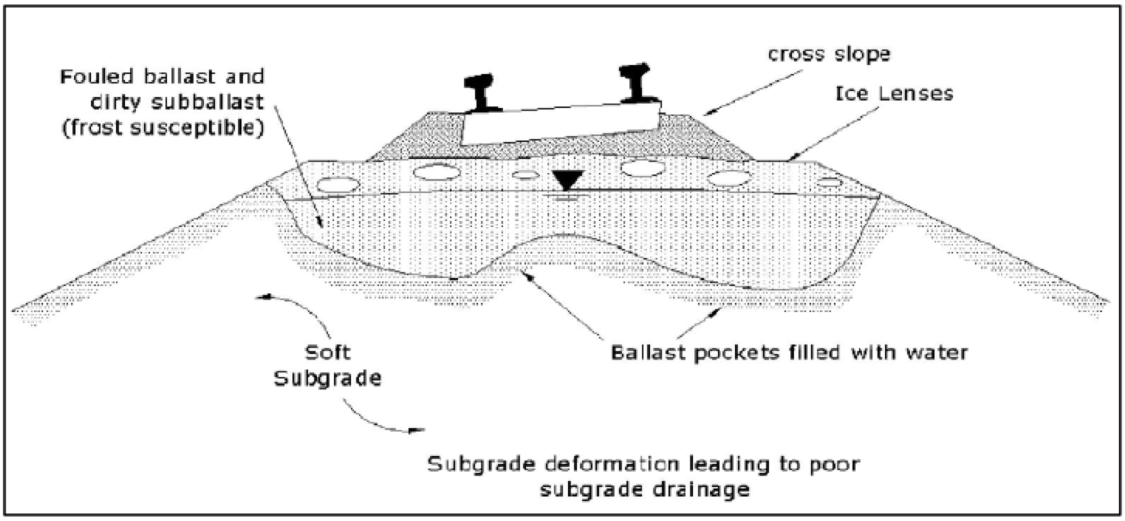


Fig. (4.7) Ballast Pockets in Subgrade

Subgrade

The purpose of the subgrade is to support the track structure with limiting deflections .Every subgrade will undergo some deflection (strain) as loads (stress) are applied. The total displacement experienced by the subgrade will be transmitted to other components in the track structure. The stiffer the subgrade (i.e., the higher the modulus of elasticity), the lower the deflection values will be. It is important that adequate subgrade strength and stiffness be available on a year-round basis, particularly during spring thaw and following heavy precipitation events.

The strength, stiffness and total deflection of the subgrade can be improved by:

Carefully selecting materials that are naturally strong (sand, gravel, boulders) with ahigh angle of internal friction.

- Limiting access to water to avoid buildup of porewater pressure and subsequent reduction of strength.

- Improving the soil properties, using techniques such as compaction, in situdensification, grouting and preloading.

- Maintain good drainage.

- Maintain stable subgrade geometry.

Sub-ballast

The purpose of sub-ballast is to form a transition zone between the ballast and subgrade to avoid migration of soil into the ballast, and to reduce the stresses applied to the subgrade. In theory, the gradation of the sub-ballast should form a filter zone that prevents migration of fine particles from the subgrade into the ballast. In practice, insufficient attention has been placed to subballast gradation historically, and much of the sub-ballast does not adequately perform that function. This notwithstanding, the number of occurrences of subgrade contamination of ballast are relatively few.

How Track Fails

In a nutshell, track fails when differential rail deflections become excessive.
This differential deflection may be expressed in differential elevation between tracks, punching of ties, elastic or plastic deformation of the subgrade, or degradation of ballast.

When the bearing capacity of the subgrade is exceeded, the subgrade will deform plastically, resulting in a small amount of permanent deformation under each wheelload. A progressive deterioration of the track begins, as illustrated in Fig.(4.8 &9). It starts with minor deflections and may progress to a fully visible surface heave, where subgrade material is pushed above the elevation of the rail and ties. Under those conditions, ballast drainage is impeded, resulting in further softening and degradation of the subgrade to a point where large, saturated pockets of ballast are trapped in the subgrade.

Frost heave and further degradation commonly follow, leading eventually to a severe loss of utility of the track structure

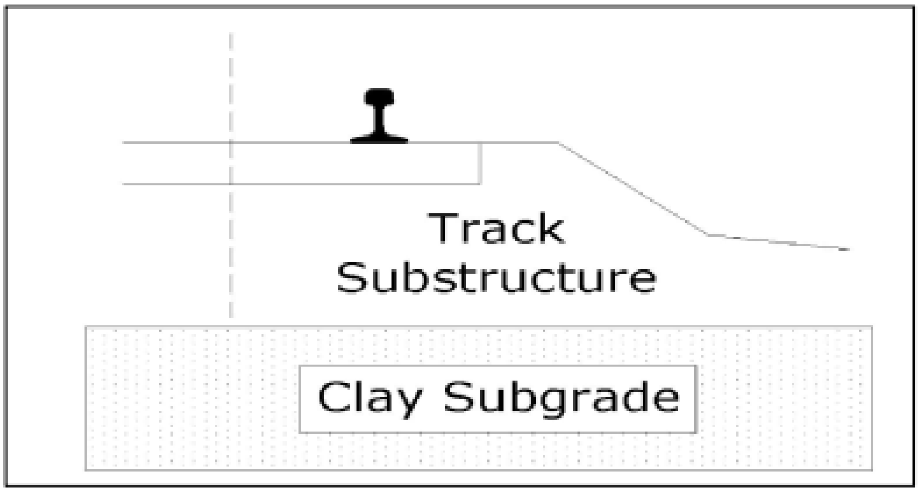


Fig. (4.8) Stable Site

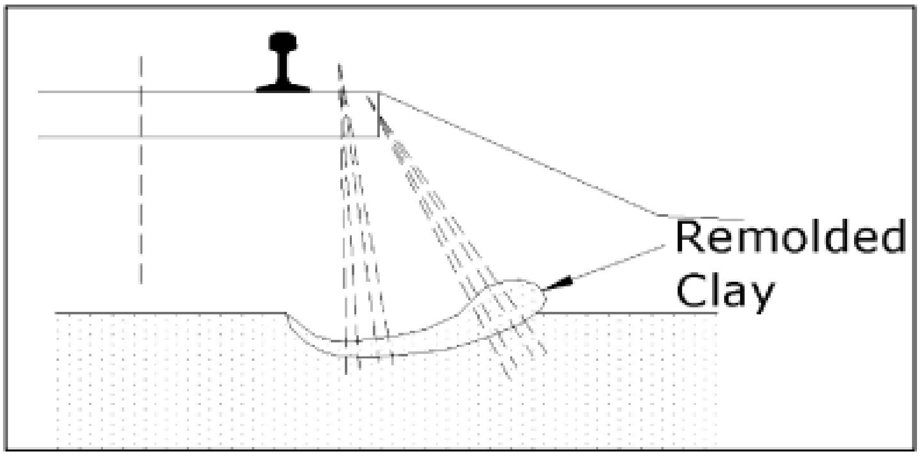


Fig. (4.9) Onset of Instability

Settlement Basic Theory Settlement results when the soil changes volume, when load is added because pore fluid is squeezed from the pores. The characteristics of settlement behavior include:

- Very little settlement occurs during initial placement of fill, since virtually novolume change takes place until the preconsolidation pressure is reached. Thus, the initial settlement is mostly elastic in nature.
- Beyond the preconsolidation pressure, settlement increases with the increasingload. This is called the zone of primary consolidation, which takes place until all ofthe excess porewater pressure in the soil is dissipated. This may take from severalminutes in the case of sand or

gravel, to tens of years in the case of lowpermeability clay. For this reason, sand and gravel are preferred, both asfoundations and as fill construction materials.

- Even after all porewater pressure is dissipated, settlement may go on in some soils.This is called secondary consolidation, and is particularly common in organic soilssuch as peat or organic floodplain deposits. This is the reason that settlement iscommon where these materials from either the fills or the foundation for fills.Secondary consolidation may go on for several decades or more.

While total settlement is important, it is the differential settlement that causes tracks to be rough and some parts of fills or structures to settle more than other parts. As a rule of thumb, differential settlement within a fill typically is about 50 percent of the total settlement. This is important because it is the differential settlement that causes the need for resurfacing.

Influence of Construction Methods Construction methods can have a dramatic effect on the total amount of settlement experienced. Settlement occurs both in the fill and in the foundation. Uncompactedfills can experience settlement equal to more than 10 percent of the fill height, while properly compacted and conditioned fills may experience no settlement. Further, moisture conditioning of the fill plays a very important role in controlling future settlement. For instance, any cohesionless fill compacted dry of optimum is likely to experience severe settlement upon first wetting. Settlement in excess of 10 percent of fill height has been recorded where fills were compacted dry and subsequently were saturated by runoff or ponding water. A combination of heavy watering and compaction using a vibratory roller produces the best results, reducing settlement to manageable values.

Influence of Soil Type Settlement can be experienced with all types of materials. Rapid settlement of foundations will be experienced in sand and gravel, while settlement of clay foundations may take several decades to complete. As indicated earlier, secondary consolidation of peat or organic soil foundations can go on for many decades, requiring ongoing maintenance.
The type of material used in the construction of fills also influences

settlement behavior. Sand and gravel are preferred, because once wet and compacted, they will produce a stable fill with low settlement characteristics. Silt is difficult to use as construction material, because it is extremely moisture sensitive and very difficult to compact. Clay must always be compacted, since if placed loose, long-term, chronic consolidation settlement can be expected. Highly organic soils should never be used for construction of fills for railway subgrades, because of their low bearing capacity and high resilience, and because of the characteristic long-term secondary consolidation that can be expected. In some cases, low level organic soils may be acceptable for use below the subgrade level.

Settlement is pure vertical movement, which may be due to expulsion of pore fluidfrom the soil. There is no shear movement associated with settlement. On the other hand, when the shear strength of foundation soils is exceeded, shear displacement commonly takes place in both horizontal and vertical directions.

While bearing capacity failures and other forms of slope instability may produce characteristic settlement profiles that require lifting, strictly speaking, this is not a settlement problem.

Settlement can usually be improved by improving soil characteristics by compaction or jet grouting in the case of coarse grained soils, or compaction or replacement of clay soils. Such treatment will normally not provide any relief if the shear strength of the foundation soils is being exceeded.

Summary In summary, the approach to natural hazard management includes:

1. Understand the contributing factors:

•Terrain components:

- Landforms

- Natural materials

- Groundwater regime

- Earthquakes

•Climatic influences:
- Precipitation
- Frost, thawing
- Runoff
- Erosion
•Vegetation influences:
- Vegetation impacts
- Vegetation management
- Deforestation
•Influence of humans on aspects such as:
- Drainage
- Development
- Maintenance
- Engineering
- Work on railway property by others

2. Understand the mechanisms:

•Principal of effective stress:
- Role of pore water pressure
- The difference in behavior between cohesive and cohesionless soils
•How the track structure works:
- Dependent on subgrade
- Principal of limiting stresses on subgrade
- Importance of ballast
- Importance of pore water pressure
•Landslides
•Bearing capacity
•Drainage
•Seepage
•Freezing and thawing
•Settlement

3. **Identify hazards:**

• By inspection
• Concentrate on high risk areas
• Concentrate on high risk periods for runoff and breakup:
• Extreme precipitation events

4. Describe hazards:

- Landforms
- Materials
- Groundwater conditions
- Geometry
- Mechanisms (type of hazard)
- Effects
- Actions required

5. Take appropriate action:

- Immediate action to mitigate hazard
- Urgent
- Priority
- Routine
- Request assistance
- Monitor

6. Provide documentation:

- Notes and diaries
- Photographs
- Records of observations

Chapter Three

The Methodology

Chapter Three

3.1 Introduction

The research in this project shall cover the study, analysis, upgrading & rationalization of the exiting SRC business facilities to the stage of producing two upgrading phases, superseding SRC present phase {phase (0)}. The purpose of this is to cater for the expected future freight transportation for more than a hundred year to come.

This necessitates establishing of a work frame avoiding repetition of work done before. Therefore all projects of similar objectives have been thoroughly revised.

Any railways business components specifications depend one on the other, e.g. the specifications depend track dictate the specifications of motive power and rolling stock & vice versa. Therefore thorough study of the related lecture & information on the railway business components are the foundation to build on the outcome of this project.

With points clarified above the methodology & the work frame shall be the specification of theories, formula & tools for upgrading & rationalization of the existing SRC railway. These shall be used for the study of :

1. The track
2. Signaling, telecommunications & operations.
3. Motive power & rolling stock, and shall be presented in the separate parts (1-3).

3.2 Theories, formulae & tools for upgrading & rationalization

The three parts shall include information & theories used in design, manufacture, construction, etc, of railway industry components to answer the users requirements.

3.2.1 Part One: The Track

3.2.1.1. Background

The track is the backbone of any railway business. It consists not only of individual components reviewed separately, but the “railway wheel-track” system as a whole.

Figure (3/1) gives an overview of the track structure. It shows that the entire system consists not only of ballast structures with supported on them, but also of track formation as of the subsoil itself.

The track forces must be compensated by compensating resistance which the track itself provides. The very high force of pressure in the wheel/rail contact point is gradually reduced in the individual system components through to the subsoil (figure 3/2).

3.2.1.2 Outline Design of railways [1]

Before dealing specifically with route selection we can with advantage look at some of the underlying reasons for wanting to build a new railway. These may be ready categorized and the following, are four of the most important:

A) The development of National resources such as the exploitation of mineral deposits or commercial development. This can take the form of a new railway or be a branch from an existing system.
B) The improvement of an existing railway. Many of the earlier railways were designed so as to minimize earthworks and were constructed following the natural contours of the country. This was done in the days when construction was labor intens.ve but in modern days, it is frequently necessary to straighten what was inevitably a curving railway and to improve gradients.
C) The opening up u new territory as pan of a National development plan.
D) The construction of a strategic railway; that is a railway which is being constructed either as part of National security or as an improvement in the internal communications within the transport infrastructure.

It is recognized that the building of a new railway is a major investment, and in economic terms, the investment is frequently difficult to justify. Apart from the actual costs of construction, there are many other costs that have to be carried and unlike highways, which can be started and added to, railways have to be completed in a unit before they are fully effective.

This involves the provision of non-productive costs such as signaling and administration, necessary simply to keep the system going. These costs are a fixed charge to the system and do not necessarily relate either to the size o the new construction or to the amount of traffic carried.

Many new railways are justified in terms of social cost benefits, and whilst these are often meaningful in countries with a highly developed transport infrastructure, they are not so in less well developed countries where long distances are normal, and the provision of a railway is not beneficial, say, in terms of taking traffic off adjacent road systems.

While it is not the intention to pursue this line of further than these brief comments, there is one aspect that is truly relevant and does constitute an important factor for n4aga design. This is a matter of costs.

As stated earlier, the cost of building a railway is unavoidably high, and so the availability of finance is in factor in determining the standard of railway to be built. You may well say, as practical railway men, we would not embark on a project we could not afford. Unhappily this is not always true and certainly one of the contributory factors in embarking on expensive railway projects is the attraction arising from the rapid advance of railway technology. There has been. A tendency for some countries to be rather less than circumspect than they should have been in selecting those technologies which they really need, and which they can really afford .

This aptly brings us to the point where a new railway is being considered and the first questions to be answered are why the railway is required? What do you want it to achieve? I would refer you back to the four simple categories that were suggested at the start.

In the case of the new mineral railway, the operating pattern would have been determined by the quantities and type of material to be carried.

This would have been translated into a “train plan” and the design engineers will, as a result, have very useful data available.

i) Axle loading which will enable the track and formation to be designed

ii) The line capacity and an indication as to whether double track or single track with passing loops are required, together with any major siding requirement.

iii) The size of the trains, together with a general specification of the locomotive and wagons that are envisaged to work the new railway. From this the ruling gradient can be calculated.

iv) The type of signaling and telecommunication systems required.

All their features will affect the costs and at quite an early stage you will be looking for broad costing to be available to be measured against the expected commercial returns.

In many ways, similar criteria can be applied to the improved railway, with the important exception, that some factors have already been pre-determined by the characteristics of the existing railway. It can be a matter of policy of course as to whether the construction shall be to a comparable or higher standard than the existing railway. Certain factors could be a constraint especially if the overall standards of operation cannot be improved. There is however, always a saving in track maintenance to offset again any costs of improvements. The main consideration here may well be the possibility of local realignment which may be short or up to many kilometers a length, to cut out slow and difficult parts of the existing railway. The improved railway may need to cope with a new mix of passenger and freight trains, with different speed requirements. Strategically placed passing loops may be required. The aim would be to increase the efficiency of operation of the railway at reasonable costs.

"Development" and "strategic" Railways are governed by different criteria. In the first case, the commercial success of the railway cannot accurately be determined and so cost effectiveness is of prime importance in the second case the requirements are predetermined and the Government concerned can put a price against it based on the standards of construction required.

The only factor that we have not mentioned is the High Speed Railway". By this we would mean when its alignment is designed to accommodate speeds of 200/250 km/hr over long distances. This is a highly specialized requirement and falls within totally different parameters of improved track characteristics, sophisticated operations and very high costs. This is not the function of a development railway. It would be possible however, under certain circumstances to combine the needs of both.

These factors are all to be considered within the basic concept, a railway is being constructed limits:

a) Within the limit of finance available
b) To meet the technical and safety requirements
c) To requirements that the recipient authority needs and not what external agencies might suggest they need.

3.2.1.3 The Track Structure

3.2.1.3.1 The subsoil:

If the tearing capacity is insufficient, the alternations of load caused by the vehicle wheel sets will lead in the course of time, to plastic deformation of the subsoil. Non-cohesive as well as obsessive soil is compacted due to the rearrangement of gains. In addition, the volume of the c6heive soil is reduced, as the pore water is pressed out of it, which leads to an enlargement of hollows in the ballast bed and the soil formation.

Types of soils and their parameters

Soil types may be roughly divided as follows:

- **Coarse- grained soil:**

Particles can be distinguished with the naked eye:

- Boulders larger than 300 mm,
- Round or square cobbles 75-300 mm,
- gravel<75 mm and>5mm,and
- sand<5 mm and >0.06 mm

Coarse-grained soils are distinguished by density, grain size distribution (grading curve) and grain form. Sand and gravel, in dry conditions form heaps of large grains lying loosely next to each other. Hence they are called non-cohesive 01 loose, as opposed to silt and clay. The share of fine grains in coarse-grained soil IS less than 5%. Fine grains are grains smaller than 0.063 mm. Soils with mixed grain size are soils with a share of fine grains between 5 and 40%.

- **Fine-grained soil:**

Silt and day belong to the category of fine-grained soils. Fine-grained soils are described by their plasticity, structure, colour and smell. Plasticity is determined by the content of clay. The share of fine grains with a grain diameter below 0.063 mm in fine-grained soils IS over 40%.

- **Organic soils:**

Organic soils are e.g., bog and peat. The organic components of the soil may be of animal or vegetable origin. As they burn at high temperatures, they are characterized by the loss due to burning $V_{d'}$ which is the percentage loss in weight. Soil analyses determine characteristic soil parameters, parameters of carrying capacity, sensitivity to settlement and frost.

- **Defects of the soil formation:**

Traffic loads and atmospheric influences (precipitation, erosion and wind) on various types of soils lead to various levels of excessive stress, thus causing deformation and damage to the soil formation. Irregular settlement under the sleepers occurs. The following defects can be observed:

  - in uniform soils, such as uniform sand, the sand , as a consequence of soil vibration, creeps through the ballast bed up to the sleeper surface,
  - in non-cohesive and slightly cohesive soils the soil formation and the subsoil are loosened by dynamic load, which can lead to the formation of cracks and crack zones,
  - in silty soils in wet weather the soil formation quickly

becomes undulated and muddy soil is pumped up to the ballast surface under the influence of load alternation, i.e., wet spots occur and the ballast sinks into the ground below the sleepers (ballast pockets). During rainy weather the track position becomes poor immediately and recovers stability relatively quickly when the weather is dry,

- In highly cohesive soils which are compacted under the influence of load alternation hollows are formed under the sleepers and the soil arches between the sleepers and towards the cess. During rainy weather mud is also pumped up to the ballast surface in the area of sleepers. These soil deformations take place very slowly in rainy as well as in dry weather.
- In cohesive (silty, clayey) soils frost heaves occur in winter and thawing damage with loosened zones particularly at the edge of the track formation in spring, and
- In uniform-grain sand damage can occur due to wind erosion, and in highly- cohesive soils shrinkage cracks in the dry season and swelling movements during rainy weather, particularly in hot climate areas.

This damage to the soil formation occurs only after a longer lifetime, if the traffic load is low, but at high traffic load may occur even after a short lifetime.

Reasons for damage to the soil formation

The reasons for damage to the soil formation are:

- Poor subsoil, i.e., subsoil consisting of inadequate types of soils.
- High static and dynamic load on the subsoil,

- Insufficient compaction of the soil formation and other loss in volume of the subsoil,
- Insufficient drainage of the soil formation or the subsoil during rainy weather, flooded track, p high groundwater level,
- Mud cracks in the soil are filled with precipitation water, the water is stored,
- Use of rails the bearing capacity of which is insufficient for the prevailing operational conditions,
- The sleeper spacing is too wide and sleepers with too small a support surface and .too high a weight are used, and
- Defective condition or construction of structure.

Soil drainage

Water is never desirable in earthworks. Its negative influence has to be eliminated by ‘drainage measures. It is important that water can flow away without hindrance. The service life of earth structures depends to a high degree on the quality of the drainage facilities.

If there is much water, the water content of the soil below the soil formation is increased and, in connection with soil vibrations, the shear strength of the soil is reduced. Silty soils begin to flow even after minor water absorption. This creeping “is supported by local soil fracture occurring under load as a consequence of too large a difference between vertical and horizontal tensions. Shearing deformations occur in sliding areas of highly cohesive soils. Within a limited surface range the water content of the soil becomes so high, due to subsequent compaction because of load alternations and due to additional water absorption, that it finally exceeds its liquid limit. The high interstitial pressure which exists when cohesive soils are filly saturated by water prevents an increase of the frictional resistance, i.e., the shear strength at load, which favours deformation of the soil formation.

a) Water in the soil:

The following forms of water in the soil can be distinguished.

- Surface water from rainfall,
- percolating water: that portion of surface water which seeps into the ground and moves downwards according to the law of gravity to fill the cavities in the ground,
- groundwater: is banked-up percolating water. When the perc1ating water reaches an impermeable soil layer, it fills the soil pores above this layer entirely,
- capillary water which is drawn up into the cavities above the groundwater level, even against the law of gravity, due to the surface tensions of the soil bodies (capillary effect), and
- Contact moisture: water adhering to grains, such as adsorption water which moistens the surface of the grains, but does not cover them.

b) The influence of water on the soil:

The finer the soil particles, the more water they are able to absorb. The surface of particles and consequently also the surface tension rapidly increases, when particles get smaller. This is why fine-grained soils bind not only capi1lary water, but also great amounts of contact moisture and adsorption water. Once fine-grained soils have absorbed water, it is practically impossible to set this water free by structural measures.

Pressure procedures (such as trains passing) increase the interstitial pressure, which may lead to a sudden loss in bearing capacity (a similar effect is well known to everybody who stands on the shoreline at the edge of the sea where waves are coming and going due to the tidal effect - here you can literally feel the loss in bearing capacity under your feet). In fine-grained subsoil the surface water, soaks the ground. The ballasted then shows deformations under operational load. These deformations frequently lead to the formation of very deep ballast pockets.

3.2.1.3.2 The Formation [2]

1. Introduction

A stable formation is necessary to:

- Enable passenger trains to run safely at design speeds
- Support the heavy axle loads imposed by freight trains
- Minimize future track maintenance costs This can only be acheved by:
- limiting settlement of the original ground (sub-grade) and consolidation within the embankment filling
- providing an arrangement that will be stable under the imposed railway loadings and the weight of the earthworks
- ensuring that the condition of the formation does not deteriorate during its working life

Consequently when designing and constructing formation works, the nature of the ground crossed by the railway, the provision of drainage, the choice of embankment material, and the protection of the earthworks directly beneath the track ballast may need special attention. The techniques that can be applied to ensure a stable formation, particular where unfa1ourabIe site conditions exist, are described below.

2. Preliminary Design Considerations

Before any decisions can be made it is essential to obtain sufficient information about the site.

Geological, topographic, climatic, seismatic and environmental data are required before design work can proceed. Initially such details may be gathered from site reconnaissance, old maps, mining records, previous site investigations and published material, to the extent that alternative railway alignments can be identified.

However, since soils are very variable a detailed site investigation and soil testing programme should be carried out by specialised personnel capable of appraising the ability of the soils to support the proposed loadings and interpreting the test results. Such an investigation will indicate:

- whether material for embankment construction is available on site or fill is to be imported
- where weak ground requires treatment before filling can commence
- where ground water levels may cause problems
- the measures necessary to ensure the stability of earthworks

slopes

- where cuttings require particular drainage or protective measures
- the appropriate type of plant to be used for cut and fill operations

The data acquired should also be comprehensive enough to provide all the parameters necessary to carry out such analyses as slope stability, bearing capacity of the sub-grade, permeability calculations, etc.

3. Cuttings

Where cuttings are to be excavated, information concerning soil type ground water levels and the existing surface water drainage is important, since the most common modes of failure arise from slips in the side slopes and bearing failure of the formation beneath the track.

i. Slope Stability

Cutting formations can become unserviceable as a result of circular slips in the cutting slopes extending under and displacing the track. This may arise due to inherent instability within the soil through which railway is cut, by the ingress of surface water weakening a previously stable soil, by removal of material from the toe of a slope or by the application of surcharge loads at the top of the slope.

It is therefore prudent to carry out slope stability analyses for all cuttings, but particularly those over 4m deep to determine stable angles for the earth slopes. It is also necessary to avoid a build-up of water pressures or the softening of potential slip planes by providing intercepting drains above the slopes to direct surface water away to the main drainage system.

Open channels should be lined, particularly in clay excavations to avoid seepage into shrinkage cracks.

When cuttings are in clay, caution is required with design since slopes which may have been stable for years have been known to tail. Consequently, safety can only be assured at some sites by assuming slips are inevitable and designing the geometry of the cut to allow the slope to move without affecting rail traffic.

Stability can, in less severe cases, be improved by reducing pore-water pressures in the soil by installing counterfort or other deep drainage. Alternatively, stability may be obtained by applying weight at the toe of the cutting slopes; that is, by the provision of a berm.

Similarly, during construction or maintenance operations, work should be organised to avoid stacking materials or spoil at the top of the slopes and uncontrolled excavation at the toes.

ii. Bearing Failure

The formation supports the loads from the track after they have been distributed through the rails, sleepers and ballast. It should do this without deforming, without fouling the ballast and without being affected by frost heave.

Formations can become unserviceable as a result of bearing failure in the sub-grade. This can arise because in its natural state the sub-grade is incapable of supporting the distributed loads or a naturally strong sub grade becomes weakened by an increase in moisture content.

In both these circumstances it is necessary to further spread the load to avoid over-stressing the soil. This is done by providing a suitable depth of granular material beneath the ballast.

Where cohesive or silty sub-grade exists, a waterproof membrane should also be installed, laid falling to cess drains. Such a membrane will shed rainwater which percolates through the ballast into the lineside drainage system and hence avoid softening of the formation. It 'may consist of polythene sheeting, bitumen spray or cement stabilised materials.

A typical cross-section for a cutting incorporating this sort of arrangement, known as a track blanket, is illustrated in Fig.1 . Track blanketing has the effect of both increasing the load bearing capacity of the formation and minimising future track maintenance costs.

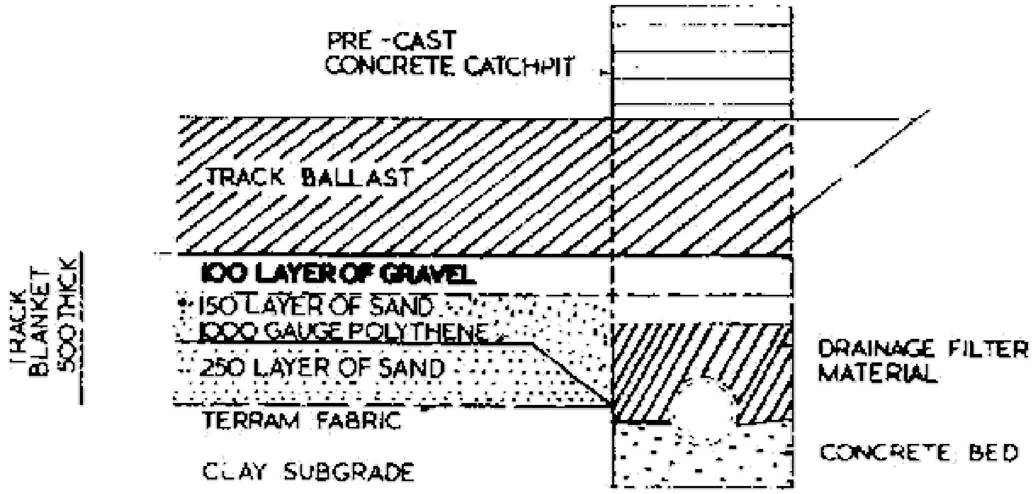


Fig. (3/1) Typical cross-section of track blanket

iii. Drainage

The importance of effective drainage in cuttings or indeed in any earthworks design cannot be over-emphasised. Where the water table is high or on impermeable ground, sub-surface drains are required to draw down the water levels if the formation is not to be weakened by softening.

Sub-surface drains should comprise porous or perforated pipes surrounded by filer material. They should be laid at the right level for the most effective drainage of the track (about 0.5m to 1.5m below cess level). Gradients to, the drains should be sufficient to ensure the water does not fill the pipes and to prevent silting up. A suitable gradient for such drains is 1 in 150 to 1 in 200. Gradients flatter than 1 in 500 are to be avoided.

Where long sections of drain are necessary, outlets should be provided at intervals to keep the drain from being laid at too great a depth (which would reduce its effectiveness as a track drain). If this is not possible, a deep carrier drain may be laid and intermediate outfalls can be provided outfalling to this.

Track drains should be at least 225mm diameter and catchpits should be built every 30 metres, to facilitate inspection and periodic cleaning.

Drains crossing beneath the track must be strong enough to resist the railway loadings and should also be deep enough to be unaffected by ballast cleaning operations.

iv. Cutting Construction

It is good practice to install any intercepting drains before starting cutting works. It is also prudent to lay lineside drains in all cuttings and in advance of completion of the formation, or track blanketting.

During construction, site traffic should be prohibited from running over any cutting formation as this can cause rutting which may re-appear in the railway formation when operational, allowing water to collect and weaken it.

Finally, cutting work should be carried out as early as the construction programme will permit, to allow any perched water in the side slopes or ground water at formation level to drain away and stabilise before final trimming is carried out.

4. Embankments

When designing and constructing railway embankments, it is necessary to ensure that both the original ground on which the fill is to be placed and the till itself are stable under traffic.

i. Original Ground

The original ground should not only have the strength to support all traffic loads, the weight of the track, the maximum anticipated depth of ballast but also the weight of the embankment. Furthermore, the amount and rate of settlement under these loads should be limited so that when trains run they can do so at the design speeds without the need for emergency or unplanned speed restrictions. It should be noted that mining subsidence can create unacceptable settlement and stability conditions in earthworks. Consequently, future planned workings should be known when designing new railway alignments and avoided if possible.

- **Settlement Considerations**

Returning now to ground settlements, for the construction of a 200 km.p.h. line recently completed in the United Kingdom it was decided that settlement should not exceed 75mm during the first year of renewing trains and that the rate of settlement should not exceed 25mm in any 4 week period. These criteria were set to ensure safe track tolerances for this high speed and to limit the amount of track maintenance.

Where ground is of suspect quality, calculations based on the parameters established from the soil tests referred to earlier should be used to predict settlements against time.

These will indicate whether it is possible to achieve acceptable settlements within the chosen Construction Programme. They will also indicate whether it is necessary to specify that certain embankment sections are to be built early in a Contract to achieve acceptable results.

If acceptable settlements are still not achievable the following special techniques are available:

- Pre-loading the ground
- Provision of vertical drainage
- Surcharging the embankment
- Flattening embankment slopes
- Use of lightweight fill
- Removal of weak ground
- Vibroflotation
- Dynamic Consolidation
- Bridging over bad ground
- Piled support to the earthworks

Where the Site and fill material are available an embankment can be built under a preliminary Contract months before the Main Contract is let for constructing a new railway. By pre loading the ground in this way, the time the embankment weight is in place can be extended as long as necessary to obtain acceptable residual settlements and rates of settlement.

In certain soils, (silts, silty clays, sandy clays, etc.) settlement can be accelerated during the construction period by the installation of vertical drainage. This can consist of sand filled boreholes or proprietor corrugated plastic wicks.

Shows the latter form of vertical drain being driven on the site of a new railway. The technique is most effective in situations where the horizontal permeability of a soil is inadequate to dissipate excess pore water pressures. The drains provide a shorter path for the water pressures down to any underlying permeable material or a drainage blanket of rock or granular material at the underside of an embankment Spacing of the drains is designed to suit the permeability of the soil and the rate of settlement required.

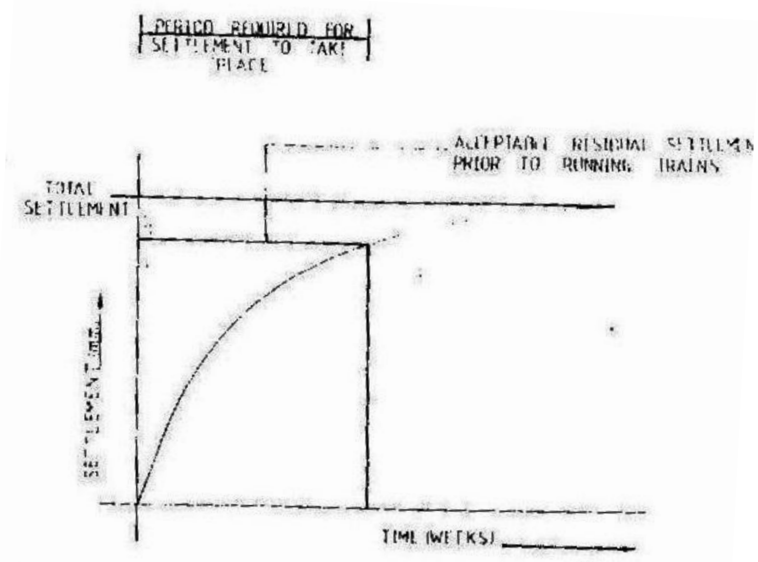


Fig. 2 Simplified time/settlement curve

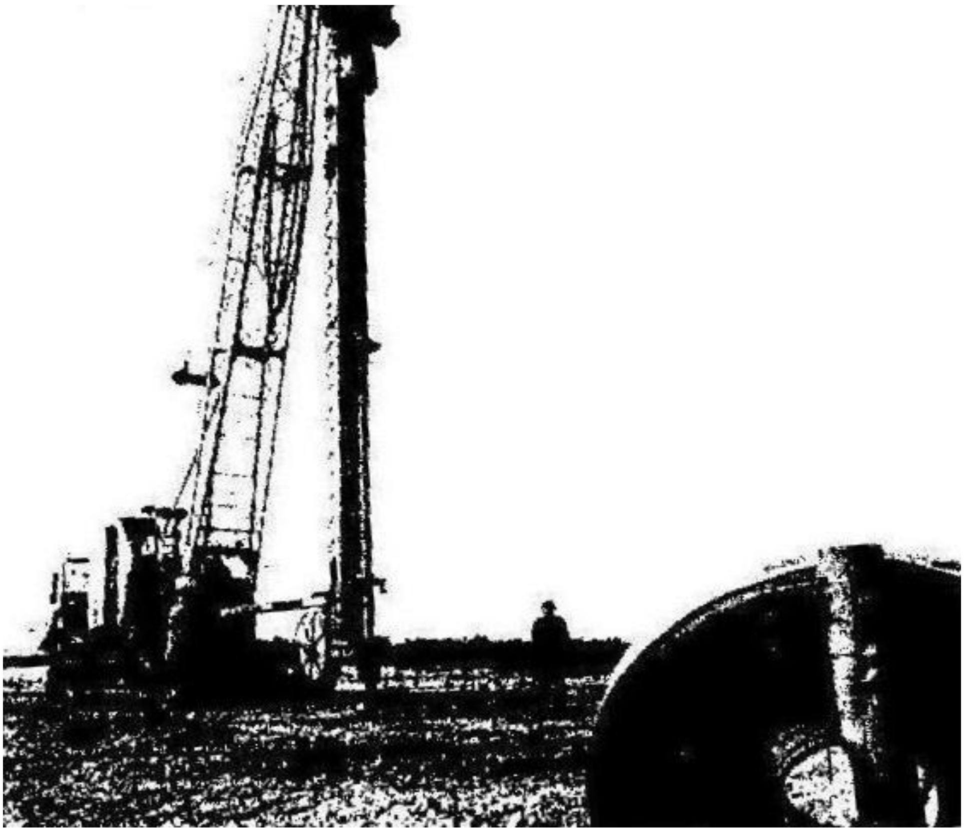


Fig (3/3) Vertical drainage installation

Surcharging is another method of accelerating, settlements, in this case, an embankment is built to a highest level than is required for the vertical alignment, to apply extra load to the ground and force the settlement to take place at a faster rate during the Contract. Settlement calculations are parried Determine the weight of surcharge to be placed on the earthworks to achieve the desired settlements. Clearly, stability and bearing calculations should be carried out to check that the extra height of fill does not induce failure of the earthworks, the extra filling s removed from site when acceptable conditions prevail.

At sites where ground conditions are not suitable for surcharging or vertical drainage, a settlement problem may be solved by reducing total settlement. This can be done by reducing the weight per unit area on the sub-grade. One method of reducing the imposed load is flattening embankment side slopes to increase the width of the base and spread the loads over a large area.

A more effective method used extensively in Britain, is to reduce the weight of the earthworks by building them from lightweight fill. Pulverised Fuel Ash (p.f.a) is readily available as a waste product from coal fired power stations. When compacted, it has a density of approximately 1700 kg. per cu.m. compared with 1900 kg. per cu.m. for sand fill and 2100 kg. per cu.m. for rockfill.

Unfortunately, although the total settlement is reduced by applying lighter loads, the time required for the settlement to take place is not necessarily less. Consequently, the above techniques can still be incapable of producing the required settlement criteria. Consideration must then be given to removing the weak ground, improving its properties r transferring the loads onto stronger material.

When the weak ground is shallow, overlies stronger material rind is localsied a positive solution which can sometimes be economic to excavate and remove the weak material from site, prior to building the embankment. Alternatively, the weak material may be displaced by tipping single sized (200mm) rock over the site and punching this into the weak material using compaction plant. Rock tipping and compaction continues until a stable surface is formed under the rollers.

If the weak materials are too deep for removal or displacement, vibroflotation or Dynamic Consolidation may be suitable for improving ground conditions over the base of the earthworks. Vibroflotation consists of forming gravel or crushed stone columns within the soft material to improve the bearing strength of the soil and requires specialist knowledge for its design or construction.

The method is effected by using a large poker vibrator suspended from a crane. It penetrates the ground under its own weight assisted by the vibration. When the required depth is reached the vibrator is withdrawn and a small quantity of coarse granular material is tipped into the hole and compacted by re-introducing the vibrator. The process is repeated until the gravel columns extend to ground level. The number and spacing of the columns are designed to suit the ground conditions and the loads to be supported. These piles can be sunk to depths of up to 12m.

Dynamic consolidation consists of dropping a large weight from 10 to 20m, using crawler cranes. The weights are of steel or concrete of up to 20 tonnes. The base area and weight of the blocks are chosen for the particular site conditions as are the height of drop and the spacing of impacts. This system develops ground compaction and consolidation, reducing air and water voids in the ground and improving its properties.

Where soils are particularly weak, extensive. the timescale for construction is short, and the settlement criteria stringent as for high speed railway embankments, more extreme methods may provide the only possible solution. For instance, at locations where there are considerable depths of peat or organic clays and silts, bridging over the soft material or supporting the embankment on piles can be economically viable.

Consideration may be given to carrying the railway on a viaduct over the bad ground, transferring the loads through pile foundations to stronger materials below.

Alternatively, where a low embankment is to be built over the soft material, bridging may be done by means of reinforced concrete slabs or beams below the fill, at ground level, again supported on piles. The embankment itself is then carried by the slabs and piles.

If the embankment is more than 3m high, however, the fill material can be designed to act as the slab structure, being made to arch between piles. Piles are driven to a grid of about 2m to 4m centres (depending on the height of fill) to a load bearing layer below ground. They are designed to carry the whole of the applied loads and are cut off at ground level where a reinforced concrete pile cap and load distributing blanket are provided. Fig. 4 shows an arrangement designed by Thorburn Associates for British Rail, used to support part of a new 200 km. p.h. railway. The piles wore 305 x 305 x 110 kg/m steel H-piles at 3m centres with 1.5m dia. circular reinforced pile caps and carried a 4.5 m high rockfill embankment.

This form of support can be used to particularly good effect where embankments on poor ground conic up against bridges on piled foundations. Being piled the bridge structure is rigid and will not settle whereas the adjacent embankment on poor ground will subside. Generally, this will result in an unacceptable vertical alignment in the railway at the bridge site. Bridge Approach Support Piles can he installed to ensure acceptable conditions exist under traffic. Immediately behind the bridge abutment, the piles are as illustrated in Fig. 4 supporting the earthworks on bedrock and inhibiting downward movement. Further away from the bridge, the pile spacings are increased and driven short of the bedrock (see Fig. 5). In this way the loading on the piles increases with distance from the abutment and the piles will also settle by an increasing amount. The pile loadings and spacings can he arranged to provide an acceptable vertical curve, after settlement has occurred.

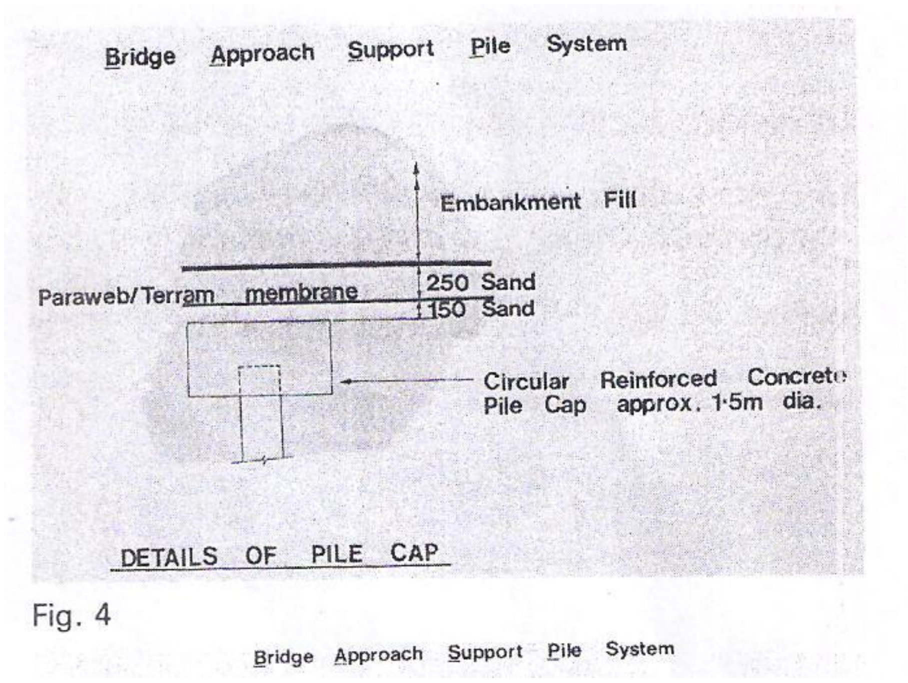


Fig (3/4)

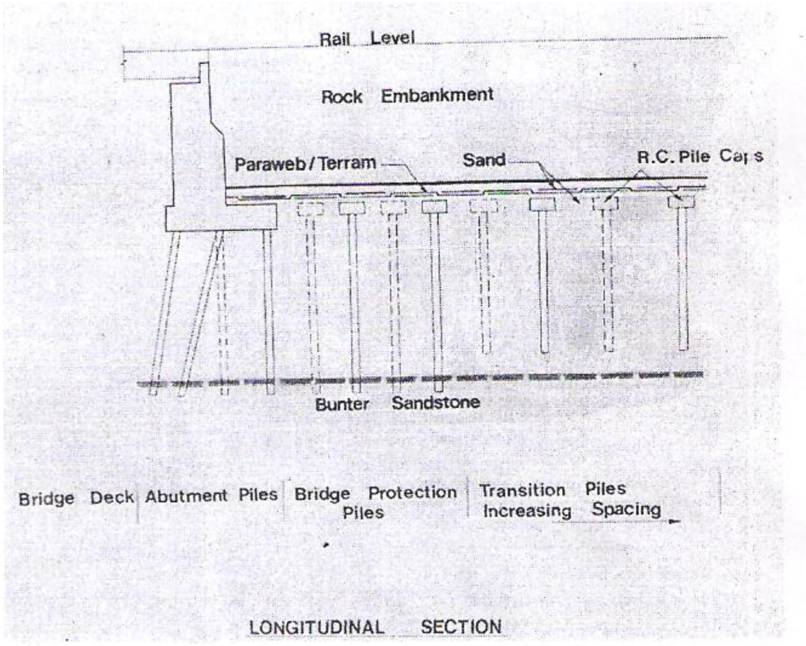


Fig. 5

Fig (3/5)

ii. Embankment Fill

Fill should be compactable so that settlement within the completed embankment material is minimal, the earthworks are stable and they retain their shape.

