

INTRODUCING THE NEXT GENERATION LOCOMOTIVE TO THE AUSTRALIAN RAIL NETWORK

Noel Ramsey, Frank Szanto, Paul Hewison

SCT Logistics, Downer EDI Rail, Halcrow

SUMMARY

The following paper describes the introduction of what is now the most powerful and efficient locomotive operating across Australia's Defined Interstate Rail Network. The locomotive was originally conceived by SCT Logistics after analysing the market and commissioning a study from Halcrow to determine motive power configurations that would best suit their expanding rail business. The designer and manufacturer of the SCT locomotive designated the GT46C Ace, is Downer EDI Rail. The paper gives an insight into how the locomotive was conceived, including the planning and modelling that determined SCT's decision for choosing AC traction and the associated cost benefit analyses. Also discussed are the risks considered by SCT in taking ownership of their own fleet with technology which supersedes present locomotive fleets operating across Australia's mainline rail networks.

The paper details the innovative solutions provided by Downer EDI Rail in engineering and manufacturing a locomotive to meet SCT's demanding requirements for operation and those of the State Regulators and track access providers.

The paper concludes by comparing the operating performance of the new locomotive with the operator's expectations.

INTRODUCTION

Australia's first AC traction locomotive that has been certified to operate across the Australian Defined Interstate Rail Network was commissioned by a small private rail company, SCT Logistics, which at the time of tendering did not own any mainline locomotives. To understand why a private family owned company would tackle the challenges involved in being the first rail company to procure AC locomotives, including working through all the risks and constraints to ensure certification across five states, it is necessary to understand the history of SCT.

1. NOTATION

DIRN	Defined Interstate Rail Network
SCT	SCT Logistics
DEDIR	Downer EDI Rail
GTO	Gate Turn Off Inverter
IGBT	Insulated Gate Bipolar Transistor

2. BACKGROUND

SCT was originally established in 1974 as a rail freight forwarding company; however it was in 1995 that SCT made the milestone decision to compete with the National Rail Corporation on the

Melbourne to Perth corridor. On 13 July 1995 SCT operated the first private rail freight train between Melbourne and Perth. The train was 600 metres long, made up from discarded louver van wagons from National Rail and hauled by a V/line Freight G Class Locomotive. Refer to Figure 1.



Figure 1: SCT's first train with founder, Peter Smith.

SCT continued to expand its services and successfully competed with National Rail, later to be owned by Pacific National, by developing a relationship with V/Line Freight, later to be privatised and become Freight Australia. SCT continued to develop its relationship with Freight Australia and expanded its services operating up to four trains per week. Over this time SCT built up new rail distribution facilities in Melbourne, Adelaide, Perth and more recently Parkes. SCT's greater focus on rail and its competitive nature has enabled the rail freight rates for the East and West corridor to reduce significantly. Figure 2 shows an SCT train leaving Altona, Melbourne.



Figure 2: SCT train leaving Melbourne

3. MOTIVE POWER OPTIONS

It was in 2003 after successfully establishing their East to West coast rail operation that SCT recognised their future in rail was under threat due to the impending sale of Freight Australia to Pacific National. SCT was totally reliant on Freight Australia for Hook and Pull services, i.e. the provision of locomotives and crews. To remain competitive in the rail industry SCT had to look at alternative options rather than rely on a competitor to haul its services. SCT commissioned Halcrow to review their current operation and assist with determining their future direction.

The options that were available to SCT included:-

- Seeking an alliance with another Rail Operator for hook and pull services.
- Sourcing second hand or remanufactured locomotives.
- Procuring new locomotives.

4. EXPLORING THE OPTIONS

SCT determined very early into the review that there was little chance of another Rail Operator supplying Hook and Pull services for their trains. Also a survey of the market identified that there would not be any suitable second hand locomotives available that would be able to reliably operate the East West service.

The review highlighted that the source of locomotives to meet Australian requirements included a number of companies offering remanufactured locomotives and new locomotives from the mainstream suppliers as well as some alternative suppliers.

5. REMANUFACTURED AND REPOWERED LOCOMOTIVES

During the early 2000's a number of companies in Australia were repowering and remanufacturing older locomotives. Most of these locomotives were re-powered with higher horsepower turbocharged engines taking them to over 2400 kW (3000 hp).