Such requirements can be satisfied by carefully selecting the material to be used, controlling construction and controlling the future condition of the material by the installation of drainage, etc.

The choice of material must take account of the strength of the ground and the overall stability of the embankment and underlying soils. Consequently, at the design stage bearing capacity and slope stability analyses with slip circles passing below the base should be carried out to determine the required cross- sections for the filling.

Where construction is on sloping ground, the earthworks should be designed to prevent them from sliding down the slope. Cut oft drains may be required on the uphill side of the embankments and stability checks should be carried out on the original slope taking into account the effect of the fill which acts as a superimposed load on the original slope.

If these stability calculations indicate unstable conditions, it is necessary to take weight from the top of the earthworks, add weight to the toe or improve the strength of the original ground. Lightweight fill can he used to reduce overturning forces, while the provision of a berm will increase the resisting forces. The strength of the original ground can be improved using those techniques described in Section 4.1 for improving settlement criteria.

Table (3/1):

Type of compaction plant	Category	Cohesive soil: Max. depth of compacted layer (mm)	Cohesive soil: Minimum No. of passes	Well-graded granular and dry cohesive soils: Max. depth of compacted layer (mm)	Well-graded granular and dry cohesive soils: Minimum No. of passes	Uniformly graded materials: Max. depth of compacted layer (mm)	Uniformly graded materials: Minimum No. of passes
Smooth wheeled roller	Mass per metre width of roll:-						
	More than 2100 kg. but not more than 2700 kg.	125	8	125	10	125	10*
	More than 2700 kg. but not more than 5400 kg.	125	6	125	8	125	8*
	More than 5400 kg.	150	4	150	8	Unsuitable	
Pneumatic-tyred roller	Mass per wheel:-						
	More than 1000 kg. but not more than 1500 kg	125	6	Unsuitable		150	10
	More than 1500 kg. but not more than 2000 kg	150	5	Unsuitable		Unsuitable	
	More than 2000 kg. but not more than 2500 kg.	175	4	125	12	Unsuitable	
	More than 2500 kg. but not more than 4000 kg	225	4	125	10	Unsuitable	
	More than 4000 kg. but not more than 6000 kg	300	4	125	10	Unsuitable	
	More than 6000 kg. but not more than 8000 kg	350	4	150	8	Unsuitable	
	More than 8000 kg. but not more than 12000 k .	400	4	150	8	Unsuitable	
	More than 12000 kg.	450	4	175	6	Unsuitable	
Vibrating roller	Mass per metre width of vibrating roll:						
	More than 270 kg. but not more than 450 kg.	Unsuitable		75	16	150	16
	More than 450 kg. but not more than 710 kg.	Unsuitable		75	12	150	12
	More than 710 kg. but not more than 1300 kg.	100	12	125	12	150	6
	More than 1300 kg. but not more than 1800 kg	125	8	150	8	200	10*
	More than 1800 kg. but not more than 2300 kg	150	4	150	4	225	12*
	More than 2300 kg. but not more than 2900 kg	175	4	175	4	250	10*
	More than 2900 kg. but not more than 3600 kg	200	4	200	4	275	8*
	More than 3600 kg. but not more than 4300 kg	225	4	225	4	300	8*
	More than 4300 kg. but not more than 5000 kg.	250	4	250	4	300	6*
	More than 5000 kg.	275	4	275	4	300	4*

*For items thus marked, rollers shall be towed by track laying tractors. Self propelled rollers shall not be used.

Embankment cross-sections should be designed to cater for loss of material from erosion by water, frost or wind and the fill should be chosen or protected to minimise these effects. Additionally, settlement of the earthworks should be assessed and the width of the embankment top increased to allow for future lifting of the track to maintain the vertical alignment and standard track cross-section.

For economic reasons, embankment fill is generally obtained from cutting excavation. Care in selection is required, however, since it must be compactable. Furthermore, it must be strong enough to support the railway loads particularly having in mind that it lies directly below the ballast where there can be concentrations of load

If high speed, heavily trafficked lines are to be built and run at design speeds immediately they are complete, well-graded rock fill or granular materials are essential. The rock should be strong and durable, having an aggregate crushing value of not more than 30% and a maximum aggregate size of 150mm. Normally, therefore, it is necessary to crush rock from cutting excavation and employ screening to provide a properly graded stone for this type of work.

Soils other than rock can be used for railways that are not subjected to heavy axle loads and high speeds. Sands and gravels in their natural state are generally acceptable but may require care to compact and may also require protection from erosion.

A mixture of sands and gravel with a clay binder provides a strong stable embankment. Silts and clays can often be compacted to provide a stable fill but they are susceptible to freezing and changes in water content leading to maintenance problems. Fine sands, top-soils and organic soils should be rejected as fill.

The overall cost of fill is very much governed by excavation, transportation, placing and compaction costs and the choice of fill, clearly where possible should be made to minimise these items. Sources of fill may therefore be from adjacent "borrow" areas or commercial Suppliers as well as from cuts. When old mining spoil tips are used as borrow pits tests should be carried out to check that the material is not liable to spontaneous combustion. The combustible content should be less than 8% as measured by a "loss of ignition test" and the air voids after compaction should be less than 6% to obviate this problem.

Where sites are susceptible to flooding, the embankments should not only be built to carry the railway above the highest recorded water levels but the choice of fit should allow the flood water to rise and fall without adversely affecting the properties of the material and without creating instability of the earthworks. A well graded crushed rock is ideal for these conditions.

iii. Embankment construction:

As for cuttings, drainage should be installed ahead of embankment construction to perpetuate surface water drainage systems to keep the embankment site as dry as possible. Normally, ditches or french drains parallel to the railway formation directing water away to main drainage watercourses are adequate for this purpose. It is reiterated, however, that care should be taken in the siting of ditches relative to the toes of the slopes to ensure the excavation does not withdraw support and cause instability in the earthworks.

Generally stripping of top-soil should be done and particularly where the surface organic material will create a weak zone; for example on sloping ground.

At certain places, sub still is weaker than the overlying top-soil. In this case top soil should be left in place. Any crops or vegetation should be cut and taken from site, a filter fabric such as “Terram” or “Fibretex” laid to spread the loads onto the sub-grade and prevent clay or silt fines from contaminating the embankment fill, and the ground rolled prior to placing the fill.

Again as for cutting works the movement of traffic over the site of the earthworks should be prohibited to avoid the creation of ruts that will hold water and weaken the sub-grade. A well graded rock-fill base at least 600mm thick should be placed over the base of an embankment if the site is to be used as a haul route or working area for plant installing vertical drainage, piles, etc. The fill should be placed in thin layers and be subjected to a number of passes of the compaction plant as shown in Fig. 6. Work should also be organised to avoid placing materials of widely divergent characteristics in embankments. Where this is unavoidable the different materials should be spread and compacted in separate clearly defined areas.

During construction of an embankment it may be necessary to Control the rate of filling so that there is time for the sub-grade to Consolidate and increase in strength to remain stable. As the embankment raises in level, so the pore water pressures increase and the shear strength in the ground reduces. Stability is most critical during construction and immediately after completion of the earthworks since, with time, the pore water pressures dissipate and stability improves It is therefore necessary to monitor the pore water pressures, settlement and lateral movement of the ground using various items of instrumentation The data from these instruments must be carefully studied as work progresses and calculations carried out to assess the factors of safety against failure. Such calculations can show that filling operations should be temporarily halted until conditions improve. Consequently it t is felt that this situation may arise in a Contract, the Specification should be written to inform the Contractor that pauses will be necessary at particular locations and define the maximum duration of these pauses.

5. Conclusion

Because of the variability of ground conditions, a very detailed site investigation should be carried out before any major railway earthworks are designed. Invariably this will indicate that the ground conditions are less than favourable. Nevertheless techniques do exist which will enable a desired alimentary railway to be constructed over poor ground. Earthwork can be constructed to satisfy the load bearing capacity and settlement criteria for both heavy axle loads and high speeds. Site instruments are available to check that the design requirements are being met. The application of these methods will ensure the sound construction of earthworks and will minimise future maintenance costs.

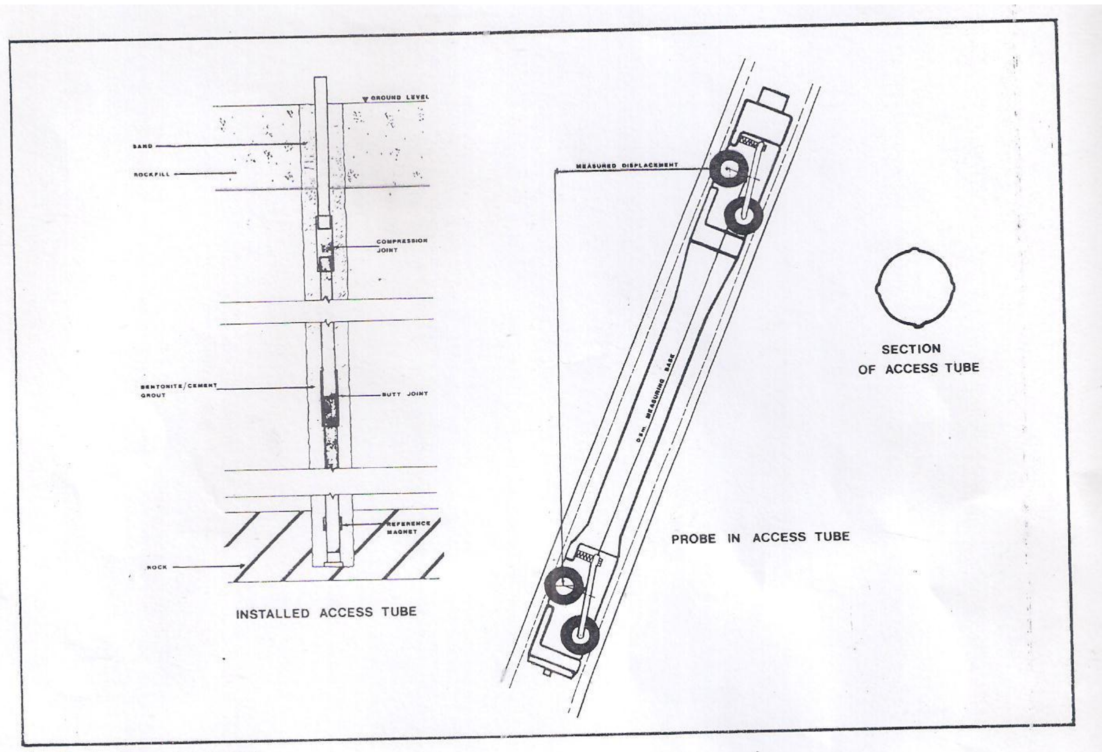


Fig. 7 Inclinometer system

Fig (3/6)

3.2.1.3.3 The Ballast [3]

Structural Requirements and Specification

1. Introduction

Track ballast is defined simply as the material placed between the sleepers and the formation, the latter being the natural or constructed ground over which the railway passes. Changes in the condition to ballast and underlying formations are the two factors most likely to produce a rapid deterioration in the quality of associated track. This may be difficult to reverse if not promptly recognized and attended to subsequently therefore, problems may be minimized by understanding the initial functions that ballast in particular performs, together with a suitable specification which will also satisfy long term requirements,

2. Structural Requirements of Ballast

Ballast has four main functions, namely:

a) Distribution of dead and live loads adequately to the formation.

b) Provision of lateral and longitudinal stability to the track.

c) To enable the track to be maintained to line and level.

d) To facilitate rapid dispersal of water.

By inspection of the above it is clear where the difficulties in specifying suitable ballast material lie. The functions are clearly contradictory in some respects. It could be argued that for good load bearing characteristics and added track stability the ballast needs to be well graded and compact, which in turn however makes dispersal of water more difficult, together with associated maintenance. It is a balance between these various factors that ballast seeks to maintain. Considering the four functions in more detail.

i. Distribution of loads

This is best achieved by a hard, angular stone specified within an overall grading envelope to ensure that the size fractions present will allow suitable maintenance whether by hand or machine methods. Dust should be minimized by suitable choice of the lower bound of the specification envelope. Exclusion of stone shapes that resist compaction by being non-angular is essential and to achieve this specification, criteria to limit elongation and flakiness are normally included.

Having specified the stone type and composition, varying traffic densities and line speeds combine to introduce the third factor affecting performance, namely depth of ballast.

On B.R., ideal ballast depths are specified according to the mix of speed and tonnage given in the table, Fig. 1. These are arrived at by theoretical and practical assessments of the various loadings and their frequencies, but by necessity are general in their application. It remains a distinct possibility that poor formations may still be over-stressed even with full ballast depths and although ballast achieves the required load spread it also adds more dead load into the track structure. In this respect analysis of the whole track and substructure condition is necessary when faced with a problem.

Finally it is essential to ensure that an initially acceptable stone remains broadly so during its lifetime in the track to this end ii is necessary to define qualities of hardness and attrition.

LINE SPEED (km/h)	LINE TONNAGE	BALLAST DEPTH (mm)
160 to 200	All	380
120 to 159	Over 12 Million	380
120 to 159	2 to 12 Million	300
120 to 159	Below 12 Million	230
80 to 119	Over 12 Million	300
80 to 119	Below 12 Million	230
Below 80	Over 2 Million	230
Below 80	Under 2 Million (Concrete sleepers)	200 (Min)
Below 80	Under 2 Million (Wood sleepers)	150 (Min)

Table (3/2) Recommended ballast depths

ii. Provision of stability to the track

If ballast specifications are derived primarily to satisfy vertical loading conditions is no less important to ensure longitudinal and lateral stability using the same material. The former is achieved by filling cribs between sleepers with ballast up to sleeper top level. Good frictional contact at ballast/sleeper interface also assists in this respect.

TRACK TYPE	WIDTH OF BALLAST SHOULDER (mm)
C.W.R. – Straight	380
C.W.R. – Curved track, Radii Flatter than 800m	460
C.W.R. – Curved track, Radii 800m and less; also at insulated joints, catchpoints, adjustment switches	530-600
In all C.W.R. track shoulders should be heaped 125mm above sleeper top level.	
Jointed track – All	300

Table. (3/3) Recommended width of ballast shoulders

Lateral stability has received more attention with the advent of continuous welded rail in the last decade, with the result that ballast shoulders are now specified on B.R. to the standards given in Fig. 2. As ballast has a limiting density when tipped which is much less than natural in-situ stone, full opportunity has also been taken to develop heavier concrete sleepers in this same period to assist in overall stability. Areas between tracks are now ballasted also.

iii. To allow adequate maintenance of track

It is now generally accepted that ballast is supplied to a single specification which covers both the initial load bearing criteria under 2.1 and which also is acceptable for general maintenance purposes. This means that an upper limit of stone size is defined such that minor adjustments of line and level are not made unduly difficult: this is presently set so that all material passes a 50 mm sieve. Smaller ballast sizes are desirable for maintenance purposes and the grading seeks to provide these.

iv. To facilitate rapid dispersal of water

The presence of water within the ballast sub grade is probably the single most serious factor likely to cause a rapid change in the strength and/or properties of materials present.

Progressive clogging to ballast can be due to numerous "external" sources in addition to breakdown of the ballast itself. All processes are accelerated by the addition of water and with transient live Load provided by the passage of trains the classic pumping mechanism of formation failure is initiated. Additional external sources which can clog the ballast include windblown fines and breakdown of the sleeper by erosion.

Assuming the ballast is free draining initially, having a "no fines" specification, then only softer stone will break down in time to produce appreciable clogging, thus reducing its free draining properties. Specification limits for hardness and attrition are detailed later in the paper which combats this tendency.

3. Sources of Ballast Supply

It is recognized that generally, in Britain, adequate supplies of good quality natural stone are available. This varies regionally but we benefit by being geographically compact, enabling local shortages to be overcome.

It will certainly be that on railways worldwide, ballasting economies and supply will hinge on the use of whatever local material is available. Reduction in specification to allow the introduction of lower grade material will result in a change of the performance “balance” mentioned earlier. This will be affected such that adequate load bearing and stability are maintained at the expense of free draining properties or vice-versa.

As an illustration of the above, some of the alternative materials available in this country are worthy of mention, compared to the preferred granite or whinstone. These have been discarded as specifications have evolved, following assessment of practical shortcomings.

Limestone is abundant and on crushing produces suitable ballast. It is susceptible to break-down by attrition and free draining characteristics are not maintained. Gravels are available in some localities but although possessing excellent hardness and free draining properties, they are not angular and therefore possess poor stability characteristics in unconfined situations experienced in the track bed. Ashes are excellent for packing but being very soft and generally of small particle size they crush easily to fines which again prevent drainage.

In addition to the alternatives covered so far, man-made we products have been used for ballast with son success; notably crushed stag, being a waste product from iron and steel making processes. A mixture of dense and lighter more honeycombed particles, this material was below specification when attrition limits were introduced about ten years ago. Much of it still remains, however, in track today.

More recently attempts have been made to re-introduce a heavier and more acceptable slag referred to as “steel-slag”. This contains a higher proportion of metal and if not used for ballast would be suitable as overburden in steel making. It has good density and better attrition qualities than the old slag but to date, its use has been confined to test stretches only. Materials such as slag are only available in areas of heavy industrial activity, thus limiting their availability.

- **B.R. Track Ballast Specification**

A summary of the main specification items is given below:

1. The ballast shall be good hard stone, angular in shape with all dimensions nearly equal, clean and free from dust.

2. The ballast shall consist of a mixture of sizes expressed as percentages by weight and evenly graded in any wagon. On a square mesh grid, the grading shall conform to:

SIZE	FRACTION
50 mm	100% to pass
28 mm	20% to pass
14 mm	0% to pass

The 80% retained on a 28 mm sieve shall consist of a general graduation in sizes up to 50 mm.

3. Crushing value shall not exceed 30%

4. Impact value shall not exceed 25%

5. Flakiness Index - maximum permissible 50%

6. Elongation Index - maximum permissible 50%

7. Wet attrition value - shall not exceed 6%

On main lines

Items 1 to 7 effectively translate the basic requirements of mixture, size, hardness, shape and resistance to wear, into laboratory based test procedures carried out under controlled conditions, than can be applied to any stone sample. Reference should be made to British Standards ❶ ❷ for interpretation of sampling and testing methods.

Excluding the grading requirement which is self explanatory a brief resume of the mechanical tests is given below.

4.1 Crushing Value $\ngtr$ 30%

A sample of single size ballast is subjected to a gradual increasing load reaching 400KN after 10 minutes. The load is released immediately and the material removed carefully from the compaction mould. The weight of fines passing a 2.36mm sieve expressed as a percentage of the original sample weight is called the aggregate crushing value.

4.2 Impact Value $\ngtr$ 25%

A sample of single size ballast (similar to A.C.V. test) is subjected to a series of fifteen blows from a 14kg hammer dropped from a height of 380mm. The agitate impact value is the percentage of fines by weight relative to the original sample weight.

4.3 Flakiness index $\ngtr$ 50%

Carried out during the sieve analysis, each fraction is measured for the weight of material expressed as a percentage of the whole whose least dimension is less than 0.6 of its normal dimension. Special flakiness sieves are used for this.

4.4 Elongation index $\ngtr$ 50%

Carried out during the sieve analysis, each fraction is measured for the weight of material expressed as a percentage of the whole whose greatest dimension is more than 1.8 times its normal dimension. Elongation gauges are used to assess this.

4.5 Attrition Value $\ngtr$ 6%

Reproduced in Fig. 3 is the Deval attrition machine used to carry out this test. It consists of one or two standard steel cylinders fitted with water-tight covers and mounted on a rotating shaft. The cylinder axes are inclined at 30^o to the shaft. Preparation of a stone fraction to BS 812 : 1951 ❸ is carried out and after thorough washing, drying and weighing, the sample is placed in a cylinder with an equal amount of water and rotated 10000 times at a rate of 30 to 33 revolutions per minute. This has the effect of simulating extensive wear on the ballast in service and on completion of the test the contents are sieved on a 2.36 mm sieve. After drying, the ratio of the loss in weight of the sample compared to the original weight is expressed as a percentage and called the wet attrition value.

3.2.1.3.4 The sleepers

At the beginning of railway technology the preferred sleeper material was wood and it continued to be so for the next 50 years. Wood is susceptible to weathering and other external influences. This and the intense steel production in the last quarter of the 19th century finally led to the changeover to steel sleepers. These were used for more than 50 years in many parts of the world including Europe. However, increase axle loads and train speeds soon required heavier sleepers. The first concrete sleepers were introduced at the end of the 19th century. The French gardener Moinier designed the first reinforced concrete sleeper before the turn of the century and applied for a patent. In 1906 the first experiment with a conventionally reinforced concrete sleeper was made in Germany on the line Nurnberg-Bamnerg. During World War lithe concrete sleeper production was extended and in 1939 the production of steel sleepers was discontinued. In general, two different basic types of concrete sleepers where developed:

- the twin-block concrete sleeper where two prestressed concrete blocks are connected via a steel rod or a steel beam, and

- the mono-block concrete sleeper which consists of one prestressed concrete beam.

The introduction of heavy prestressed concrete sleepers was essential to enable the use of long welded tracks.

High Speed traffic with speeds of 200-350 km/h led to the development of different types of ballast less track. At the same time new systems of concrete sleepers, such as the broad sleeper, the frame sleeper and the ladder sleeper were developed and presented.

Nowadays classic steel sleepers are hardly used. The only exception is a special form of the steel sleeper, the so-called Y steel sleeper which is used under special conditions due to its small overall height and width. A total number of approximately 3 billion sleepers are used all over the world. Only 20% of them are concrete sleepers. About 5% of the sleepers are replaced annually. The total production of concrete sleepers all over the world amounts to about 20 million.

Comparison between wooden and concrete sleepers

The advantages of concrete sleepers compared to wooden sleepers are the following:

- longer life cycle and service life,
- less expensive than hardwood sleepers,
- lower maintenance of the fastenings.
- higher resistance to lateral displacement due to higher weight.

On the other hand concrete sleepers have the following disadvantages:

- susceptible to shock and impact.
- difficult handling due to greater weight, and
- maintenance of longitudinal level is somewhat more difficult because of the higher moment of inertia and the lower elasticity.

The purpose of sleeper

The purpose of the sleepers is:

- to establish and maintain track gauge,

- to distribute and transmit forces to the ballast bed, such as:
- the perpendicular axle loads,
- the horizontal centrifugal, forces, and
- the longitudinal forces within the rails.
- to hold the rails
- in height (in the case of arching or settlement),
- to the sides, against centrifugal and transversal forces (*H*forces),
- in the longitudinal direction against rail creeping, brake, acceleration and temperature forces
- to secure the track
- under construction,
- in the case of a rail breakage, and
- after derailment (in such cases the measures prescribed by the railway authorities, such as temporary rail connection, have to be taken), and,
- to dampen rail vibration and
- to reduce the influence of sound and impact waves on the environment.

These manifold tasks can be fulfilled by:

- transversal wooden, steel or reinforced concrete sleepers.
- longitudinal reinforced concrete sleepers, and
- reinforced concrete sleeper plates.

- **Sleepers (ties):**

They are five main types of support for rail, namely:

Concrete slab

Concrete sleeper

Steel sleeper

Softwood sleeper

Hardwood sleeper

All have their advantages and disadvantages from a technical point of view. In broad terms the factors which have to be borne in mind in economic selection are not necessarily those which will give technical excellence. For instance indigenous materials are likely to be cheaper than imported sleepers and indeed different governments may wish to use such materials because of the hard currency or strategic situation. On the other hand there is not much point in using softwood if there are local conditions such as termites/fungi which would destroy them within a very short period. It is a matter of weighing up all the factors of first cost against availability against life against maintainability. Even then a definite decision cannot be made in isolation from the rest of the track components and several alternatives should be evaluated to ensure a minimum overall cost solution.

We think that environmental as well as economic pressures will force most railways away from timber sleepers in the foreseeable future. Concrete and steel sleepers, properly designed, can do everything that timber can do. Concrete has the problem of weight which makes it expensive to export/import although if the projects are big enough local production can overcome some of these logistic problems. Personally I think that if the steel firms make a sustained attack on the sleeper market with a product in the right price range they will eventually take the majority of the business in most countries. Steel sleepers are light compared with concrete, are less bulky and therefore are easier to transport and handle and have a high residual value.

Ties are typically made of one of four materials:

- Timber
- Concrete
- Steel
- Alternative materials

The purpose of the tie is to cushion and transmit the load of the train to the ballast section as well as to maintain gage. Wood and even steel ties provide resiliency and absorption of some impact through the tie itself. Concrete ties require pads between the rail bases and tie to provide a cushioning effect.

Timber Ties

It is recommended that all timber ties be pressure-treated with preservatives to protect from insect and fungal attack.3 Hardwood ties are the predominate favorite for track and switch ties. Bridge ties are often sawn from the softwood species. Hardwood ties are designated as either track or switch ties.

Factors of first importance in the design and use of ties include durability and resistance to crushing and abrasion. These depend, in turn, upon the type of wood, adequate seasoning, treatment with chemical preservatives, and protection against mechanical damage. Hardwood ties provide longer life and are less susceptible to mechanical damage.

i. Track Ties

Timber track ties are graded with nominal dimensions of 7” x 9” x 8’-6 or 9’-0” or smaller ties which are 6” x 8” x 8’-0”. See fig (3/7).

The 6” x 8” x 8’-0” are typically utilized for sidings, industry tracks and very light density trackage. An industrial grade of both ties is also available. These ties have more wane, bark, splits or other surface related defects than recommended under the timber grading rules. Both AREMA and the Railway Tie Association (RTA) publish specifications and standards relating to the grading of timber and the definitions for the above timber physical characteristics. The cost savings may make industrial grade ties attractive for some plant trackage exposed to infrequent and light tonnage. It is generally acknowledged that the quality of hardwood tie availab1e today does not meet yesteryear’s standards. Thus, the additional cost of providing gang plates, S-irons or C-irons for the tie ends may be a worthwhile investment in extending tie life from end splitting failures. Track ties may be orderedazed and pre-drilled for the appropriate rail section to be used if desired. Secondhand ties, reclaimed from line abandonments, may also be available. There is wide debate regarding the suitability and cost effectiveness of using recovered ties.

Deterioration of that part of the tie previously buried in the ballast occurs rapidly once the tie is exposed to the air. If second-hand ties are used, do not turn the tie over, thus providing a fresh surface for the top of the tie.

These ties will deteriorate very quickly. Better to plug the tie, adze the surface if necessary and insert the tie as it was originally orientated. Occasionally, softwood ties may be specified for a track tie. Their use is limited to temporary track situations such as shoe-fly's, etc., or where tonnage is very light or hardwood species are prohibitive in cost.

For quality maintenance, ties should be not less than 8 ft. 6 in. in length. For moderately heavy or heavy-traffic conditions, especially on curves of 6 degrees or more, the 9-ft. tie is preferred, 7 in. by 9 in. in cross-section, because of the greater or more, the 9-ft. tie is preferred, 7 in. by 9 in. in cross-section, because of the greater stability from the larger support and friction area. It also assists in restraining continuous welded rail.

For lines of moderate to medium tonnage, a tie spacing equivalent to 22 ties per 39-ft. rail (21-1/4 in.) is sufficient. Heavy tonnage lines or lines, with sharp curves will find 24 ties per rail panel (19-1/2-in.) to have advantages in holding gauge and reducing bending moment stresses in the rail.

Fig (3/7) Hardwood Track Ties - Photo by J.E.Riely

ii. Switch Ties

Switch-ties Fig. (3/8) are commonly hardwood species, usually provided in either 6” or 12” increments beginning at 9’-0” up to 23’-0” in length. Nominal cross-section dimensions are 7” x 9”, although larger ties are specified by some railways. The primary use for switch ties is relegated to turnouts (thus their name). However, they are also used in bridge approaches, crossovers, at hot box detectors and as transition ties. Some railways use switch ties in heavily traveled road crossings and at insulated rail joints. Switch ties ranging in length from 9’-0” to 12’-0” can also be used as “swamp” ties. The extra length provides additional support for the track in swampy or poor-drained areas. Some railways have utilized Azobe switch ties (an extremely dense African wood) for high-speed turnouts. The benefits associated with reduced plate cutting and fastener retention may be offset by the high import costs of this timber.

Fig (3/8) Switch Timber

iii. Softwood Ties

Softwood timber figure (4.9) is more rot resistant than hardwoods, but does not offer the resistance of a hardwood tie to tie plate cutting, gauge spreading and spike hole enlargement (spike killing). Softwood ties also are not as effective in transmitting the loads to the ballast section as the hardwood tie. Softwood and hardwood ties must not be mixed on the main track except when changing from one category to another. Softwood ties are typically used in open deck bridges.

Fig (3/ 9) Softwood Timber - Photo by J. E. Riely

iv. Concrete Ties

Concrete ties Fig. (3/10) are rapidly gaining acceptance for heavy haul mainline use, (both track and turnouts), as well as for curvature greater than 2^o. They can be supplied as crossties (i.e. track ties) or as switch ties. They are made of pre-stressed concrete containing reinforcing steel wires.

The concrete crosstie weighs about 600 lbs. vs. the 200 lb. timber track tie. The concrete tie utilizes a specialized pad between the base of the rail and the plate to cushion and absorb the load, as well as to better fasten the rail to the tie. Failure to use this pad will cause the impact load to be transmitted directly to the ballast section, which may cause rail and track surface defects to develop quickly. An insulator is installed between the edge of the rail base and the shoulder of the plate to isolate the tie (electrically) An insulator clip is also placed between the contact point of the elastic fastener used to secure the rail to the tie and the contact point on the base of the rail.

Fig (3/10) Concrete Ties - Photo by Kevin Keefe

v. Steel Ties

Steel ties figure (4.11) are often relegated to specialized plant locations or area not favorable to the use of either timber or concrete, such as tunnels with limited headway clearance. They have also been utilized in heavy curvature prone to gage widening. However, they have not gained wide acceptance due to problem associated with shunting of signal current flow to ground. Some lighter models have also experienced problems with fatigue cracking.

Fig. (3/11) Steel Ties

vi. Alternative Material Ties

Significant research has been done a number of alternative materials used for ties. These include ties with constituent components including ground up rubber tires, glued reconstituted ties and plastic milk cartons. Appropriate polymers are added to these materials to produce a tie meeting the required criteria. To date, there have been only test demonstrations of these materials or installations in light tonnage transit properties. It remains to be seen whether any of these materials will provide a viable alternative the present forms of ties that have gained popularity in use.

3.2.1.3.5 The rails

a) Rail requirements

The rail is running surface, carrier and guiding element at the same time. It is subject to equal static and dynamic stress. In heavy haul traffic, axle loads up to 35 t are applied. Nowadays in regular high-speed traffic speeds of up to 300 km/h the cached. Depending on the topography rails are laid with radii as low as 300 in, therefore, they are subject to the very high lateral forces exerted by the wheel flange striking against the gauge corner of the outer rail. To be able to withstand these manifold and high forces, the rails must meet the following requirement:

- High resistance to wear,
- High resistance to compression,
- High resistance to fatigue,
- High yield strength, tensile strength and hardness, High resistance to brittle fracture,
- Good weld ability,
- High degree of purity,
- Good surface quality,
- Evenness and observance of profile and 1ow residual stress after manufacturing.

b) Rail defects

The so-called catalogue of nil defects with defmitions of rail defects is edited by the ‘LJIC. Rail defects arc cracks, fractures and damage to rails and rail connecting areas.

Defects are catalogued according to their position, appearance and cause, The UIC half let 712 “Rail defects” deals with this topic. A system of 4 figures is used for cataloguing:

1st figure: *position of the defect in the rail*

2nd figure: *position of the defect in profile*

3rd figure: *direction and type or cause of the defect*

4th figure: *additional features*

The contents classical ion contains 55 different types of rail defects. Table (3.4) indicates the most frequent and typical defects occurring at present in long welded tracks.

Rail defects and incipient cracks are detected by ultrasonic tests. As an ultrasonic wave is reflected by any surface, the damage can be recorded. For tills purpose several oscillator crystals with water contact are mounted on the running face. Type and dimension of a fracture may be recognized from the reflected. Picture of a fracture or cavity.

Table (3/4) most frequent rail defects in long welded tracks.

Short designation of the rail defect
Tacheovale
Shelling
Head Chechs
Belgospis
Squats Indentions
Skid marks
Corrugation
Waves
Cross-cracks (welding)

c) Lateral forces (acting across the track)

Dynamic forces acting across the track are partially absorbed by the compressed elastic rail pads, the remaining force may be transmitted directly to the sleepers via vertical elastic rail pads.

The lateral forces acting on the track may be very high. The rail fastenings have to transmit them to the sleepers via a firm connection. If this is not possible, the occurring forces will increase to such an extent, that the track will be crushed.

3.2.2 Part Two: Signaling, Telecommunications & Operations [4]

i. Background:

The signaling & operations systems in SRC are of the nineteen century technology.

Moreover the equipment used is old & obsolete. It is high time alternative systems must be adopted & installed.

There are two important studies done to SRC by Kampasax of Germany suggesting certain major measures for Canarail of Canada, the replacement of the existing signaling systems arrangements in stations to upgrade the capacity of transportation of SRC.

Five scenarios have been suggested by Canarail to SRC to choose from. The scenarios are shown in reference (4).

This part of the chapter is to help in producing firm suggestions on the role of the signaling and operations systems in upgrading the transportation capacity.

Therefore a lengthy summary of Canarail Final Report on signaling is presented here under.

ii. INTRODUCTION

OBJECTIVE:

The safety of trains and maintenance vehic1es operation is mainly based on signaling and communications systems. Ratability of the existing systems in Sudan Railways Corporation (SRC) is seriously deteriorating. As a result has decided on undertake this study to review present systems and equipment and recommend an appropriate course of action.

In close cooperation with the SRC Study Task Force,

CANARAIL's experts have completed the study with the following objectives:

- Review the existing signaling and communicator systems covering the railway network identify SRC's present and future needs in signaling and Communications
- Develop the various technical solutions which could meet these requirements.
- Base on technical as well as economic analyze, select the best after marvel and develop the implementation plan.
- Prepare cost estimates for the chosen solutions.
- Prepare an implementation plan considering priorities and traffic forecasts containing projects as appropriate for achieving the improvement objectives established in the previous phase.
- Prepare a preliminary assessment of staffing, training requirements and other related operation arid maintenance elements.

iii. Executive Summary

This is the Executive summary to the Final Report of the **Study of Signaling and Telecommunication Systems Development and Modernization for the Sudan Railways Corporation** undertaken by CANARAIL in association with SOFRERAIL. The purpose of the study was to prepare a Business Plan to fulfill SRC'S signaling and telecommunications needs for the next 10 to 15 years.

During fiscal year 1993/1994 the traffic flows over the SRC network were shown to be heaviest for PORT SUDAN to KHARTOUM at over a million and a half tonnes annually. KHARTOUM to EL OBEID was next with six hundred thousand tonnes a year. All other sections were significantly lower in traffic. Details of each section as provided by SRC are listed in Appendix 6 of this report.

Traffic is forecast by the SRC to double between 1993/94 and 1996/97, and quadruple between 1993/94 and 2003/04.

Presently, the safety of train operations is assured by mechanical signaling in stations and a token block control between stations. The links for these systems are on physical open wire circuits and owned but no longer maintained by SUDATEL. VHF radios are used for some communications between stations and trains.

The present SRC telecommunications infrastructure is inadequate for present and future operational needs for train dispatching, block signalling, permanent way, wagon control and administrative communications. These conditions are not conducive to efficient operation or management of the railways.

The study recommends the upgrade of both the SRC signalling and telecommunications facilities to satisfy their station and inter-city circuit: requirements. Based on train traffic: on costs derived for the various scenarios and on, requirements for reliability and flexibility, certain measures are ecommended. In terms of viability for the various projects, it makes sense to- undertake telecommunications and signals modernization from PORT SUDAN to KHARTOUM. Sections south of Khartoum and extending beyond EL RAHAD to BABANOUSA do not necessarily justify the same upgrades and some other measures are recommended.

For signalling, due to the age of the system and the direct bearing this system has on train movements and safety, it should clearly be upgraded between KHARTOUM and PORT SUDAN. The present mechanical interlocking and lever frames are old, inflexible and problems ridden. Spare parts are no longer available. The signal system must be simplified, modernized and made more flexible for future adaptations. CANARAIL is recommending a progressive modernization programme which includes new signals and switches as well as a cdmputer assisted control function (DOS). This is a system being now implemented by many North American railways and elsewhere. It requires good communication links between controllers and station masters. The program also proposes elimination of most of the present mechanical systems. New electric signals would be installed along with trailable or spring switches in wayside stations. The modernization of larger stations is dealt with as a specific subject, and SRC has agreed to study track layouts of these stations in view of simplifying them prior to complete modernization.

In all projects to be considered by SRC, future support and flexibility for system growth are also important criteria as well as standard equipment and parts. New systems should conform to recognized standards, either international such as CCIU and CCIR for telecommunication or the AAR for signalling.

The principal benefit of the proposed improvements would be positive effects on train movements with less delay and therefore better efficiency, in turn leading to reductions in locomotive and wagon fleet size.

1. The Progressive Signalling Modernization Programme including DOS is viable in all sectors given that good communications are available.
2. A fibre optic backbone system is viable for the heavy traffic routes
3. The “cellular type” radio viability should be re-examined because it is presently too distant a planned implementation.
4. The best results are obtained between PORT SUDAN and KHARTOUM as these track segments have the highest traffic density, and therefore present the best opportunity for savings in rail operating costs.

3.2.2.1 Signaling and telecommunication needs

Signaling Needs:

1. Difficulties with Present Systems:

SRC has recognized that the present systems have inherent problems that are hampering efficient operation of the railway. These are:

- The present signaling is old and run down; it is difficult to obtain replacement parts;
- It is based upon inadequate and unreliable communications systems;
- The token block system requires a train to stop at each station.

In addition, the mechanical interlocking system is rigid and difficult to. It thus locks SRC into a track layout designed for earlier days. (Present layout is excessive, and yet must be kept and maintained.) Ta a lesser degree this rigidity is also created even by conventional electric interlocking systems.

2. Requirements for an Ideal Signal and Control System

A new signal and traffic control system should:

- Provide for overall direction and traffic management by a central controller.
- Provide safety for trains, track maintenance work. etc.
- Not impose unnecessary or arbitrary restrictions on train movements, such as speed limits, or flexibility of operation (including shunting and special movements). In other words it should encourage maximum efficiency of operations.
- Be adaptable and expandable to meet hanging traffic requirements.
- Be economical to install.

- Make optimum use of advanced but proven technology as computers, electronics, and radio communications.
- Permit advantageous use• of new technology as it becomes available.
- Be easily maintainable.
- Be adaptable1 with suitable variations, to the entire railway network.

i. Technical and Other Considerations

The following points must be recognized in the design of new systems:

- The periodic storm damage in some area as; i.e., the system must be easy to rebuild and restore to service;
- The existing poor track conditions anti particularly the blowing sand will make track circuits expensive and probably unreliable (bad ballast; sand on rail surfaces may prevent good electrical wheel-to- rail contact);
- Commercial power is not available in all areas;
- Use of electric, spring or trailable switches will require the existing switch structure to be upgraded and reinforced. Use of such switches should be limited to locations where the cost can be justified over other alternatives.

In addition, it is obviously desirable to maximize the use of local source material and expertise.

ii. Requirements for Successful Signal System Operation

For any signal system to operate reliably the following condition is, among others, must be present:

- Reliable communications.
  - Between stations.
  - Between stations and central control.

Complete and well considered preventive maintenance procedures

- Trained and responsible employees
  - Maintenance staff
  - Operating personnel

3. Telecommunication Needs:

i. Overview:

As the existing communications facilities impose heavy constraints and limitations on train operations and the railway's performance, it is crucial that the whole telecommunications network be improved, whether or not the track and signaling systems are upgraded or renewed.

The future telecommunications system must be designed for:

- Short, medium and long distances,
- multi-purpose applications:

- train security (signaling circuits)
- train operation (dispatching)
- freight and passenger transportation (commercial)
- railways administration (service and maintenance)
- railway management

An efficient communication system will improve:

- Ability to manage the railway
- Train movement (track capacity)
- Freight car flow (turn around efficiency of rolling stock)
- Safety
- Emergency response time
- Staff utilization and rationalization
- Service to freight consignees
- On-time performance
- Maintenance efficiency

A computerized network system with data transmission circuits between major stations is needed to manage the wagon and locomotive fleet.

ii. Backbone transmission support

The present transmission support is totally inadequate for SRC's needs. The whole network must be equipped with a new and efficient transition backbone system.

This improvement plan will take several years and the chosen system must use technology which allows it to evolve with future developments in telecommunications equipment.

The future capacity needs of the telecommunications network should take into account SRC's long-term development.

iii. Long Distance Circuits

The future communication network should provide all necessary circuits between major centres and railway regional centres.

4. Voice

▪ General Management

In addition to requiring facilities directly concerned with train security and operation, the SRC will need good communications between all important locations in order to operate as an efficient organization.

Commercial: remote clients

Direct voice communication is needed with SRC's most important clients.

5. Data

Data communications are needed for rolling stock locomotives, wagons, spare parts control, and accounting functions.

6. Dial telephone network

Some of the main stations are lacking general-purpose telephone facilities. The existing PABX network should be expanded by the addition of 2 new PABXs, one in Sennar and one in Medani. All the 7 PABXs be interconnected and linked to the public SUDATEL telephone network.

7. Trunk lines

The SRC must also rent more reliable trunk lines to link its PABXs together so as to extend its internal private telephone network. This will also result in reducing the number of long distance calls through SUDATEL network.

8. Circuit requirements

Figure below summarizes the minimum communication needs or each station according to its importance.

3.2.2.2 Proposed Signalling Improvement

The rapid development of technology and worldwide changing conditions has led many railways to methods and to adopt less costly and yet safer and more efficient operating systems. This is an opportune time for SRC to do the same as it re-assesses needs, traffic operations, rules and methods, and signaling systems and facilities.

This chapter discusses some of the principles involved in train control systems and recommends a progressive modernization programme including new station signals and a modern system of computer-aided traffic control and management method. The programme recognizes the present difficulties noted in Chapter 4, section 4.1.1 and meets the requirements listed in section 4.1.2.

In 1990s after several years of analysis and development, Canadian railways adopted a radically new set of operating rules that permitted much more efficient and yet safer operating methods. As a result the system that had been used for many years evolved into the Occupancy Control System (DOS) as it exists today.

Many of the objectives and operating requirements identified by Canadian Railways are the same as those of SRC, including emphasis on a high level of safety. It is considered that OCS is appropriate for SRC and that it can be provided for a reasonable cost.

Other somewhat similar systems are used in other parts of the world. They are known by various names, differ in technology to varying degrees, and in their completeness, flexibility and adaptability to changing needs. SRC may wish to investigate other systems, but this report is based on the system developed by Canadian Pacific Railway.

It should be noted that OCS, and CAMBS (Computer Assisted Manual Block System) the other very similar Canadian system, are in service on about 50,000 kms of railway in Canada and an equivalent amount in the U.S.A.

The Progressive Modernization IS based on the following elements:

1. Modernization of the wayside (small and medium stations making use of signal lights, spring and trailable switches (with manual switches as option) and electric interlocking, of signals and switches as applicable,
2. The control of train shall remain under master controllers in Conjunction with station masters. The programme foresees a step- by-step evolution of this function to a computer assisted control (named OCS) of train movements and track Occupancy management. The ultimate goal of the modernization process will be dispatching by radio directly from master controllers to train crews and maintenance-of-way crews.

In addition, modernization of the three major stations (Port Sudan, Atbara and Khartoum) was examined and as agreed with SAC, a three step programme is outlined in Section.5.5.

In order for SRC to make more informed decision about this modernization programmes some paragraphs are included here concerning safety, switches and track circuits.

3.2.2.3 Railway Safety

SRC is justifiably proud of its safety record and any new system must continue this achievement and even further enhance it.

Safety consists of both avoiding accidents and minimizing consequences. However no system is totally safe, regardless of how well designed, complex or expensive. For instance, in interlocking, there is the possibility of a train over-running a signal, or being mis-routed into an occupied track. Safety could be improved with cab signals, train stops, to the use of track- circuits. Yet, a recent accident occurred in the Toronto Subway even though all these features were in place. Similarly, a recent and tragic accident occurred in India on a stretch of what seems to be token block-interlocked territory.

In OCS, it is conceivable that a clearance could be misread or violated in some way. However, the system incorporates a number of checks and procedures that make such an event extremely unlikely. The system has many internal checks for the clearances issued and transmission of these clearances by telecommunication have sophisticated error checking to ensure proper reception of data. In addition the rules require “read-back” of the clearance by the recipient to the controller so as to verify correct reception and understanding.

However, it is clear that most accidents involve human error in some way, usually by a rules violation or such things as poor maintenance practice. Thus, regardless of the type of system, the most important factors are well thought out rules, trained and dedicated employees, and continuous supervisory vigilance to ensure proper procedures are followed.

Beyond this, safety involves a value judgment, considering the most likely events, the alternatives available to avoid them, the costs and the effects of V imposing certain types of restrictions on operating practices. Among influencing factors are traffic levels and train speeds. As these increase, it becomes more desirable to supplement basic systems with others. For example, OCS operation could be supplemented with, say, an automatic block signal (ABS) system. In most cases, the additional systems improve efficiency and reduce delays as well as increasing safety.

In summary, improved safety can be provided in many ways, and careful thought is required before traditional or arbitrary systems are continued.

3.2.2.4 Signal Systems

1. General

Signal systems fulfill a variety of useful functions that can be identified and considered separately. Some of these functions may be achieved in other ways as well. Partly because signal systems are expensive, both in first cost and in continuing maintenance, it is important to be clear on the need for and value of each of these individual functions, and to consider the best way of achieving them.

For instance, a possible signal system function is to remotely operate a switch, as within an interlocking. One simple alternative is to use switch attendants ("switch tenders") who, under direction, manually operate switches. In North America, the vast majority of switches are manual, they are operated as required by The train crew. It is also possible to install electric remote operation, with certain precautions, without interlocking.

It is desirable to distinguish between “locking” a switch and physically “securing” it for sate passage of a train. Locking prevents the switch from being operated except under prescribed conditions. In North America, many switches are merely padlocked but are otherwise, free to be operated, the physical alignment is assured by the design of the hand throw mechanism. The driver of an approaching train is aware of the correct alignment by viewing the simple mechanical reflectorized target that displays point position. This arrangement is used even in territory with both passenger trains and heavy high speed freight trains (normally up to 80 km/h and in some cases even up to 145 km/h).

Clearly, this appears less safe than full interlocking, but only marginal additional safety is achieved at high cost.

One possible compromise could be to install a type of signalling that is much less costly than interlocking, to detect switch alignment electrically and control signals accordingly, but without actually locking the switch. A variety of relatively inexpensive systems can be considered.

The objective of interlocking is to prevent setting up conflicting or improper routes. But even with interlocking unless some form of track occupancy detection is in use, mistakes can be made. For instance, a train can be routed into an already occupied track. Where traffic is not too dense and the track layout relatively uncomplicated, the same objective can be achieved without the great expense of interlocking by establishing proper procedures and discipline.

Relatively simple non-interlocked systems using track circuits, can warn an approaching train that the track ahead is occupied.

A value judgment must be made to determine where limited funds can be most wisely spent. After considering some of the points discussed above1 SRC should be in a position to make an informed decision.

SRC wishes to replace the present mechanical interlocking with modern electric signals. The following section discusses this. However, with present and foreseen traffic levels and train speeds, SRC still may wish to consider a simplified system which is also outlined at the end of this chapter.

2. Switches

The simplest form of swi.tch control and security is the type of hand throw mechanism as used in North America. (See Figure 5.5) Use of hand throw switches simplifies the signal circuitry since it is clearly in one position or the other, or else neither. it is satisfactory for all types of operation including heavy, high speed traffic.

Spring switches have the benefit of being semi-automatic in that they restore themselves to the normal position. Since they are “trailable” the governing signal for a movement from the loop must be cleared while the switch is nominally still lined for the main track. Circuitry can provide for this and adds a small degree of complexity. A spring switch must be lined manually for a movement which is to enter the loop, and then restored afterwards.

Because the operation depends upon a spring mechanism, security of point position is not as assured as with a hand operated switch. For this reason, in North America where a spring switch is used in main line service, it is usually equipped with a fairly complicated facing point lock mechanism. However, the facing point lock is not required where train speed through the switch is restricted to less than 30 km/hr and for economy this latter arrangement is proposed for SRC.

Trailable switches are not common in North American main line service for some of the same reasons as for spring switches. They are however used in yard service where speeds are low and should be suitable for many locations on SRC as they offer a degree of semi-automatic operation. Further investigation should be made of other types.

It is recognized that spring switches and trailable switches may be applicable on certain segments of the SRC network depending on blowing sand conditions (e.g. spring switches may be adequate for areas closer to Khartoum and may have prove problematic closer to and north of Atbara).

Within an interlocking, electric switches must incorporate point locking which adds greatly to cost. Electric switch operating mechanisms of various types are available without locking. Most designs do, however, secure the points from being physically moved from the desired alignment, and this type should be suitable for many SRC requirements at this time. Train speed must be restricted to 25 to 30 km/h at such switches.

After initial investigation, it is recommended that SRC obtain samples of suitable switch mechanisms for trial installation before making final decisions.

3. Track Circuits

Track circuits greatly increase the safety offered by signal systems. However, the environmental and track quality conditions existing in

Sudan currently indicate that the sate operation of track circuits is uncertain. The existing mechanical interlocking does not incorporate track circuits and for these reasons the new systems proposed do not either.

However, where the signal systems are confined to station areas, track circuits would be relatively short and there is at least a fair possibility that they could be applied successfully with a minimum of track and ballast work. Tests are required and should be conducted as soon as possible.

Various types of track circuits are available but for most applications the basic simple dc type will be suitable.

4. The OC System & its Operating Principles

Most North American railways are now implementing a form of traffic control known as an Occupancy Control System (OCS), or Computer Aided Manual Block (CMBS). Essentially, this is a set of operating rules and formal procedures that manage traffic movements and block occupancy. OCS is an operating concept rather than a set of hardware such as signals, interlocking, arid switches. It will be a major step forward for SRC and meets all of the essential characteristics for train control required by SRC.

The OCS is a readily available microcomputer system with two screens of which one allows graphic displays. The specialized software provides safety checks in assisting the controller perform the following activities:

- Monitor block assignments for trains, track work crews, and on- track vehicles

- Issue and retain a copy of clearances issued
- Display train paths and track blockages
- Transfer requests, information, and authorizations in the prescribed format.

Trains are issued clearances in order to enter and occupy a segment, or block of track. Only the central controller can so authorize a train to occupy a track block. Track maintenance and on-track vehicles that obstruct train movement through a block or that require protection for safety reasons, also require authorization from the central controller under the operating rules. It is the central controller's responsibility aided by the computer system, to monitor and control occupancy use and ensure that only one authorization is issued for any block.

Three photographs (kindly provided by CP Rail) are included to help visualize and understand the system proposed and the operating principle of OCS.

Photo 1: Clearance Issue Screen. Using a computer "mouse" as pointing device, the central controller can "click" on train and generate a menu driven text screen for issuing clearance or train movement authority. The clearance form is displayed and the controller selects valid options. The information, once completed is read off the screen, transmitted by voice (radio or phone) to the train crew. The information is written by the crew on a pre-printed form and read back to the controller. The controller checks every item by moving the space bar to highlight each word on the screen as the crew reads it to him. In the future, when an on board terminal becomes available, this read-back procedure will become obsolete. In the case of SRC, at least initially, a clearance for a train to enter a block can be issued only after adjacent station masters have confirmed that the block is free. It is essential that the voice links be sufficiently clear and reliable so that the central and station controllers can accurately and unambiguously transfer and verify the clearance information. The Clearance Issue Screen has a similar counterpart which is used for releasing clearances. Any clearance or authorization for a train to proceed stays in effect until it is either released by request from the train crew or cancelled. In the case of a track or occupancy release, the train crew must agree on the correct location of the rear of the train before transmitting the track release which must then be confirmed (read back correctly) by the controller before the release becomes effective.

Photo 2: Train Sheet Graphic. This gives an overview of the line stations, mileage points, passing track capacity and switch positions. Each column represents either a train, a track vehicle or a maintenance-of-way force.

The grey and pink backgrounds indicate the maximum limits of the clearance given to that train or crew foreman. The colour coded bars indicate the active authority type. Blue applies to a maintenance-of-way crew, Red is for a train authorized to move in either direction (work train), Green is for a train authorized to proceed in one direction only and stay on the main track at destination (end of the clearance), Yellow is for a train authorized to proceed in one direction only and clear the main track at destination.

Photo 3: Track Profile Screen. This provides a view the line segment or territory and can b custom tailored to the controllers needs. A scrolling function allows the controller to move up or down the track. Clearances appear as colour bars with train numbers and in the same colours as described above. This track profile displays actual track configurations as well as the limits of “active” authorities (clearances).

In OCS, more responsibility is placed on train crews, and correspondingly less on wayside station staff. The 003 bulletins inform the crew of any conditions that will affect their train, the precise route to be followed, and in some cases, restrictions on the movement of the train are imposed. In all cases, the train is authorized to precede up to a defined point on the line, such as a particular switch at a station ahead, a mileage marker, or other suitable location. The controller, assisted by the computer, selects the precise location so that conflicts are not created with other trains or maintenance work.

5. Progressive modernization with OCS & electric signals

The long term objective of the proposed modernization programme is a full OCS system. Eventually, authorizations will be issued by a central Controller or Dispatcher, by voice radio directly to locomotives, maintenance forces and others concerned. An even further step could be to have the messages delivered by computer control direct by data radio to an onboard terminal on each locomotive for display to the driver.

The proposed modernization also recommends changes to the signaling equipment. The mechanical interlocking will be replaced by simpler, modern electric signals and new switches. The implementation of OCS and the signals can be carried out almost independently and will therefore be discussed separately.

Before any operating or signal changes are made, the long term plan must be clearly laid out, so that each step wilt lead directly to the next and always towards the final objective. This will take considerable initial planning.

The Canadian OCS system has been well thought out and tested in practice for many years, under a wide variety of conditions. It is recommended that SRC plan to adopt the system essentially as it exists. However, some of the procedures incorporated may be radically different from present SRC practices and probably should be implemented slowly as familiarity with the system concepts grow. The basic OCS system is flexible enough to accommodate this.

Ultimately, tour Central Controllers will be needed:

- Port Sudan to Atbara
- Atbara to Khartoum
- Khartoum to Kosti
- Kosti to Babanousa

Although traffic levels and other characteristics differ for each of the territories, the OCS is essentially the same for all. Each territory can be progressed independently but for estimating purposes certain initial costs such as the basic development and software costs have been assigned to the first section to be implemented.

- **Steps to OCS: Evolution of the Control Function**

The following is a simplified outline of the steps that might be taken to make the present train and track control function evolve to the final OCS. The details will have to be developed and will depend upon the final objective visualized and the conditions that exist at the time.

Step 1: Much as is case now, and to the extent that communications facilities permit, traffic management will be under the supervision of the Central Controller. He will instruct Station Masters to hold or expedite the various trains for greatest efficiency. Station Masters will keep him informed as to train passage and other matters that affect traffic movement.

The safety of operations shall remain on the present station-to-station basis. The present token block operation. may be continued, but as local cxwmntnicabons improve and the basic principles of OCS are grasped, it should be progressively replaced by use of. paper: clearances using defined formats similar to OCS. They would be initiated by the appropriate Station Master, and issued after agreement with the next Station Master, but should also be approval by the Controller whenever possible. In a way, these clearances would be similar to those used now, but should also include additional information as to the route to be used, other trains in the area, and track maintenance work in progress.

The train must stop to pick up the clearance, and The crew must formally acknowledge their correct understanding. One possible way to eliminate unnecessary train stops is discussed below.

Step 2: As soon a possible, the central computer system will be placed in service. The Controller would record all of the information received from the Station Masters and other sources, and enter the clearances issued by them:

He could then use the system to help him plan the traffic management, and most importantly to verify the correct actions of the Station Masters. At this stage however, the computer system will be used in a sort of passive mode. This will assist in understanding the system, for training and to help work out the details of following steps.

Step 3: As soon as communication links become sufficiently reliable from Central Control to a group of stations, authority for issuing clearances should be transferred to the Controller. He would initiate the clearance, and following normal OCS procedures would transmit them to the appropriate Station Masters, verbally. Each clearance would be addressed to the train crews, Station Master, and maintenance gangs concerned and each must follow the acknowledging procedures established, The Station Master would have prepared sufficient copies for all concerned and would deliver copies to the train crew in written form.

OCS is flexible enough to permit the clearance to give movement authority up to any point. Initially, SRC may wish to limit each authority to go only as far as the entering end of the next station, and then progressively to permit wider limits, such as to the leaving end of the next station, and then later for a train to pass through several stations as appropriate.

At this point the Station Master would still be responsible for lining the route within the station. However, he would act in accordance with the overall planning of the Controller. In other words, both the train crew and the Station Master will be party to the clearance as issued and both must fulfill their duties as instructed by the clearance.

Step 4: At some point, when communications permit, it will be desirable to incorporate a computer controlled printer at each station to replace the verbal with written (printed) procedures, This will permit to further expand the clearance system to full OCS capabilities with paper copies, still being delivered by the Station Masters.

Step 5: When the complete wayside-to-train voice radio system is available, the Controller should be able to issue clearances directly to the train. If at that time, station routing is still performed by station masters, their copy could be issued verbally or by means of the printer system described in Step 4. in practice, once direct communication from controller to train becomes feasible, he role of station masters would have to be reexamined.

6. Signals

OCS alone is capable of providing a very high degree of safety, providing that the procedures are followed correctly. In many applications, this is considered perfectly adequate. However, there is no question that safety can be further enhanced by the addition of some form of signaling, end operating efficiency improved as well.

SRC wishes to eliminate the present mechanical interlocking and replace it with modern electric signals. The proposed new system is designed to augment the basic safety of OCS in the station areas, to improve operating efficiency, and yet be economical to install and maintain.

A typical small station is shown in Figure 5.1, and a possible new arrangement in Figure 5.2 in which track layout has been simplified. Such simplification will have many benefits such as:

- Reduce the cost of new signalling
- Modernize the facilities to meet the requirements of present operations.
- Improve safety by eliminating switches

YEAR		INITIAL FLEET					FLEET REQUIRED WITHOUT PROJECT		PRODUCTIVITY INCREASE. PORT SUDAN – KHARTOUM		FLEET REQUIRED WITH PROJECT PORT SUDAN – KHARTOUM				PURCHASES WITHOUT PROJECT		PURCHASES WITH PROJECT KHARTOUM – PORT SUDAN			
		INITIAL FLEET									SIGNALS		FIBRE OPTIC				SIGNALS		FIBRE OPTIC	
Fiscal	Project	In Service, 1993/94	Rehabbed	Purchased	RETIRED	TOTAL IN SERVICE	High Forecast	Low Forecast	Signals	Fibre Optic	High Forecast	Low Forecast	High Forecast	Low Forecast	High Forecast	Low Forecast	High Forecast	Low Forecast	High Forecast	Low Forecast
1993/94	-1	3,430	0	0	0	3,430	3,430	3,430	0%	0%	3,430	3,430	3,430	3,430	0	0	0	0	0	0
1994/95	0	3,430	500	100	0	4,030	4,868	4,868	0%	0%	4,868	4,868	4,868	4,868	838	838	838	838	838	838
1995/96	1	3,430	500	200	747	3,983	5,303	4,629	0%	0%	5,303	4,629	5,303	4,629	481	0	481	0	481	0
1996/97	2	3,430	0	0	0	3,983	5,664	4,439	0%	0%	5,651	4,429	5,658	4,435	361	0	348	0	355	0
1997/98	3	3,430	0	0	0	3,983	6,714	4,287	1%	0%	6,668	4,258	6,682	4,267	1,051	0	1,018	0	1,024	0
1998/99	4	3,430	0	0	0	3,983	7,460	4,491	1%	1%	7,392	4,450	7,382	4,444	746	0	724	0	700	0
1999/2000	5	3,430	0	0	372	3,611	8,206	4,704	1%	2%	8,132	4,661	8,074	4,629	1,118	255	1,111	212	1,064	179
2000/01	6	3,430	0	0	1,507	2,104	8,953	4,928	1%	2%	8,871	4,883	8,783	4,835	2,253	1,730	2,246	1,728	2,216	1,713
2001/02	7	3,430	0	0	0	2,104	9,699	5,162	1%	2%	9,610	5,115	9,515	5,064	746	234	739	232	732	230
2002/03	8	3,430	0	0	0	2,104	10,445	5,407	1%	2%	10,349	5,358	10,247	5,305	746	245	739	243	732	241
2003/04	9	3,430	0	0	0	2,104	11,191	5,664	1%	2%	11,089	5,612	10,979	5,557	746	257	739	254	732	252
2004/05	10	3,430	0	0	0	2,104	11,191	5,933	1%	2%	11,089	5,879	10,979	5,821	0	269	0	267	0	264
2005/06	11	3,430	0	0	52	2,052	11,191	6,215	1%	2%	11,089	6,158	10,979	6,097	52	334	52	331	52	328
2006/07	12	3,430	0	0	717	1,335	11,191	6,510	1%	2%	11,089	6,451	10,979	6,387	717	1,012	717	1,010	717	1,007
2007/08	13	3,430	0	0	161	1,174	11,191	6,819	1%	2%	11,089	6,757	10,979	6,690	161	470	161	467	161	464
2008/09	14	3,430	0	0	216	958	11,191	7,143	1%	2%	11,089	7,078	10,979	7,008	216	540	216	537	216	534
2009/10	15	3,430	0	0	0	958	11,191	7,482	1%	2%	11,089	7,414	10,979	7,341	0	339	0	336	0	333
2010/11	16	3,430	0	0	0	958	11,191	7,838	1%	2%	11,089	7,766	10,979	7,690	0	355	0	352	0	349
2011/12	17	3,430	0	0	0	958	11,191	8,210	1%	2%	11,089	8,135	10,979	8,055	0	372	0	369	0	365
2012/13	18	3,430	0	0	110	848	11,191	8,600	1%	2%	11,089	8,522	10,979	8,437	110	500	110	496	110	493
2013/14	19	3,430	0	0	121	727	11,191	9,009	1%	2%	11,089	8,927	10,979	8,838	121	530	121	526	121	522
2014/15	20	3,430	0	0	0	727	11,191	9,437	1%	2%	11,089	9,351	10,979	9,258	0	428	0	424	0	420

- release track material for re-use elsewhere
- reduce track maintenance costs

Train operational needs should be examined at each station and terminal, and every switch and section of track be justified by an identifiable need. Wherever possible, stations should be closed and trackage removed. Generally, the layout of the remaining stations should be standardized.

New electric station entry and starter signals will be installed. For estimating purposes, spring return switches (Appendix 3) are proposed for the loop. Alternatives include hand operated switches, trailable switches (Figure 5.6), and where justified, electric switches. The proposed modernization does not make use of track circuits"

Conceptually, some of the requirements for this type of signal operation are as follows:

- a station control panel and station, signals are illustrated in figures 5.3 and 5.4 respectively. Signals are normally held at stop, until a train movement is imminent. After train passage, the station master would restore the signal to stop.
- clearing an entry signal would prevent clearing the opposing entry signal and the opposing starter signals.
- clearing a starter signal would prevent clearing the opposing entry signal as well as the corresponding starter signal on the parallel track.
- switch alignment is automatically detected and no signal can be cleared if the switch at that end of the station is not properly

lined in either the normal or reverse position. (The exact arrangement depends upon the type of switch.) Switch alignment determines the signal aspect displayed.

The switches to the siding and to any other auxiliary trackage (if any) are not included in the signal system, and can thus be of any desired type. Ideally, they would be hand throw switches protected by padlocks,

A station approach sign is located outside the station limits at a distance allowing the train to stop, if necessary, at the station entry signal.

Figures 5.7 to 5.10 show, in a very simplified way, examples of system operation. The signal aspects shown are for illustration only. In reality, during the: initial detail planning stage, SRC will wish to develop a cohesive full range of aspects that can be applied to all foreseeable situations into the future. Figures 5.11 to 5.13 illustrate operation with trailable and spring switches.

It is emphasized that this proposed system is not: interlocking and is intended only to augment the inherent basic safety and operational methods of OCS. Proper operation is ensured by following the procedures defined in them rules.

Before giving the authorization to enter the station, the station master will verify that the switch is correctly aligned for the intended movement and that the track, onto which the train is to run, is clear. He operates the station entry control lever on the control panel to clear the station entry signal, authorizing the train to proceed to a position short of the switch for the loop at the far end of the station.

Train movements within the station limits are restricted to speeds which can allow a stop short of any obstruction. In no case should speeds exceed 25 km/h within station limits.

With OCS, the day can be foreseen when wayside station staff is not required for operational purposes. Since the proposed system is locally controlled, significant signal changes would be needed to permit this. Thus any signal system installed in the near future should be as inexpensive as possible and yet still serve its defined purposes.

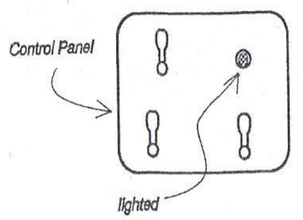
In addition to providing improved safety, this signal system should make it possible to avoid unnecessary stops to deliver certain OCS clearances. As described in step 1, Section 54.1, the Station Master must deliver each clearance to the train crew. In most cases, the clearance would authorize the train to advance towards the next station without any restriction, in such cases, the clearance procedures should provide that the starter signal can be cleared, and the clearance handed up to the train crew while the train is still in motion. Conversely, where a train is to be advanced with some sort of restriction, the starter signal must be held at stop, the clearance given to the driver who must acknowledge his understanding. Only then can the starter signal cleared.

YEAR		INITIAL FLEET							FLEET REQUIRED WITHOUT PROJECT		PRODUCTIVITY INCREASE		
		FLEET			RETIREMENTS			TOTAL					
Fiscal	Project	Initial Fleet	Rehabs	Purchases	Initial Fleet	Rehabs	Purchases	Total in Service	High Forecast	Low Forecast	Port Sudan – Khartoum	Khartoum – Kosti	Kosti – Babanousa
1993/94	−1	39	0	0	0	0	0	39	39	39	0%	0%	0%
1994/95	0	44	0	10	0	0	0	54	55	55	0%	0%	0%
1995/96	1	44	8	0	18	0	0	44	47	41	0%	0%	0%
1996/97	2	44	0	0	0	0	0	44	43	33	1%	0%	0%
1997/98	3	44	0	0	0	0	0	44	45	29	3%	1%	1%
1998/99	4	44	0	0	0	0	0	44	50	30	4%	2%	2%
1999/2000	5	44	0	0	0	0	0	44	55	31	4%	2%	2%
2000/01	6	44	0	0	3	0	0	41	60	33	4%	2%	2%
2001/02	7	44	0	0	10	0	0	31	65	34	4%	2%	2%
2002/03	8	44	0	0	0	0	0	31	70	36	4%	2%	2%
2003/04	9	44	0	0	0	0	0	31	75	38	4%	2%	2%
2004/05	10	44	0	0	0	0	10	21	75	40	4%	2%	2%
2005/06	11	44	0	0	5	8	0	8	75	41	4%	2%	2%
2006/07	12	44	0	0	0	0	0	8	75	43	4%	2%	2%
2007/08	13	44	0	0	0	0	0	8	75	45	4%	2%	2%
2008/09	14	44	0	0	0	0	0	8	75	48	4%	2%	2%
2009/10	15	44	0	0	4	0	0	4	75	50	4%	2%	2%
2010/11	16	44	0	0	0	0	0	4	75	52	4%	2%	2%
2011/12	17	44	0	0	4	0	0	0	75	55	4%	2%	2%
2012/13	18	44	0	0	0	0	0	0	75	57	4%	2%	2%
2013/14	19	44	0	0	0	0	0	0	75	60	4%	2%	2%
2014/15	20	44	0	0	0	0	0	0	75	63	4%	2%	2%

YEAR		FLEET REQUIRED WITH PROJECT						PURCHASES WITHOUT PROJECT		PURCHASES WITH PROJECT					
		PT. SUDAN–KH.		KH.–KOSTI		KOSTI – BABA				PT. SUDAN–KH.		KH.–KOSTI		KOSTI – BABA	
Fiscal	Project	High Forecast	Low Forecast	High Forecast	Low Forecast	High Forecast	Low Forecast	High Forecast	Low Forecast	High Forecast	Low Forecast	High Forecast	Low Forecast	High Forecast	Low Forecast
1993/94	−1	39	39	39	39	39	39	0	0	0	0	0	0	0	0
1994/95	0	55	55	55	55	55	55	1	1	1	1	1	1	1	1
1995/96	1	47	41	47	41	47	41	2	0	2	0	2	0	2	0
1996/97	2	42	33	42	33	42	33	0	0	0	0	0	0	0	0
1997/98	3	44	28	44	28	44	28	0	0	0	0	0	0	0	0
1998/99	4	48	29	49	29	49	29	3	0	1	0	2	0	2	0
1999/2000	5	53	30	54	31	54	31	5	0	5	0	5	0	5	0
2000/01	6	57	32	59	32	59	32	8	0	8	0	8	0	8	0
2001/02	7	62	33	64	34	64	34	15	2	15	1	15	1	15	1
2002/03	8	67	35	68	35	68	35	5	2	5	2	5	2	5	2
2003/04	9	72	36	73	37	73	37	5	2	5	2	5	2	5	2
2004/05	10	72	38	73	39	73	39	10	12	10	12	10	12	10	12
2005/06	11	72	40	73	41	73	41	13	15	13	15	13	15	13	15
2006/07	12	72	42	73	43	73	43	0	2	0	2	0	2	0	2
2007/08	13	72	44	73	45	73	45	0	2	0	2	0	2	0	2
2008/09	14	72	46	73	47	73	47	0	2	0	2	0	2	0	2
2009/10	15	72	48	73	49	73	49	4	6	4	6	4	6	4	6
2010/11	16	72	50	73	51	73	51	0	2	0	2	0	2	0	2
2011/12	17	72	53	73	54	73	54	4	6	4	6	4	6	4	6
2012/13	18	72	55	73	56	73	56	0	3	0	3	0	3	0	3
2013/14	19	72	58	73	59	73	59	0	3	0	3	0	3	0	3
2014/15	20	72	61	73	62	73	62	0	3	0	3	0	3	0	3

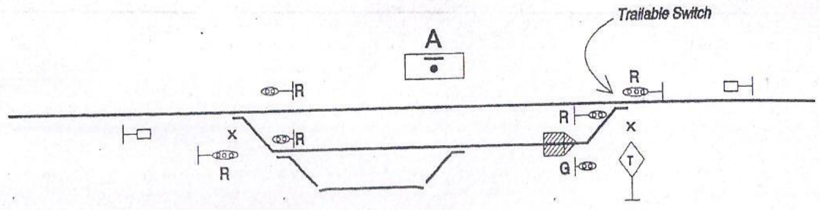
Figure 5.12 Operation of the Panel Indication for Trailable Switch

5.12.1 Normal Condition

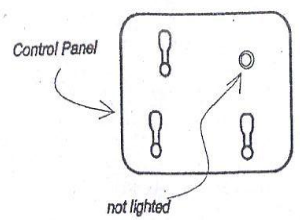


The electric switch is aligned correctly for the main track.
Yellow reflectorized target is displayed to an approaching train.

Train #1 may proceed.



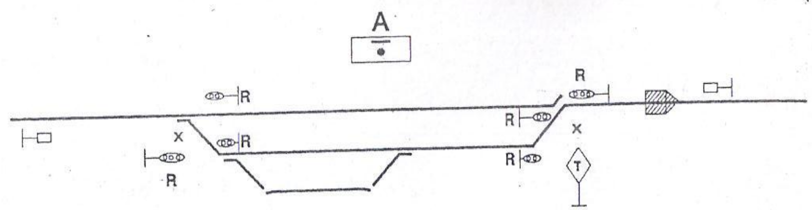
5.12.2

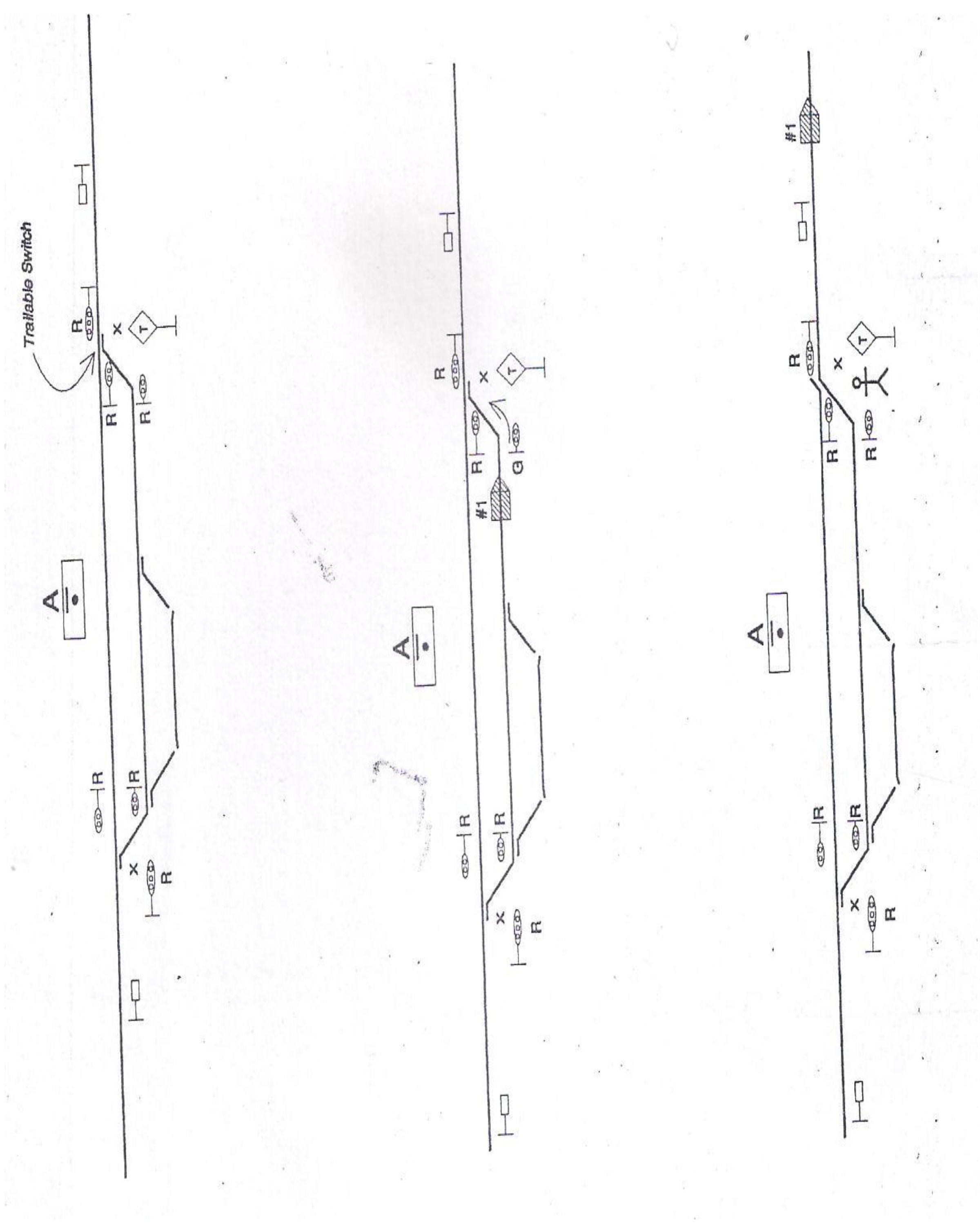


Switch has been trailed through.
White target is displayed.

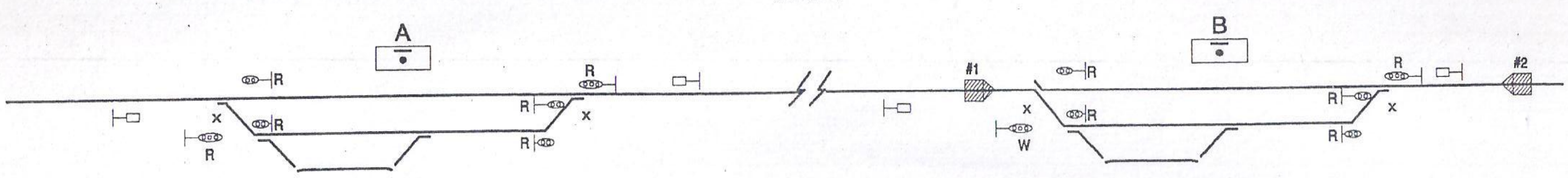
Panel light is extinguished, informing the Station Controller that the switch is <u>not</u> "Normal", ie, not aligned for the main track.

Note: It may be full reverse, or in an improper alignment. After each use, it must be checked manually and restored to normal alignment for the main track.



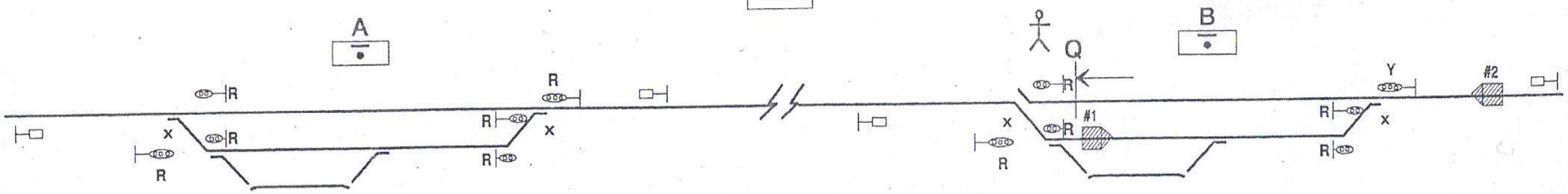

Trailable Switch
#1

5.10.4 Train #1 Entering the Loop at B



a) The Driver of Train #1 sees the White aspect on the entry signal and observes the reflectorized target on the switch showing that it is lined for the loop. He verifies that this corresponds to the instructions on his copy of the clearance.
He controls the speed of the train for safe entry to the loop.

5.10.5 Train #1 In the Loop at B



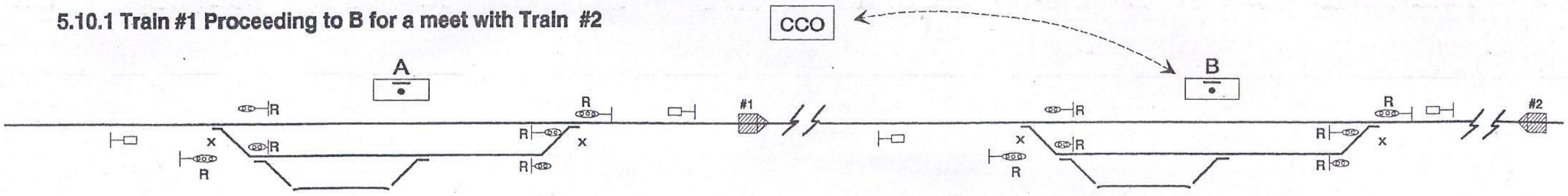
a) Station Controller B advises the CCO of the arrival of Train #1

b) Station Controller B may now clear the entry signal for Train #2 to use the main track.
By rule, the driver knows he must stop at Q and not proceed without further authority.

c) The switch must be manually lined for the main track after Train #1 is fully clear.

Figure 5.10

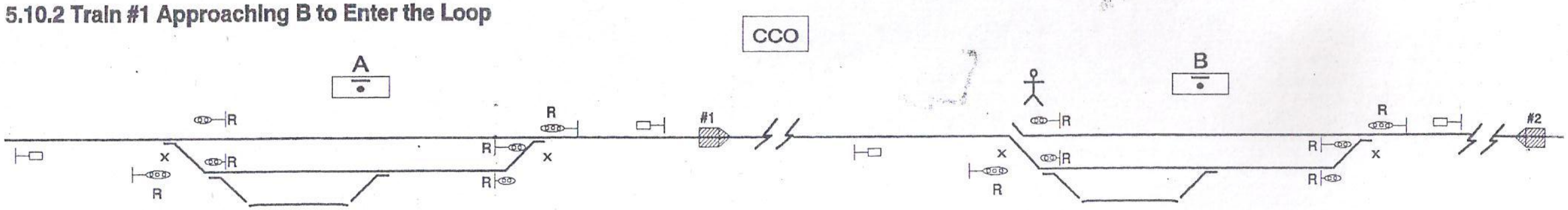
5.10.1 Train #1 Proceeding to B for a meet with Train #2



By means of an appropriate OCS clearance, CCO advises Station Controller B that Train #1 is to use the loop and Train #2 will use the main track.

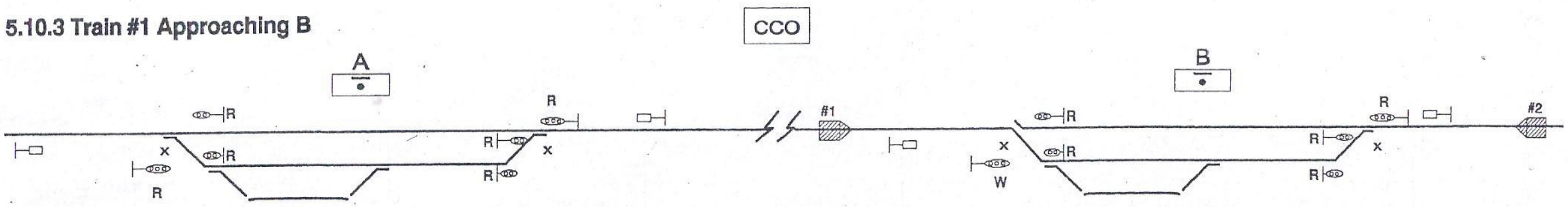
Station Controller B confirms understanding.

5.10.2 Train #1 Approaching B to Enter the Loop



Station Controller B (or a switch attendant) goes to the switch and lines it for the loop. He visually checks the points are aligned correctly.

5.10.3 Train #1 Approaching B



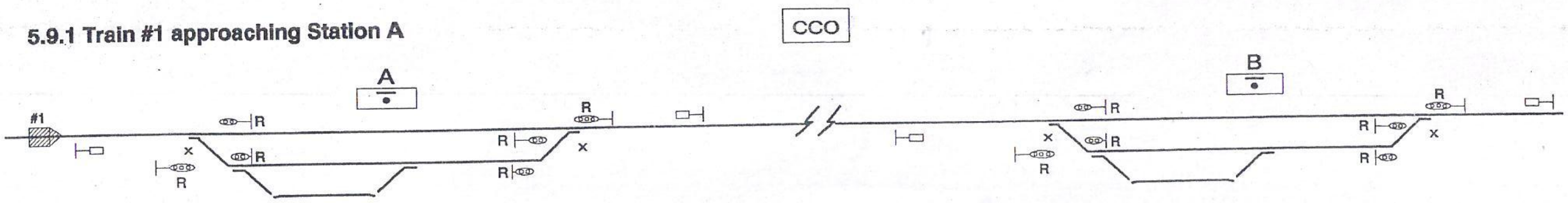
a) Train #1 is approaching B, preparing to stop, if necessary.

b) Station Controller B checks that all is correct for Train #1, and then clears the station entry signal

c) The switch point detector device automatically causes the entry signal to display White (instead of Yellow as in Figure 5.9.2) for entry to the loop.

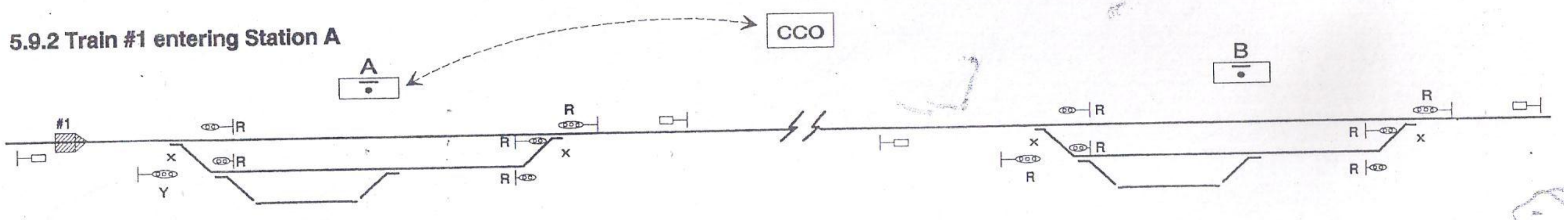
Figure 5.9 Station Entry

5.9.1 Train #1 approaching Station A



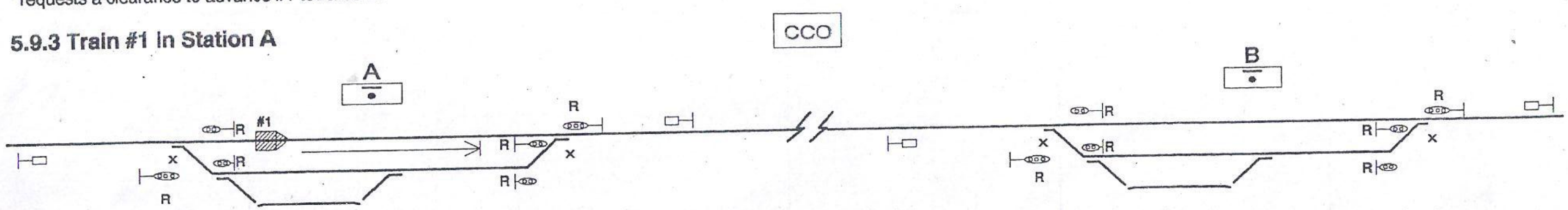
By rule, train #1 will approach the station entry signal prepared to stop, unless the signal is seen to be clear.

5.9.2 Train #1 entering Station A



After an appropriate OCS clearance has been issued, station Controller A clears the entry signal, authorising train #1 to enter the station on the main line. He checks that the train is complete.
He advises CCO, and if not already issued, he requests a clearance to advance #1 towards B.

5.9.3 Train #1 in Station A

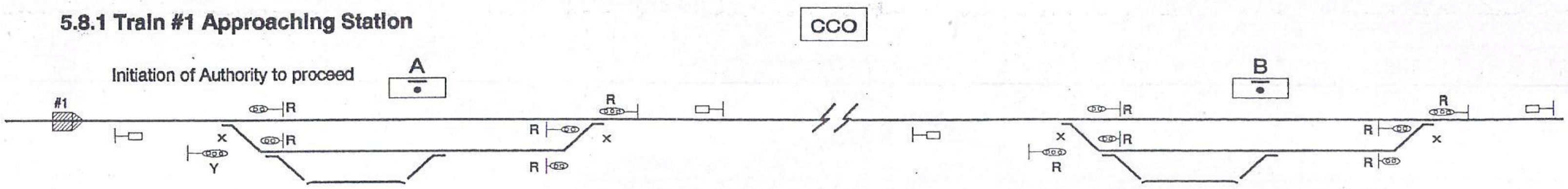


By rule, train #1 is prepared to stop clear of the switch, unless authorization is received to continue toward station B.
Immediately after train #1 has passed it, the Station Controller restores the entry signal to stop.

Figure 5.8 Issuing a Clearance Towards the Next Station

5.8.1 Train #1 Approaching Station

Initiation of Authority to proceed

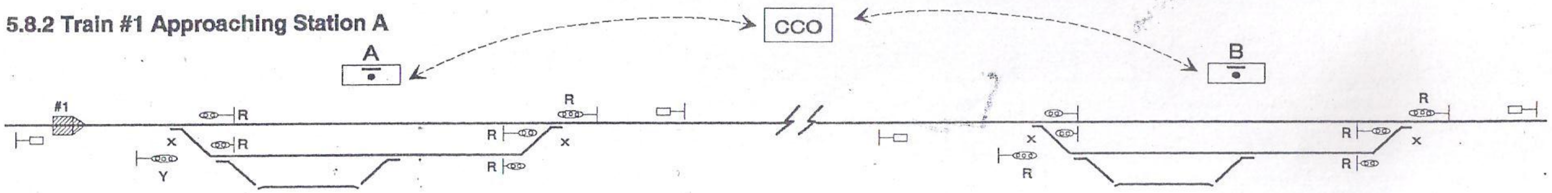


a) The CCO plans to allow train #1 to proceed toward B

b) He verifies from the computer system that there is no previously issued conflicting clearance.

c) If a conflict would b created, the computer system will not allow him to take further action until the conflict is resolved

5.8.2 Train #1 Approaching Station A

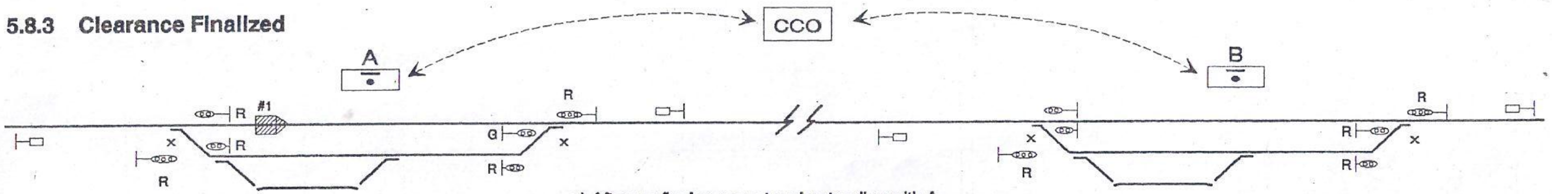


a) Using the formal wording displayed on the computer screen, the CCO dictates the clearance form to A and B

b) A fills in the blanks on the pre-printed forms as dictated by the CCO.
He confirms correctness with the CCO.

c) A fills in the blanks on the pre-printed forms as dictated by the CCO.
He confirms correctness with the CCO.

5.8.3 Clearance Finalized



a) After confirming correct understanding with A and B, the CCO authorizes A to allow train #1 to proceed.
This is registered in the computer system.

b) A clears the starter signal authorizing train #1 to proceed towards B.

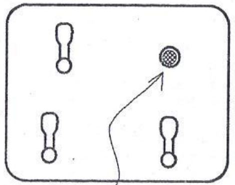
He delivers a copy of the clearance to the crew of the train #1.

c)After the train has passed the signal, A must return it to stop, and advise CCO that the train has left.

Figure 5.7 Use of Station Control Panel

5.7.1 Normal Condition

Control Panel

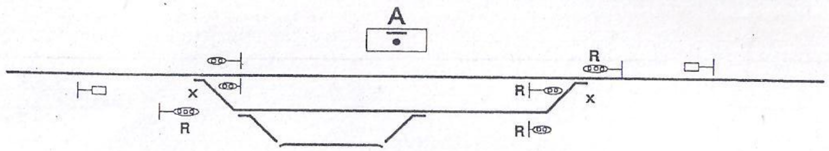


See figure 5.12 for operation of the trailable switch

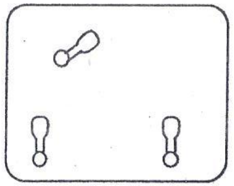
See figure 5.3 for details of Panel

Both Station Entry Signals at Stop
All starter Signals at Stop

All controls should remain in this position unless a train or trolley movement is to be authorized. Immediatelly after the train or trolley has passed the signal, the control should be returned to Normal position.