SCT looked at these new classes of locomotives and considered that although they were significantly cheaper than a new locomotive, they utilised older refurbished engines and traction equipment that could not offer the same hauling capacity and efficiencies of new locomotives. Other issues identified with the remanufactured locomotives on offer at the time of the review, were that none were fully certified to operate across the Australian Network and most had operational limitations due to their older technology. Furthermore, their fuel efficiency was not comparable with that of the latest commercially available locomotives.

Early in the review SCT also considered contracting the building of new locomotives utilising alternative engine suppliers to the two traditional suppliers of freight locomotives in Australia. These alternative companies were keen to supply engines that potentially demonstrated greater efficiencies and higher power to weight ratios. It was also identified that there were also other potential suppliers for the other key subsystems required for a complete locomotive, i.e. for the traction systems, bogies etc.

This option was however ruled out as it was determined that by building up a locomotive with different subsystems from various suppliers, SCT had to take the responsibility and risk for the whole package not performing. This risk was too great for SCT and hence the decision was made to procure a new fleet of latest generation locomotives.

6. THE DECISION FOR AC TRACTION

To determine the size and type of locomotives required, the review had to look in detail at SCT's operation, both current and proposed. Preliminary simulations were undertaken for the SCT Trains being hauled by different locomotive types and

sizes, especially on the Melbourne to Adelaide section through the Adelaide Hills. The typical SCT train in 2003 was up to 4400 tonnes between Melbourne and Adelaide and over 5000 tonnes between Adelaide and Perth. These trains were hauled by up to four Pacific National G Class locomotives. These DC traction locomotives are 2460 kW (3340hp) with tractive efforts of 340 kN @19.5 kph allowing them to haul 1100 trailing tonnes through the Adelaide Hills. The best locomotives operating this service at the time of the review were the Pacific National NR locomotives, these are 3000kW (4020hp) and rated to haul 1250 tonnes. Both these locomotives were compared with a hypothetical AC traction locomotive which was predicted to haul in excess of 1600 tonnes through the Adelaide Hills that have ruling grades of greater than 1 in 45.

Following the review of different locomotives available it was determined that the most suitable locomotive for SCT's trains would have AC traction. Although the main downside of AC against DC traction locomotives is the higher cost the key advantages were determined as follows:-

- SCT could potentially operate services with one less locomotive than the current four required through the Adelaide Hills and if the AC locomotive was fitted with a higher horse power engine, potentially one less locomotive across the desert. This not only meant that fewer locomotives needed to be procured but operational costs would also be reduced.
- The cost of maintaining DC traction motors is greater than AC traction motors. DC traction motors have brushes that must be inspected every exam and generally have an expected life of less than 100,000 kms.
- Locomotive reliability would be improved with AC traction. SCT determined that DC traction motor faults were accountable for up to 20% of all SCT train failures. AC traction motors handle higher loads for longer periods, whereas the DC traction motors are more prone to overheating if subjected to higher loads for extensive periods. It was identified that DC traction motor failures represented approximately 20% of the total recorded faults on locomotives hauling SCT trains.

The review however identified some disadvantages with AC traction locomotives and these had to be assessed for their potential impact on SCT operations, including:-

- AC traction locomotives tend to weigh 2 to 3 tonnes more than their DC counterparts. This issue had to be considered as weight savings are gained generally from reducing a locomotive's fuel load which potentially could restrict SCT's operations.
- The challenges and risks for gaining full certification for the first AC traction locomotives to operate across five states had to be considered, including the potential for massive time delays and possible restrictions that would eliminate any advantages gained by having AC traction. The main issues identified, following preliminary discussions with Regulators was to ensure that any AC traction system was compatible with all track signalling systems and ensure it would not damage track.
- Other regulatory guidelines that could restrict the advantages of AC traction had also to be considered, including the requirement for a train to be held by the locomotive's independent brake through the Adelaide Hills. For three AC traction locomotives operating through the Adelaide Hills it was determined that to maximise their load hauling potential up to eight wagons had to be fitted with brakes that operate when the locomotives independent brake is applied.