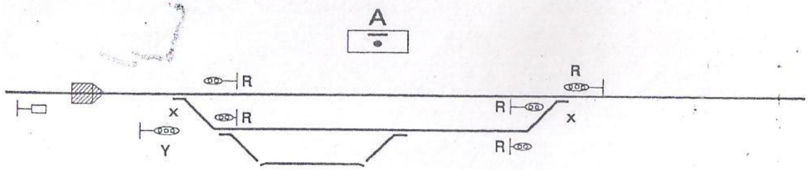
5.7.2 Station Entry Signals



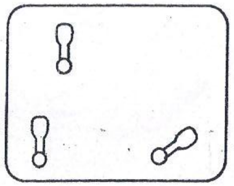
Control lever moved to the right
- Station entry signal displays an aspect for a train to enter the station.

Note 1: The entry signal would automatically display white if the switch had been lined for the loop.

Note 2: Moving the control lever to the left would clear the signal at the other end of the station. Only one signal can be cleared at a time.



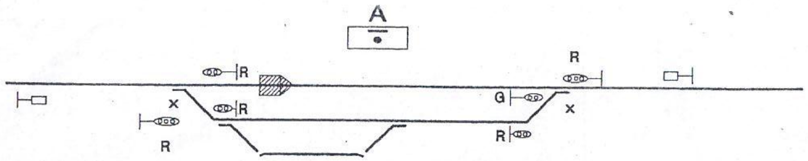
5.7.3 Starter Signals

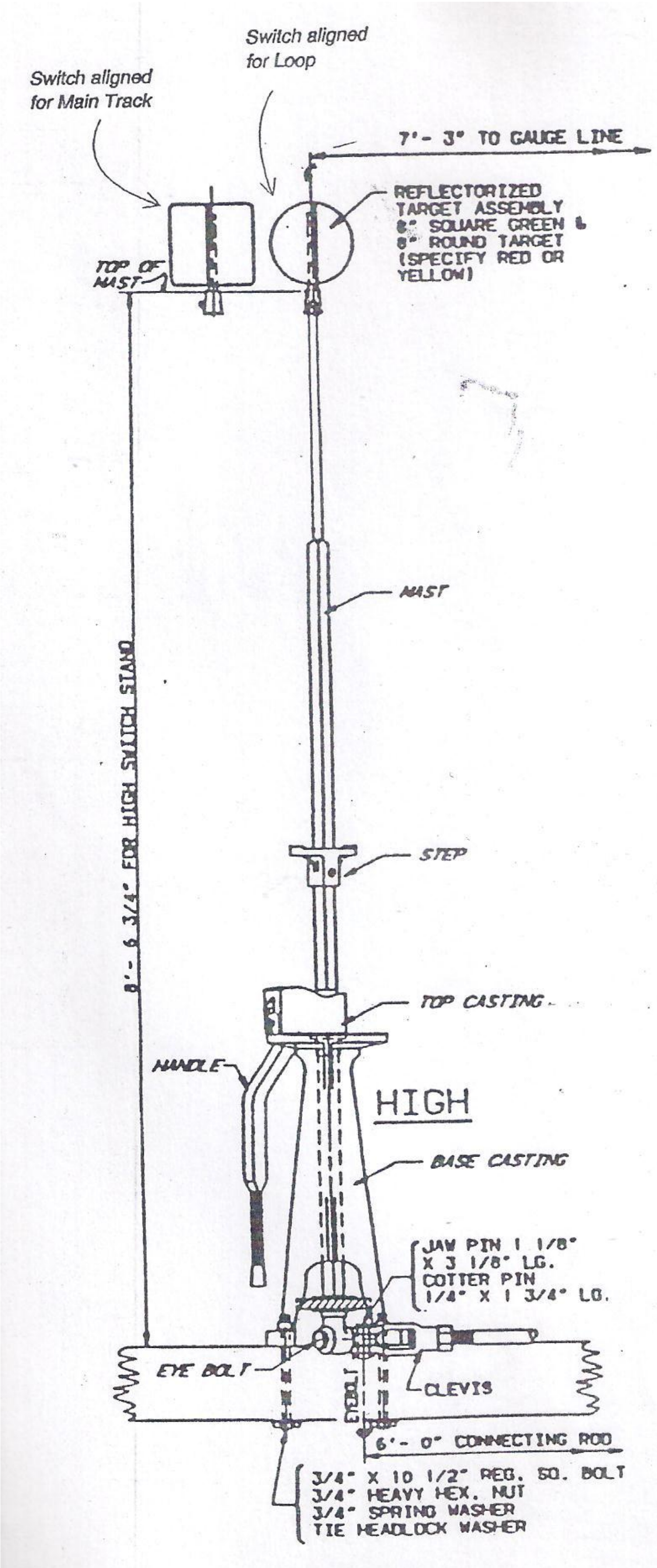


Control lever moved to the right
Starter Signal displays Proceed for a train or trolley (on the main track) towards the next station

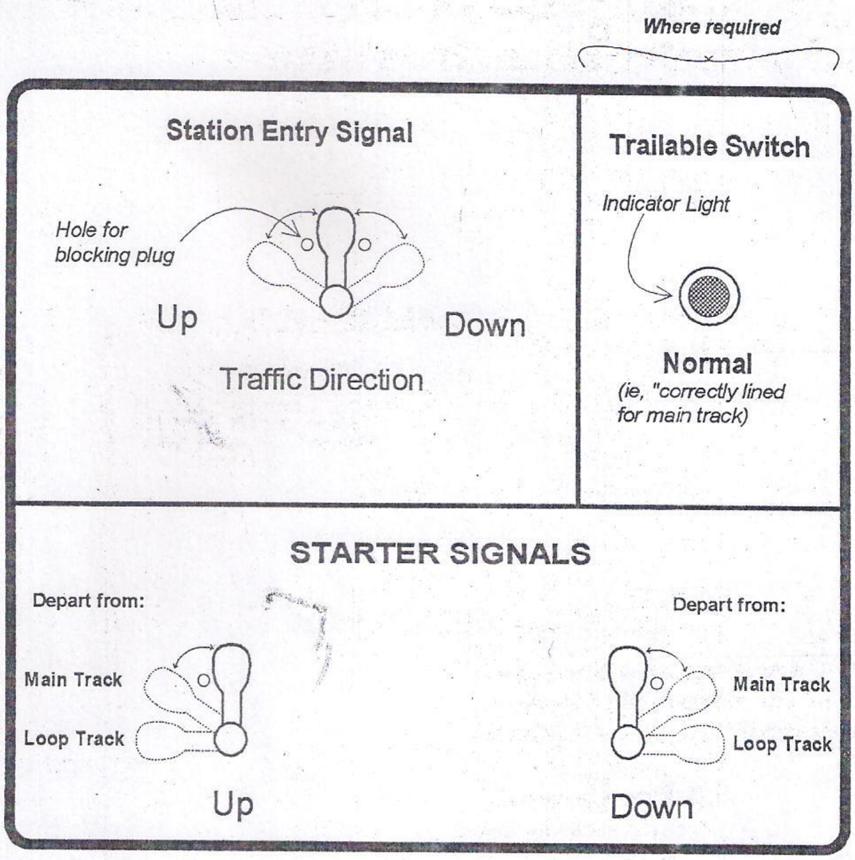
Note 1: Use of the other control lever would clear a signal at the other end of the station for traffic in the other direction.

Note 2: A third position of the control lever would clear the signal from the loop, rather than the main track.



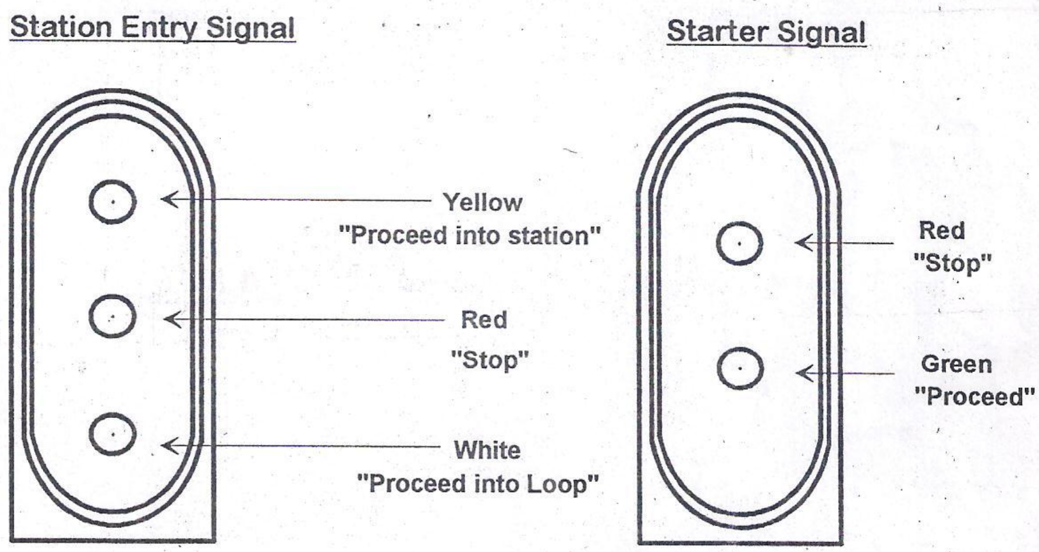


Switch aligned for Loop
Switch aligned for Main Track
7'- 3" TO GAUGE LINE
REFLECTORIZED TARGET ASSEMBLY 8" SQUARE GREEN & 8" ROUND TARGET (SPECIFY RED OR YELLOW)
TOP OF MAST
8'- 6 3/4" FOR HIGH SWITCH STAND
MAST
STEP
TOP CASTING
HANDLE
HIGH
BASE CASTING
JAW PIN 1 1/8" X 3 1/8" LG.
COTTER PIN 1/4" X 1 3/4" LG.
EYE BOLT
EYEBOLT
CLEVIS
6'- 0" CONNECTING ROD
3/4" X 10 1/2" REG. SQ. BOLT
3/4" HEAVY HEX. NUT
3/4" SPRING WASHER
TIE HEADLOCK WASHER



This diagramm is conceptual only: details are dependent upon actual circuit design

Figure 5.4 Light Signal Head Illustrations



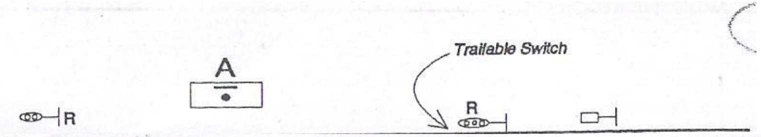


Figure 5.1 Typical Station Configuration Existing

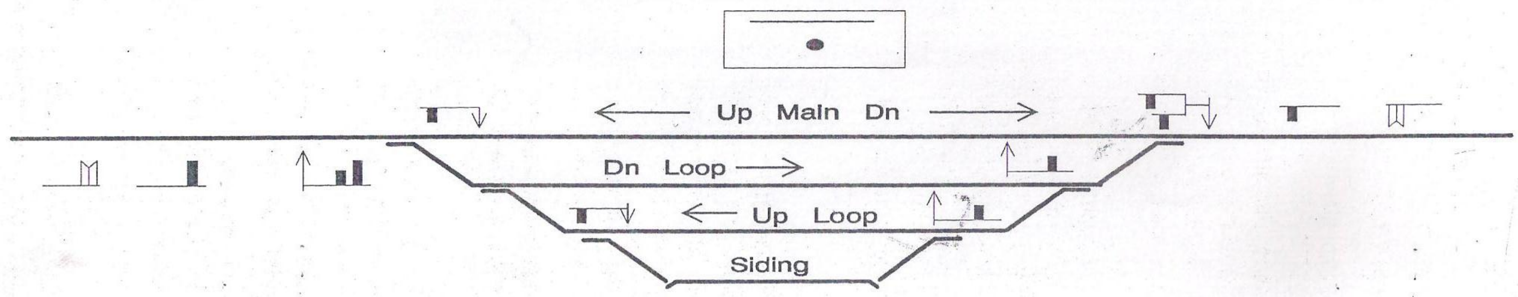
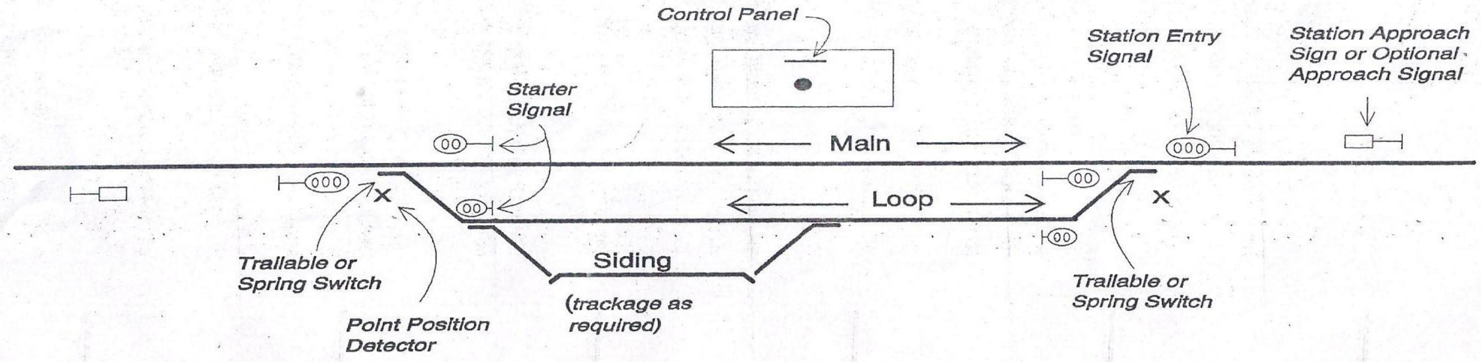


Figure 5.2 Typical Station Configuration Proposed



YEAR		INITIAL FLEET							FLEET REQUIRED WITHOUT PROJECT		PRODUCTIVITY INCREASE		
		FLEET			RETIREMENTS			TOTAL					
Fiscal	Project	Initial Fleet	Rehabs	Purchases	Initial Fleet	Rehabs	Purchases	Total in Service	High Forecast	Low Forecast	Port Sudan – Khartoum	Khartoum – Kosti	Kosti – Babanousa
1993/94	−1	39	0	0	0	0	0	39	39	39	0%	0%	0%
1994/95	0	44	0	10	0	0	0	54	55	55	0%	0%	0%
1995/96	1	44	8	0	18	0	0	44	47	41	0%	0%	0%
1996/97	2	44	0	0	0	0	0	44	43	33	1%	0%	0%
1997/98	3	44	0	0	0	0	0	44	45	29	3%	1%	1%
1998/99	4	44	0	0	0	0	0	44	50	30	4%	2%	2%
1999/2000	5	44	0	0	0	0	0	44	55	31	4%	2%	2%
2000/01	6	44	0	0	3	0	0	41	60	33	4%	2%	2%
2001/02	7	44	0	0	10	0	0	31	65	34	4%	2%	2%
2002/03	8	44	0	0	0	0	0	31	70	36	4%	2%	2%
2003/04	9	44	0	0	0	0	0	31	75	38	4%	2%	2%
2004/05	10	44	0	0	0	0	10	21	75	40	4%	2%	2%
2005/06	11	44	0	0	5	8	0	8	75	41	4%	2%	2%
2006/07	12	44	0	0	0	0	0	8	75	43	4%	2%	2%
2007/08	13	44	0	0	0	0	0	8	75	45	4%	2%	2%
2008/09	14	44	0	0	0	0	0	8	75	48	4%	2%	2%
2009/10	15	44	0	0	4	0	0	4	75	50	4%	2%	2%
2010/11	16	44	0	0	0	0	0	4	75	52	4%	2%	2%
2011/12	17	44	0	0	4	0	0	0	75	55	4%	2%	2%
2012/13	18	44	0	0	0	0	0	0	75	57	4%	2%	2%
2013/14	19	44	0	0	0	0	0	0	75	60	4%	2%	2%
2014/15	20	44	0	0	0	0	0	0	75	63	4%	2%	2%

YEAR		FLEET REQUIRED WITH PROJECT						PURCHASES WITHOUT PROJECT		PURCHASES WITH PROJECT					
		PT. SUDAN–KH.		KH.–KOSTI		KOSTI – BABA				PT. SUDAN–KH.		KH.–KOSTI		KOSTI – BABA	
Fiscal	Project	High Forecast	Low Forecast	High Forecast	Low Forecast	High Forecast	Low Forecast	High Forecast	Low Forecast	High Forecast	Low Forecast	High Forecast	Low Forecast	High Forecast	Low Forecast
1993/94	−1	39	39	39	39	39	39	0	0	0	0	0	0	0	0
1994/95	0	55	55	55	55	55	55	1	1	1	1	1	1	1	1
1995/96	1	47	41	47	41	47	41	2	0	2	0	2	0	2	0
1996/97	2	42	33	42	33	42	33	0	0	0	0	0	0	0	0
1997/98	3	44	28	44	28	44	28	0	0	0	0	0	0	0	0
1998/99	4	48	29	49	29	49	29	3	0	1	0	2	0	2	0
1999/2000	5	53	30	54	31	54	31	5	0	5	0	5	0	5	0
2000/01	6	57	32	59	32	59	32	8	0	8	0	8	0	8	0
2001/02	7	62	33	64	34	64	34	15	2	15	1	15	1	15	1
2002/03	8	67	35	68	35	68	35	5	2	5	2	5	2	5	2
2003/04	9	72	36	73	37	73	37	5	2	5	2	5	2	5	2
2004/05	10	72	38	73	39	73	39	10	12	10	12	10	12	10	12
2005/06	11	72	40	73	41	73	41	13	15	13	15	13	15	13	15
2006/07	12	72	42	73	43	73	43	0	2	0	2	0	2	0	2
2007/08	13	72	44	73	45	73	45	0	2	0	2	0	2	0	2
2008/09	14	72	46	73	47	73	47	0	2	0	2	0	2	0	2
2009/10	15	72	48	73	49	73	49	4	6	4	6	4	6	4	6
2010/11	16	72	50	73	51	73	51	0	2	0	2	0	2	0	2
2011/12	17	72	53	73	54	73	54	4	6	4	6	4	6	4	6
2012/13	18	72	55	73	56	73	56	0	3	0	3	0	3	0	3
2013/14	19	72	58	73	59	73	59	0	3	0	3	0	3	0	3
2014/15	20	72	61	73	62	73	62	0	3	0	3	0	3	0	3

3.2.2.5 Rail Operation Saving

The investment projects being considered would result in savings in the costs of rail operations. The nature of these savings and the methods used to estimate the amounts involved are described in the following subsections.

i. savings in Locomotives

The proposed signalling project would reduce the running time required for line-haul movements of trains. This would give rise to savings in the number d locomotives required for operation at a given level of traffic. For example, the sooner a train from Khartoum arrives in Port Sudan, the better the chance that the locomotive can be inspected and serviced in time to be used on the return train t Khartoum. line savings resulting from the signalllng project were estimated for tie Khartoum-Port Sudan run as follows.

The delay at the loop due to the exchange of the tokens can be eliminated by the use of the tokenless block system. The savings resulting from this were estimated at four minutes per station, These savings would apply to a tam which ran straight through, i.e., one that did not have to pull over due to train meets, however on average there are 2.5 train meets between Khartoum and Port Sudan. Time savings estimated as described above were, therefore, reduced to account for these meets, resulting in the following net savings:

Gross time saving: 144 minutes Reduction for meets: 10 minutes Net time saving: 134 minutes In addition, the improved signalling and switch system would be more reliable than the present system. Benefits from improved reliability were estimated to save 30 minutes on a one-way run between Port Sudan and Khartoum.

No savings in run1hrough time were attributed to the telecommunications program under consideration.

Line haul times were provided by the SRC for the various segments making up a round trip between Khartoum and Port Sudan. The total of these times comes to 75.7 hours. The estimated time savings due to signalling improvements were multiplied by two to reflect a round trip and divided by the total round trip time. This resulted in productivity improvements of six percent due to the change to a tokenless block system, and one percent for improved reliability, giving a total improvement of seven percent for the program as a whole.

Productivity improvements estimated for the Khartoum-Port Sudan run were assumed to apply elsewhere on the system as well1 That is, it was assumed that it improved signalling was instafled everywhere on the system the overall performance would improve by seven percent.

Benefits were attributed to the three segments under consideration (Port Sudan to Khartoum, Khartoum to Kosti, Kosti to Babanousa) by first applying this percent improvement to the system as a whole, then factoring it down in proportion to total net ton-kilometres accounted for by each of the two segments. Net kilometres used for this purpose were developed from data provided by the SRC showing traffic density by segment. This data was subject to two adjustments. First, the traffic level between Kosti and El-Rahad was adjusted downward on the basis of observations made by CANARAIL experts during their inspection of the system. This change was agreed to by the SRC. Second, the additional petroleum traffic from the refineries near Babanousa was added to the traffic. This was assumed to move by rail from Babanousa to Khartoum. The projected traffic level for 1996 (3,000 tonnes per day) was used for this purpose, with traffic elsewhere on the system assumed to have grown to a level sufficient to account for the base case projection for that year.

These estimated productivity improvements were translated into an increase in the capacity of the railway's locomotives, which in turn would lead to a reduced requirement for locomotives.

An initial estimate of locomotive capacity was developed from figures for the fiscal year 1993/1994. The total fleet of operating locomotives in that year was 47. These were not assigned to freight or passenger service on a dedicated basis. Train kilometres were estimated for both types of service, then compared to total locomotive kilometres (on the assumption that each train had one locomotive). There was a small unexplained difference between the two figures; this was allocated to freight service. The fleet was then allocated between freight and passenger service on the basis of locomotive kilometres, resulting in 39 locomotives being assigned to freight service and 8 to passenger. Total system tons and ton-kilometres were divided through by operating locomotives in freight service to develop measures of locomotive capacity. This resulted in a capacity of 45 thousand tons or 41 million ton-kilometres for the fiscal year 1993/1994.

Although ton-kilometres per locomotive is the more meaningful measure of the two, we used tons per locomotive in our calculations. Assuming no change in operating patterns, in particular, no change in average length of haul (ton-kilometres per ton)1 the two measures can be used interchangeably. In the present case, there is no reason to assume that operating patterns will change.

It was convenient to use annual tons per locomotive, as the traffic forecasts were expressed in tons rather than ton-kilometres, the present locomotive capacity is constrained by the large number of derailments on the SRC's lines.

It is expected that a planned program of track repair will decrease derailments substantially. Locomotive-kilometres per month are expected to rise from 4458 to 10,000 per month over a three-year period. To reflect this planned change, we increased Locomotive capacity in proportion to the increase in kilometres per month so that it stood at 100,638 tons (91 million ton-kilometres) per locomotive by fiscal year 1997/1998.

Locomotive capacity calculated in this way was used, in conjunction with the traffic forecast data, to estimate the locomotive fleet required by the SRC for each year of the analysts period on the assumption that no improvements are made to the signalling system. The fleet was then estimated in the same way, but taking into account productivity improvements due to improved signalling.

The two sets of estimates of the required fleet were compared to the available fleet. The available fleet was developed as follows. The fleet as of January 1995 was taken as the starting point. This amounted to 52, not counting a recent purchase of second-hand locomotives. Of this, eight locomotives were assigned to passenger service. The recently-purchased locomotives were added in 1994/1995.

Eight locomotives currently scheduled for rehabilitation were also added in 1995/1996. Retirements were calculated on the basis of a twenty-year service life for the initial fleet and a ten-year service life for the second-hand and rehabilitated locomotives. Dates of purchase were obtained from the SRC for the initial fleet and were used to develop retirement dates.

The initial fleet of locomotives was thus tracked over the twenty-year analysis period. This was then compared to the required fleet with and without improved signalling, and any difference made good by a purchase in the year in which it appeared. The details of this calculation are shown in Table 7.5, overleaf. The resulting two streams of purchases were used to estimate the savings in investment due to the project. We used a price of $ 2.5 million per locomotive, this being the price given by the SRC for a heavy locomotive.

Some consideration was given to attributing a reduction in maintenance costs, on the assumption that these are partly a function of the size of the fleet. However, discussions with SRC representatives indicated that maintenance is attributed 100 percent to distance (locomotive-kilometres) by the railway, so no savings of this type were estimated.

ii. Savings in Wagons

The estimation of savings in freight wagons was similar to the calculations described above for locomotives. That is, productivity improvements due to improved signallng and telecommunications Were assumed to increase the capacity of the freight wagons. The requirement for freight wagons was estimated with and without the project under consideration, and compared to the available fleet, with any differences being made good by purchases. There were, however, a number of differences between the two sets of calculations.

Time savings on the line haul movement due to signaling improvements were estimated as described for locomotives. However, the line haul movement accounts for only a part of the total wagon-cycle. According to data supplied by the SRC, a round trip between Khartoum and Port Sudan took 12.7 days in 1993/1994. As noted above, the line haul portion of this trip was only 75.7 hours, or 3.2 days. Time savings attributable to signalling improvements were therefore factored down to reflect the fact that they only apply to a part of the total wagon cycle.

Improved communications can save considerable time in detention of wagons at yards and terminals. The manifest for each train can be sent ahead to the stationmaster, thereby allowing him to plan the shunting operations required. A five percent decrease in detention time was attributed to this improvement. This, in turn was multiplied by the percent of the total wagon cycle accounted for by detention time to translate it into an overall percent productivity improvement. Detention time was derived by subtracting line haul time from the overall car cycle. Thus, for a round trip between Khartoum and Port Sudan, the total wagon cycle was 12.7 days, the line haul time 3.2 days and the detention time 9.5 days, or 75 percent of the total.

The estimation of retirements also differed somewhat from the corresponding process for locomotives. The service life for wagons was obtained from the Chief Accountant's office. This is 30 years Data available to calculate retirements as of the 1993/1994 fiscal year were a breakdown of the operating fleet by type of wagon, and a detailed schedule showing dates of entry into service for the entire fleet (operating arid out of service). Dates of entry into service were given for various groups of wagons within the broader categories shown for the operating fleet, usually in the form of a range of years, rather than as a single year for each group.

Using these data, we developed retirements as follows, First, the midpoint was calculated for the years of entry into service for each group shown in the detailed schedule. Then, the wagons in the detailed schedule were grouped into vintages. Any vintage which would have been more than 30 years old at the beginning of the analysis period was eliminated. However, where the remaining vintages did not suffice to account for the operating wagons in each broad category, the difference was assumed to have been brought into service in 1965. If there was a 1965 vintage for the category in question, this difference was added to it. If not, an artificial 1965 vintage was created.

The various vintages by category were then regrouped for the wagon fleet as a whole. In this way, the entire operating fleet as of 1993/1994 (3,430 wagons) was accounted for. Another 11000 wagons are currently scheduled for rehabilitation. On the advice of the Mechanical Directorate, the rehabilitated wagons were not given a separate service life from the rest of the fleet. These were simply added back into the fleet, and the same service life and average age were attributed to them. Thus, each vintage was factored up by 4430/3430 to reflect the rehabilitated wagons. Each vintage developed in this way was retired on reaching the end of its 30-year service life.

As noted above, aside from these differences the calculation proceeded in the same way as for locomotives. The results are shown for the Port Sudan-Khartoum segment in Table 7.6, overleaf. A purchase price of $ 100,000 (supplied by the SRC) was assumed for each wagon saved in this way. As with locomotives, the attribution of additional savings due to reduced maintenance costs was considered, but rejected because the SRC considers all maintenance costs to be distance-related.

3.2.2.6 Conclusions & Recommendations

The results of the study have shown that the modernization projects proposed by CANARA1L as outlined in chapters 5 and 6 of the present report, are financially and economically justifiable based on the traffic assumptions provided by SRC Projects analyzed have been shown to be viable as "stand-alone" projects, i.e. SRC can implement any single one of the numerous options on their own and still obtain a good economic result. The only note of caution concerns the proposed radio project south of Khartoum the economic and financial analyses demonstrate that the modernization of the telecommunications system between Port Sudan and Khartoum, Using fiber option technology is justifiable. The analysis also supports CANARAIL'S recommendation to modernize the signaling system between Port Sudan and Khartoum based on the proposed OCS scenario. Both conclusions are robust and remain true under sensitivity analyses performed.

The implementation strategy of the modernization of the SRC's signalling and telecommunication infrastructure should be developed taking into account some or all of the following factors:

- The amount of funds available to the SRC to implement the project.
- The choice of an implementation strategy on the basis of giving priority to those options yielding the best economic results.
- The urgency expressed by the transportation department concerning some sections of the line, particularly in the busiest sector between Khartoum and Port Sudan.
- The possibility of leasing long distance telecommunications circuits from SUDATEL between Khartoum and Port Sudan, once they have implemented their own fibre optic project.

It is recommended that the SRC first concentrate in modernizing its telecommunications and signalling systems in its busiest corridor, i.e. between Port Sudan and Khartoum, this modernization includes two parallel projects:

- Installation of fibre optic cable on the existing pole lines with an interface at each station.
- Implementing signal modernization together with OCS.

The construction strategy to be adopted involves starting the construction site at Atbara and gradually progressing towards Khartoum and Port Sudan.

The cost of implementing this first phase of telecommunications and signalling modernization between Port Sudan and Khartoum is estimated at USS 1415 million of which amount US$ 10.6 million represents the telecommunications modernization and USS 3.8 million, the signaling modernization.

Modernization of the telecommunications between Khartoum and Babanousa should be carried put during a future phase which would be viable with the coming on stream of large economic development projects, such as the development of petroleum fields. This decision may be of strategic importance tor, the Sudan and the SRC's future development plans.

Prior to the start of the parallel projects1 SRC must negotiate with SUDATEL the question of ownership of the pole lines1 since a rehabilitation of the pole line is the first step prior to installing a new fibre optic backbone.

The possibility of leasing circuits from SUDATEL or of joint ventures with SUDATEL should be considered as negotiations could lead to mutually beneficial development for both SRC and SUDATEL.

For the segment stretching from Khartoum to El-Rahad, the "cellular" radio project should be re-examined in about three to five years in order to recess its feasibility. Other technical solutions may then prove more beneficial for SRC.

3.2.3 Part Three: Motive Power & Rolling Stock

- **Background:**

The literature which shall be presented in this part shall cover main components of the railway business.

The motive power, the rolling stock & the train resistance.

The railway needs to select its motive power & rolling stock to efficiency perform its specified duties. Therefore the information we need, which shall be presented here, include design parameters, locomotive performance, electrification, rolling stock design & train resistance.

Motive Power Selection - Diesel Electric Locomotives [5]

The cost of locomotive is proportional to functions of its mass and power output. For a given performance curve however, the cost per unit of power decreases as the mass of the locomotive increases. It follows the heaviest locomotives will provide the most economical provided that all the power paid for is being used to satisfy this requirement it is necessary to produced performance curves for the haul route.

From these a duty point can be selected which will satisfy the critical operating requirement .the total motive power can be designed to meet this duty point with the minimum whole number of locomotives .

The axle load of the locomotive may be exceed the truck axle design load by ten percent insofar as the permanent way and information are concerned, but the structures must be checked for locomotive dynamic loading .

Design Parameters

Before we can start to design our locomotive let us look at the application and all the relevant information we need to know.

1. Climate-temperature range, humidity, rainfall, snow, sandstorms etc.

2. Altitude.
3. Track gauge.
4. Moving structure gauge.
5. Maximum permissible axle load, as determined by permanent way, bridges etc.
6. Route profile of the track over which the locomotive will operate.
7. Track curvature.
8. Maximum speed of the locomotive and various classes of trains.
9. Speed restrictions and braking rates.
10. Make-up and weight of trains-types and details of rolling stock.
11. Type of brakes required.
12. Train resistance information.
13. Average speed or total time allowed for runs.
14. Its multiple units working required?
15. Is dynamic braking required?
16. Auxiliary power requirements - Locomotives and train.

Having all this information, let us briefly run through the basic design calculations with an example:

It is required to start a train with a total weight including the locomotive, of 1050 tonnes (1033 tons) on a 1.25% grade (in this case the whole train is assumed to be on the grade, but in the case of long trains only that pan on the grade would be considered)

Grade resistance = l000/00 x 1.25x 1050 = 13125 kg

(28928 Ibs)

Train "break-away" resistance = 7.6 x 1050 = 7980 kg (17588 Ibs)

Total resistance = 21105 kg (46516 Ibs)

(21.11 tonnes) (20.77 tons)

The locomotive must be capable of exerting this attractive effort without the wheels slipping and this is dependent upon the adhesion between rail and wheel and the weight (adhesive weight) of the locomotive.

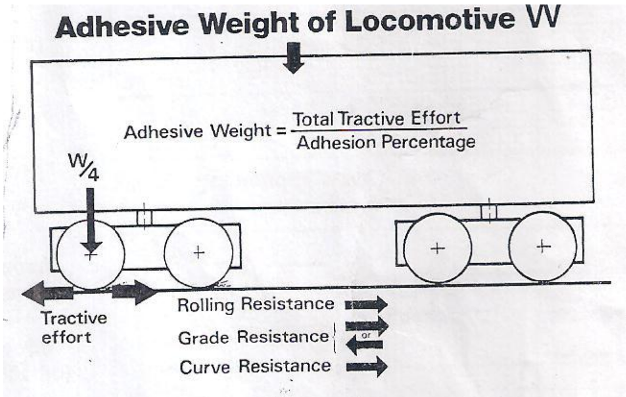


Fig. 1 Forces acting on locomotive.

Fig (3/12)

The adhesion varies with the state of the rail and a set of curves covering different conditions is shown.

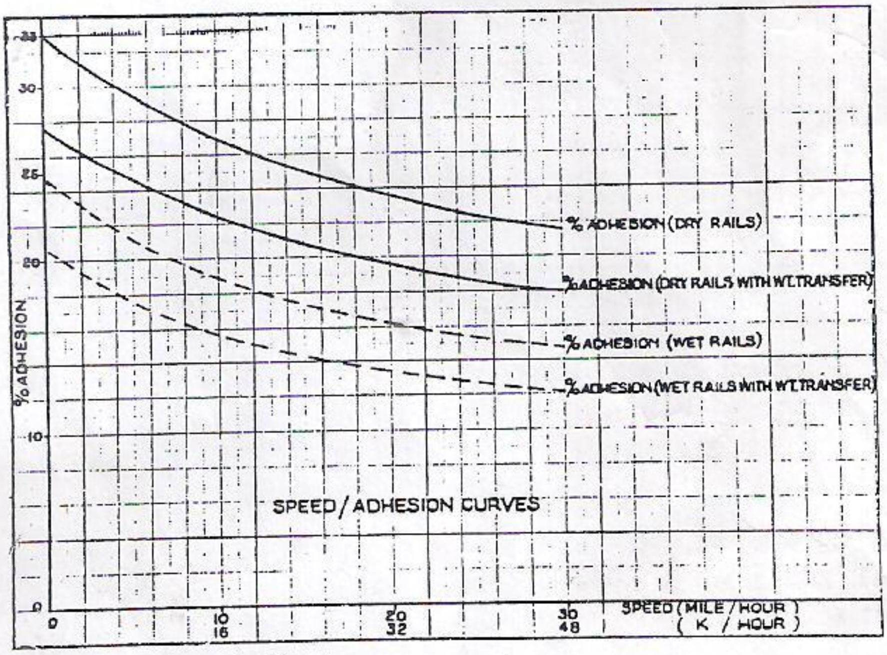


Fig. 2 Speed/adhesive curves.

Fig (3/13)

Careful consideration must therefore be given to determine the adhesion factor to be used to ensure being able to start a train under the worst local conditions, and this can be as low as 20%. The transmission must be capable of utilizing an adhesion in excess of this and 30% is a usual figure although higher values can occur and must be considered, particularly where wheels are coupled by side rods or carding shafts and wheel slip provides the ultimate measure of protection against overloading. Considering our example, therefore, and an adhesion of say 25% at standstill;

The adhesive weight is 21.11/ 0.25 = 84.44 tonnes

(83.08 tons)

If permitted axle load is 15 tonnes (14.76 tons), then the number of driven axles is six 84.44/15 = 5.63 15

This is the simplest terms and the effects of weight transfer have been ignored.

As a first approximation, the power required to meet the proposed timing over the route is determined from the average required and the steepness and length of the nett effective grade or the average grade.

The value of this gradient is obtained by study of the route profile. For example, if it is required to move the 1050 tonne (1033 ton) train over an average gradient of 1% at an average speed of 48 km/h (30 mile/h):

Grade resistance = 10 kg/tonne (22.4 lbs/ton)

Rolling resistance at 48 km/h = 2.68 kg/tonne (6 lbs/ton) For Power we use the formula:

Power (metric) = Tractive Effort (kg) X Speed (km/h) 270

Or

Power (imp.) = [Tractive Effort (lb) x Speed (mile/h)]/375 where tractive effort is equated to the effort required to overcome the grade resistance and rolling resistance.

thus Grade Power = [1050x l0 x 48]/270 = 1867 metric hp at rail (1851 hp)

Train Resistance = [l050x2.68x48]/270 = 500 metric hp Power at rail (496 hp)

Total Rail Power = 2367 metric hp (2347 hp).

The rolling resistance will have been obtained from tests with the type of rolling stock in question or by using one of the many formulae evolved for its calculation such as David formulae. The principal factors which give rise to rolling resistance are:

(i) Journal friction which can be considered as a constant at all speeds.

(ii) Friction between wheel and rail and track resistance which vary directly with the speed.

(iii) Air resistance which is dependent upon the square of the speed.

Obviously, these factors will vary with weather conditions and in climates where extremes of temperature of high winds are encountered some compensation allowance should be considered.

We have now derived “rail power” and must next consider the “Power losses” in the transmission together with the power requirements of all auxiliary machinery and services within the locomotive to determine the gross installed power requirement of the diesel engine.

Reference to the U.I.C. definitions of locomotive power will assist at this point.

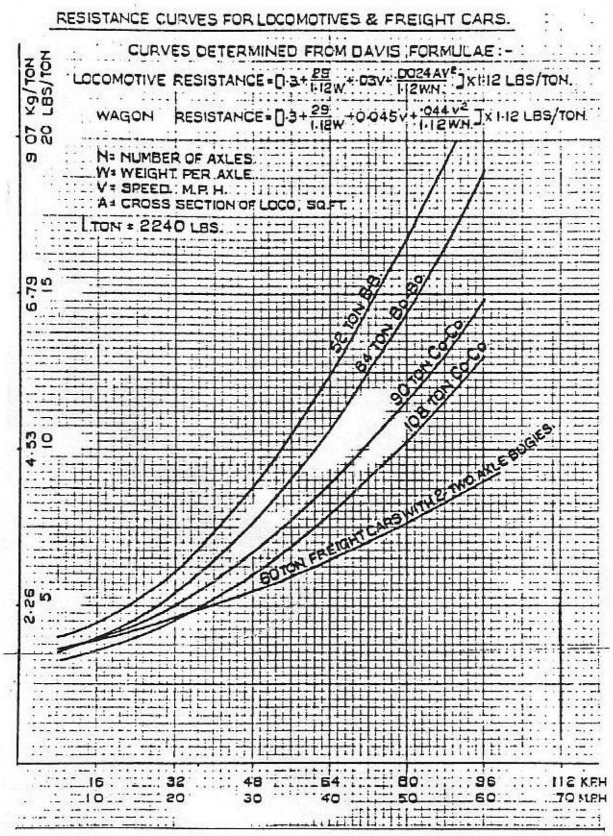


Fig. 3 Resistance Curves.

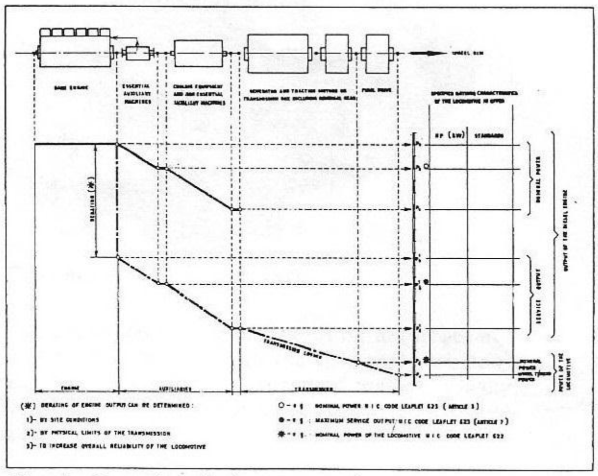


Fig. 4 Gross installed power requirement.

Fig (3/14), (3/15)

We have now derived maximum power so next let us examine some other critical areas using a basic curve of locomotive attractive effort and speed.

Maximum locomotive speed

Subject to the suitability of the general locomotive design, bogie suspension etc. speed is restricted only by the maximum allowable rev/mm of the traction motor armatures.

Maximum locomotive speed on full power

This depends on a combination of factors, the most important being the correct selection of generator characteristic for the planned duties. The transmission may be designed to accept full engine power up to the maximum desired locomotive speed, or it may unload at some lower speed.

Maximum tractive effort

This may be either the limit of effort that the likely wheel/rail adhesion will permit, or the effort corresponding to the maximum current permitted in the electrical machines.

Continuous and short-term ratings

The continuous rating is that current level at which the electrical machines can operate continuously without the machine temperature rise exceeding specified level. During periods of acceleration or severe gradient operation, heavier currents may occur for short periods, but these would be within acceptable limits dependent upon the designed in thermal capacity of the machines.

For locomotives on shunting or secondary duties an intermittent rating, possibly one hour, is more applicable as a guide to comparative suitability.

Where a traction duty can be accurately defined, then for maximum efficiency, the machines may be rated by design to suit that duty, but for general purpose work, a good approach is to design for a continuous rating at attractive effort level approximating to the likely adhesion limit point on full power.

Remembering that this paper is on diesel-electric systems, we should also take note of the continuous and intermittent ratings applying to the diesel as sensible matching of all equipment is advisable economically.

Transmission efficiency

This is the ratio of effective output at the wheel rim to not input to the generator for traction purposes only and with the electric system a usual value is 82-83%. Locomotive overall efficiency will take account of all diesel engine and auxiliary systems losses.

Locomotive performance:

An example to show how designers / manufactures respond to the request of SRC to fulfill. The locomotive performance item of its specification is goaled here and from the offer of GEC presented in tender for purchase of locomotive.

Electrification

Electrification is the future of all railways worldwide. Its progress is fast in rich countries, slow in poor countries.

The Economic Merits of Diesel and Electric Motive Power[6]

1. The Importance of Choice of Motive Power Policy

The selection of motive power policy is of crucial importance to any railway. It can be considered as one of the fundamental parameters of the railway system along with such items as track and loading gauges, maximum axle load, etc. Once a choice has been made and the resulting commitments implemented then subsequent fundamental changes in the policy can only be instituted at an economic cost over a Long period of time. Meanwhile, the Costs of the original mistake, if mistake there be, continue until a complete changeover is affected.

The crucial economic importance of selecting appropriate motive power policy will be apparent when it is realized that on typical railway systems the proportion of total assets in motive power and the proportion of running expenses concerned with motive power are substantial, say between ¼ and ½ in each case, so that comparatively small changes in the level of assets or expenses due to changes of policy will generally have a large effect on the overall financial position of the railway.

There is no universal answer to the problem of choice of motive power policy. There are, however, universal principles which can be use to investigate, assess and make proposals for each project. The application of these principles to varying situations is the subject of this lecture. Neglect of the use of these principles by a railway administration is tantamount to admitting that it does not have a soundly-based motive power policy and perhaps not even a policy at all.

2. An Example of Economic Comparison between Diesel and Electric Motive Power

The main issue is whether diesel locomotives are the right choice or whether electrification is better. Electrification normally shows a clear economic advantage on provision, maintenance and operating costs of locomotives only, hut against this must be set the cost of providing and maintaining the fixed electrical supply system. Thus for example a system has a volume of traffic which would require:

40 diesels costing £1000000 each

or 25 electrics costing £800000 each

(It will be seen later why the locomotive provision is different in each case).

The estimate of annual costs might be:-

diesel (interest and depreciation, maintenance, servicing, crew and fuel) £9.2 million electric (interest and depreciation, maintenance, servicing, crew and fuel) £5.6 million

This is £3.6 million a year in favor of electric traction before allowing for the cost of the fixed electrical equipment. Suppose this has a first cost of £30 million, with

Annual costs (interest, depreciation and maintenance) of £6m. The total costs then become:

Diesel £9.2 million

electric £ 11.6 million

which shows diesel to the better proposition by £2.4 million per year.

But suppose that over the same railway the traffic doubled necessitating twice as many locomotives, and therefore twice the locomotive costs, the totals then become: -

diesel 2 x £9.2 million = £18.4 Milton £18.4rn

electric 2 x £5.6 million = £11.2 million

fixed equipment £6.0 million f17.2m

This now shows electrification to be the better proposition by £1.2 million per year.

Several important conclusions of universal application can be drawn from this simple example:

2.1 Lower traffic densities tend to favor diesel traction. Higher traffic densities1 electri1cation. The actual traffic levels at which one becomes better than the other is completely dependent upon costs applicable to the particular project under study.

2.2 A short term view can give a very misleading picture, and if acted upon can result in an incorrect decision. Thus, if in this example the traffic level was expected to rise over a period of time from the lower level to the higher, what then is the correct decision for motive power choice? Again, if relative cost of fuels, for instance, is likely to change over a period, how can this be taken into account in an evaluation?

Various techniques are available for financial appraisal of projects whose individual cost elements vary From time to time. The most common and widely used of these is that of discounted cash Flow'' (dcf.).

2.3 Only on routes which have a clear continuing future will there be economic justification for electrification. The annual costs in the example assumed that the equipment had a useful life of some 20 or 30 years. A reduction in this life increases annual costs to the disadvantage of electrification.

If traffic demand alters, the electric locomotives can be transferred to another electrified line. The fixed equipment must remain. On the other hand. diesel locomotives permit transfer of the whole of the assets at any time to another route. The fixed electrification system limits freedom of movement of the locomotives to those lines which are electrified and a joint diesel and electric system may be proposed as the best compromise between a fully electrified railway and one which relics entirely on diesel operation.

2.4 The viability of an electrification scheme will be strongly influenced by the timing of its introduction. Electrification is more easily justified on a new railway or where major expenditure is necessary to refurbish an
existing one i.e. when useful assets are not displaced.

3. Restraints on Choice of Motive Power Policy

These arise from considerations of national policy, political and social factors. The effects of these may be difficult to turn into money values but they may completely override some or all of the factors discussed elsewhere in this lecture.

i. Local manufacture or importing locomotives and equipment

(National considerations may effectively influence the ultimate decision and outweigh economic considerations. imported material may be too expensive or even prohibited due to adverse balance of payments. Local industry, may not have the capability to design and manufacture to the railway's requirements. -A possible compromise may well be local manufacture under license of foreign designs or even "buying-in" of certain foreign skilled personnel.

An important direct economic factor is the source of. and conditions attached to, any loans which may be raised to assist the particular project under consideration. It is not unknown for these to be granted subject to purchase of equipment in one particular country only.

ii. Fuel

In spite 'of the importance of fuel and energy supplies to modern industrial states, very few have any explicit long term national fuel policy. Most governments, however, do have short term ad hoc fuel policies which are adjusted to suit changes in international and national conditions. Whilst this makes Ion term railway planning difficult, it is suggested that the most important factor in fuel selection is long term availability, taking into account those strategic factors Likely to have an influence.

Price is the major factor in fuel selection but its effect may be subordinated to availability by national policies. For diesel locomotives oil is the only fuel, but an electrified system may be electively powered by any or all of coal, oil, gas, waterpower and nuclear energy. Electricity is, therefore, generally cheaper than oils having a wide range of energy sources to draw upon. Further, countries having little indigenous oil are likely to be able to forecast and control the cost of electricity much more effectively than they can the cost of oil.

Diesel oil has the advantage of portability, whereas an electrified railway of any extent depends upon the existence of a reasonably substantial and appropriately widespread public power supply system. In its absence an expensive railway-owned power generation and transmission system will be required.

iii. Railway staff and maintenance facilities

It is essential to obtain men of the right quality to operate and maintain new Locomotives; otherwise the potential savings may be lost. For some locations this may be difficult. If so, the new motive power could be deferred until Labor can be trained or competent staff could be imported and train local labor. The costs of each course of action must be taken into account in selecting motive power.

Equally, one cannot afford to skimp equipment and building for servicing and maintenance. A fleet of 100 diesel locomotives costing about £100 million might require maintenance and overhaul Facilities costing up to £16 million. Failure to provide proper Facilities might lead 10 the need to purchase further locomotives to move the same traffic.

Incidentally, a dieselized railway, being more labor intensive than an electrified one will offer more employment opportunities. This may be a factor in some countries.

4. Technical and Operating Differences

This section is concerned only with those Factors leading to assessment of locomotive productivity and total locomotive requirements.

The total volume of triadic must be expressed in net tone-km per year. Passenger-km per year or similar quantities.

Locomotive productivity in net tone-km (or passenger-m) per locomotive per year

= Average net tones (or passengers) per train

X Average speed of train (km/h)

X Locomotive Utilization (hours per day hauling trains)

X Locomotive Availability (%)

X Number of Working days in year.

The parts or this statement will be different for various forms of motive power and groups of traffic. The productivity divided into the traffic volumes vices the total locomotive fleet subject to the addition of operating and maintenance spares. The method can he applied for sections of the railway system, and separately for deterrent groups of traffic. It should not be overlooked that the volume of traffic might change according to the new choice of motive power and the deterrent qualities of service that can then be provided.

The size and load of each train will be constrained by:

(i) Route Limit on physical length

(ii) Track Limit on axle loads

(iii) Strength of rolling stock drawgear

(iv) Route capacity

(v) Locomotive characteristics

(vi) Ability to start loads

The first four may often have to he accepted as unchangeable, but track strengthening and/or new rolling stock, associated with a change in motive power, may give the greasy overall advantage. similarly, new motive power may mean an increase in train sizes on existing track Figs. I and 2 show the different capabilities, affecting loads and speeds, for typical examples of larger BR locomotives, illustrated by the characteristics of a Class 47 diesel and a Class 87 electric as used for timing purposes with performance limited4by adhesion.

The starting abilities of each are related to the loading on the driven axles. With an electric locomotive high power can be obtained from light vehicles. However, on difficult gradients this feature might be of little value if it were an essential requirement to start very heavy trains.

In the middle range of speeds, although short-time rated, the electric locomotive, with its high output, allows rapid acceleration and sustained high speeds on rising gradients which, in the U.K. with mixed traffic and steep short gradients, are attractive characteristics.

Both diesel and electric locomotives are subject to short-time rating limitations at higher tractive efforts but the speed range over which this applies will usually be much wider for the electric.

Consequently, prevention of over-heating must be more carefully safeguarded. In the examples shown the diesel is short time rated up to about 40 km/h but the electric up to 130 km/h.

At the highest speeds on flat routes these particular locomotives can put up similar performances on long distance services with light trains. On hilly routes the more powerful electric Locomotive will have a distinct advantage subject to starting.

These locomotives are typical examples of their breeds. Other lectures will indicate how the best locomotive of a given type is selected for particular duties. Having looked at these things, it should be possible to define

The optimum load and speed of each type of train. The average speed for electric trains will normally be rather higher than that of diesels. Also the speed band between the fastest and slowest trains will be narrower for electric trains than for diesels. This has implications on the route capacity.

Two other factors remain:

(i) utilization, which is a measure of operating efficiency,

(ii) availability, which is a measure of engineering excellence.

Utilization means the number of useful hours in traffic during every 24 for which the locomotive is available to the operating department. For high utilization a good operator will ensure day and night transit at a steady load but it will be low if the traffic is unbalanced by daily or seasonal variations. Typical figures for BR. are in the range 12 to 15 hours for diesel and electric traction.

Availability, expressed as a percentage, gives the proportion of total time in which the locomotives are available for use by the operator.

Typical values for B.R. are 80% for diesel and 90% for electric traction, which of course will not be achieved by some locomotives but exceeded by others. Thus diesel availability may decline towards 75% if utilization improves to 15 hours per day and locomotives cover over 250,000 km a year each, due to the additional maintenance work particularly on the engine. Note, however, that although availability has fallen overall productivity increases. It is because the factors of productivity are so varied that the earlier example suggested *25* electric locomotives might be equivalent to 40 diesels.

A more direct way of assessing requirements is to draw up the complete timetable and locomotive working diagram, or each alternative considered. In anything but a very simple scheme, however, this will be quite unacceptably time-consuming.

5. Comercial Consideration

In making a judgment whether to travel by rail on a particular service or by another mode of transport, a passenger evaluates for himself the standards altered in such items as:

- Journey time
- Reliability
- Comfort
- Frequency of trains
- Convenience of terminals to other transport facilities
- Punctuality
- Cleanliness
- Absence of fumes
- Catering facilities

Different people apply different value/price comparisons in making judgments based on these factors and hence arrive at different conclusions, perhaps not soundly based. It is the function at the passenger marketing department to set relevant standards in these fields based on passengers' subjective performances and to present a unified passenger business image to the public.

Such Studies arc normally required to provide the revenue estimates which must be made if correct economic assessments of alternative forms of motive power are to be made.

Variation in frights revenue will normally not be as dramatic as those found for passenger services, because other aspects of service qua1ity independent of motive power, have more significant effects.

6. RAILWAY FACTORS

Important differences of approach arise in considering motive power policies for completely new and for existing lines. In the first case all the alternatives require outlay of capital not only on locomotives but on all maintenance and servicing facilities, and in the case of electrification the fixed equipment for power supply as well. in the second case, some form of motive power and facilities exists and, therefore, has some merit over the alternatives, because whatever the present problems and difficulties may be, they are known, largely understood, and the methods of over-coming them are established.

Characteristics of the railway itself will affect the choice of motive power by offering differing opportunities to the peculiarities of each form of traction. What must not be ignored is the different opportunity for development which each type of motive power will offer. The real Question is not "What type of railway are we?" but "What type of railway do we want to become?”

7. OTHER TYPES OF MOTIVE POWER:

Nothing has been said about steam traction, which exists and will continue for some time on certain railways, probably with some moderate improvements in technology. However, very little research effort is now being directed to it so that further progress will be limited. Steam is not likely to be thought about seriously for a new railway. If dependence upon coal is an overriding consideration then it will be better to have an electrified railway with energy supplied from coal-fired power stations

Gas turbines are a possible alternative but are also unlikely to be seriously considered, except for very special applications such as high speed light weight trains, owing to their low efficiency and high fuel cost.

Consequently, the problem today really resolves itself into adopting, or making a change to, diesel or electric traction.

8. SUMMARY

i. Look at the national problems to see if any of the options are not available anyway.
ii. Look at the commercial situation - traffic volumes and revenues.
iii. Assess the physical requirements in locomotives, (rains, depots, etc.
iv. See if complementary changes are needed to track and signaling.
v. Convert all estimates to financial terms to compare the alternatives.

9. Conclusions

Conclusions reached will be varied in the future by social, economic and technical development. That factor must be considered in flexible planning to give good advice to railway management. The nature of railways makes this work complex, but it must he accomplished for each railway situation in order to have the right motive power available at the right time at the right price.

Rolling Stock

The economic potential of a heavy haul railway line can be increased through the optimum choice of railway trucks. To meet this needed may be necessary to design and manufacture a new truck with a maximum load to tare ratio for the specific commodity to be transported. The design of high capacity trucks is complex and recently monocoque techniques have been employed to obtain maximum advantage of the limited dimensions available or truck size. The maximum size of rail trucks is limited by the following:

1. Structure gauge, width and height;
2. Minimum radius of track curvature;
3. Dynamic stability;
4. Standardized bogie, wheel and bogie centers;
5. Type of wheel and center plate bearing;
6. Wheel diameter to limit wheel to rail contact stresses;
7. Braking equipment.

Conventional trucks normally have a low load to tare ratio because they are frequently designed to carry a variety of products. Typical values of load to tare ratios for conventional and unit trains are given in table (3/).

TABLE (3/) Load to tare ratios railway trucks.

Truck Type	Load to Tare Ratio	Axle Load
Closed Box Cars	2.0:1	20
Tankers Closed Grain Trucks Open Dropside Truck	1.7:1	20
Flat Bed Trucks	2.0:1	20
Bottom Dumpers	1.5:1	20
Rotary Dump Ore Wagon Conventional Design	1.2:1	20
Rotary Dump Ore Wagon Monocoque Design	4.55:1	25

For a unit train application it may be possible to use an existing wagon designed to carry a lighter product, which has sufficient volume and strength to achieve the required payload. In this case the wheel and center plate bearing capacities must be checked and replaced if necessary.

The correct choice of bogie will significantly reduce rail and wheel wear especially if the alignment has a high degree of curvature.

The Train Resistance:

Resistance

Any opposing or retarding force.

Force

The cause of the acceleration of the movement of physical bodies.

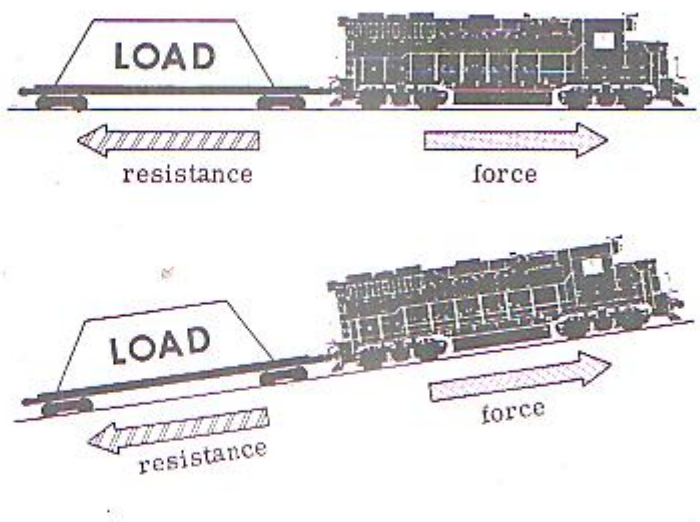


Fig (3/16)

In all cases where the force exceeds the resistance, the load will be accelerated.

As acceleration continues. i.e., as speed increases, the force will diminish and the resistance increase until they are equal. At this point a "balance speed" is obtained.

All locomotive performance calculations are, in effect, nothing more than a process of equating force and resistance under a given set of conditions.

Rolling resistance

The rolling resistance of a train can be determined by formula, but more generally is taken from tables and curves based on formula. The most widely used of such formulae is the “Davis Formula.” Rolling resistance is generally expressed in pounds per ton.

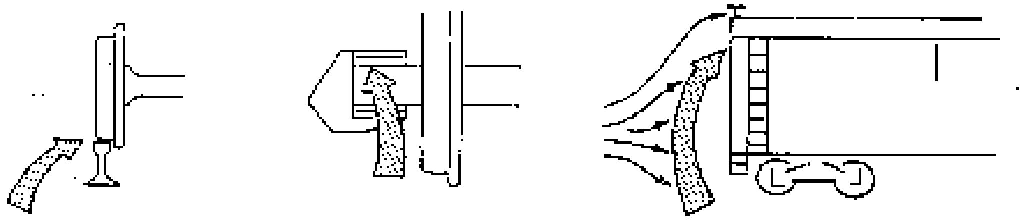
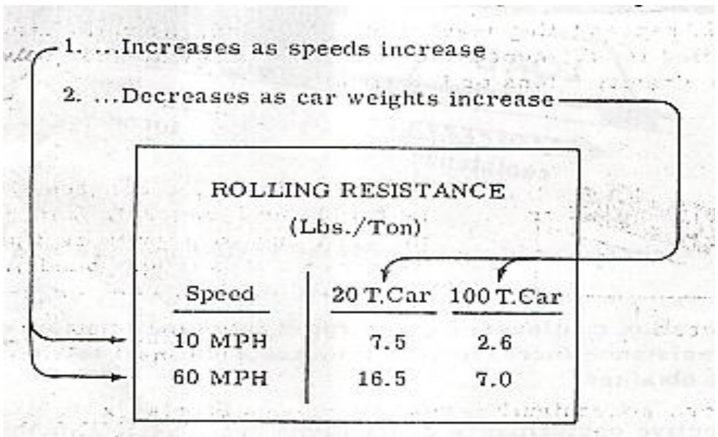


Fig 3(/17)

Flange Resistance + Journal Resistance+ Air Resistance= Total Rolling Resistance

Other things being equal, total rolling resistance, expressed in pounds per ton....



1. ...Increases as speeds increase
2. ...Decreases as car weights increase

ROLLING RESISTANCE
(Lbs./Ton)

Speed	20 T.Car	100 T.Car
10 MPH	7.5	2.6
60 MPH	16.5	7.0

Fig (3/18)

(Note, however, that when expressed in total pounds, the 100 ton car naturally offers more resistance than the 20 ton car.)

RESISTANCE/CAR

20 Tons X 7.5 = 150 LBS Total RESISTANCE/CAR

100 Tons x 7.6 = 260 LBS Total RES/CAR

Davis Formula for rolling resistances

The rolling resistance of locomotives and cars is affected by so many variable factors (weight, speed, size, journal type, configuration, wind, temperature, etc.) that it can be accurately determined only by test. Obviously performance calculations must rely on something more practicable. The most widely known and universally accepted of the several formulae for calculating resistance of given train is the one developed by W. J. Davis.

$$R = 1.3 + \frac{29}{W} + 0.045*v + \frac{0.0005*AV^2}{W_n}$$

Where:

R = resistance in kilo’s. /ton on level tangent track

W = weight per axle in tons

n = number of axles per car

A = cross section of car in square feet

V = speed in miles per hour

- Factors are for freight cars; other values are substituted for passenger cars and locomotives.

In the formula, the expression 1.3 + $\frac{29}{W}$ represents journal resistance;

0.045V represents flange resistance; and $\frac{0.0005*AV^2}{W_n}$ represents air resistance.

As an example, the rolling resistance (R) of a forty ton (W = 10, n=4) boxcar of 80 square feet cross section (A = 80) at 10 m.p.h. (V = 10) would be:

$$R = 1.3 + \frac{29}{10} + (0.045 * 10) + \frac{(0.0005 \text{ X } 80 \text{ X } 10^2)}{(10 \text{ X } 4)} = 4.75 \text{ IBs. /ton}$$

(The formula is not applicable to starting resistance, i.e., to speeds of 0m.p.h.)

Considering only the resistance of the load due to gravity.. in Fig. 1, for every foot it travels ,the load also rises one foot The ratio between rise and distance traveled, being 1:1, establishes this as a 100 percent grade. In such a case, the resistance of the load is apparently equal to its weight, and maybe expressed either as 100 tons or as 2000 lbs./ton.

.... in Fig. 2, representing level track operation1 the ratio between rise and distance traveled is 0:1, hence the grade is 0percent, and the resistance of the load due to gravity 0 tons or 0lbs./ton.

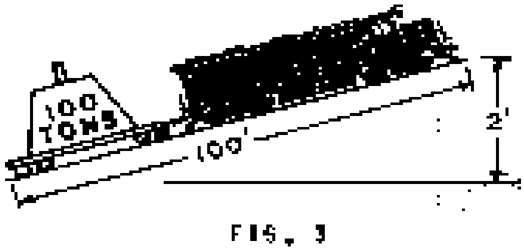


Fig (3/19)

In .Fig. 3/19, the ratio between rise and travels 2:100, or 2 percent.

The resistance of the load due to gravity is 2 percent of its weight or 2 tons (4000 pounds). Resistance expressed in pounds per ton is equal to:

$$\frac{400\text{ Ibs.}}{100\text{ Tons}} = \frac{40\, Ibs.}{Ton}$$

Expressed more conveniently, resistance equals $\frac{\text{rise X 100}}{\text{Travel}}$ X 20 Ibs./tonor, is equal to 20 pounds/ton for each percent of grade (or .379 lbs./ton for each foot of rise per mile).

Grade resistance, (Cont.)

Grade resistance, expressed in pounds per ton, Is Independent of and unrelated to train speed. It is always equal to 20 pounds/ton for each percent of grade.

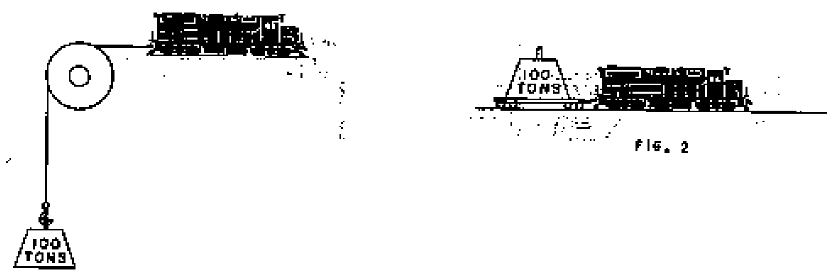


Fig (3/ 20)

In the sketch above, grade resistance of the car is equal to 48 pounds/ton derived thus:

$$\frac{\text{Rise in elevation x 100}}{\text{Distance traveled}} \text{ X 20 Ibs./T.} = \frac{1200}{500} \text{X 20 Ibs./T}$$
$$= 48\, pound\ /ton$$

1f the grade is not “compensated” (i.e., if the physical grade is not reduced to negate the effect of curvature upon it),allowance must be made for track curvature. Each degree of curvature adds one pound per ton to grade resistance, or is the equivalent of a 0.5 percent grade. Thus, in the above example, if there were a three degree curve over the entire 500 foot section, the allowance for the effect of curvature to be added to the basic 2.4percent grade would be:

3 degrees X .05 percent = .15percent

And the effective (total) grade resistance would be: (2.4% + .15%) X 20 lbs./T. = 2.55% X 20 lbs./T. = 51.0 lbs./T.

Curve resistance

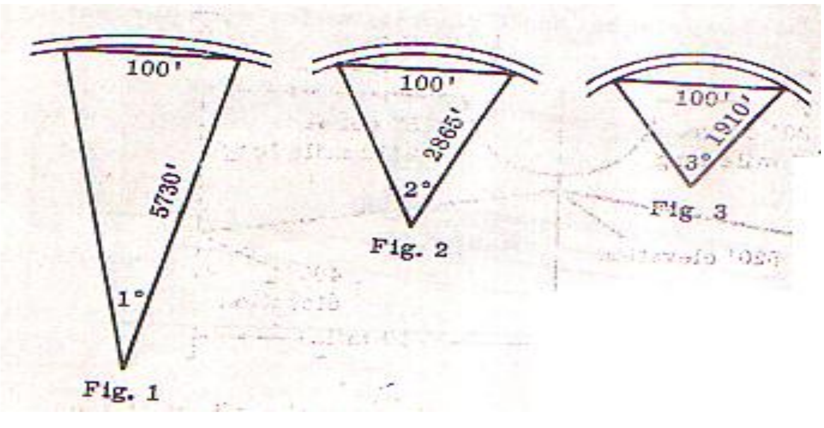


Fig (3/21)

Because the wheels of rail road rolling stock are fixed to, and therefore rotate with, their axles in rounding a curve there is a tendency for the wheel fol1owing the inside track to be skidded or for the outside wheel to spin. Whether one or the other occurs or whether the tendency is overcome by lateral movement of the axle within its Journals, friction (resistance) is created. The “sharper” the curve, the greater this resistance becomes.

By definition, a one degree curve is a curve 100 ft. chord of which determines, a one degree central angle (see Fig. 1). It happens that such a curve has a radius of 5730 feet. Given the degree of curvature, radius can be determined by dividing 5730 feet by the degree of curvature, Thus two and three degree curves (see ‘Figs. 2 and 3) have respective radii of

$\frac{5730\,ft}{2}$ and $\frac{5730\,ft}{3}$, or 2865 and 1910 feet.

The effect of varying degrees of Curvature on train resistance has been determined by test, and most simply stated, indicates that one degree of curvature offers the same resistance to train movement as a 0.05 percent grade, i.e., 1 pound/ton (0.04 X 10) for each degree of curvature.

Allowance for curvature

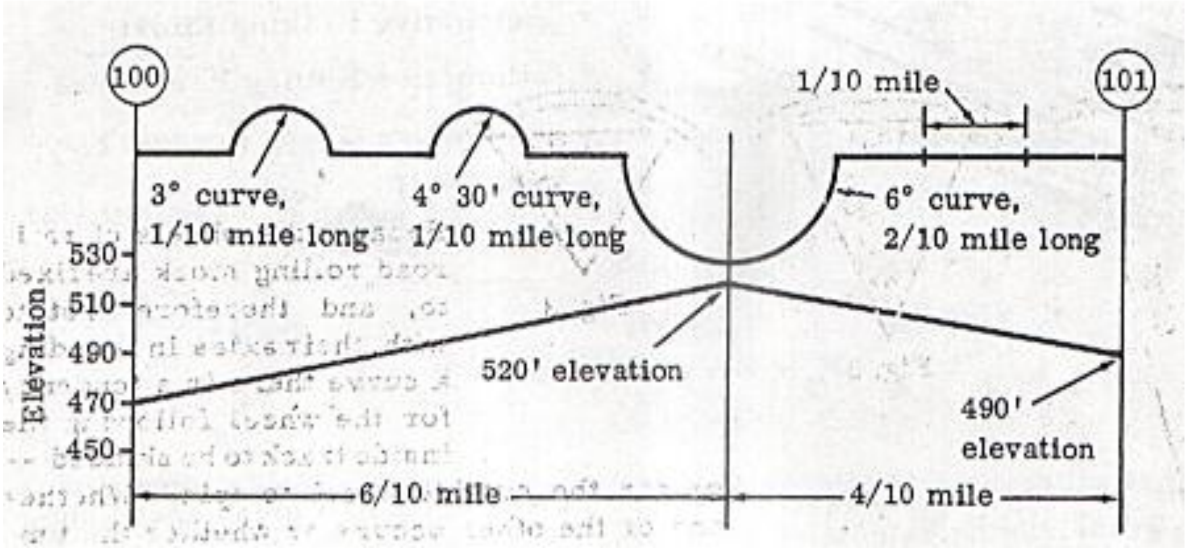


Fig (3/22)

The method for adjusting gradient calculations to allow for the effect of the resistance added by track curvature can le illustrated with the above representation of a one-mile section of track chart and profile:

1. **<u>Determination of gradient</u>**

   From milepost 100 to location 100.6:

$$\frac{\text{Rise X 100}}{\text{Distance}} = \frac{(52\acute{0} - 47\acute{0}) \text{ x } 100}{0.6\, mi.X\ 5280\, ft} = \frac{5000\, ft}{3168\, ft} = 1.58\%$$

2. **<u>Determination of average curvature</u>**

   From milepost 100 to location 100.6:

$$\text{Avg. curve } = \frac{(3^0\text{X .1 mi.}) + (4.5^0\text{X .1 mi.}) + (6^0\text{X .1 mi.})}{\text{0.6 mi.}}$$

$$= \frac{1.35^0\, mi}{0.6^0\, mi.} = 2.25^0$$

3. **<u>Determination of grade equivalent 2.25° curve</u>**

   grade equivalent = 2.25° X 0.05 = .1125%

4. **<u>Determination of effective grade</u>**

   From milepost 100 to location 100.6:

   Effective grade = Actual Grade + Grade Equivalent =

   1.58% + .1125% = 1.69%.

   (Descending, the effective grade = -1.58% + .1125% = 1.47%

Braking effort

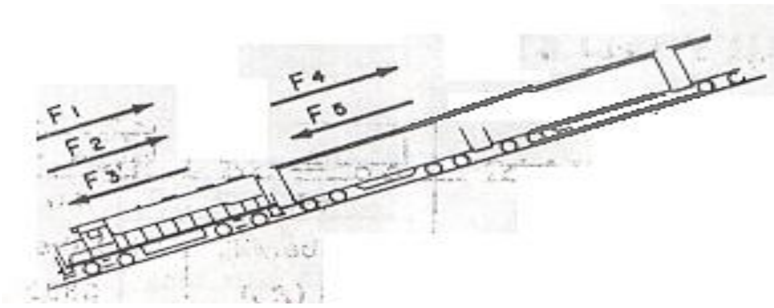


Fig (3/23)

Where:

F_1=Locomotive Braking Effort

F_2=Locomotive Rolling Resistance

F_3= Locomotive Grade Force

F_4=Train Rolling Resistance

F_5= Train Grade Force,

$F_1 + F_2 + F_4 = F_3 + F_5$, or, $F_1 = F_3 - F_2 + F_5 - F_4$

Thus the braking effort required to hold a given train to a given speed on a given grade can be calculated according to formula.

For example what braking effort (F_1) is required to hold a 2000 ton train and 130 ton locomotive to 15 mph on a 2 percent grade?

F_2 (in pounds) = 480*

F_3(in pounds) = 130 T. x 20#/T. /% x 2% = 5200

F_4 (in pounds) = 2000T. x 4.3#/T.* = 8600

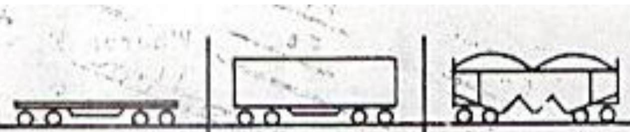
F_5 (in pounds) = 5200 T. x 20#/T./% x 2% = 80000

F_1 (in pounds) = 5200 - 480 + 80000 - 8600 = 76120

The braking effort required to satisfy any given set of operating conditions can be determined in this way. Similarly, of course, given the available braking capacity, the maximum train size can be established. It can be shown that greater braking effort would be required for a 2000 ton train made up of heavier cars. These relationships are unaffected by the presence or absence of dynamic brakes on the locomotive.

* From rolling resistance tables for 130 T. locomotive and 50 T. car

Adjusted tonnage ratings



Car Weight - Tons		20	50	80
Resistance - 1% grade 10 mph		27.5 lbs./T.	24.0 lbs./T.	22.9 lbs./T.
Rating	Tons	2800 (R_1)	3200 (R_2)	3360
	Cars	140 (N_1)	64 (N_2)	42

Fig (3/24)

Given the above resistance data, tonnage ratings for a hypothetical locomotive might be calculated as shown. Apparently, no single rating can be used as a basis for assigning maximum tonnage where can sizes vary from train to train or within individual trains. A system has therefore been devised (and is in use on some railroads) which makes it possible to express tonnage ratings without regard to the sizes of different cars comprising a train. Such ratings are "adjusted tonnage ratings," and are based on the formula,

Adjusted Tonnage Ratings = Actual Tonnage + (Car Factor x No. of Cars),where the "car factors" in turn, is derived thus:

$$Car\ Factor\ = \frac{R_2 - R_1}{N_1 - N_2} = \frac{3200 - 2800}{140 - 64} = 5.26$$

Then Adjusted Tonnage = 3200 + (5.26 x 64) = 2800 + (5.26 x140) = 3537

Note, however, that the adjustment is an approximation only. To illustrate:

1. Using data for 20 T. and 80 T. cars (instead of 20 and 50 T. cars) in the car factor formula would produce a different car factor and therefore a different adjusted tonnage rating.
2. Applying the 5.26 factor to 80 T. cars gives a 3581 T. adjusted rating.

The steeper the grade, the smaller the car factor, since rolling resistance becomes a less importance part of total resistance.

Adhesion

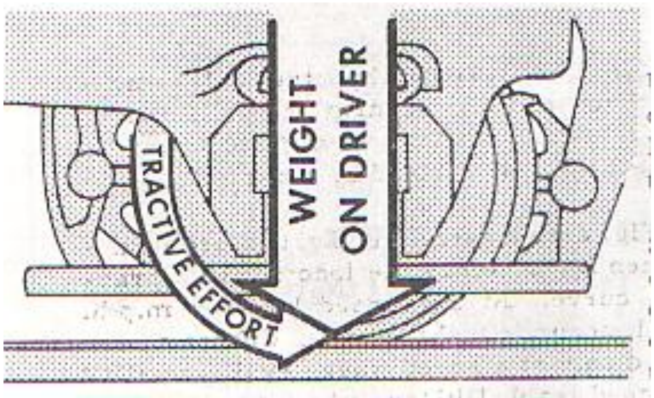


Fig (3/25)

Unless the ratio of weight on drivers to tractive effort is at least 4:1, chances are good that the wheel will slip.

Stated conversely when "adhesion" (or the ratio of tractive effort to weight on drivers) exceeds 25%, chances are good that the wheel will slip.

The amount of tractive effort that can be developed is wholly independent of locomotive weight.

Nor does locomotive weight by itself affect the percent of adhesion that will be reached before slipping occurs. This is a function solely of rail conditions.

Reducing throttle to correct a wheel slip condition

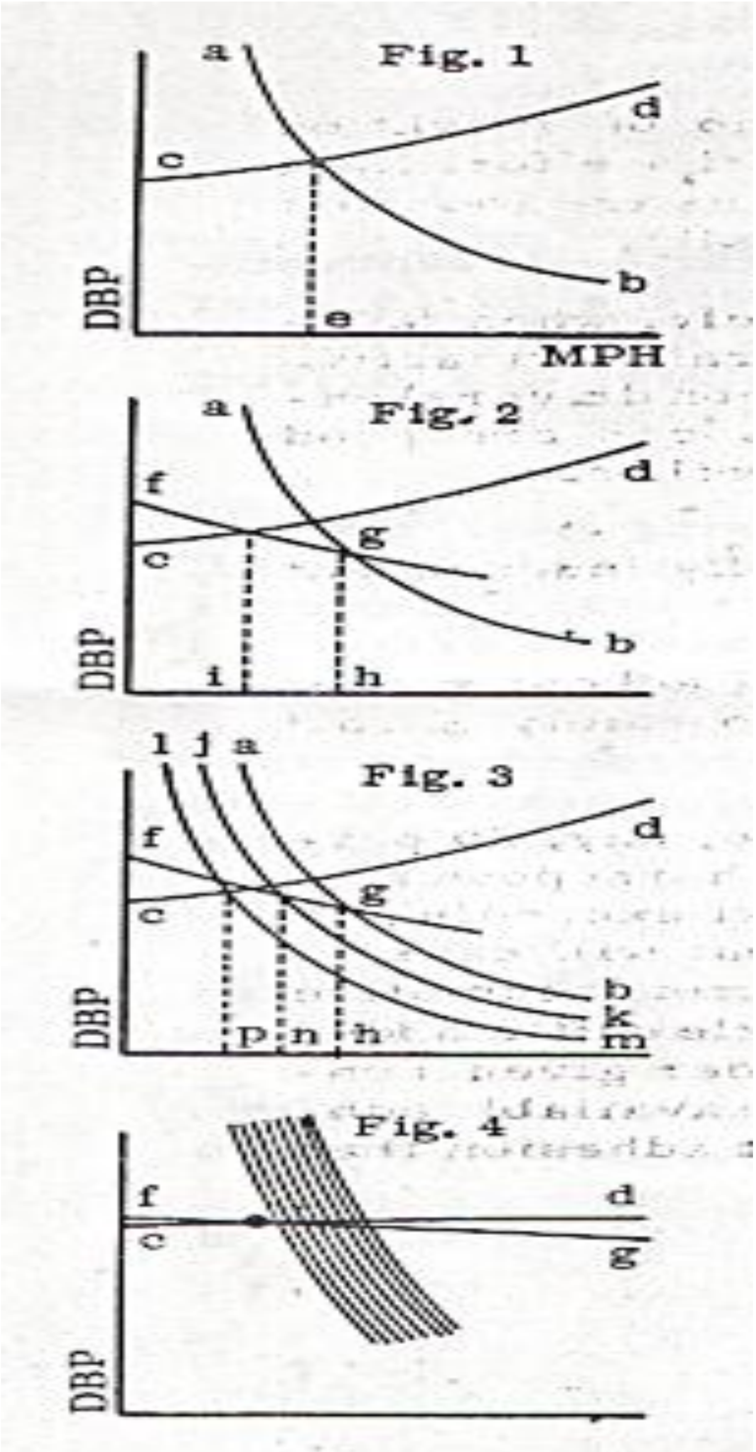
1. With a given set of rail conditions which limits adhesion to, say, 20 percent, any and all locomotives - regardless of weight or horsepower -- will slip whenever their operation calls for tractive effort exceeding 20 percent of the weight on drivers. Thus under conditions that will cause a Let ab in Fig. 1 represent a prophetical locomotive's full

throttle available drawbar pull, and cd total train resistance. With no adhesion limit, a balance speed will be attained at e. m. p. h. b

2. Let fg n Fig, 2 represent the limit to usable, adhesion. Then fgb becomes the locomotive's practical DBP curve. At any speed below h m.p.h. slipping will, occur in full throttle operation can be sustained only at a speed .where available DBP does not exceed usable DBP and where train resistance does not exceed available DBP. Apparently full throttle operation 'does not satisfy these conditions. Also it is apparent that it would be impossible to satisfy the conditions at any speed above i m.p.h.
3. Let jk and 1m in Fig. 3 represent available DBP for successive reduced throttle operations. The first throttle reduction (jk) will still produce slipping, but at a higher DBP output and lower speed (n m. p. h.) than full trott1e. A second throttle reduction (Im) will sustain a balance speed at p m.p.h., since at that speed DBP and train resistance are equal and available DBP does not exceed usable DBP.
4. The train resistance carve (cd) and adhesion limit curve (fg) should more realistically approximate horizontal lines, in Fig. Obviously conditions might be such that no number of throttle reductions can correct a wheel slip condition even though at some speed usable DBP exceeds train resistance.

four axle locomotive to skip at 20 percent adhesion1 a six axle locomotive will slip at the same 20 percent adhesion level. The six axle units added weight increases the amount of tractive effort usable under given conditions. But does not increase - - or in any way affect - -the available adhesion. The six motor unit is no more capable of 30 percent adhesion than the four motor unit.

Adhesion ≡ Ratio of tractive effort to weight on drivers (at least 4:1, chances are good that the wheel will slip) (T.E /wt).



Figs (3/26), (3/27),(3/ 28), (3/29)

Gear ratios

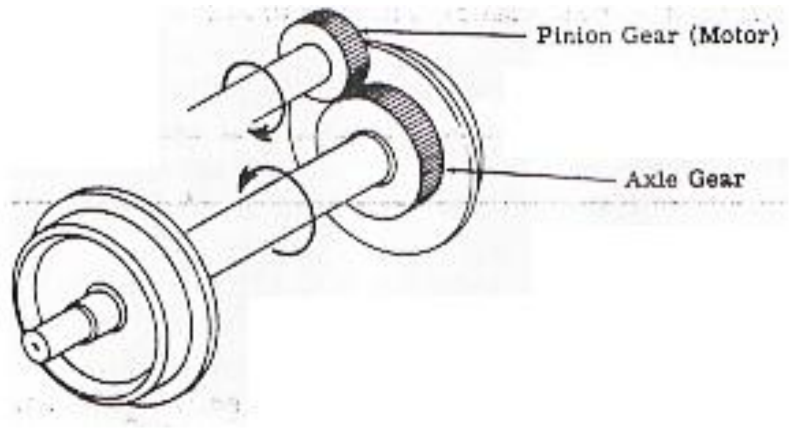


Fig (3/30)

A 62 tooth axle gear - - 15 tooth pinion gear comprises a 62:l5 gear ratio. For every 62 revolution of the motor armature, the driving wheel makes 15 revolution.

Given constant horsepower, the ratio between the driving gear and the driven gear has no effect on the tractive effort developed at a given speed.

Thus if a given locomotive with a 62:15 gear ratio delivers 35,000 pound so tractive effort at 20 m.p.h., the same locomotive with a 60:17 or a 59:18ratio would deliver the same 35.000 pounds at 20 m.p.h.

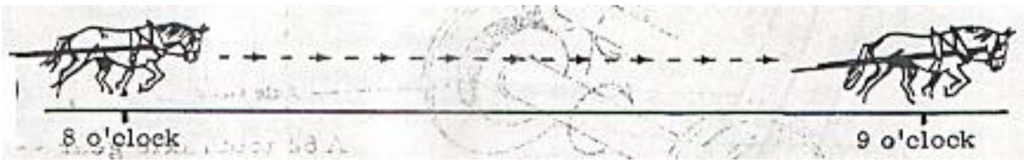
And since at full load, a given current will produce a corresponding armature speed regardless of gear ratio, the effect of changing gear ratios is to change the train speed at which a given current or armature speed obtains.

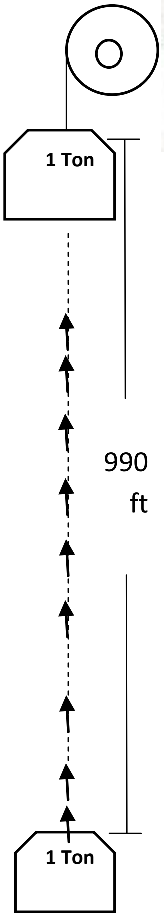
Therefore:

1. Increasing the gear ratio (e.g. going from 60:17 to 62:15) reduces the minimum speed (hence increases tonnage) at which a given locomotive can operate without heat damage to its motors.
2. Decreasing the ratio increases the maximum speed at which a given locomotive can operate without mechanical damage to its motors.

Horsepower is the rate at which work is performed

Work the product of a resistance and the distance through which it is moved.





By definition I horsepower = 550 ft.-lbs./sec 375lb.- miles/hr=

1875 ton-miles/hour. Thus a "1 horsepower horse" could lift a one ton load .1875 miles (990 ft.) in one hour.

But pulling a one ton load, riding on wheels, a long a railroad track and lifting it against gravity are two different things.

Theoretically, as horses are added to the lifting job, the rate at which the work is performed (i.e., the horsepower) will increase proportionately – assuming that the pulley drag and air resistance of the load are negligible.

As the number of horses approaches infinity, the resistance to be overcome by each one approaches zero and, the speed approaches that of one horse with not load.

Fig (3/31)

As a practical matter, as horses are added to the pulling job, the rate at which the work is performed (i.e., the horsepower) will increase, but less than proportionately. This is because as the rate increases of the load.

Other things being equal, adding horsepower has the effect of:

1. Proportionately increasing the load that can be pulled at a given speed.
2. Increasing but less than proportionately, the speed at which a given load can be pulled.

Horsepower and tonnage

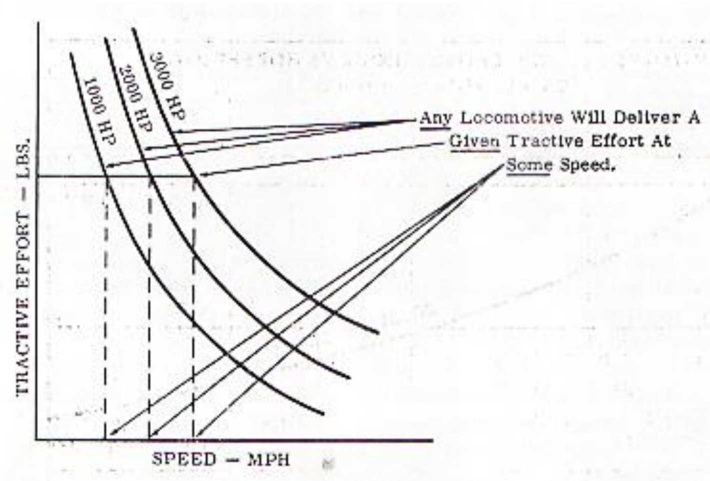


Fig (3/32)

If the, 1000 horsepower locomotive slips at the indicated tractive effort output, so too w111 the 2000 and 3000 horsepower units -provided that all three have the same weight on drivers.

And since tractive effort (after allowance for locomotive resistance) is the force actually pulling the train, the 1000 horsepower unit can pull as much tonnage as the larger units, although at a lower speed.

Similarly, locomotives identical except for horsepower outputs will reach their motor ratings at the same tractive effort output, but at different speeds.

Horsepower increases alone cannot increase a locomotive tonnage rating.

Increasing Horsepower

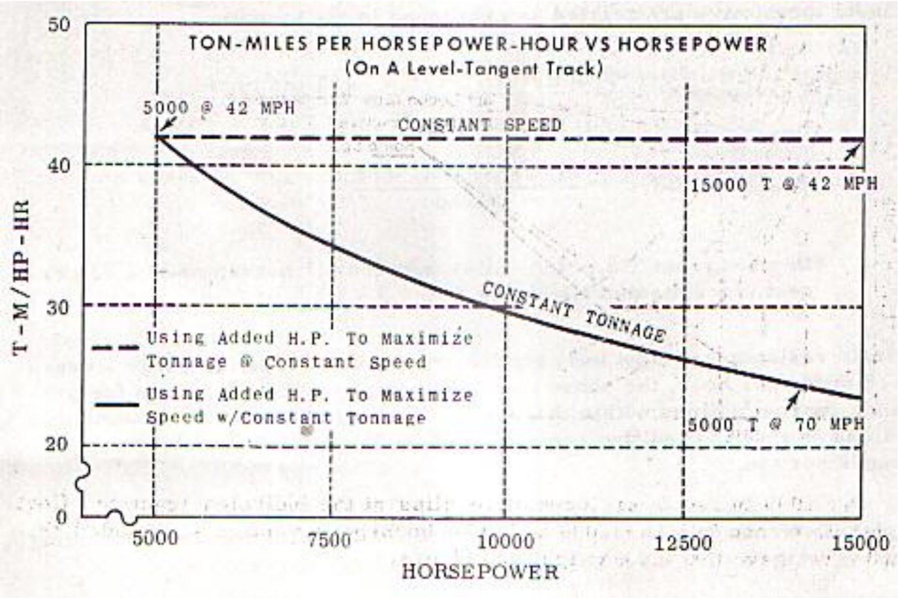


Fig (3/33)

Its effect on speed and tonnage.

15000 T • 42 MPH

1. A 5000 H.P. locomotive can pull 5000 tons at 42 m.p.h. on level tangent track.
2. Three such locomotives (15,000 H.P.) can either

   a ...... pull 15,000 tons -- three times as much -- at the same42 m.p.h. speed, or

   b …… pull the same 5000 tons at 70 m.p.h. - - the equivalent of a 66 percent speed increase - - in return for a 200 percent horsepower increase.
3. It would require 45,000 horsepower to pull the 15,000 ton train at 70 m. p. h

For a given horsepower investment, tonnage offers a better return (measured in performance) than do miles-per-hour.

Horsepower and tractive effort

Of a diesel locomotive are related as expressed in the formulae:

$$\text{Horsepower} = \frac{\text{Tractive Effort (lbs.) X Speed (mph)}}{308^*}$$

$$\text{Tractive Effort} = \frac{\text{Horsepower X } 308^*}{\text{Speed}}$$

*Derived from 375 pound-miles per hour (1 horsepower) x 82 percent transmission efficiency

Since train resistances do not vary significantly with speed in the range between8 and 15 miles per hour, the above formulae can be used as the basis for performance approximations within that range. Such approximations assume that regardless of speed the rolling resistance of an “average” 40-60 ton boxcar is4.0 pounds per ton.

Example: Determine the horsepower required to lift a 1750 ton train (including locomotive weight) over a 2.0 percent grade at 12 miles per hour.