Figure 3: The first SCT AC locomotive

Following the review that determined that SCT would procure AC traction locomotives a specification was drafted with a tender, and in August 2005 a contract to supply AC locomotives was awarded to Downer EDI Rail (DEDIR).

The decision to procure locomotives from DEDIR was not just a commercial decision but also because of other features offered including, DEDIR stipulating that their AC locomotive would provide the hauling capacity required, carry at least 10,000 litres of fuel and comply with the requirement that allows for a maximum weight of 134 tonnes for fully provisioned locomotive accessing the DIRN. Figure 3 shows the first SCT locomotive.

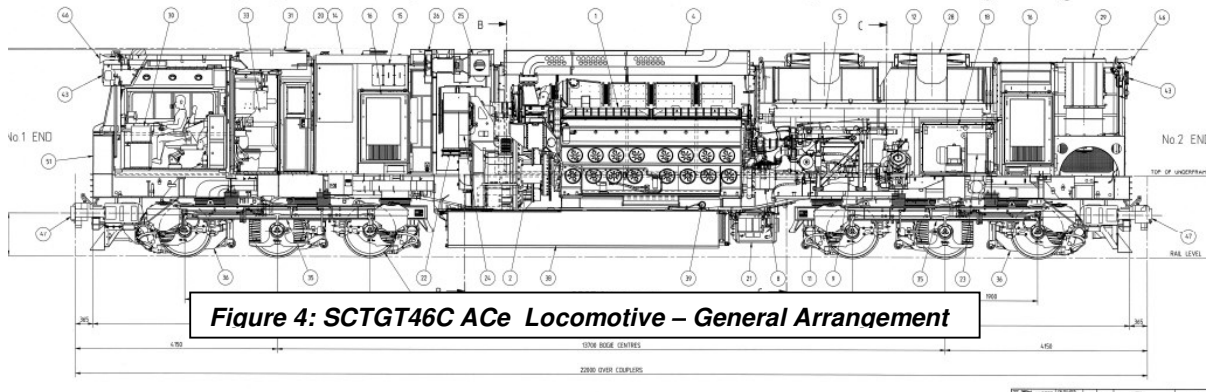


Figure 4: SCTGT46C ACe Locomotive – General Arrangement

7. DOWNER EDI RAIL AND AC TRACTION

The following details the engineering challenges addressed by DEDIR in manufacturing the SCT GT46C Ace locomotive and the background of the AC traction package that has been supplied to Australia by DEDIR's technology partner, Electro Motive Diesels (EMD).

As with other locomotive manufacturers of railway traction systems, GTO technology made 3-phase traction a possibility in the 1980s. EMD experimented with a number of demonstrators in the late 1980s, and received an order for 350 SD70 MAC locomotives from Burlington Northern in 1992. This was a 188 tonne locomotive with 790 kN starting Tractive Effort (TE) which offered a potential three for five replacement of existing DC locomotives.

Australian operators did not show much interest in AC traction until, after evaluating both AC and DC options for new locomotives on the Moura line, QR chose to use AC traction in 1998. Clyde Engineering, later to become DEDIR, supplied 38 locomotives based on 70MAC technology. Designated the 4000 class these locomotives were scaled down for use on narrow gauge lines. This was followed by further orders in Queensland, but through the 1990's there were still no takers for AC traction on the DIRN.

In the meantime, inverter technology was advancing, in 1988 EMD released their next generation loco, the SD70ACe, which utilised IGBT inverters. These allow a higher switching frequency than GTO inverters, and are simpler and more efficient. The ACe locomotive featured a 4500 hp version of the EMD two stroke 710 engine.

With seven decades of development, this engine complies with the US Tier 2 emission standards and provides good fuel economy. While incorporating a number of other technological advances, the SD70ACe design also places a great deal of emphasis on reliability and maintainability.

When SCT released tenders for AC mainline locomotives in late 2004, DEDIR was examining how to package the SD70ACe equipment into a locomotive suitable for mainline operation in Australia. This was a considerable challenge, as the SD70ACe weighs nearly 190 tonnes, compared to the 134 tonnes allowed for mainline operation throughout Australia. Also the ACe's dimensions exceeded the allowable gauge for Australia's mainline operation; the main issue was that it exceeded the height of the recognised RoA Plate "A" Rolling stock outline by 600mm.