1. TE = Train Resistance (including locomotive),and therefore.
2. TE = 17S0 T. (4.0 lbs./T. + (20 lbs./T./percent 2 percent*)
   = 1750 T. x 44 lbs./T. = 77000 lbs.
3. $Horsepower = \frac{77000\ Ibs.\ X\ 12\ mph}{308\ lb.-mph} = 3000$

* Grade resistance = 20 lbs./ton for each percent of grade.

See Appendix (1).

Chapter Four

Analysis, Calculations & Suggestions for Adoption

Chapter Four

4.1 Introduction

The specific objective of the project is to suggest applicable schemes for upgrading of SRC business to cater for transportation by mixed traffic up to the first half of the 22^{nd} century .

The contents of this chapter are the analysis, calculations and suggestions for adoption to cover the specific objective of the project.

If we looked into the components of the railway business (track, signaling, telecommunications, motive power , rolling stock , workshops …. etc) . We shall find the track with the systems necessary for its operation are the backbone which when unhealthy the whole business may be paralised.

But the track & the systems for its safe & efficient operation , when there is a need for a decision to be taken for upgrading &rationalization to raise the transportation capacity , this DECISION MUST BE a PROHIBITED AREA for the intruders who have not had ON THE JOB TRAINING within the railway qualify themselves for top management jobs which are the authority for taking such decision .

Where practicable the existing railway infrastructure should be upgraded & used in order to minimize the capital cost involved in developing a new railway line .

Perhaps one should start by defining the word economics In the context of track selection we define it as “minimizing expenditure to achieve a stated objective” This immediately gives rise to another question “Who determines what minimum expenditure is and who sets the objective?”

So far as the objective is concerned we have no hesitation in identifying general management as the body responsible for this decision. Only they can identify the traffic to be moved in terms of gross tonnage per annum, the speed at which it is to be moved and the maximum axle loading. In addition they must indicate the anticipated life of the project. With these four pieces of information it is possible for the engineer to undertake his part of the task, namely providing a minimum cost track to meet the business needs.

We emphasize most forcibly that the objective must come from general management in clear unambiguous terms. Without a clearly defined objective the engineer is likely to provide a track having an overlong life and capable of taking any traffic thrown at it. Possibly the only realistic consideration would be speed limitation. In such ,a situation the probability is that a too expensive track would be the end result. This does not mean that once an objective is provided that there is no further discussion between general management and the engineer. If after evaluation of track costs it is found that the project is not profitable then consideration must be given to an amended objective namely reduced speed or reduced track life.

Thus constant recycling is likely to take place until a decision can be made [7].

4.2 How do railways specify their philosophy

Let us start by British Railways (BR) philosophy to take it as a guide for specifying Sudan Railway (SR) philosophy which shall enable it to plan &execute its business components of the future for freight & passengers transportation to the first half of the 22nd century .

British Rail Philosophy [8]

In order to elaborate on the future thinking of one authority, the British Rail philosophy will be covered in detail.

There are three Business Groups within the system, Inter-City, Suburban and Freight and the proposed new build details are shown in fig [4/1].

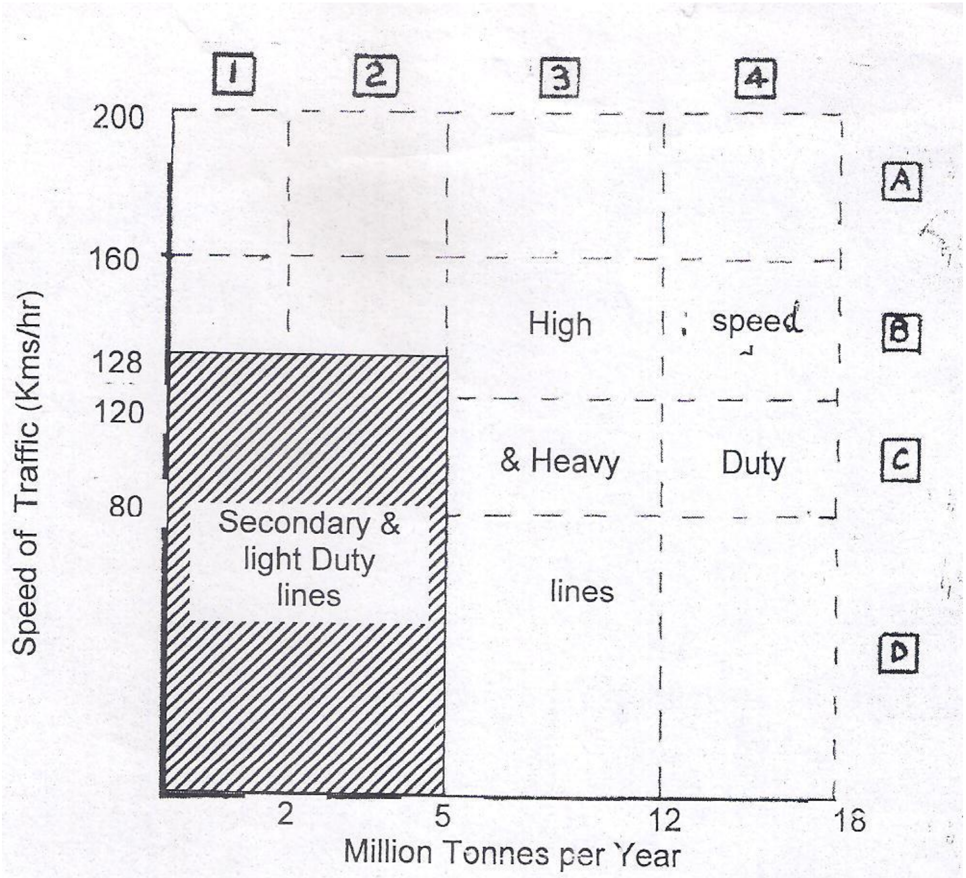


Fig (4/1)

1. The Inter-City group covers all the main line passenger services and the plan is to phase out all the existing diesel locomotives when they reach the end of their useful life of 20 - 30 years.

   Electrification of main lines is a major objective so that high speed locomotive hauled trains and Advanced Passenger Trains (APT) can be introduced. There will however, be a major requirement for fast diesel trains and this requirement will be met by the High Speed Train (HST) If, in the unlikely event that all Inter-City lines are mot electrified, then for routes with a high percentage, of curves, a diesel APT could be considered where its tilting ability will enable it to give improved timings over the HST.

The HST is giving excellent results and traffic on the East Coast Main line in particular is growing so that some services operate to maximum capacity.

Consideration will therefore be given to upgrading the engine from l680 kW (2250bhp) to 1865kW (2500 bhp), to enable additional coaches to be inserted and the schedules maintained.

2. The Suburban group is responsible for all Electric and Diesel Multiple Units (EMU and DMU) and a gradual increase in electrification will result in an increase in the number of new DMU's on the diesel side, the majority of the existing 2,984 DMU's are in excess of 20 years old. Replacement of this fleet will be partially by new EMU's, but also by two new DMU designs, namely, the Class 141 and Class 210.

   The Class 141 is a design based on bus technology and Consists of a modified Leyland National bus body mounted on an under frame, The power unit will be a 6 cylinder horizontal turbocharged engine of 149 kW (200 bhp) driving each car and all trains will consist of multiples of two-car sets. The transmission is a specially developed four speed gear box incorporating a free wheel and reversing gear driving one axle.

   The Class 210, is a more sophisticated vehicle and has been designed to meet the new EMU specification. Although meeting the general coachwork specification has been no problem, achieving comparable performance and particularly similar acceleration has been more difficult. The resulting design has an inboard engine of 932 kW (1250 bhp) with electric transmission. Two prototype trains are in service, one with an MTU 396 12 cylinder V engine running at 1500 rpm and a bmep of 15.6 bar and the second with a PaxmanValenta 6 cylinder in-line engine running at 1500 rpm and a bmep of 17.0 bar.

The business specification calls for a through corridor in the power car for multiple operation, which has resulted in the engine having to be mounted off-centre, and a preference for the maintenance to be possible from one side of the engine to prevent dirt and oil ingress into the passenger corridor.

3. The Freight Business group is responsible for all diesel locomotives and therefore, has some responsibilities on the Inter-City side, if there is a requirement to haul passenger trains with locomotives.

The plan during the next two decades, as the passenger services are taken over by electric and HST trains, is that all the existing locomotives and shunters will be phased out with the exception of the Class 56 locomotive which is already exclusively for freight duties. Three new types of locomotives will be introduced.

The Class 58 will be used on heavy freight services and is fitted with a Ruston 12 cylinder engine of 2610 kW (3500 bhp) at 1000 rpm and a bmep of 17 bar. A great deal of thought has gone into the assessment of the maximum h.p. required to meet British Rail's heavy freight locomotive duties and it has been Concluded at present, that powers in excess of 2610 kW (3500 bhp) wil1 not be necessary.

The introduction of high speed trains on British Rail is a success story and much has been learned since October, 1976 when the first 200 k.p.h. passenger trains were brought into regular service. The travelling public have shown their support for this fast and comfortable means of Inter-City travel and permanent way staff at all levels have gained confidence that the high standard of track needed for these fast trains can be achieved provided maintenance is carried out on a systematic and carefully controlled basis.

	Locomotive class	Engine	Cylinders	Bore m.m	B.M.E.P. bar	**Engine speed r.p.m**	**Engine weight kg.**	**Engine power kg.**	**No.in service year 2000**
Inter-city	H.S.T	PaxmanValenta	12V	197	17	1500	7717	1680	200
	A.P.T	not yet specified					7000	2610	?
Suburban	141	Leyland TL11	6H	127	9.0	1950	1044	150	800
	210	PaxmanValenta	6L	197	17	1500	5089	860	315
		M.T.U 396	12V	165	15.6	1500	3210	933	
Freight	56	Ruston RK3	16V	254	14	900	15000	2626	135
	58	Ruston RKC	12V	254	17	1000	12000	2610	282
	Type 3	not yet specified						≅1680	440
	Shunter/ Tirp	not yet specified						≅895	475

Table (4/1) Forecast of British Rail diesel locomotives and engine types , at year 2000.

All railway systems need to have a method of classifying the status of lines, this is essential if resources and investment are to be correctly distributed.

On British Railways a system based on speed and tonnage is employed (See Fig. 4/1 & 4/2) [9].


GREAT BRITAIN
1435 mm gauge (electrified)
914 mm gauge
North Sea
Irish Sea
0
50
100 km
N
FRANCE
Channel Tunnel
Thurso
Wick
Elgin
Kyle of Lochalsh
Inverness
Aberdeen
Mallaig
Fort William
Oban
Perth
Dundee
North Berwick
Helensburgh
Glasgow
Edinburgh
Largs
Berwick
Kilmarnock
Ayr
Stranraer
Carlisle
Newcastle
Sunderland
Workington
Darlington
Middlesbrough
Whitby
Ramsey
Isle of Man
Douglas
Port Erin
Barrow
Scarborough
Skipton
Ilkley
York
Leeds
Blackpool
Hull
Preston
Bradford
Southport
Grimsby
Manchester
Doncaster
Liverpool
Lincoln
Sheffield
Holyhead
Stoke
Skegness
Bangor
Chester
Nottingham
Crewe
Cromer
Kings Lynn
Pwllheli
Derby
Norwich
Yarmouth
Stafford
Shrewsbury
Leicester
Peterborough
Lowestoft
Birmingham
Rugby
Aberystwyth
Bedford
Cambridge
Stansted
Ipswich
Hereford
Worcester
Milton Keynes
Felixstowe
Harwich
Fishguard
Carmarthen
Oxford
Clacton
Swindon
Swansea
Newport
Reading
London
Southend
Ramsgate
Cardiff
Bristol
Basingstoke
Barnstaple
Salisbury
Dover
Taunton
Ashford
Southampton
Hastings
Portsmouth
Brighton
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Exeter
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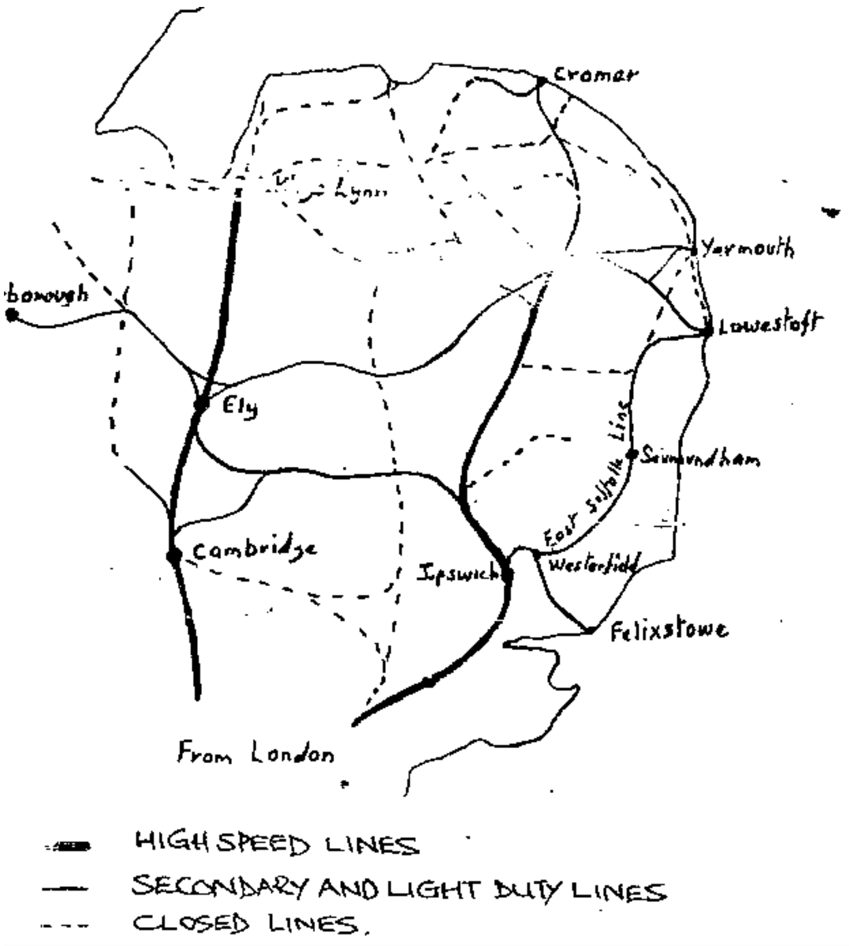


Fig (4/2) British Railways— Track categories

Speed is denoted by a letter : A.160-200 kms/hr; B. 120-160 kms/hr; C. 80-120 kms/hr and D. 0-80 kms/hr.

Tonnage is denoted by a figure: 4. 12-18 million tonnes/annum; 3. 12-5 million tonnes/annum 2-25 million tonnes/annum and 1.0-2 million tonnes/annum.

Thus a line with route speed of 90 kms/hr carrying 7 million tonnes per annum would be classified as a category C.3 line.

For the purposes of this article secondary and light duty lines are taken to be those with a route speed of 128 kms/hr or less and annual tonnage of 5 million tonnes or under. (See fig. 4/1).

According to BR method of classification of lines , SRC lines are in the lowest category of the secondary& light duty lines since they are of category (D2) (see fig 4/3 below).

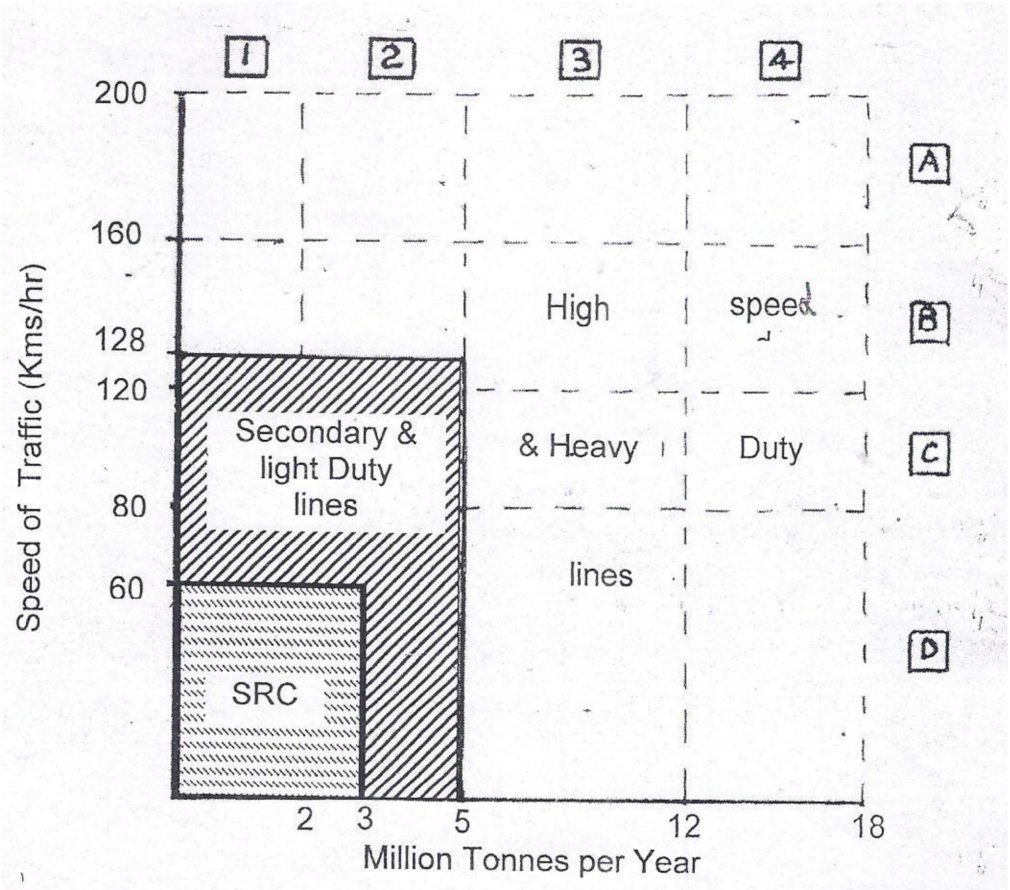


Fig (4/3)

4.3 Sudan Rail Philosophy

There are four types (categories) of railway lines based on the duties they are intended to serve.

1. Category (A) lines – High Speed Rail .
2. Category (B) lines – Heavy Haul Lines .
3. Category (C) lines – High Speed & Heavy Duty Lines .
4. Category (D) lines – Secondary & Light Duty Lines .

We Shall Quote Some information about each type of line and the demand for it which necessitated its construction & see if there is such demand in Sudan .

A) High-Speed Rail [10]

High-speed Rail (HSR) is a type of rail transport that operates significantly faster than traditional rail traffic, using an integrated system of specialized rolling stock and dedicated tracks. While there is no single standard that applies worldwide, new lines in excess of 250 km/h and existing lines in excess of 200 km/hr are widely considered to be high-speed, with some extending the definition to include much lower speeds (e.g.160 km/h) in areas for which these speeds still represent significant improvements. The first such system began operations in Japan in 1964 and was widely known as the bullet train. High-speed trains normally operate on standard gauge tracks of continuously welded rail on grade-separated right-of-way that incorporates a large turning radius in its design.

Many countries have developed high-speed rail (HSR) to connect major cities, including Austria, Belgium, China, France, Germany, Italy, Japan, Poland, Portugal, Russia, South Korea, Spain, Sweden, Taiwan, Turkey, United Kingdom, United States and Uzbekistan. Only in Europe does HSR cross international borders. China has 19,000 km of HSR as of December 2015, accounting for two-thirds of the world’s total.

While high-speed rail is most often designed for passenger travel, some high-speed systems also offer freight service .

Breakthrough: The Shinkansen [10]

Japanese research and development

With some 45 million people living in the densely populated Tokyo-to-Osaka corridor, congestion on road and rail became a serious problem after World War II, and the Japanese government began thinking seriously about a new high-speed rail service.

Japan in the 1950s was a populous, resource-limited nation that for security reasons did not want to import petroleum but needed a way to transport its millions of people in and between cities.

Japanese National Railways (JNR) engineers then began to study the development of a high-speed regular mass transit service. In 1955, they were present at the Lille's Electro technology Congress in France, and during a 6-month visit, the head engineer of JNR accompanied the deputy director Marcel Tessier at the DETE (SNCF Electric traction study department). JNR engineers returned to Japan with a number of ideas and technologies they would use on their future trains, including alternating current for rail traction, and international standard gauge.

The first narrow-gauge Japanese high-speed service

In 1957, the engineers at the private Odakyu Electric Railway in Greater Tokyo area launched the Odakyu 3000 series SE EMIL.

This EMU set a world record for narrow gauge trains at 145km/hr (90 mph), giving the Odakyu engineers confidence they could safely and reliably build even faster trains at standard gauge. The original Japanese railways generally used narrow gauge, but the 1ncreased stability offered by widening the rails to standard gauge would make very high-speed rail much simpler, and thus standard gauge was adopted for high-speed service. With the sole exceptions of Russia, Uzbekistan and India all high speed rail lines in the world are still standard gauge, even in countries where the preferred gauge for legacy lines is different [ ].

A new train on a new line:

The new service, named Shinkansen (meaning new trunk line) would provide a new alignment, 25% wider standard gauge, continuously welded rails between Tokyo and Osaka using new rolling stock, designed for 250 km/hr (155 mph).

However, the World Bank, whilst supporting the project, considered the design of the equipment as unproven for that speed, and set the maximum speed to 210 km/h (130 mph).

After initial feasibility tests, the plan was fast-tracked and construction of the first section of the line started on 20 April 1959. In 1963, on the new track, test runs hit a top speed of 256 km/hr (159 mph). Five years after the beginning of the construction work, in October 1964, just in time for the Olympic Games, the first modern high-speed rail, the Shinkansen, was opened between the two cities.

The first Shinkansen trains, the O Series Shinkansen, built by Kawasaki Heavy Industries—in English often called “Bullet Trains”, after the original Japanese name Dangan Ressha, outclassed the earlier fast trains in commercial service. They traversed the 515 km (320 mi) distance in 3 hours 10 minutes, reaching a top speed of 210 km/h (130 mph) and sustaining an average speed of 162.8 km/h (101.2 mph) with stops at Nagoya and Kyoto [ ].

High-speed rail for the masses

Speed was only a part of the Shinkansen revolution: the Shinkansen offered high-speed rail travel to the masses. The first Bullet trains had 12 cars and later versions had up to 16, and double-deck trains further increased the capacity.

After three years, more than l00 million passengers had used the trains, and the milestone of the first one billion passengers was reached in 1976. In 1972, the line was extended a further 161 km (100 mi), and further construction has resulted in the network expanding to 2,616 km (1626 mi) as of March 2015, with a further 548 km (341 mi) of extensions currently under construction and due to open in stages between March 2016 and 2035. The cumulative patronage on the entire system since 1964 is over 10 billion, the equivalent of approximately 140% of the world's population, without a single train passenger fatality. (Suicides, passengers falling off the platforms, and industrial accidents have resulted in fatalities).

Since their introduction, Japan's Shinkansen systems have been undergoing constant improvement, not only increasing line speeds. Over a dozen train models have been produced, addressing diverse issues such as tunnel boom noise, vibration, aerodynamic drag, lines with lower patronage ("Mini shinkansen"), earthquake and typhoon safety, braking distance, problems due to snow, and energy consumption (newer trains are twice as energy efficient as the initial ones despite greater speeds).

B) Heavy Haul Railways [11]

In recent years Railway orgainsations have developed heavy had railways in order to meet the increasing Competition in worldwide markets for bulk raw materials by reducing the transportation costs. The main objective of heavy haul railway systems is to maximise the payload whilst minimising the combined capital and operating cost. Different philosophies exist and lie between solutions offering high capital with minimum maintenance and running costs, and the minimum capital with consequential high maintenance and running costs. Before decisions are taken on any scheme, it is necessary to carry out engineering and economic studies which would investigate the present infrastructure, track construction and reconstruction, economical axle load and train length, available rolling stock, operating staff conditions, sea port capacity, operating, signalling and communication requirements and the overall maintenance of the whole system.

Many railway authorities have successfully developed heavy haul routes for narrow and standard gauges, but there have been some costly mistakes during development.

For this reason it is essential that experienced engineers and economists should be employed at an early stage to study all relevant factors for each scheme .

Term Heavy Haul Railway had different interpretations by many railway authorities. The correct meaning of the term Heavy Haul Railway is one which operates longer than normal trains utilizing heavier than normal axle loads directly between the point of loading and the point of unloading, without any intermediate handling or shunting. These trains are sometimes called ‘unit’ trains. They usually comprise purpose built wagons cauying one product in one direction only, being empty on the return trip. The reasons for developing such a railway are purely economical and the intention is to transport bulk materials from the point of supply to the point of consumption or export, as cheaply as possible, If the railway authority tariff applicable to a heavy haul railway is higher than that on the existing normal train system then the decision to build it is economically unsound. Table 1 compares some of the characteristics of trains operating on Conventional railways with those on heavy haul railways.

There is an uncommitted range between the two which is evidence of the absence of a formal definition.

Table (4/2)

Comparison of train characteristics

Train Characteristics	Conventional Railway	Heavy Haul Railway Unit Trains
Train Total Mass	Less than 3 000 t	Greater than 5 000t
Axle Load	Less than 18t	Greater than 20t
Train Length	Less than 800m	Greater than 1 000m
Number of Wagons	Less than 40	Greater than 100
Braking System	Vacuum and Air	Air

Economic justification

Reasons for a Heavy Haul Railway

A heavy haul railway is often built to transport exploitable mineral reserves from the mines to a process works or a port. The railway tariff is usually the major variable cost over a period of time. A low railway tariff would make the commodity more competitive on world markets as most customers buy products at “Free on Board” (F.O.B.) prices and not at source prices. With the advances in railway truck design it is also becoming possible to transport lighter products in sufficient bulk to justify using heavy haul railway lines. Corn has been transported this way in Australia and the concept could be developed to include rice, maize, wheat and other basic foods.

Existing Railway Infrastructure

Most countries have a conventional railway system and, where practicable this should be strengthened and used in order to minimise the capital cost involved in developing a new heavy haul railway line, It is often necessary for the whole of the existing system to be upgraded to the higher axle load. The heavy loads will apply to a limited number of specific routes which must be strengthened and conventional traffic will be carried elsewhere. The existing track may be able to carry the occasional unit train without being strengthened.

New Railway Line

The justification for a heavy haul line may rest entirely upon the economic evaluation of exploiting a single resource, and constructed to serve that project. Alternatively, the new construction could have an alignment that is suitable for serving areas for the first time and thereby helping in the development and economic growth of a country.

Economic Comparison

A heavy haul railway line can be provided by either strengthening the existing line, building a new one or a combination of both.

Before a decision is taken to build a heavy haul railway line, the total costs of transporting the products on the existing system should be calculated. These costs should be projected forward over a period of at least 20 years and should include for:

a) Capital replacement depreciation;
b) Maintenance.
c) Operating.

C) Heavy Duty High Speed Lines [12]

The growth ¿f private r ownership and the extension of the motorway network in the 1960s presented serious competition to passenger train business in the U.K., while over longer distances there was a further threat from domestic airlines. Experience on the recently electrified lines from London on the West Coast route showed that the public would support fast, reliable Inter City service, so after a great deal of market research, it was decided that the replacement of the ageing locomotive fleet provided an ideal opportunity to introduce a high speed passenger service. Overseas new specially built railways were being constructed or planned, but the situation in the U.K. was such that a financial case could not be made for new lines.

Of the principal routes. In Great Britain two could be developed to carry conventional trains at high speeds, but the alignment of the remainder was such that frequent speed restrictions would have been necessary. The decision was therefore taken to develop two new trains, one based on proven technology and the other of more advanced design (Advanced Passenger Train) with a tilt mechanism to enable existing curves to be negotiated at higher speeds .

D) Secondary & Light Duty Lines:

Certainly on B.R. up to a few years ago the future for secondary and light duty lines looked bleak. This situation has, however, rapidly changed with the introduction of new and improved systems not only for Civil Engineering activities but also the operation of lines. The success of the trials with Radio Train Dispatch (R.T.D) could provide an assured life for rural lines for many years to come [9].

a) High Speed Rail (HSR): This type of rail was first introduced in the second half of the twenty century in countries of first class economy . There was demand for Such service & investment is very attractive.

   This type of line has not been constructed in any African country up to date (2016).

   It is not foreseen for more Than hundred year such track shall be constructed in a country with a third world economy.

   Therefore it is clear that the HSR shall not be part of SR lines for the time specified .

b) Heavy Haul Railway : This is a Special railway line .When there is need for such line & the studies prove its feasibility , it shall be constructed . For the period specified for the upgrading , building such line in SR is not foreseen.

c) Heavy duty High Speed lines : BR upgraded Some of its secondary& light duty lines to these lines when there was demand for raising the transportation capacity of its secondary lines .

   When we study fig (4/1) we find that the categories of track are expressed as A4 to D1 .

   Therefore 16 categories of tracks are permissible.

   In the future SR, after exhausting all the categories within the range of secondary &light duty lines, may transfer to some categories of lines of the high speed & heavy duty.

Secondary & light Duty Lines : This is The area where SR Lines stand but at its lowest categories.

Therefore our studies concentrated on upgrading these lines.

The result of the analysis above leave only one type of line (The secondary & light duty) to be up upgraded &used to cater for the future transportation up to the first half of the 22nd century.

We see that SR shall not need a train running speed of more than 120km/hr .till the duration specified.

With this speed (120 km/hr) the line must be fully protected with automatic gates on level crossings .

4.3.1 Investment in Passenger transportation

The investment in passengers transportation in Sudan Railways (SR) is not a successful commercial business when compared by freight transportation.

SRC is a government owned enterprise & the passengers transportation has its social reasons, therefore the government has to support it when there is a need for it or the tariff for tickets shall be very high.

Passengers transportation in railways of the first world is a commercially competitive business while it is the reverse in the third world.

Comparison with other modes of transport

Optimal distance

While commercial high-speed trains have lower maximum speeds than jet aircrafts, they offer shorter total trip times than air travel for short distances. They typically connect city center rail stations to each other, while air transport connects airports that are typically farther from city centers.

High-speed rail (HSR) is best suited for journeys of 1 to 4½ hours (about 150—900 km or 93—559 mi), for which the train can beat air and car trip time. For trips under about 700 km (430 mi), the process of checking in and going through airport security, as well as traveling to and from the airport, makes the total air journey time equal to or slower than HSR. European authorities treat HSR as competitive with passenger air for HSR trips under 4½ hours.

HSR eliminated most air transport from between Pans-Lyon, Paris-Brussels, Cologne-Frankfurt, Madrid-Barcelona, Nanjing-Wuhan, Chongqing-Chengdu.

Tokyo-Nagoya, Tokyo-Sendai and Tokyo-Niigata.

China Southern Airlines , China's largest airline, expects the construction of China's high-speed railway network to impact (through increased competition and falling revenues) 25% of its route network in the coming years [10].

From SRC budget of 1993/1994 the income from passengers transportation is 10% of the total revenue , but it is known for SRC that the cost of running the passengers trains is more than the income.

The Nile DMUS run on a section of 313 km . Its rebuilding costed more than $100 million & the investment on the DMU purchase is about $10 million. It can be estimated that the price of the ticket is about 25% of the cost of running these units .

Here under we give actual price for three modes of transport from Oxford in England to Glasgo in Scotland .

The prices are for return ticket as in june 2016.

1/By bus £50

2/By airlines £61

3/By train £120

From all what has been presented above it is clear that there will only be one type of line (secondary & light duty) to be upgraded & rationalized to carry mixed traffic (freight / passengers) in three categories of lines specified as below :

a) category one lines :
   - axle load 23 tons
   - max speed 100- 120 km / hr
   - rail weight 110 lb/Yd(54kg /m)
b) category tow lines :
   - axle load 20 tons
   - max speed 90 km /hr
   - rail weight 90 lb/yd (45kg/m)
c) category three lines:
   - axle load 16.5 tones
   - max speed 70 km /hr
   - rail weight 75 lb /Yd (37.5 kg/m).

This arrangement of categories of lines is useful and important because it gives the chance of making use of used materials from the high category of lines when they are no longer useable there but can be used in lines of lower category

This system was first adopted by the German railway .

It has been decided to institute a system known as Track Economy which has been in use on the German Federal Railway and other Railways for a number of years. This system involves the resuse of track components, particularly rail. It is accepted practice for new materials to be installed in the High Speed and Heavy duty lines when renewal is carried out. This, however, ¡s not the case for lighter, used slower speed lines where serviceable material of varying weights from different line categories is perfectly adequate.

Based on line classification standard of materials both new and serviceable can be specified for each line category. The object is then to attempt, as far as possible, to balance the quantity of reusable material recovered each year against that required for the annual renewal program.

In theory, for this system to work-to maximum efficiency it should be introduced at the construction stage of a railway network. Consideration should be given to laying the lower category lines with serviceable material of such quality that its life matches that of the new material installed in the higher category Lines. The maximum possible useful life of the materials can then be obtained.

On B.R. the system has had to be adapted to suit the existing situation whilst the optimum life for rails in the 200 km/hr lines is assessed at 10 to 12 years if fatigue failures such as black spot, gauge corner shelling, etc. are to be avoided. Rails have in fact already been in this type of track for 15-20 years and fatigue failures have started to occur. Despite this these rails are still perfectly adequate for reuse in the lowest category lines [9].

A further problem arises in that whilst rails recovered from high speed/heavy duty lines are generally continuously welded and can be immediately used for installation as continuously welded track in lower category lines, a very large Percentage of reusable rails is recovered from fishplate jointed track in lengths of 18.3 meters. These rails suffer from the disadvantage that they contain fishplate holes at either end and varying degrees of rail end batter.

It is the policy carry out all renewals with continuously welded track in order to take advantage of the considerable savings in reduced maintenance costs available. To achieve this rail is taken to a central welding depot where 76 cms is cut off each end of the rails to eliminate fish bolt holes and rail end batter. They are then flash butt welded into 87m or 174m lengths ready for transportation to renew sites.

It is normal practice when reusing serviceable rail to install it so that the unused rail face becomes the running face. Lipping and/or unevenness on the rail head, however, can lead to poor running. To overcome this use has been made of the Plasser Theurer self-propelled rail planning machine. This machine is bussed on an 07 tamper/liner with planning heads tilted on either side in place of the tamping banks. All four axles are powered during planning to produce the thrust necessary to cut the metal and the machine can operate in either direction. Three passes are usually sufficient to profile the running edge of a rail but six are required if the full head is to be done. Many miles of replaning of reused serviceable rail has been undertaken with results which provide riding similar to that obtained on new rail [9].

The future of SR philosophy for its motive power could be summed up in the following:

- Due to the problem of fossel fuel the future of diesel engine is not guaranteed .

Electrification of the railways is its future.

- The electric locomotive costs less in maintenance and operation but the civil engineering costs for the supply of the electric current along the line & the other electric equipment necessary for the operation outweigh the other benefits .
- The investment in electrifying the railway lines is big.
- Port Sudan – Khartoum section has future potencials. Therefore it is elegible for electrification.

At this stage of study we got convinced that SRC business needs to be rationalized & upgraded to raise its transportation capacity.

The upgrading process could be provided by either strengthening the existing line, building a new one or combination of both

Let us see which of the three choices mentioned above is the right choice.

SRC have about 5000 kilometers of main line track all of it is of NARROW GAUGE 1067mm (3' 6").

4.3.2 Metre, narrow& standard gauges

The standard gauge is wider than the narrow gauge (1435mm) & the metre gauge (1000 mm) is narrower than the narrow gauge (1067mm)

There are tracks of wider gauges than the standard gauge (1520/ 1676mm) .

Each of these gauges of tracks has a limit of maximum speed and axle load beyond which it will become unsafe and unstable.

If a railway needs to upgrade a line transportation capacity when the line reached its limiting speed (max. speed allowed in the particular gauge), this line has to be built with a wider gauge which will allow higher speed than the existing line.

We can see this here under when the Japanese national railways (JNR) wanted to raise the transportation capacity in its narrow gauge railway

They preferred to build a new high speed rail with standard gauge and 250 km /hr speed to the other alternative which is doubling the existing narrow gauge track with 160 km /hr line

This was in 1964. Before this JNR has 27,000 km of narrow gauge track .

Railway Operation in Japan [13]

The history of railways in Japan dates back to September 1872 when commercial operation started over a 29-km track between Shimbashi (Tokyo) and Yokohama.

Japan has achieved a tremendous development, both social and economic, over the following 125 years, and railways have been no exception. The railway networks in this relatively small land total over 27,000 km, and up to 2.2 million people ride trains each day. The five shinkansen lines stretch 2200 km with operating speeds of 260 to 300 km/hr.

Shinkansen cover the 515-km stretch between the two largest cities, Tokyo and Osaka, in 2 hours and 30 minutes. The high efficiency of railway transportation puts railways ahead of air transport in Japan the dense population is scattered along the Pacific coastal plain.

The progress of railways and their role in society is supported by new technological achievements in many areas. Safety, speed, and ride comfort have always been major concerns for Japanese railway companies[13].

Shinkansen track structure [13]

The Tokaido Shinkansen began operation in 1964 between Tokyo and Osaka at a maximum speed in excess of 200 km/h for the first time in the world. When the line was first envisaged, there were two plans for the gauge. One was to increase the transport capacity by adding narrow-gauge double track to the existing Tokaido line. The other was to increase the capacity while halving the journey time by building a standard-gauge double-track line. The latter plan was eventually chosen, and the new line took a different route from the old Tokaido Line with many viaducts, embankments, and tunnels and without level crossings.

New rails, sleepers, and fastenings were designed for the high-speed line.

The Tokaido Shinkansen track features:

- 1435-mm standard gauge.
- CWR and concrete sleepers throughout.
- Movable nodes eliminating gaps at turnouts and crossings.
- Long rails joined by expansion joints to minimize gauge fluctuation due to thermal elongation and shrinkage.
- New-design 53 kg/m rail (50T and later entirely replaced by 60 kg/m rail)

The Tokaido Shinkansen was soon followed by the Sanyo, Tohoku, Joetsu and Hokuriku Shinkansen built from 1972 to 1997. The maximum speed was raised from the initial 210 km/h to a more recent 260 to 300 km/h. Around 1967, efforts were started to develop slab tracks to prepare for the expected sharp increase in transport demand and higher operation speeds Slab track was first introduced on the Shin-Osaka to Okayama section of the Sanyo Shinkansen which started operation in 1972. Today, it is the standard.

Also in South Africa (S.A) all the railway main lines are of narrow gauge or less.

That means the NARROW GAUGE has a POTENCIAL to serve the economy of some of the industrialized countries.

The maximum speed in the narrow gauge main lines of S.A is 160 km /hr .

When you refer to the definition of high speed rail mentioned above you shall find that a line with160km/hr .is considered a high speed line.

The wide & the standard gauges are basically found in highly developed countries the metre & the narrow gauges are found in developing countries.

More than ninety percent of the African countries have meter & narrow gauges.

They are in south America , Asia , Australia & in some European counties. May be for some times.

Equipment production for these gauges is as good business as for the standard gauges & better than for the wide gauges .

Changing from narrow gauge to standard is not as simple as unspecialized people think

It has to be studied again & again by experts smelling the sweat of their arm pits.

The two narrow gauges(metre & narrow) are transporting billions of tons & billions of passengers annually round the world and they will continue to do so for a couple of centuries in an appreciable number of countries of the world.

The above facts could be found in The Railway Directory which is produced yearly by the Railway Gazette containing statistics, coulored maps of lines, etc, for almost all railways of the world (see the railway maps attached & reference [14]).

With this we come to the conclusion that the narrow gauge track shall serve Sudan as proper as a standard or wide gauge without wasting money which Sudan desparety needs.

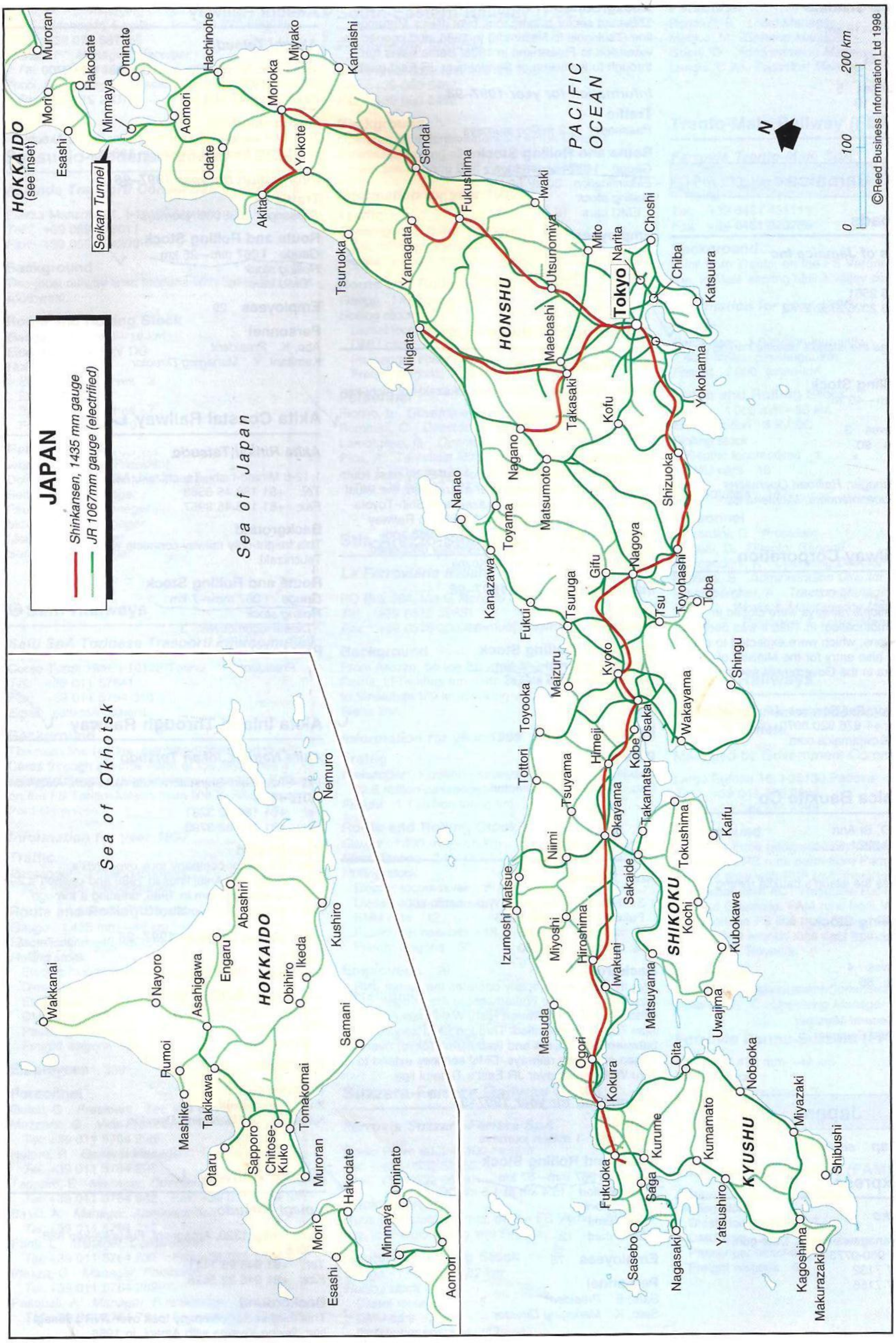
Any track built in standard gauge SHALL HAVE REDUNDANT CAPACI TY Which Sudan shall not use to the end of this track life.

To upgrade the capacity of transportation of railway is many fold.

1) The track
    - Gauge
    - Axle load
    - Speed
    - Etc

2) Operation & stations arrangement
3) Signalings & Telecommunications
4) Motive power & rolling stock
5) Training & training institutions
6) Management & organization

The coming section shall be detailed studies, calculations & applicable suggestions to upgrade SRC business to cater for transportation up to the first half of the 22^{nd} century.