To find solutions DEDIR utilised the experiences they had gained when designing and building two previous locomotives; the QR 4000 class AC locomotive and the Westrail Q class DC locomotive. Both locomotives are 22 metres in length over the couplers, which is the desired length for an Australian locomotive. This dimension has proven suitable for fitting the 16 cylinder EMD engine to DC locomotives like the Q Class however the 4000 class is only powered by the smaller 12 cylinder EMD engine. With two 70MAC style inverter modules being required for AC locomotives, the longer engine could only be shoe-horned in between the inverters by repositioning other equipment upwards. Refer to Figure 4 for the general arrangement drawing and Figure 5 showing the SCT locomotive being gauge tested.



Figure 5: Locomotive being tested for gauge

Other design solutions for fitting the required equipment into the allowable dimensions came from the use of the SD70 Tier 2 radiators, which are shorter than those in the Q class. These radiators are also much wider and deeper, having 10 rather than eight rows of cooling tubes than those radiators fitted to Q class. These radiators however have to be reorientated due to their size to form a flatter “Vee”, protruding out from the narrow hood to allow for clearance of the outline gauge and ensure sufficient height below for a 95th percentile man to walk under. The squarer arrangement also allows for the use of two 1320 mm diameter cooling fans instead of the three smaller 1220 mm fans as fitted to the Q class. Refer to Figure 6 showing the radiators in a cross sectional drawing.

Another major potential limitation identified with the final design of the SCT locomotive was its determined final mass. The DC traction Q class was already at the maximum allowable limit for the DIRN of 134 tonnes, and for the SCT locomotive it was necessary to add the heavier equipment including the AC inverters and a bigger cooling system. The challenge throughout the design process was to maintain the same weight as the Q class, with minimal sacrifice of fuel capacity, which would obviously reduce the locomotives operating range.

Additional issues to address included noise emissions. Although the USA has strict emission regulations, there are no restrictions on external noise. Data obtained from EMD determined the SD70ACe would emit around 93-94 dB(A) of noise at 15 metres. The maximum allowable noise

emission in NSW is 87 dB(A) under self load, and 85 dB(A) in pass-by.

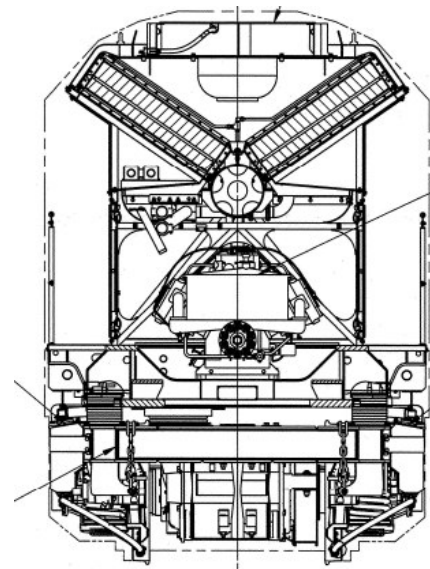


Figure 6: Cross section at radiators

8. ADVANTAGES OF AC TRACTION

One of the original reasons for developing AC traction was the simplicity of AC induction motors. Without brushes and commutators the AC traction motors are more compact than the same capacity DC motors, hence they not only require less maintenance but also less space on each axle thus allowing greater capacity motors to be fitted. For example, the D87 traction motors on a Q class can provide 410 kN of continuous TE, while the 2630 AC motors can provide 520 kN TE.

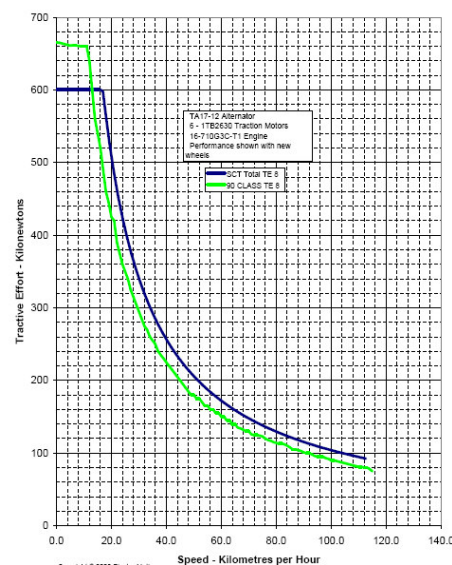


Figure 7: Tractive Effort Curve for the SCT locomotive

The greatest benefit gained from using AC traction is the much higher levels of wheel to rail adhesion that can be achieved. Using EMD's Super-series creep control, present locomotives fitted with DC traction motors achieve around 29-30% for all weather adhesion. With AC traction, all weather adhesion of 37-38% is achievable. During testing the SCT locomotive achieved up to 46% adhesion in favourable weather and track conditions. This means that the starting tractive effort of 600 kN is not a theoretical figure but performance that could be achieved in regular service. Refer to Figure 7 for the tractive effort curve for the SCT locomotive.

The resultant performance gained from the AC traction has meant that SCT's goal to reduce the number of locomotives required to haul a load up to 5000 tonnes through the Adelaide Hills has been achieved. The SCT locomotives during testing has successfully lifted loads equivalent in excess of 1700 tonnes per locomotive with around 2500 L fuel in each loco, i.e. this represents the locomotives near minimum mass. Refer to Figure 8 for the typical grades and curves experience in the Adelaide Hills.

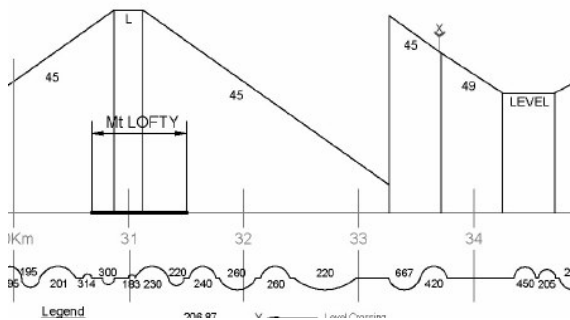


Figure 8: Adelaide Hills - grades and curves

AC traction also allows for better control of the dynamic brake, with a constant dynamic brake effort achievable from around 42 km/h down to almost zero speed. Compared to the dynamic braking effort of the DC Q class, that has extended range dynamic braking the SCT AC locomotive has almost 50% more effort available, which corresponds to 25% adhesion. Refer to Figure 9 for a comparison of dynamic brake performance curves. With a higher performing dynamic brake the AC SCT locomotive can descend the 1 in 45 grades leading into Adelaide at 40 km/h, and brake almost to standstill with no use of friction braking.

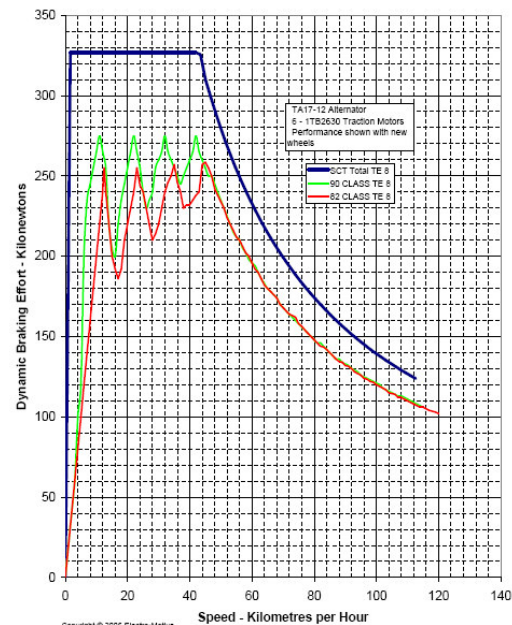


Figure 9: Comparison of the Dynamic Brake Effort Curves

9. STEERING BOGIES

The SCT locomotive is fitted with semi-radial steering bogies, refer to Figure 10. The first locomotive in Australia fitted with this type of bogie was the Westrail Q class. The radial steering bogie uses swing arm type axle boxes, with a rubber bush in the pivot which allows a longitudinal displacement of up to 10mm. A diagonal linkage connecting the leading and trailing axles enforces an equal movement on both axles. An improved version of this arrangement is also used on the QR 4000 class locomotive. By allowing the wheelsets to go out of parallel in a curve, and adopt a "radial" attitude, wheel flange wear is greatly reduced.