JAPAN
Shinkansen, 1435 mm gauge
JR 1067mm gauge (electrified)
HOKKAIDO (see inset)
Seikan Tunnel
Sea of Japan
PACIFIC OCEAN
HONSHU
SHIKOKU
KYUSHU
Sea of Okhotsk
HOKKAIDO
N
0
100
200 km
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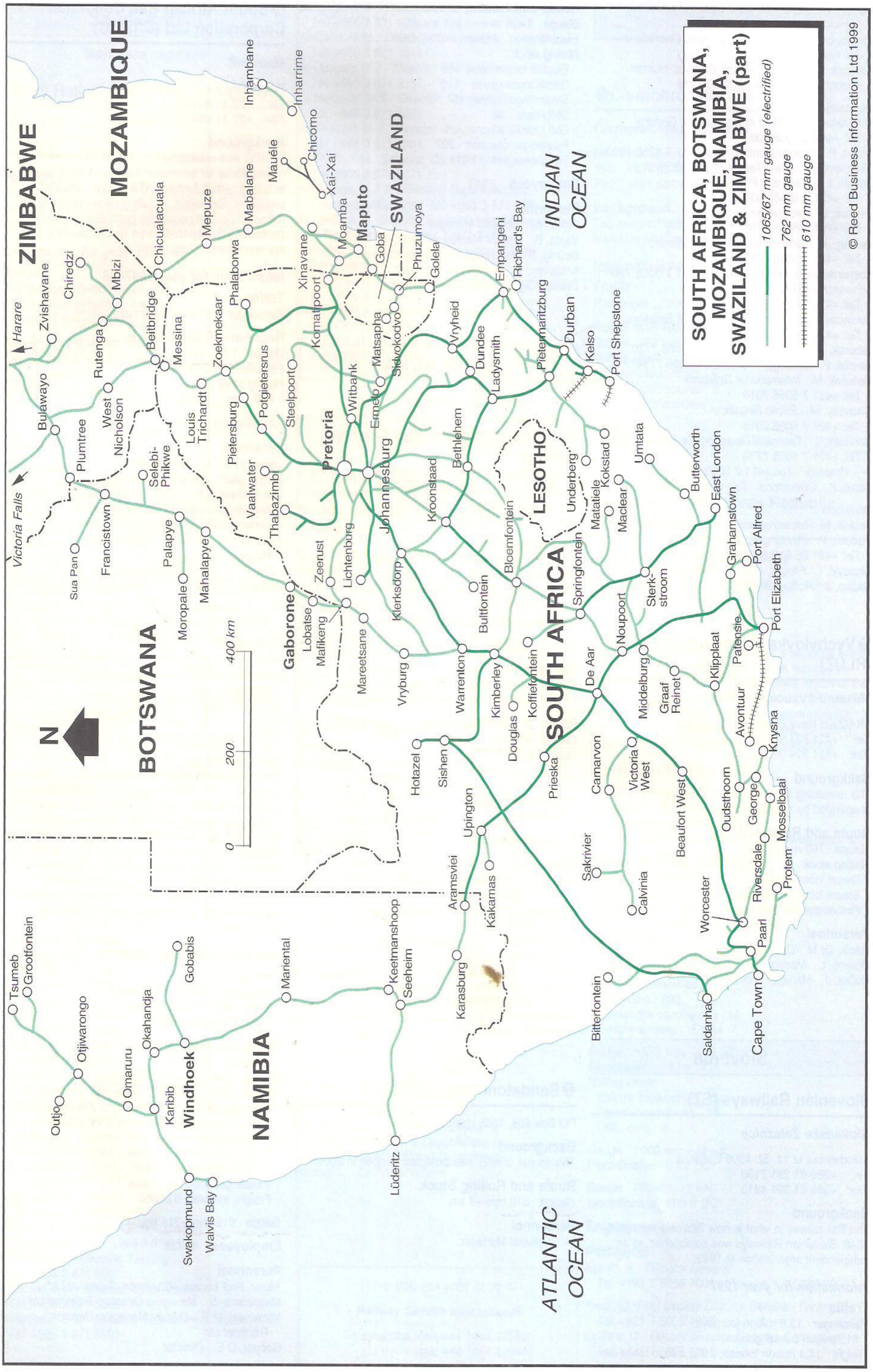
Esashi
Morio
Muroran
Hakodate
Minmaya
Ominato
Aomori
Hachinohe
Odate
Morioka
Miyako
Kamaishi
Akita
Yokote
Sendai
Fukushima
Iwaki
Yamagata
Tsuruoka
Niigata
Utsunomiya
Mito
Narita
Choshi
Maebashi
Takasaki
Tokyo
Chiba
Katsuura
Yokohama
Kofu
Nagano
Matsumoto
Toyama
Nanao
Kanazawa
Shizuoka
Nagoya
Toyohashi
Gifu
Fukui
Tsuruga
Tsu
Toba
Maizuru
Kyoto
Osaka
Kobe
Wakayama
Shingu
Toyooka
Tottori
Himeji
Tsuyama
Okayama
Takamatsu
Niimi
Sakaide
Tokushima
Kaifu
Izumoshi
Matsue
Miyoshi
Hiroshima
Kochi
Kubokawa
Iwakuni
Matsuyama
Masuda
Uwajima
Ogori
Oita
Nobeoka
Kokura
Fukuoka
Kurume
Saga
Kumamoto
Miyazaki
Sasebo
Nagasaki
Yatsushiro
Kagoshima
Shibushi
Makurazaki
Wakkanai
Nayoro
Rumoi
Asahigawa
Engaru
Abashiri
Nemuro
Kushiro
Obihiro
Ikeda
Samani
Mashike
Takikawa
Otaru
Sapporo
Chitose-Kuko
Tomakomai



SOUTH AFRICA, BOTSWANA, MOZAMBIQUE, NAMIBIA, SWAZILAND & ZIMBABWE (part)
1065/67 mm gauge (electrified)
762 mm gauge
610 mm gauge
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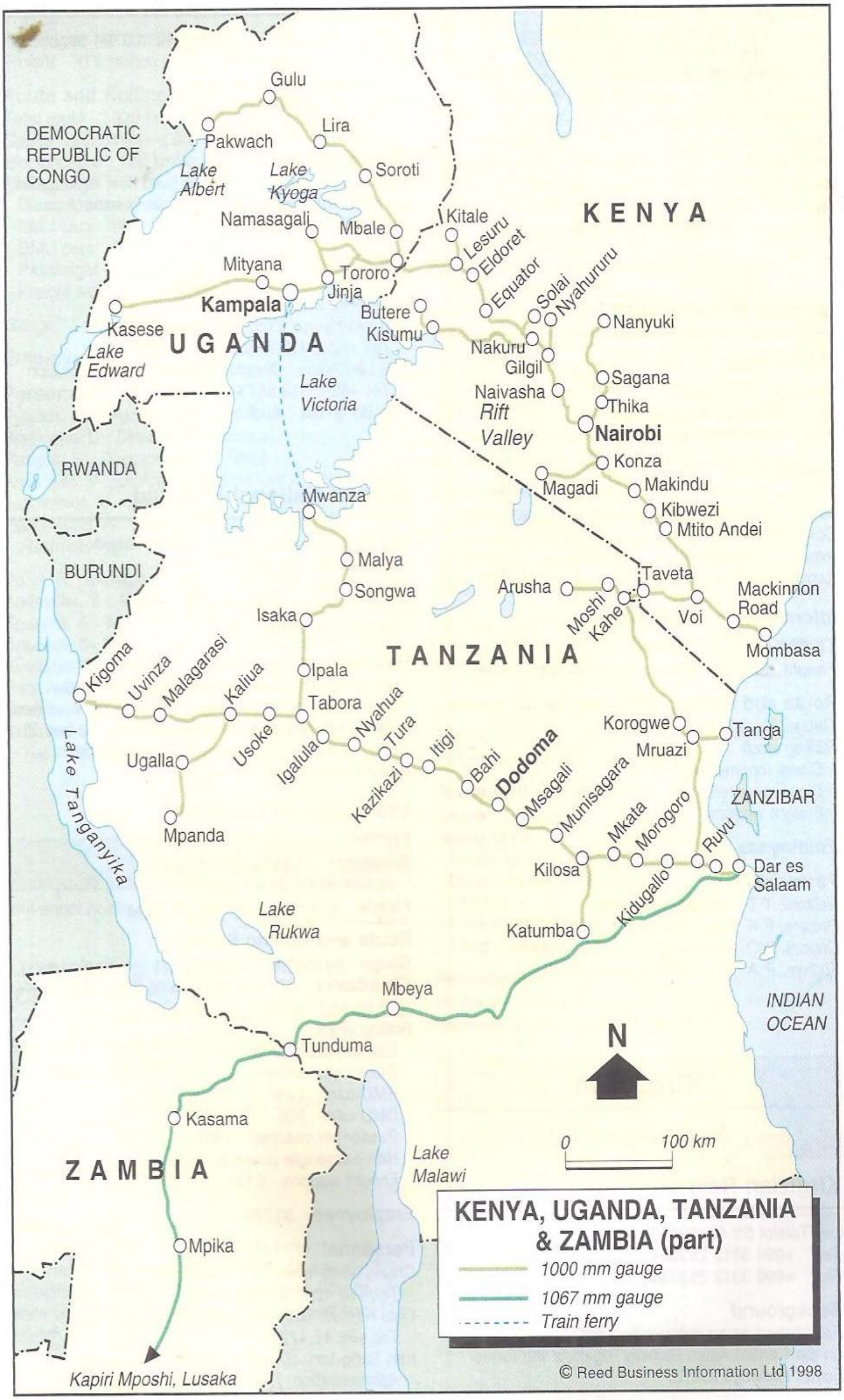
N
0
200
400 km
ZIMBABWE
MOZAMBIQUE
BOTSWANA
NAMIBIA
SWAZILAND
LESOTHO
SOUTH AFRICA
INDIAN OCEAN
ATLANTIC OCEAN
Victoria Falls
Harare
Bulawayo
Zvishavane
Chiredzi
Plumtree
Rutenga
Mbizi
Chicualacuala
West Nicholson
Beitbridge
Messina
Sua Pan
Francistown
Selebi-Phikwe
Louis Trichardt
Zoekmekaar
Phalaborwa
Mepuze
Mabalane
Inhambane
Inharrime
Maueíe
Chicomo
Xai-Xai
Xinavane
Komatipoort
Moamba
Maputo
Goba
Phuzumoya
Golela
Matsapha
Sidvokodvo
Palapye
Mahalapye
Moropale
Pietersburg
Potgietersrus
Steelpoort
Vaalwater
Thabazimbi
Pretoria
Witbank
Ermelo
Johannesburg
Gaborone
Lobatse
Mafikeng
Zeerust
Lichtenburg
Mareetsane
Vryburg
Klerksdorp
Kroonstaad
Bethlehem
Vryheid
Dundee
Ladysmith
Empangeni
Richard's Bay
Pietermaritzburg
Durban
Kelso
Port Shepstone
Underberg
Kokstad
Matatiele
Maclear
Umtata
Butterworth
East London
Bloemfontein
Bultfontein
Warrenton
Kimberley
Koffiefontein
Douglas
Springfontein
Noupoort
Sterkstroom
Grahamstown
Port Alfred
Port Elizabeth
De Aar
Middelburg
Graaf Reinet
Klipplaat
Patensie
Avontuur
Knysna
Hotazel
Sishen
Prieska
Carnarvon
Victoria West
Beaufort West
Oudtshoorn
George
Mosselbaai
Upington
Sakrivier
Calvinia
Aramsviei
Kakamas
Worcester
Riversdale
Protem
Paarl
Cape Town
Saldanha
Bitterfontein
Tsumeb
Grootfontein
Otjiwarongo
Outjo
Omaruru
Okahandja
Gobabis
Karibib
Windhoek
Mariental
Keetmanshoop
Seeheim
Karasburg
Lüderitz
Swakopmund
Walvis Bay


DEMOCRATIC REPUBLIC OF CONGO
UGANDA
KENYA
RWANDA
BURUNDI
TANZANIA
ZAMBIA
ZANZIBAR
INDIAN OCEAN
Lake Albert
Lake Kyoga
Lake Edward
Lake Victoria
Lake Tanganyika
Lake Rukwa
Lake Malawi
Rift Valley
Gulu
Lira
Pakwach
Soroti
Namasagali
Mbale
Kitale
Lesuru
Eldoret
Mityana
Tororo
Jinja
Kampala
Kasese
Equator
Solai
Nyahururu
Butere
Kisumu
Nanyuki
Nakuru
Gilgil
Sagana
Naivasha
Thika
Nairobi
Konza
Magadi
Makindu
Kibwezi
Mtito Andei
Mwanza
Malya
Songwa
Isaka
Arusha
Moshi
Kahe
Taveta
Voi
Mackinnon Road
Mombasa
Kigoma
Uvinza
Malagarasi
Kaliua
Ipala
Tabora
Nyahua
Usoke
Igalula
Tura
Itigi
Kazikazi
Bahi
Dodoma
Msagali
Munisagara
Korogwe
Tanga
Mruazi
Ugalla
Mpanda
Mkata
Morogoro
Ruvu
Kilosa
Dar es Salaam
Kidugallo
Katumba
Mbeya
Tunduma
Kasama
Mpika
Kapiri Mposhi, Lusaka
N
0
100 km
KENYA, UGANDA, TANZANIA & ZAMBIA (part)
1000 mm gauge
1067 mm gauge
Train ferry
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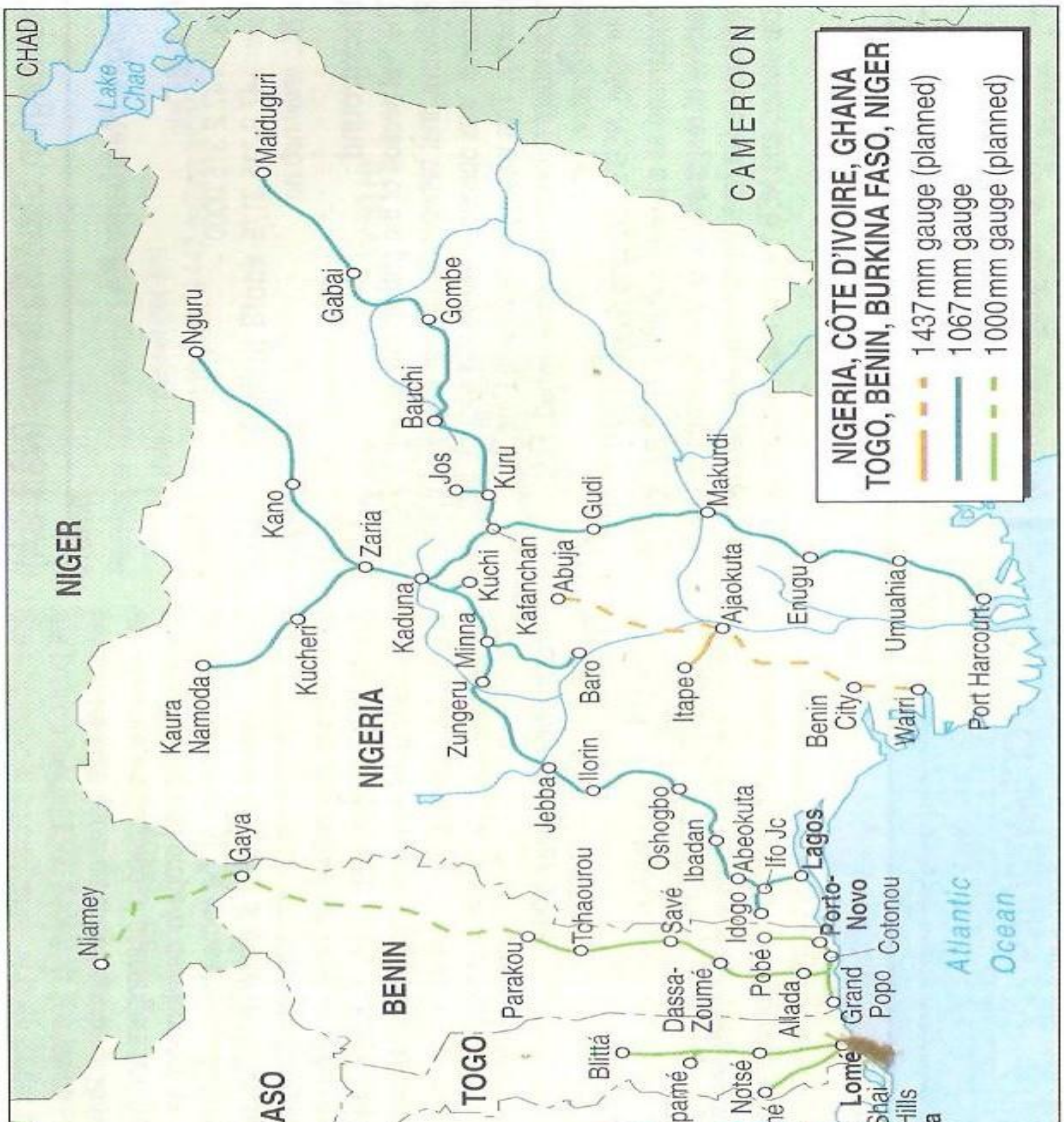
NIGERIA, CÔTE D'IVOIRE, GHANA
TOGO, BENIN, BURKINA FASO, NIGER
1437mm gauge (planned)
1067mm gauge
1000mm gauge (planned)
N
0
100
200 km
MALI
NIGER
CHAD
Lake Chad
CAMEROON
GUINEA
LIBERIA
BURKINA FASO
CÔTE D'IVOIRE
GHANA
TOGO
BENIN
NIGERIA
Atlantic Ocean
Lake Volta
Bandama Blanc
Tambao
Kaya
Ouagadougou
Koudougou
Bobo-Dioulasso
Banfora
Niangoloko
Ferkéssédougou
Tafire
Katiola
Bouake
Dimbokro
Agboville
Abidjan
Port Bouet
Niamey
Gaya
Awaso
Dunkwa
Kumasi
Kade
Huni Valley
Prestea
Tarkwa
Sekondi
Takoradi
Anyinam
Accra
Shai Hills
Kpalimé
Atakpamé
Notsé
Blitta
Lomé
Parakou
Tchaourou
Dassa-Zoumé
Savé
Pobé
Allada
Grand Popo
Porto-Novo
Cotonou
Idogo
Ifo Jc
Lagos
Abeokuta
Ibadan
Oshogbo
Ilorin
Jebba
Zungeru
Minna
Baro
Itape
Ajaokuta
Benin City
Warri
Port Harcourt
Umuahia
Enugu
Makurdi
Abuja
Kafanchan
Kuchi
Kaduna
Gudi
Kuru
Jos
Bauchi
Gombe
Gabai
Maiduguri
Nguru
Kano
Zaria
Kucheri
Kaura Namoda
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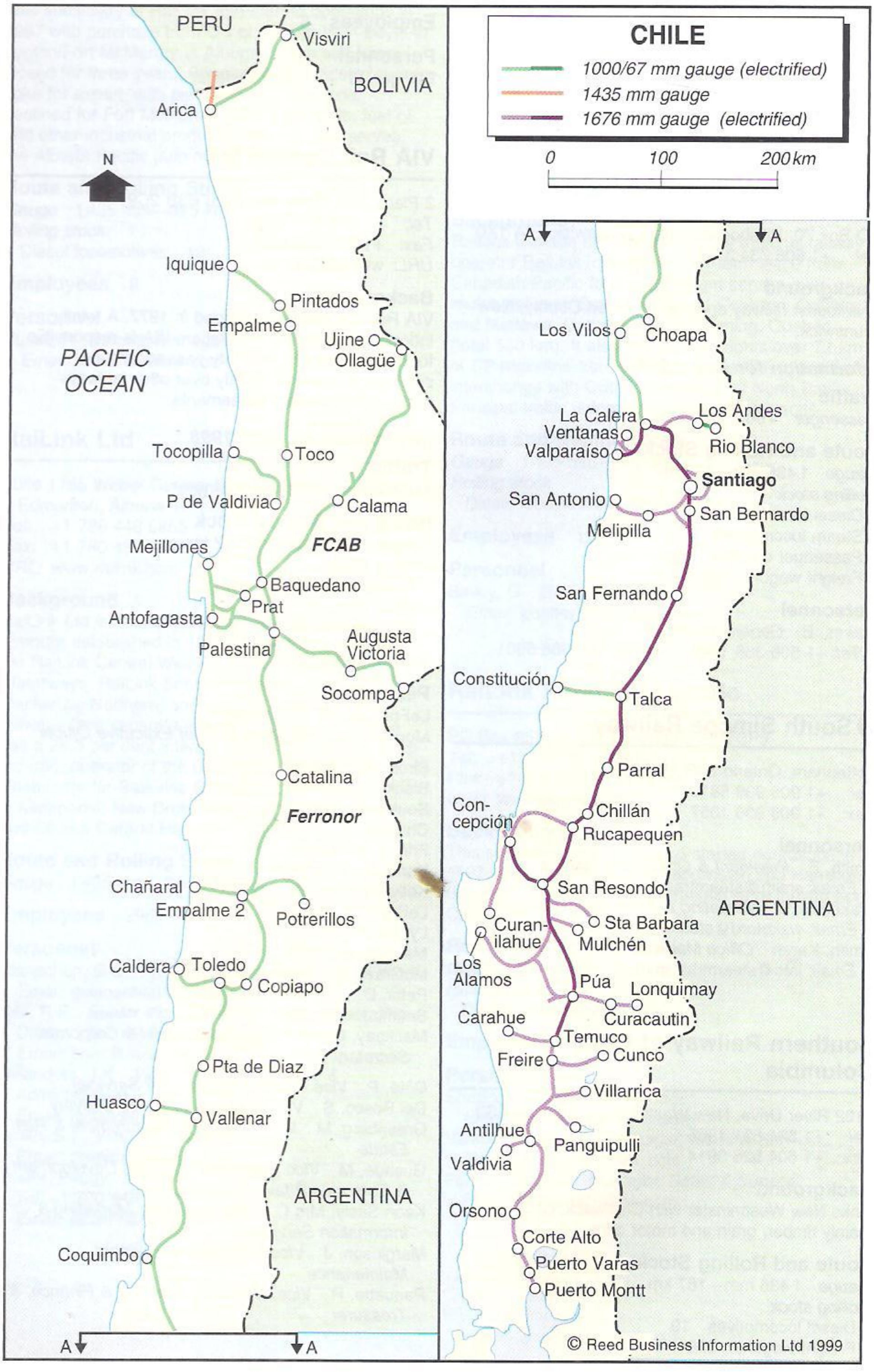
CHILE
1000/67 mm gauge (electrified)
1435 mm gauge
1676 mm gauge (electrified)
0
100
200 km
N
PERU
Visviri
BOLIVIA
Arica
Iquique
Pintados
Empalme
Ujine
Ollagüe
PACIFIC OCEAN
Tocopilla
Toco
P de Valdivia
Calama
FCAB
Mejillones
Baquedano
Prat
Antofagasta
Palestina
Augusta Victoria
Socompa
Catalina
Ferronor
Chañaral
Empalme 2
Potrerillos
Caldera
Toledo
Copiapo
Pta de Diaz
Huasco
Vallenar
ARGENTINA
Coquimbo
A
A
Los Vilos
Choapa
La Calera
Los Andes
Ventanas
Rio Blanco
Valparaíso
Santiago
San Antonio
San Bernardo
Melipilla
San Fernando
Constitución
Talca
Parral
Con-cepción
Chillán
Rucapequen
San Resondo
ARGENTINA
Curan-ilahue
Sta Barbara
Mulchén
Los Alamos
Púa
Lonquimay
Carahue
Curacautin
Temuco
Freire
Cunco
Villarrica
Antilhue
Panguipulli
Valdivia
Orsono
Corte Alto
Puerto Varas
Puerto Montt
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Teresinha
Macapá
Puerto Santana
Belem
Santa Ines
São Luiz
Rosario
Parnaiba
Fortaleza
Macau
Natal
Mossoro
João Pessoa
Altos
Teresina
Souza
Recife
Crato
Salgueiro
Maceio
Acailandia
Maraba
Imperatriz
Carajas
Estreito
Juazeiro
Aracaju
Bonfim
São Francisco
Salvador
Iacu
N
0
500 km
BRAZIL
1600 mm gauge (electrified)
Under construction
1435 mm gauge
1000 mm gauge (electrified)
Under construction
Janauba
Montes Claros
Brasilia
Anapolis
Pirapora
Corinto
Goiânia
Roncador
Vitória
Belo Horizonte
Ibia
Campos
Uberaba
Passos
Colómbia
Rib Preto
Três Rios
Niteroi
Rio de Janeiro
Barra Mansa
Sta Fe do Sul
Três Lagoas
Itirapina
BOLIVIA
Corumba
Indubrasil
Bauru
Sao Paulo
Panorama
Pres. Epitácio
Sorocaba
Santos
Ourinhos
T Sampao
Registro
Itapeva
Dourados
Apucarana
Ponta Pora
Cianorte
Paranagua
Ponta Grossa
Curitiba
S.Francisco do Sul
Cascavel
Guarapuava
Mafra
Foz do Iguaçu
PARAGUAY
Lajes
Imbituba
Tubarão
Passo Fundo
Vacaria
Posto Sangão
ATLANTIC OCEAN
Sta. Rosa
Sao Luis Gonzaga
Roca Sales
Cruz Alta
Porto Alegre
S. Borja
Santa Maria
Itaqui
Cacequi
Uruguaiana
ARGENTINA
Rio Grande
Santana do L
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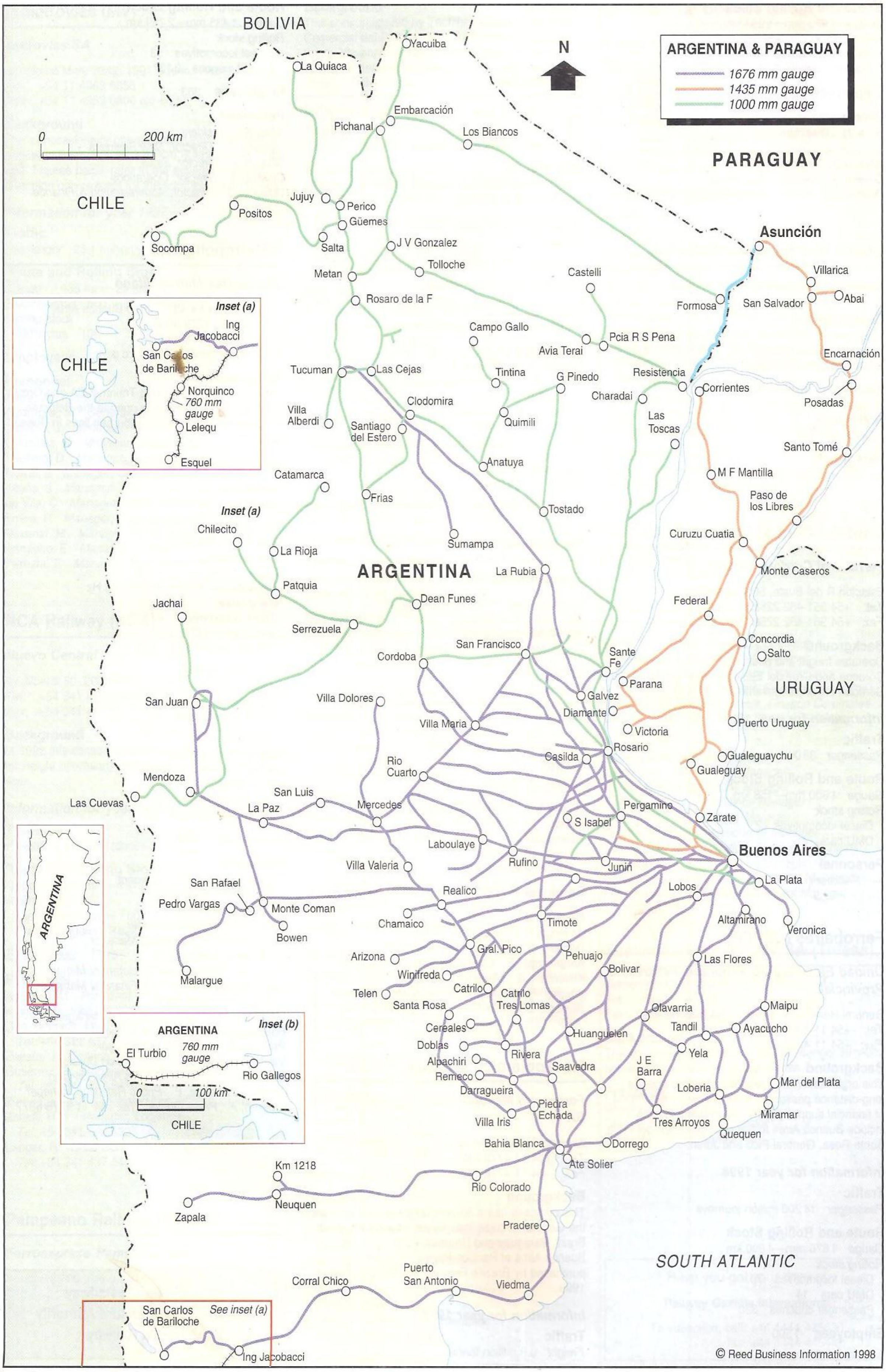
ARGENTINA & PARAGUAY
1676 mm gauge
1435 mm gauge
1000 mm gauge
N
0
200 km
BOLIVIA
CHILE
PARAGUAY
ARGENTINA
URUGUAY
SOUTH ATLANTIC
Yacuiba
La Quiaca
Embarcación
Pichanal
Los Biancos
Jujuy
Perico
Positos
Güemes
Socompa
Salta
J V Gonzalez
Tolloche
Metan
Castelli
Asunción
Villarica
Abai
San Salvador
Formosa
Rosaro de la F
Campo Gallo
Pcia R S Pena
Avia Terai
Encarnación
Tucuman
Las Cejas
Tintina
G Pinedo
Resistencia
Corrientes
Charadai
Posadas
Clodomira
Quimili
Las Toscas
Villa Alberdi
Santiago del Estero
Anatuya
Santo Tomé
Catamarca
M F Mantilla
Frias
Paso de los Libres
Inset (a)
Tostado
Chilecito
Sumampa
Curuzu Cuatia
La Rioja
La Rubia
Monte Caseros
Patquia
Dean Funes
Federal
Jachai
Serrezuela
Concordia
San Francisco
Salto
Cordoba
Sante Fe
Parana
Galvez
Villa Dolores
San Juan
Diamante
Puerto Uruguay
Villa Maria
Victoria
Rosario
Rio Cuarto
Casilda
Gualeguaychu
Gualeguay
Mendoza
San Luis
Las Cuevas
La Paz
Mercedes
Pergamino
Zarate
S Isabel
Laboulaye
Buenos Aires
Villa Valeria
Rufino
Junin
San Rafael
La Plata
Lobos
Realico
Pedro Vargas
Monte Coman
Chamaico
Timote
Altamirano
Veronica
Bowen
Arizona
Gral. Pico
Pehuajo
Las Flores
Winifreda
Bolivar
Malargue
Catrilo
Catrilo
Tres Lomas
Telen
Santa Rosa
Olavarria
Maipu
Cereales
Tandil
Ayacucho
Huanguelen
Doblas
Rivera
Yela
Alpachiri
J E Barra
Saavedra
Remeco
Mar del Plata
Darragueira
Loberia
Piedra Echada
Miramar
Villa Iris
Tres Arroyos
Quequen
Bahia Blanca
Dorrego
Ate Solier
Km 1218
Rio Colorado
Neuquen
Zapala
Pradere
Puerto San Antonio
Corral Chico
Viedma
San Carlos de Bariloche
See inset (a)
Ing Jacobacci
Inset (a)
Ing Jacobacci
San Carlos de Bariloche
CHILE
Norquinco
760 mm gauge
Lelequ
Esquel
ARGENTINA
Inset (b)
El Turbio
760 mm gauge
Rio Gallegos
0
100 km
CHILE
ARGENTINA
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CAMBODIA, LAOS, MALAYSIA
THAILAND & VIETNAM
1000 mm gauge (electrified)
Under construction
1000/1435 mm gauge
CHINA
N
MYANMAR
(BURMA)
Lao Cai
Quan Trieu
Dong Dang
Yen Bai
Vinh
Yen
Hanoi
Halong
Haiphong
Nam Dinh
Ninh Binh
Thanh Hoa
Gulf of
Tongking
HAINAN
LAOS
Chiang Mai
Vinh
Nakhon
Lampang
Vientiane
Den Chai
Uttaradit
Nong Khai
Udon Thani
Dong Hoi
Quang Tri
Hue
Sarvankhabk
THAILAND
Muang Khon
Kaen
VIETNAM
Phitsanulok
Bua Yai
Ubon
Ratchathani
Da Nang
Lop Buri
Chai Badan
Surin
Si Sa
Ket
Nakhon Ratchasima
Quang
Ngai
Suphan
Buri
Nam Tok
Phu My-
Phu Cat
Bangkok
Nakhon
Pathom
Sammut
Poipet
Sisophon
CAMBODIA
Battambang
Tuy Hoa
Sattahip
Maung
Pothisat
Mekong
River
Nha Trang
Da Lat
Khiri Khan
MYANMAR
(BURMA)
Gulf of
Thailand
Phnom Penh
Phan
Rang
Bien Hoa
Takeo
Chumphon
Siahnoukville
Ho Chi Minh City
(Saigon)
Kampot
Surat Thani
Ratthanikom
Nakhon Si Thammaret
0
100
200
300 km
Khao Chum Tong
Ban
Kantang
Hat Yai
Yala
Padang Besar
Alur Setar
Tumpat
Pasir Mas
South China Sea
Kota Kinabalu
Putatan
Papar
Kimanis
SABAH
Butterworth
Taiping
Mawao
Beaufort
0
50 km
Tenom
Gua Musang
Ipoh
Kuala Lipis
Jerantut
MALAYSIA
Mentekab
Kuala Lumpur
Port
Klang
Seremban
Gemas
South China
Sea
Port
Dickson
Tampin
INDONESIA
Kulai
SUMATRA
Johor Bahru
Singapore
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4.4 Upgrading & Rationalization Schemes for SRC Promotion

After specifying the near future PHILOSOPHY OF SRC by having one group of business to run a mixed traffic (Freight/ Passengers trains) in three categories of lines and the documentation by actual facts that the NARROW GAUGE of SRC has not exhausted its full POTENCIAL transportation capacities to fulfill the duties expected for more than a hundred year in the future, we also add that, to adopt a Standard Gauge (S.G) you have to go too far: new buildings, new stations, new workshops, new structural & loading gauges, new plateforms, new motive & rolling stock, new bridges, new track components ..etc, while you DEFENITLY DO NOT NEED a (S.G).

Upgrading & rationalization of the existing SRC business systems are the subject of this last part of the chapter.

It is a sort of preliminary technical studies to upgrade the railway systems but these studies are not ready for execution because such studies have to be carried out by expert engineers & economists.

The upgrading & rationalization of SRC business shall be in three phases, phase (0), phase (1), phase (2). Phase (0) is the base.

The areas to be upgraded shall be followed one by one to reach the final goal.

4.4.1 Upgrading of axle load

This is one way of raising the transportation capacity of a railway line.

To raise the axle load of an existing railway line is a process of strengthening every component of track to the correct specifications &

materials. This way, it involves introduction of new materials if the existing ones are not suitable for the new axle load, the addition of ballast to the appropriate depth, treatment of the subsoil and the formation, strengthening of bridges, choice of the right materials, the drainage systems, much consideration for the maintenance works (manual, semi automatic or automatic), etc.

In chapter two, project NO.(9), you shall find two annexes which cover the construction, histories, European & American view points on sleepers &their users &the railway bridges to show how the axle load can be upgraded.

4.4.2 Upgrading of maximum running speed

Here under we present the main features of SRC main lines (75/90 lb/yd rails) and two model examples of calculations for the actual maximum speed of SRC (60 km/hr) &a speed of (120 km/hr) which is intended after phase (2) upgrading {This is from project (9) with two annexes on CANT & CENTRIFUGAL FORCE}.

Also we present six examples for speeds which can be attained in the NARROW GAUGE of SRC after the upgrading & nationalization.

Main features of standards SRC main lines (75/90lb/Yd. rails)

_single line

_ Narrow Gauge 1067mm (3′ 6″)

_flat bottom Rails

_ Jointed Track

_wooden & steel sleeper

_ suspended Rails Joints

_ Square Rails Joints

_ Sleepers Density (N +2)

_ Built-up Bolted Common Crossings

_ Resilient Fastening & Rigid Fastening

_ Max Gradient 1%

_ Max Axle load 16.5tons

_ Max Degree of Curvature 4^0 $30^{//}$ (Mir 388)

_Max Superelevation (cant) 76.602mm ($3^{//}$)

_ Max Speed 60 Km/hr

_ Cant of Bearing plates 1in 20

<u>Example :</u> **60km/hr**

To find e (cant) of existing main lines of SRC which is already known to be $3^{//}$ (76.602 mm).

Equilibrium speed ≡ the speed in which a moving vehicle shall be in equilibrium.

We calculate the cant (e) in a curve of 3^0 with 60 km/hr speed in a gauge of ($3^{/}$ _$6^{//}$ _1067 mm)

$$\frac{e}{g} = \frac{F}{w}$$

Where

G ≡gauge, $3' 6''$(1067 mm)

F ≡centerefugal force on vehicle

W ≡weight of vehicle

F = $\frac{WV^2}{gR}$

Where:

V≡speed in km/hr

g≡gravity, 32.2 ft/sec^2

$$\frac{e}{G} = \frac{WV^2}{gRW} \Longrightarrow e = \frac{GV^2}{gR}$$

The American colonial practice is to describe the curve by the angle suspended at the centre by a chord of 100 feet.

This latter system will be made clear by considering the whole circumference of a circle to be made up of 360 sections, each of 100 feet. Each of these sections will thus subtend an angle of 1^0 at the centre.

The length of the circumference $2\pi R$, will thus be for practical purpose 36000 feet & the radius will be.

R = $\frac{36000}{2\pi}$ = $\frac{36000}{26.28}$ = 5730 ft

Thus a 1^0 curve has radius of 5730 ft

R ≡ the curve radius in ft or in

R = $\frac{5730}{d^0} = \frac{5730}{3^0}$ = 1910 ft

G = 3́ 6̋ = 3.5 ft

V = $\frac{60X3.28X1000}{60X60}$ = 104/3 ft/sec

g = 32.2 ft/sec^2

$\therefore$ e = (3.5 X($\frac{104}{3}$)^2 X $\frac{1}{32.2X1910}$) X 12 = 2 in

2 inch cant for a 3 degree curve 2$^{//}$

Cant for 1^0 = $\left(\frac{2}{3}\right)$

The cant of SRC main line curve of 3^0 30$^{//}$ (4.5^0) is:

$$\left(\frac{2}{3}\right) X \left(\frac{9}{2}\right) = 3^{//}$$

Which is max cant in SRC.

The max radius & min radius:

$$\frac{5730}{3.28} = 1746\ m, \frac{1764}{4.5} = 383\ R\ min. (Main\ Line)$$

$$\frac{1746}{12.8} = 137\ R\ \text{max}(Sidings).$$

Example : **120km/hr**

We calculate the cant (e) in a curve of 3^0 with 120 km/hr speed in a gauge of (3$^/$ _6$^{//}$ _1067 mm)

$$\frac{e}{g} = \frac{F}{w}$$

Where

G ≡gauge, 3́ 6̋(1067 mm)

F ≡centerefugal force on vehicle

W ≡weight of vehicle

F = $\frac{WV^2}{gR}$

Where:

V≡speed in km/hr

g≡gravity, 32.2 ft/sec^2

$$\frac{e}{G} = \frac{WV^2}{gRW} \Rightarrow e = \frac{GV^2}{gR}$$

The American colonial practice is to describe the curve by the angle suspended at the centre by a chord of 100 feet.

This latter system will be made clear by considering the whole circumference of a circle to be made up of 360 sections, each of 100 feet. Each of these sections will thus subtend an angle of 1^0 at the centre.

The length of the circumference $2\pi R$, will thus be for practical purpose 36000 feet & the radius will be.

R = $\frac{5730}{d} = \frac{5730}{3}$ = 1910 ft

Thus a 1^0 curve has radius of 5730 ft

R ≡ the curve radius in ft or in

R = $\frac{5730}{d^0} = \frac{5730}{3^0}$ = 1910 ft

G = 3′ 6″ = 3.5 ft

V = $\frac{120X3.28X1000}{60X60}$ = 109.333 m/sec

g = 32.2 ft/sec^2

∴ e = (3.5 X$(109.333)^2$X $\frac{1}{32.2X1910}$) X 12 = 6.83 in

6.83 inch cant for a 3 degree curve $2^{//}$

Cant for 1^0 = $\left(\frac{6.83}{3}\right)$ = $2.28^{//}$

The cant of SRC main line curve of 3^0 $30^{//}$ (4.5^0) is:

e = 2.28 x 4.5 = $10.245^{//}$

(4.5^0) e = $\left(\frac{2.28 \text{ x } 9}{2}\right)$ =$10.245^{//}$

(2^0) e for 2^0 curve = 2.28 x 2 = $4.56^{//}$

(2.5^0) e for 2.5^0 curve = 2.28 x 2.5 = $5.7^{//}$

For a speed of 120 km/hr the maximum degree of curventive 4^0 $30^{//}$ (for the 60 km/hr speed) needs to be changed to a 2^0 – 2.5^0 curve to have a cant within the allowable limits.

Example (1): **70km/hr**

To calculate the cant (superelevation) for a 70 km/hr speed in the existing narrow gauge track of SRC ($3^{/}$ _$6^{//}$ _1067 mm) in a 3^0 curve.

$$\frac{e}{g} = \frac{F}{w}$$

Where

G ≡gauge, $\acute{3}$ $\acute{\acute{6}}$(1067 mm)

F ≡centerefugal force on vehicle

W ≡weight of vehicle

F = $\frac{WV^2}{gR}$

Where:

V≡speed in km/hr

g≡gravity, 32.2 ft/sec^2

$$\frac{e}{G} = \frac{WV^2}{gRW} \Rightarrow e = \frac{GV^2}{gR}$$

The American colonial practice is to describe the curve by the angle suspended at the centre by a chord of 100 feet.

This latter system will be made clear by considering the whole circumference of a circle to be made up of 360 sections, each of 100 feet. Each of these sections will thus subtend an angle of 1^0 at the centre.

The length of the circumference $2\pi R$, will thus be for practical purpose 36000 feet & the radius will be.

R = $\frac{36000}{2\pi}$ = $\frac{36000}{26.28}$ = 5730 ft

Thus a 1^0 curve has radius of 5730 ft

R ≡ the curve radius in ft or in

R = $\frac{5730}{d^0}$ = $\frac{5730}{3^0}$ = 1910 ft

G = 3' 6" = 3.5 ft

V = $\frac{70X3.28X1000}{60X60}$ = 63.78 ft/sec

V^2 = 4067.6 ft/sec

g = 32.2 ft/sec^2

∴ e = (3.5 X 4067.6 X $\frac{1}{32.2X1910}$) X 12 = 2.78 in

- That is a 2.78 inch cant for a 3 degree curve

- The cant for a 1 degree curve is

$\acute{e} = \frac{2.78}{3^0}$ = 0.926 in

- The cant in the existing SRC main lines for a 70 km/hr speed shall be (with the 4.5^0 maximum curvature)

e = 0.926 X 4.5 = 4.17 in = 106 mm

- This cant is within the allowable limit of British (BR) which is 5.9 inch (150 mm).
- The maximum degree of curvature which shall give the 3 inches (76.602 mm) allowable cant in SRC main lines is:

$$1.53^{(e)} X\ x^{(degree)} = 3^{//\ (cant)}$$

  - The maximum degree of curvature is

$X^0 = \frac{3}{0.925} = 3.24^0$ curve

- $R_{main} = \frac{5730}{3.28} = 1746\ m \Rightarrow \frac{1746\ m}{3.24^0} = 539\ m$
- For 70 km/hr speed the track has to be upgraded to higher axle load to cater for the dynamic effect added by the higher speed or the track has to be used by light locomotives & rolling stock having axle load of 13 tons to run on the 16.5 axle load track.

-

	$\frac{\acute{2}}{3}$ (18 mm)
+ Max degree of curvature = 3.25^0 + R_{min} = 539 m + Cant = 3 in	70 km/hr
+ Max degree of curvature = 2^0 + R_{min} = 873 m + Cant = $3^{//}$	90 km/hr

<u>Example (2):</u> **90km/hr**

To calculate the cant (superelevation) for a 90 km/hr speed in the existing narrow gauge track of SRC ($3^/ 6^{//}$ –1067 mm) in 3^0 curve.

$$\frac{e}{g} = \frac{F}{w}$$

Where:

G ≡gauge, $\acute{3}\acute{\acute{6}}$(1067 mm)

F ≡centerefugal force on vehicle

W ≡weight of vehicle

F = $\frac{WV^2}{gR}$

Where:

V≡speed in km/hr

g≡gravity, 32.2 ft/sec^2

$$\frac{e}{G} = \frac{WV^2}{gRW} \Rightarrow e = \frac{GV^2}{gR}$$

The American colonial practice is to describe the curve by the angle suspended at the centre by a chord of 100 feet.

This latter system will be made clear by considering the whole circumference of a circle to be made up of 360 sections, each of 100 feet. Each of these sections will thus subtend an angle of 1^0 at the centre.

The length of the circumference $2\pi R$, will thus be for practical purpose 36000 feet & the radius will be.

R = $\frac{36000}{2\pi}$ = $\frac{36000}{26.28}$ = 5730 ft

Thus a 1^0 curve has radius of 5730 ft

R ≡ the curve radius in ft or in

$R = \frac{5730}{d^0}$ = $\frac{5730}{3^0}$ = 1910 ft

G = 3′ 6″ = 3.5 (ft)

V = $\frac{90X3.28X1000}{60X60}$ = 82 ft/sec

V^2 = 6724 ft/sec

g = 32.2 ft/sec^2

∴ e = (3.5X 6724 X$\frac{1}{32.2X1910}$) X 12 = 4.5 in

- That is a 4.5 inch cant for a 3 degree curve

- The cant for a 1 degree curve is

$\acute{e} = \frac{4.5}{3^0}$ = 6.89 in

- The cant in the existing SRS main lines for a 90 km/hr speed shall be (with the 4.5^0 of curvature)

e = 1.53 X 4.5 = 6.89 in = 175.1 mm

- This cant is beyond the allowable limit.
- Therefore the existing maximum degree of curvature (4.5^0) has to be changed for a more flater curve with a degree less than the 4.5^0.
  - The maximum degree of curvature for the speed of 90 km/hr shall be:

    $= 1.53^{(e)}\ X\ x^{(degree)} = 3^{//\ (cant)}$

    $X_{\text{max degree}} = \frac{3}{1.53} = 1.96 \simeq 2^0$

- $R_{\text{main}} = \frac{5730}{3.28} = 1746\ m \Rightarrow \frac{1746\ m}{2^0} = 873\ m$
- For 90 km/hr speed the track has to be upgraded to higher axle load to cater for the dynamic effect added by the higher speed or the track has to be used by light locomotives & rolling stock having axle load of 13 tons to run on the 16.5 axle load track.

+ Max degree of curvature	$= 2^0$	90 km/hr
+ R_{min}	= 873 m	
+ Cant	$= 3^{//}$	

Example (3): **100 km/hr**

To calculate the cant (superelevation) for a 100 km/hr speed in the existing narrow gauge track of SRC (3 ft_ 6 in_1067 mm) in a 3^0 curve.

$$\frac{e}{g} = \frac{F}{w}$$

Where:

G ≡gauge, 3́6̋(1067 mm)

F ≡centerefugal force on vehicle

W ≡weight of vehicle

F = $\frac{WV^2}{gR}$

Where:

V≡speed in km/hr

g≡gravity, 32.2 ft/sec^2

$$\frac{e}{G} = \frac{WV^2}{gRW} \Longrightarrow e = \frac{GV^2}{gR}$$

The American colonial practice is to describe the curve by the angle suspended at the centre by a chord of 100 feet.

This latter system will be made clear by considering the whole circumference of a circle to be made up of 360 sections, each of 100 feet. Each of these sections will thus subtend an angle of 1^0 at the centre.

The length of the circumference $2\pi R$, will thus be for practical purpose 36000 feet & the radius will be.

$R = \frac{36000}{2\pi} = \frac{36000}{26.28}$ = 5730 ft

Thus a 1^0 curve has radius of 5730 ft

R ≡ the curve radius in ft or in

$R = \frac{5730}{d^0} = \frac{5730}{3^0}$ = 1910 ft

G = 3́ 6̋ = 3.5 ft

$V = \frac{100X3.28X1000}{60X60}$ = 91.1 ft/sec

V^2 = 8301.235 ft/sec

g = 32.2 ft/sec^2

∴ e =$\frac{GV^2}{gR}$ (3.5 X 8301.235 X $\frac{1}{32.2 X 1910}$) X 12 = 5.669 in

- That is a 5.669 inch cant for a 3 degree curve
- Cant for a 1 degree curve is

$é = \frac{5.669}{3^0}$ = 1.89 in

- The cant in the existing SRC main lines for a 90 km/hr speed shall be (with the 4.5^0 of curvature)

e = 1.89// X 4.5^0 = 8.51 in = 216.21 mm

- This cant is beyond the allowable limit (150 mm for BR) .
- Therefore the existing maximum degree of curvature (4.5^0) has to be changed for amore flater curve with a degree less than the 4.5^0.
  - The cant for a 3^0 is:
    e = 1.89// X 3^0 = 5.67 in = 144.1 mm
- Which is within allowable limit (150 mm for BR).

- Therefore the existing curve has to be changed to a 3 degree or less.
  - The maximum radius shall be:

$X^0 = 1.53^{(e)}$ X $x^{(degree)} = 3^{//(cant)}$

$X^0 = 3/1.53 = 2^0$

$$R_{main} = \frac{5730}{3.28} = 1746\,m \Rightarrow \frac{1746\,m}{32^0} = 588\,m$$

- For 100 km/hr speed the track has to be upgraded to higher axle load to cater for the dynamic effect added by the higher speed or to be used by light locos & rolling stock gross load axle weight less than the 16.5 axle load.

+ Max degree of curvature = 2^0 + R_{min} = $\frac{1746}{3^0}$ = 588 m + Cant = $5.7^{//}$	100 km/hr

<u>Example (4):</u> **(130km/hr)**

To calculate the cant (superelevation) for a 130 km/hr speed in the existing narrow gauge track of SRC ($3^{/}\,6^{//}$ –1067 mm) in 3^0 curve.

$$\frac{e}{g} = \frac{F}{w}$$

Where:

G ≡gauge, $\acute{3}\acute{\acute{6}}$(1067 mm)

F ≡centerefugal face on vehicle

W ≡weight of vehicle

F = $\frac{wv^2}{gR}$

Where:

V≡speed in km/hr

g≡gravity, 32.2 ft/sec^2

$$\frac{e}{G} = \frac{WV^2}{gRW} \Longrightarrow e = \frac{GV^2}{gR}$$

The American colonial practice is to describe the curve by the angle suspended at the centre by a chord of 100 feet.

This latter system will be made clear by considering the whole circumference of a circle to be made up of 360 sections, each of 100 feet. Each of these sections will thus subtend an angle of 1^0 at the centre.

The length of the circumference $2\pi R$, will thus be for practical purpose 36000 feet & the radius will be.

R = $\frac{36000}{2\pi}$ = $\frac{36000}{26.28}$ = 5730 ft

Thus a 1^0 curve has radius of 5730 ft

R ≡ the curve radius in ft or in

$R = \frac{5730}{d^0} = \frac{5730}{3^0}$ = 1910 ft

G = $3'6''$ = 3.5 (ft)

V = $\frac{130 \ X \ 3.28 \ X 1000}{60 \ X \ 60}$ = 118 ft/sec

$V^2 = 14029 ft/sec$

$g = 32.2\ ft/sec^2$

$\therefore e = (\ 3.5\ X\ 14029\ X\ \frac{1}{32.2\ X\ 1910})\ X\ 12 = 9.581$ in

- That is a 9.581 inch cant for a 3^0 curve
- The cant for a 1^0 degree curve is

$\acute{e}\ =\ \frac{4.5}{3^0} = 3.194$ in

- The cant in the existing SRC main lines for a 130 km/hr speed shall be (with the 4.5^0 of curvature)

e = 3.194 X 4.5 = 14.4 in = 365.2 mm

- This cant is beyond the allowable limit of B.R which is 5.9 in (150 mm).
- The maximum degree of curvature which shall give the 3 inches (76.602 mm) allowable cant in SRC existing main lines is:

$= 3.19^{(e)}\ X\ x^{(degree)} = 3^{//(cant)}$

- The maximum degree of curvature is:

$= \frac{3}{3.19} = 0.94^0$carve

- $R_{main} = \frac{5730}{3.28} = 1746\ m \Rightarrow \frac{1746m}{0.94} = 1857\ m$
- For a130 km/hr speed the track has to be upgraded to higher axle load to cater for the dynamic effect added by the higher speed or the track has to be used by light locomotives & rolling stock having axle load of 13 tons to run on the 16.5 axle load track.

+ Max degree of curvature = 0.94^0 + R_{min} = 1857 m + Cant = $3^{//}$	For 130 km/hr speed

<u>Example (5):</u> **145 km/hr**

To calculate the cant (superelevation) for a 145 km/hr speed in the existing narrow gauge track of SRC ($3^{/}\,6^{//}$ –1067 mm) in a 3^0 curve.

$$\frac{e}{g} = \frac{F}{w}$$

Where:

G ≡gauge**,** $\acute{3}\acute{\acute{6}}$(1067 mm)

F ≡centerefugal force on vehicle

W ≡weight of vehicle

F = $\frac{wv^2}{gR}$

Where:

V≡speed in km/hr

g≡gravity, 32.2 ft/sec^2

$$\frac{e}{G} = \frac{WV^2}{gRW} \Longrightarrow e = \frac{GV^2}{gR}$$

The American colonial practice is to describe the curve by the angle suspended at the centre by a chord of 100 feet.

This latter system will be made clear by considering the whole circumference of a circle to be made up of 360 sections, each of 100 feet. Each of these sections will thus subtend an angle of 1^0 at the centre.

The length of the circumference $2\pi R$, will thus be for practical purpose 36000 feet & the radius will be.

$$R = \frac{36000}{2\pi} = \frac{36000}{26.28} = 5730 \text{ ft}$$

Thus a 1^0 curve has radius of 5730 ft

R ≡ the curve radius in ft or in

$$R = \frac{5730}{d^0} = \frac{5730}{3^0} = 1910 \text{ ft}$$

$$G = 3' 6'' = 3.5 \text{ (ft)}$$

$$V = \frac{145 \text{ X } 3.28 \text{ X } 1000}{60 \text{ X } 60} = 132 \text{ ft/sec}$$

$g = 32.2 \text{ ft/sec}^2$

$$\therefore e = (3.5 \text{ X } 17453 \text{ X } \frac{1}{32.2 \text{ X } 1910}) \text{ X } 12 = 12 \text{ in}$$

e' for one degree $= \frac{12}{3} = 4'' = 101.63$ mm

Which is within the allowable cant of BR ($5.9''$ - 150 mm).

With a 1^0 curve trains can travel by a speed of 145 km/hr which is within the allowable limits.

If we want to keep the maximum cant of $3''$ the maximum degree of curvature to be used in the main lines shall.

$$= 4'' * x^0 = 3''$$

$$x^0 = \frac{3}{4} = 0.75^0$$

+ Max degree of curvature = 0.75^0 + R_{min} $\frac{1746}{0.75}$ = 2328 m + Cant = $3^{//}$	For 145 km/hr speed

<u>Example (6):</u> **160 km/hr**

To calculate the cant (superelevation) for a 160 km/hr speed in the existing narrow gauge track of SRC ($3^{/}\,6^{//}$ –1067 mm) in a 3^0 curve.

$$e = \frac{GV^2}{gR}$$

$V = \frac{160\ X\ 3.28\ X\ 1000}{60\ X\ 60}$ = 145.8 ft/sec

V^2 = 21251.2 ft/sec^2

$\therefore$ e = (3.5 X 2125.2 X $\frac{1}{32.2\ X\ 1910}$) X 12 = 14.5 in

$e^{/}$ for one degree = $\frac{14.5}{3}$ = $4.8^{//}$(123 mm) which is within the allowable limit of BR ($5.9^{//}$ - 150 mm).

- With a 1^0 curve trains can travel by a speed of 160 km/hr when the maximum cant is within the allowable limit.

If we want to keep the maximum cant of $3^{//}$ the maximum degree of curvature to be used in the main lines shall be.

$$= 4.8\ X\ x = 3$$

$$x = \frac{3}{4.8} = 0.625^0$$

+ Max degree of curvature = 0.625^0 + R_{min} $\frac{1746}{0.625}$ = 2794 m + Cant = $3^{//}$	For 160 km/hr speed

- The two speeds of 145 km/hr & 160 km/hr are attainable safely in SRC narrow gauge in a curve of 1^0 with $4^{//}$ & $4.8^{//}$ cants respectively.

Annexe (1)

Centrifugal force and overturning

When a vehicle travels around a curve, centrifugal force acts on its centre of gravity and forces it outwards.

Centrifugal force results in an overturning moment. This is opposed by a stability moment. Where the vehicle speed exceeds the balancing speed for the curve, the.net result of these moments is to transfer a portion of the wheel load from the inner to the outer rail. The effect would then be to apply a greater load on the outer rail than on the inner.

Additional flange force caused by excess, unbalanced centrifugal force would normally have little influence on the total flange force as it is usually considerably less than that portion of the flange thrust due to curving. Unbalanced centrifugal forces, however, can contribute significantly to vehicle rollover tendency, particularly when the speeds exceed the design speed of the curve and/or there is a track defect that results in a sudden increase in superelevation deficiency.

Thus, for any given radius, by varying either the speed or the amount of super elevation (within limits) there is very little scope for reducing flange thrust.

Centrifugal force is given by standard physics as follows:

$$f = \frac{WV^2}{gr}$$

Where F=centrifugal force in tons

W = Mass of vehicle in tons

V = Velocity in m/sec

r = Radius of curve in meters

g = Acceleration due to gravity, or 9.8m per second

S = Superelevation in millimeters

G = Gauge of the track, or centre to centre of rail adopted as 1500mm.

The level of unbalance is represented by the cant deficiency. Standard requirements for design of curves are given in ESC 210.

Effect of centrifugal force and flange thrust

When vehicle speed exceeds the balance speed for' the existing superfetation on a curve, the resulting centrifugal force has two separate effects,

a) A flange force acting against the outer rail, and
b) An increased load on the wheel running on the outer rail 'due to

c) load transfer' from the inner wheel.

As the speed increases, so does the centrifugal force, and both flange force and wheel load on the outer rail increase together. Actually, centrifugal force acts on the centre of gravity of the vehicle body. The body rolls on its suspension, transferring additional load onto the wheels on the outer rail. Wheel climbing is less likely to occur due to increase in centrifugal force provided that the path followed by the wheel is smooth and not interrupted by a track defect.

Flange force, which promotes wheel climb, is opposed on curves at speed by the greater load imposed by centrifugal force, resulting in the wheel being held to the rail.

The probability of derailment by wheel climb, as measured by the ‘ratio between the horizontal flange force and the vertical wheel load, is remote, however great the flange force, unless some other factor enters into consideration which tends to reduce the wheel load. For instance, a low joint on the outer rail may momentarily reduce the vertical wheel load on the guiding wheel while leaving the flange thrust almost unaffected and to such an extent that the wheel will mount the rail.

Lurching may do likewise, and all such contributing factors may operate simultaneously to cause a derailment.

If the superelevation is much greater than that required for any given speed (i.e. superelevation excess), wheel load is transferred to the inner rail where it is least needed. In this case, vehicles travelling at slow speed, or speeds less than the curve balancing speed, may tend to climb the high rail because of the reduction in wheel load on the outer rail. This particularly applies to vehicles with a high center of gravity.

Danger of overturning

Overturning can only take place when centrifugal force, which acts horizontally, and the effect of the mass of the vehicle, which acts vertically, combine to produce a resultant force that passes through or outside the point of contact between the hee1 tread and the head of the outer rail. The vehicle is then in unstable equilibrium, as the load on the inner rail approaches zero, and any additional lateral force on the vehicle will result in overturning. The speed at which this can occur is called the "Critical speed for overturning."

Derailment by overturning on the high rail is extremely rare. A vehicle travelling around a curve at high speed is far more likely to derail owing to a high L/V ratiorather than overturning.

Overturning can occur on the low rail where a high centre of gravity vehicle is travelling at low speed and is disturbed by cyclic irregularities in superelevation. This causes the vehicle to roll towards the inside of the curve, bringing the resultant of the weight component of the vehicle and the inertial forces through or outside the low rail.

Overturning limits can be calculated from basic geometry by taking moments about the rail over which overturning occurs (normally the high rail).

F x COG = W x horizontal distance of COG from centre of high rail

Where

F = Centrifugal force in tones.

W = Mass of vehicle in tones

COG = centre of gravity

Annexe (2)

The Impact of superelevation (or cant Deficiency and why it's important)

Elsewhere we introduced the concept of unbalance or underbalance in operation through horizontal curves. In passenger rail terminology, this same concept is generally referred to as "cant deficiency." The term is drawn from British and European practice where super elevation is referred to as "cant" and the term "cant deficiency" describes the circumstance where a vehicle operates through a curve with insufficient cant to achieve equilibrium.

Superelevation (banking or track cant) is a necessary ingredient for safe and comfortable curve negotiation. Super elevation is used to counteract the effects of centripetal acceleration (centrifugal force) on the vehicle and the occupants. The amount the outer rail is elevated is determined by the sharpness of the curve and the speed the vehicles operate through it.

Some definitions are in order:

- Balance Speed: The speed at which the combination of curvature and super elevation exactly balance the centripetal acceleration and the resultant force vector is normal Lo ilia track plane.
- Cant Deficiency: Also known as Underbalance. This is the amount of super elevation, or cant that is missing from the track and would be needed to produce a balance condition for the speed operated. Underbalance is generated by operating through a curve at speeds faster than the balance speed.

- Overbalance: This is the amount of excess super elevation, or cant that is in the track in order to produce a balance condition for the speed operated.

Overbalance is generated by operating through a curve at speeds slower than balance speed, It is also generated by stopping in a. super elevates curve.

Why are these pinpoint? Passenger comfort for one, maintenance and deterioration of the track structure for the other. In track that is used by both passenger trains operating at speeds of approximately 70 mph or greater and heavy axle freight trains, there is a compromise that must be reached concerning the elevation of curves. Higher super elevation is desired by the passenger operator for higher speeds through the curves, Lower super elevation is desired in the freight operator to protect against overturning of slow or stopped freight cars with high centers of gravity. There is also the effect of the excessive burden plead on the low rail by the heavy wheel loads of freight Gars operating in the overbalance condition. This burden manifests itself by causing accelerated deterioration of the low rail surface geometry, head wear, or crushed head of the low rail; ,or increased superelevation. All of these have a snowball effect on the maintenance requirements of the curve.

Freight equipment can operate effectively at elevations up to 6 inches, although operators typically want elevations less than 4 inches. Passenger equipment can accommodate super elevations up to 8 or 9 inches, although a maximum of 6 or 7 inches is desired in passenger service as a comfort limit for a passenger’s ability to walk or stand on a train stopped in curve. Cant deficiency is used to increase the effective superelevation by taking advantage of the passenger equipment’s ability to negotiate a curve at speeds much greater than balance speed.

Therefore, design consideration can be made to accommodate freight operation by designing a curve with elevations between 4 inches and 6 inches. Then increasing the cant deficiency can create additional speed for the passenger train. Each inch of cant deficiency is equivalent- to an additional inch of supereIevaion. For example, operating at 3 inches of cant deficiency on a 6 inch elevated curve is the equivalent of operating on 9 inches of superelevation.

Car body tilt systems have been used to gain even more speed in curve. Passenger cars can typically accommodate much higher cant deficiency safely than that which is comfortable for the passengers. To take advantage of this characteristic, the bar body can be tilted to create a near balance condition in the interior of the car while externally it is developing quite a lot of centripetal acceleration. For example, for a tilting car operating at 9-inch cant deficiency on a 6-inch superelevated curve (i.e., the equivalent of 15 inches of superelevation), if the car tilts at 8 degrees, the net cant deficiency experienced by passengers in the car interior is approximately 2 inches. This a powerful method to increase speed on an existing line where major changes in alignment or curvature are not feasible.

To show the relationship between the axle load & the speed we quote from reference [ ] the following:

Sophisticated design and electronic equipment have enabled more power to be installed and usefully used than in the past, and the ambition of every railway is to install the maximum hp within their weight limits.

However, tests have shown that with certain types of transmission the stresses on the track have increased dangerously as speed has risen hence a trend to reduce axle loads as speeds increase.

High speeds are, in many cases, of great commercial value and, therefore, the maximum power must be installed in the locomotive whilst still retaining light axle loads.

To quote an example, the maximum permitted axle load on British Railways is 25 tons, but on the HST, which travels at speeds of up to 200 km/h, the maximum permitted axle loads restricted to 17.5 tons, in order to keep track stresses within acceptable limits [15].

4.4.3 Raising the transportation capacity by operational mean [11]

OPERATING [11]

The optimum length of a train ¡s determined by one of the following factors.

a) The clear standing distance in the passing loop or station.

b) The ruling gradient along the full length of the line.

c) The power of the locomotives to-achieve the minimum required operating speed.

Once the optimum train length has been determined, which may not be the same in both directions, an operating train schedule is prepared. From this the maximum number of trains that can run in both directions along the line can be determined. This takes into account the practical maximum capacity of a single line which has been found to be in the order of 80%. However, this does not allow for maintenance of the line and it is recommended that 75% of this 80% be used as the time available to operate trains along the line. As an example: -

365 days per year x 80%	=292 days
292days x75%	= 219 days

60% of 24 hours = 14.40 Say 15 hours

Therefore for all practical purposes, the line may be occupied by traffic for 15 hours out of every 24 which allows for in-service delays and track maintenance.

The operating schedule which is often termed the "working" timetable is based upon:

a) Physical limitations of track, signalling, communication, locomotives, rolling stock, station /loop facilities and staff.
b) Traffic requirement for all train classifications i.e. freight, passenger, livestock etc.
c) Financial considerations.

Fundamental to any working timetable is the need for adequate, secure communication and a form of signaling for the train drivers.

SIGNALLIING [11]

The term 'signalling' is used to cover the fixed signals, telegraphs, electric speaking instruments and various control operations, either mechanically or electrically operated.

There are a number of methods for controlling train movements, the main ones beings:

a) Non-block systems—

i) 'train following' system

b) Permissive block systems —

i)staff .

ii) staff and ticket

iii) telegraph proceed order system

c) Absolute block systems— .

i) electric token (key, tablet or staff)

ii) tokenless block

iii) centralized traffic control

Although any one, of these methods of train control may meet the demands of safety, they vary in their ability to control the unhindered and speedy movement of trains along the line. The more sophisticated the system of control, the greater the line capacity.

The following signaling system has been designed and used by BR. It may be of use for **SRC.**

Radio Train Dispatch (R.T.D) [9].

As a long term solution to the problem of operating rural tines in a cost effective manner the Research and Development Division of British Railways has designed a new system of train control known as Radio Train Dispatch or R.T.D. It is hoped that by the introduction of this system on rural lines throughout the country that their future can be assured.

Two routes have been selected for the initial trials, the Inverness to Kyle line in the North West of Scotland and the East Suffolk Line in East Anglia. It is intended to concentrate on the latter line for the purpose of this article.

The East Suffolk Line is 78 kilometers in length and double line throughout. It has nine intermediate stations between which and Lowestoft. There are twenty three manned level crossings and two which are already automated. Signalling is predominantly, semaphore, controlled from mechanical interlocking frames in nine signal boxes. There is an overhead pole route providing communication throughout the line which is in the final stages of decay and kept in operation by patch and repair.

The permanent way is as previously described for other secondary lines, a mixture of bull head and flat bottom track with aging softwood sleepers, it is manually maintained due to sleeper and ballast conditions.

The passenger train service of Diesel Multiple Units is basically two-hourly with additional train in the morning and evening. These trains connect into and out of the Main Line services at Ipswich.

Earnings for the line in 1981 were £471,000 compared with operating costs of £650,000.

The Line has been investigated for rationalization of track facilities and it has been confirmed that the line can be singled throughout with a passing loop at Saxmundham and still cater for a similar train service that which exists.

For R.T.D. operation the line will be divided into two single line sections, Westerfield to Saxmundham loop and Saxmundham loop to Lowestoft. One signalman based at a train dispatch-centre at Saxmunciham will control all traffic movements on the route. Each Multiple Diesel Unit to be used on the line will be fitted with a radio and visual display unit in each driver's cab.

A driver wishing to proceed from, say, Westerfield to Saxmundham loop will radio the train dispatch centre and request permission to proced. The train dispatcher will perform a sequence of actions to identify the train and the electronic token required for the movement. He then presses a button to transmit the token, in coded message form, to the radio in the drivers cab, and informs the driver by radio that the token has been sent. On pressing a receive button in the display unit the driver confirms receipt of the token by the words 'Westerfield to Saxmundham loop' appearing on the display unit. The driver can then proceed, confident that due to electrical interlocking no other train can enter the section.

The benefits of the introduction of R.T.D. operation will be to make the existing conventional signalling on the line redundant, this includes five signalboxes. Also the life expired overhead pole route can be dispensed with.

With the loss of telephone communication it is necessary to automate the twenty two public level crossings and this is to be achieved at the minimum cost with Automatic Open Crossings, Locally Monitored. Such crossings, however, require that train speeds do not exceed 90 km/hr and this will. therefore, be the line route speed.

The closure of signalboxes also produces a problem in the operation of switches at double to single line. To overcome this the Research and Development Divisions has produced special hydraulic pneumatic operated switches. These are set initially so that facing traffic is diverted into the left-hand side of a loop. Trains travelling in the trailing direction push through the points, this proves a build up in pressure in the, mechanism which, after the train has passed, returns the switches to their original position. All such switches are to be fitted with electric switch heaters to ensure correct operation in adverse weather conditions. A simple mechanical' signalling device is being designed to indicate to train drivers approaching these switches in a facing direction that they are correctly set.

The investment to provide" R.T.D. equipment, automate level crossings, provide the special switches' plus switch heaters is £1,600,000. However, savings to be achieved are such that it is estimated the investment will be recovered within three years Operation.

A program for introduction of this scheme has been prepared, Westerfield to Saxmundhtm being R.T.D. controlled by the end of 1984 and the whole line by the end of 1985.

It is further the intention to utilize track recovered from the high speed lines, which is only suitable for reuse on low category lines, to relay the single line section of the East Suffolk Line. As much of this will be done before the R.T.D. scheme is implemented.

Considerable additional savings in maintenance will result with the ability to introduce mechanized maintenance methods.

4.5 Possible annual tonnage of upgraded lines in Kh/P.S section

The upgrading, as we said before, in the three suggested categories of lines, shall start immediately for category (3) lines. This work is classified as phase (0). It is considered as the lowest category of SRC lines (the base lines).

The specifications of category (3) LINES are:

- Axle load 16.5tons
- Max speed 70km/hr.
- Rail weight 75Lb/Yd (37.5km/m)

The second upgrading (PHASE-1) is for category two line. It shall also start immediately to be finished within six to eight years (PHASE-1).

The specifications of CATEGORY (2) lines are:

- Axle load 20 tons
- Max speed 90km/hr
- Rail weight 90Lb/Yd (45kg/m)

The last phase (PHASE-2) is for category (1) lines.

It shall start after ten (10) years to finish within five to six years.

(Kh/P.S ≡ Khartoum / Port Sudan)

The specifications of category (1) lines are:

- Axle load 23 tons
- Max speed 100-120 km/hr
- Rail weight 110Lb/Yd (55kg/m)

The durations Specified above are not strict or definite. They are just estimations based on assumptions which may differ.

The execution of these schemes could be phased. Therefore the finances needed shall be scheduled for many years.

This was the case in SRC development schemes financing, such as conversion from plain bearings to rolling bearings & change from bell type couplers to automatic couplers. Some of these projects took up to 10 years to executed.

Tables (4/1), (4/2) & (4/3), contain the specifications of trains to be operated in the three phases of development [phase (0), (1) & (2)].

Also table 4/1 Compares phase (1) with phase (0) Table 4/2 compares phase (2) with phase (0). Table 4/3 compares phase (1) with phase (2).

It wearth mentioning that at any stage of upgrading the output of SRC is proportionally increased.

In table (4/1) we can see that the rate of increase in annual transportation after upgrading from phase (0) to phase (1) is 244% (table 4/1), from phase (0) to phase (2) is 383% (table 4/2).

Table (4/3) Comparison of the Annual transportation capacity of today's trains with upgraded trains. To start immediately phase (1) to finish within 6-8 years [phase (0) – phase (1)].

Item	*Parameters*	*Existing operating trains in SRC phase (0)*	*Immediately upgraded train within 6-8 years phase (1)*
1.	Length of train	850 m	950 m
2.	Number of wagons per train	25 – 50 No	55 – 60 No
3.	Axle load	16.5 t	20 t
4.	Gross weight of one train	1500 t	2500 t
5.	Transportation capacity of one train	950 t (one way)	1500 t (one way)
6.	Maximum speed	60 km/hr	90 km/hr
7.	Average speed	50 km/hr	75 km/hr
8.	Total turn–round time of one train	127.5 hrs (5.3 days) (two ways)	117.5 hrs (4.9 days) (two ways)
9.	Total round time frequency of one train per year	56.5 (No) (two ways)	61.5 (No) (two ways)

10.	Transportation capacity of one train per year	$56.5 X 2 X 950$ = 107,350 t	$61.5 X 2 X 1500$ = 184,500 t
11.	Total annual Transportation capacities of 10 & 20 trains	$107.350 X 10$ = 1,073,500 t	$184500 X 20$ = 3,690,000 t

The rate of annual increase in tonnage after upgrading from phase (0) to phase (1) = $\frac{2616500}{1073500}$ = **244%**

Table (4/4) Comparison of the Annual transportation capacity of today's SRC trains [phase (0)] with upgraded trains to finish within 15 years [phase (0) – phase (2)].

Item	*Parameters*	*50 wagons X 35 tons capacity trains (existing) phase (0)*	*60 wagons X 35 tons capacity trains (within 15 years) phase (2)*
1.	Train length	850 m	1000 m
2.	Number of wagons per train	25 – 50 No	60 – 65 No
3.	Axle load	16.5 t	23 t
4.	Gross weight of one train	1500 t	3000 t
5.	Transportation capacity of one train	950 t (one way)	1800 t (one way)

6.	Maximum speed	60 km/hr	120 km/hr
7.	Average speed	50 km/hr	100 km/hr
8.	Total turn round time of train	127.5 hrs (5.3 days) (two ways)	100 hrs (4.2 days) (two ways)
9.	Total turn–round time frequency of one train per year	56.5 (No) (two ways)	72 times (two ways)
10.	Transportation capacity of one train pre year	$56.5\ X\ 2\ X 950$ = 107,350 t	$72\ X\ 2\ X\ 1800$ = 259,200 t
11.	Total annual Transportation capacities of 10 & 20 trains	$107.350 X\ 10$ = 1,073,500 t	$259{,}200\ X\ 20$ = 5,184,000 t

The rate of annual increase in tonnage after upgrading from phase (0) to phase (2) = $\frac{4110500}{1073500}$ = **383%**

Table (4/5) Comparison of the Annual transportation capacity of phase (1) trains with phase (2) trains (upgraded trains) [phase (1) – phase (2)].

Item	***Parameters***	***50 wagons X 35 tons capacity trains Immediately phase (1)***	***60 wagons X 35 tons capacity trains (within 30 years) phase (2)***
1.	Train length	950 m	1000 m
2.	Number of wagons per train	55 – 60 No	60 – 65 No
3.	Axle load	20 t	23 t

4.	Gross weight of one train	2500 t	3000 t
5.	Transportation capacity of one train	1500 t (one way)	1800 t (one way)
6.	Maximum speed	90 km/hr	120 km/hr
7.	Average speed	75 km/hr	100 km/hr
8.	Total turn-round time of train	117 hrs (4.9 days) (two ways)	100 hrs (4.2 days) (two ways)
9.	Total turn–round time frequency of one train per year	61.5 (No) (two ways)	72 No (two ways)
10.	Transportation capacity of one train per year	$61.5\ X\ 2\ X\ 1500$ = 184,500 t	$72\ X\ 2\ X\ 1800$ = 259,200 t
11.	Total annual Transportation capacities of 20 trains	3,690,000 t	259,200 x 20 = 5,184,000 t

The rate of annual increase in tonnage after upgrading from phase (1) to phase (2) = $\frac{1494000}{3690000}$ = **40%**

4.5.1 The motive power required after upgrading

Of course the ELECTRIFICATION of the railways is their future but diesel Electric traction shall be the mode of traction for some time in countries of the third world for reasons mentioned before.

Here under you find three sets of calculation for three diesel electric locomotives classes to serve in hauling the three types of trains specified in the three tables shown about.

The three loads to be hauled by the three types of trains are: 1500 tons, 2500 tons & 3000 tons.

The powers of the three types of diesel electric locomotives are:

- 1768 KW(2366 H.P)
- 2298 KW(3080 H.P)
- 2678 KW(3583 H.P)

As mentioned in the operating section above the calculations shall be worked to calculate the power of the locomotives to achieve the minimum required operating speed.

4.5.2 Calcu1ations of Tractive Effort and Power Range:

Tractive Effort

The power available for traction which is converted to tractive force to overcome the resistance of a train.

Power (in force units) versus total resistance.

Where total Resistance = (Rolling Resistance + grade resistance + curve resistance).

Rolling resistance

The rolling resistance of a train (flange resistance + journal resistance +air resistance) can be determined by formula. The most widely used of such formula is the Davis formula.

The rolling resistance:

- Increases as speed increases.
- Increases as car weight increases.
- It is measured in kilograms.

Grade Resistance (Gravity)

It is the resistance of the load due to gravity

- It is the same at any speed.
- It is measured in percentage.
- It is $\frac{\text{Rise}}{Run}$e.g. 1 in 100 =$\frac{1}{100}$ = 1%

e.g. 1% grade = 10 kilograms of resistance/Metric ton.

Curve Resistance:

- Same at any speed
- Measured in degrees
- 1^0curve = 0.04% grade

e.g. l^o curve = 0.4 kilogram/metric ton.

By definition, a one degree curve is a curve, a 91.44meters chord of which determines a one degree central angle.

It happens that such a curve has a radius of 1746.5 meters.

Given the degree of curvature, radius can be determined by dividing 1746.5 meters by the degree of curvature. Thus two and three degree curves have respective radii of $\frac{1746.5}{2}$ meters and $\frac{1746.5}{3}$ meters or 873.25 and 582.2 meters.

Davis formu1a - Rolling Resistance:

R =A +$\frac{B}{W}$ + CV + $\frac{D\,a\,V^2}{Wn}$

Where

R = Rolling Resistance

W = Weight per Axle - Tons

n = number of axles

V =Velocity

a = cross sectional area

A)

B) constants depending upon

C) units and type vehicle

D

Table (4/6) CONSTANTS

U.S. Units - R - lbs./ton, W - Short tons, V-mph, a - sq. ft				
	A	**B**	**C**	**C**
Locomotives	1.3	29.	.03	.0024
Freight Cars	1.3	29.	.045	.0005
Passenger Cars	1.3	29.	.03	.00035
fleet cars	3.3	0.	.03	.0007
British Units- R –lbs./long ton, W – long tons, V- mph, A -sq. ft.				
Locomotives	1.456	29.	.0336	.0024
Freight Cars	1.456	29.	.0504	.0005
Passenger Cars	1.456	29.	.0336	.00034
Metric Units - R - Kg./M.ton, W - m. tons, V - kph, A - sq. m.				
Locomotives	0.65	13.2	0.00931	.00253
Freight Cars	0.65	13.2	0.01395	.000944
Passenger Cars	0.65	13.2	0.00931	.000642

I. Calcu1ations of power for locos to pull 1500 tons in Khartoum/ Port Sudan (Kh/P.S) section

(Phase 0)

Now it is required to calculate the tractive power needed to haul a 1500 tons train consisting of wagons, having 35 tons capacity and with 15 tons tare weight. They are of four axles design. The locomotive has six driving axles and its weight is 80 tons, Cross-sectional area of wagons and locomotive are 7.5 m^2 and 10.5 m^2 respectively.

The calculations to be based on Sudan Railways specifications as shown below:

Maximum track curvature i.e. minimum radius is:

4^0 30' (on main line R_{min} = 388 m

12° 48' (on sidings) R_{min} = 137m

The ruling gradient is 1 in 100

The maximum axle load should not exceed 16.5 long ton.

i. Rolling Resistance

Rolling resistance (R) = $A + \frac{B}{W} + CV + \frac{DaV^2}{Wn}$(See Appendix B)

R (for wagons) = $0.65 + \frac{13.2}{12.5} + 0.01395*25 + \frac{0.000944*7.5*25^2}{50}$

Total rolling resistance of wagons = 2.14 kg/Tons =

2.14* 1500 = 3210 kg.

R (for locomotive) = $0.65 + \frac{13.3}{16.5} + 0.000931*25 + \frac{0.00453*10.5*25^2}{80}$

= 2 kg/ton

Total locomotive rolling resistance = 2 x 80 = 160 kg.

160 kg.

Train rolling resistance = 3370 kg.

ii. Grade Resistance

Grade resistance (wagons) = 1420*10*1 = 14200 kg

Grade resistance (1ocomotive) = 80*10*1 = 800 k

Train grade resistance = 15000 kg

iii. Curve resistance

Curve resistance (wagons) = 1420*0.4*4.5 = 2556 kg

Curve resistance (locomotive) = 80*0.4*4.5 = 144 kg

Train curve resistance = 27000k

Totaltrain resistance (Rolling + Grade + Curve) = 2107

Tractive effort:

$$\text{(KN)} = \frac{kilowatt\ power\ * 3.57 * 0.82}{\text{Train speed (km)}}$$

$$\frac{21070 * 9.81}{1000} = \frac{KW * 3.57 * 0.82}{25} = 1765\ K = 2366\ HP$$

1765 KW is the tractive power to be specified.

2. Calcu1ations of power for locos to pull 2500 tons in Khartoum/ Port Sudan (Kh/P.S) section

(Phase 1)

Now it is required to calculate the tractive power needed to haul a 2500 tons train consisting of wagons, having 35 tons capacity and with 15 tons tare weight. They are of four axles design. The locomotive has six driving axles and its weight is 80 tons, Cross-sectional area of wagons and locomotive are 7.5 m^2 and 10.5 m^2 respectively.

The calculations to be based on Sudan Railways specifications as shown below:

Maximum track curvature i.e. minimum radius is:

(less) (on main line R_{min} = 388 m

12° 48' (on sidings) R_{min} = 137m

The ruling gradient is 1 in 100

The maximum axle load should not exceed 20 long ton.

i. Rolling Resistance

Rolling resistance (R) = A +$\frac{B}{W}$ + CV + $\frac{DaV^2}{Wn}$(See Appendix B)

R (for wagons) = 0.65 + $\frac{13.2}{16.25}$ + 0.01395*25 + $\frac{0.000944*7.5*25^2}{65}$

Total rolling resistance of wagons = 1.88 kg/Tons =

1.88* 2400 = 4510 kg.

R (for locomotive) = 0.65 + $\frac{13.3}{18}$+ 0.000931*25 + $\frac{0.00453*10.5*25^2}{108}$

= 1.682 kg/ton

Total locomotive rolling resistance = 1.682 x 108 = 182 kg.

Train rolling resistance = 4692 kg.

ii. Grade Resistance

Grade resistance (wagons) = 2400*10*1 = 24000 kg

Grade resistance (1ocomotive) = 108*10*1 = 1080 kg

Train grade resistance = 25080 kg

iii. Curve resistance

Curve resistance (wagons) = 2400*0.4*4.5 = 4320 kg

Curve resistance (locomotive) = 108*0.4*4.5 = 194 kg

Train curve resistance = 4514 kg

Total train resistance (Rolling + Grade + Curve) = 2107 kg

Tractive effort:

$$\text{(KN)} = \frac{kilowatt\ power\ * 3.57 * 0.82}{\text{Train speed (km)}}$$

$$\frac{34286 * 9.81}{1000} = \frac{KW * 3.57 * 0.82}{20} = 2298\,KW = 3080\,HP$$

2298 KW is the tractive power to be specified.

3. Calcu1ations of power for locos to pull 3000 tons in Khartoum/ Port Sudan (Kh/P.S) section

(Phase 2)

Now it is required to calculate the tractive power needed to haul a 3000 tons train consisting of wagons, having 45 tons capacity and with 20 tons tare weight. They are of four axles design. The locomotive has six driving axles and it weight is 110 tons, Cross-sectional area of wagons and locomotive are 7.5 m^2 and 10.5 m^2 respectively.

The calculations to be based on Sudan Railways specifications as shown below:

Maximum track curvature i.e. minimum radius is:

(less) (on main line R_{min} = 388 m

12° 48' (on sidings) R_{min} = 137m

The ruling gradient is 1 in 100

The maximum axle load should not exceed 23 long ton.

i. Rolling Resistance

Rolling resistance (R) = A +$\frac{B}{W}$ + CV + $\frac{DaV^2}{Wn}$(See Appendix B)

R (for wagons) = 0.65 + $\frac{13.2}{16.25}$ + 0.01395*25 + $\frac{0.000944*7.5*25^2}{65}$

Total rolling resistance of wagons = 1.88 kg/Tons =

1.88* 2800 = 5261 kg.

R (for locomotive) = 0.65 + $\frac{13.3}{20}$+ 0.000931*25 + $\frac{0.00453*10.5*25^2}{118}$

= 1.59 kg/ton

Total locomotive rolling resistance = 1.59 x 118 = 187 kg.

160 kg.

Train rolling resistance = 5448 kg.

ii. Grade Resistance

Grade resistance (wagons) = 2800*10*1 = 28000 kg

Grade resistance (1ocomotive) = 118*10*1 = 1180 k

Train grade resistance = 29180 kg

iii. Curve resistance

Curve resistance (wagons) = 2800*0.4*4.5 = 5040 kg

Curve resistance (locomotive) = 118*0.4*4.5 = 212 k

Train curve resistance = 5252 kg

Totaltrain resistance (Rolling + Grade + Curve) = 39880 kg

Tractive effort:

$$\text{(KN)} = \frac{kilowatt\ power\ * 3.57 * 0.82}{\text{Train speed (km)}}$$

$$\frac{39880 * 9.81}{1000} = \frac{KW * 3.57 * 0.82}{20} = 2673 = 3583\ HP$$

2673 KW is the tractive power to be specified.

Chapter Five

Conclusion & Recommendation

Chapter Five

5.1 Introduction

Exiting railway systems, when higher transportation demand show up, have to be revised to upgrade and rationalize the whole systems. Unspecialized persons, if involved, may give wrong advice such as replacement of systems by new designs or any other drastic measures which cost a lot without any use.

Therefore it is always advised that the bread baking has to be entrusted to its baker.

SRC is now in the stage that its systems need to be upgraded & rationalized to raise its annual transportation capacity to cater for the coming hundred years.

The specific objectives of this project are to study the case of SRC & see what major schemes are needed & possible **TO PUT SRC IN THE RIGHT TRACK.**

The study area specified the basic components of SRC business for study, upgrading & rationalization. Those components are:

a) The track.
b) The signaling, operation & telecommunications.
c) Motive power & rolling stock
d) Training institutions & training.
e) The top management.

The report of the project has been presented in five chapters.

Chapter four is a RESEARCH WORK which contains suggestions for adoption by SRC to upgrade its annual transportation capacity of Khartoum/Port Sudan section to about four times within 15 years by upgrading the existing NARROW gauge SINGLE track introducing a new signal system.

All SRC lines have also been studied & a package of upgrading phases are among, the suggestions.

Gauges of tracks, worldwide, are broad (1520/1676mm), standard (1435mm), narrow (1067mm), metre (1000mm), and even less.

The broad gauges are adopted for strategic reasons (war-countries of the Ex-Eastern block).

The gauge is a main factor in the annual transportation capacity. The wider the gauge the higher the transportation capacity (axle load/speed).

The cost of construction & maintenance of track is higher (may be twice) for the standard gauge when compared with a narrow gauge track.

The freight & passengers transportation demand for the third world countries SHALL NOT EXHAUST THE POTENCIAL CAPABILITIES OF A NERROW GAUGE (upgraded & rationalized) railway, if these countries adopted the STANDARD GAUGE they shall have REDUNDANT transportation capacity.

The conclusions & recommendations which come here under are strongly supported by technical arguments which came in the body of the text.

5.2 Conclusions & Recommendations

1. SRC SHALL NOT NEED TO CONSTRUCT STANDARD GAUGE TRACK OR HAVE DOUBLE LINES FOR MORE THAN A CENTURY TO COME.
2. The business philosophy of SRC shall consist of one business group running mixed traffic (freight / passenger trains) in three categories of lines (one, two & three) the motive power shall basically be diesel electric.
3. The axle loads & the lines running speeds for the three categories of lines shall be:
    a) For category one lines. 23 tones axle load, 100-120 km/hr line speed.
    b) For category two lines. 20 tones axle load, 90 km/hr line speed.
    c) For category three lines. 16.5 tones axle load, 70 km/hr line speed.
4. The existing signal system is out of date, old & obsolete. The first right decision to be taken is the complete replacement of the signaling & telecommunications systems by a CENTRALIZED TRAFFIC CONTROL [4].
5. For the electrification of any railway, although of top priority, investment is high. It is foreseen that SRC electrification shall be slow.
6. Passengers' transportation in the third world countries is not a successful commercial business when compared with freight transportation. In the industrialized countries the situation is reversed.
7. The results of British Rails (BR) upgrading & rationalization of

its light duty secondary lines in its eastern region shows that there are no readymade answers & solutions for upgrading of railways. For example the said lines of BR were of double track, the upgrading has been achieved by changing some of these lines to single lines the story is fully documented in reference [9].

8. The possibility of upgrading the AXLELOAD of any railway can be achieved regardless of its gauge width (narrow or standard).

If the line speed is upgraded together with the upgrading of the axle load, this shall be different than the case of upgrading the axle load only, because the dynamic load is higher than the static load [15].

There are HEAVY HAUL lines built round the world with 25-30 tons axle loads, some of them are of NARROW GAUGE & some are STANDARD [12].

9. If all parameters which are factors of the transportation capacity of a railway line, remain fixed, the transportation capacity of this line shall be doubled if the line speed has been doubled [13].

The degrees of curves & the superelevations (Cants) of the lines are the limiting factors for the speed, these can be calculated accurately by mathematical methods as can be found in chapter four.

The NARROW GAUGE track, is serving, for more than six decades, in two industrialized countries (South Africa & Japan) with a speed of 160 km/hr, this is the case up to now with the exception of the SHINKANSEN TRACK (1435mm) which is a HIGH SEED RAIL built in 1964 in Japan in preference to doubling the existing NARROW GAUGE track. See the maps (1-8). The speed of the Shinkansen is now

(2016) over 550 km/hr. The line is for passengers transportation. freight lines speeds round the world, have not exceeded 200 km/hr much.

In chapter four you find calculations for possible line speeds in SRC lines after upgrading & rationalization of its NARROW GAUGE lines.

The calculations are for the speeds: 60, 70, 90, 100, 120, 130, 145 & 160 km/hr.

This shows that there are no reasons linked with the WIDTH of the NARROW GAUGE which hinder it from attaining the above speeds.

10. The operation systems & the arrangements of stations plus the signaling & telecommunications are main factors in raising the capacity of the railways transportation capacity.
11. Table (4/2). Show that, after execution of phase (2) of upgrading the section Port Sudan-Khartoum, annual transportation tonnage shall be raised for more than %380 of today's tonnage.
12. The motive power (diesel electric) needed after the upgrading of phase (1) & phase (2) shall be avaible in the international market of diesel electric locomotives till The NARROW GAUGE RAILWAYS EXHAUST ALL Their POTENCIAL CAPABILITIES, and they have a long life to live.
13. The training, of personnel is PRIORITY NUMBER ONE SRC needs it desperately. Without it, SRC shall be paralyzed.
14. The way the board of directors of SRC is formed, is one step forward, two steps backward. It is a waste of time & money.

The BOARD OF DIRECTORS OF SRC MUST be constituted from successful, efficient & capable specialized SRC men. This is the trend followed in many famous successful railways. In appendix (2) you find how the board of the Indian Railways is formed.

15. The legal status of SRC has to be revised to give it the freedom of the companies in performing its commercial business.

SRC has to be a governmental corporation, 100% owned by the government & audited by the NATIONAL AUDIT of the Sudan.

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