Figure 10: Semi Steering Bogies as fitted to the SCT locomotive

While the steering mechanism works effectively, there is a penalty in increased design complexity, leading to higher overhaul costs. For the SCT locomotive, a decision was taken to reduce the complexity of the bogie by eliminating the diagonal linkage while retaining the flexible bushes in the primary suspension. As an added benefit, deleting

the steering beams and diagonal linkage reduced the total bogie mass by nearly a tonne, which helped offset the increased mass of the 2630 AC motors, which are each 250 kg heavier than the D87 type traction motors on the Q class. Without the linkage, the outer axles steer independently.

A concern that had to be analysed was that reducing the longitudinal stiffness of axles does tend to induce hunting, as evidenced on bogies with worn horn guides with excessive clearances. The concern about the effects of deleting the cross-coupling proved however to be unfounded. Numerical modelling of the ride performance using the program "Vampire" showed that the bogie would be stable up to 130 km/h. Subsequent ride testing of the SCT locomotive at Narrabri last November validated the theory and the performance of the SCT locomotives running consistently across the Nullarbor at 110 km/h has confirmed the initial results.

It has been demonstrated that the axles adopt a fully "radial" attitude down to a track curve radius of around 400m, giving reduced wear. Unfortunately, the Adelaide Hills has curves down to 200m radius, so flanging is not totally eliminated.

10. NOISE

As highlighted earlier the SCT locomotive is based on the EMD SD70Ace which emits around 94 dB(A) of noise. The standard noise requirement on Australian locomotives is a stationary noise test with the engine running at full power, dissipating all its energy in the dynamic brake. Noise emissions are limited to 87 dB(A) at 15 metres from the loco centreline in the current codes. It is always difficult to meet this figure, and the Q class was already slightly above the limit. As locomotives become more powerful, the rate of cooling air flow increases as well as exhaust gas volume, making the noise emission target even harder to meet.

The SCT locomotive features a 3 chamber exhaust silencer based on the Q class silencer. The Q class engine however operates at 900rpm maximum for 3800hp, while the SCT engine operates at 950rpm to give 4500hp, so some changes to the tuning of the silencers was required.

The dynamic brake cooling fan is also generally a very significant noise source. While it was originally proposed to use a Dayton Phoenix radial grid dynamic brake unit like that used on the SD70Ace, calculations showed that even with

improvements to the fan design the allowable noise levels may be exceeded. A decision was taken to seek other designs from other potential suppliers. The final arrangement chosen consists of two smaller diameter fans operating within separate box grid configurations. One advantage of this arrangement was that it allowed a small saving in overall carbody length, as the grids are arranged side by side at the end of the engine hood. This style of dynamic brake still however required extensive testing and some modifications to reduce the contribution of the fans below 82 dB(A).

The two larger diameter radiator cooling fans also gave a reduction in noise over the three 1220mm diameter fan design used on the Q class.

The resultant design alterations and the incorporating of the revised dynamic brake and cooling arrangement allows the SCT locomotive to comply with the 87 dB(A) stationary noise target, as well as all the pass-by noise limits. Refer to Figure 11.

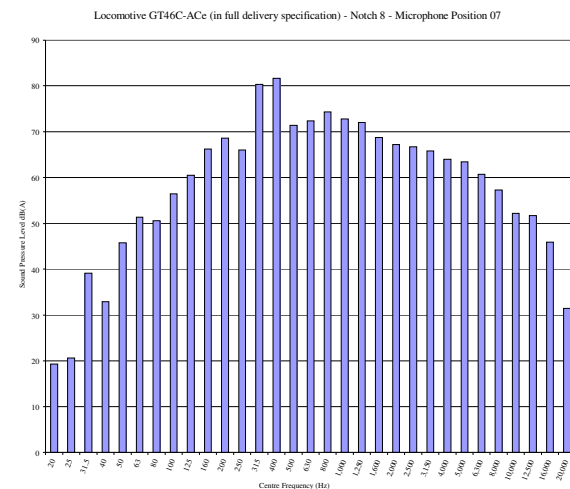


Figure 11: Noise Spectrum for Self Load at notch 8

11. EMISSIONS

The SCT locomotive is fitted with the 16 cylinder EMD 710G3C engine which in the SD70Ace locomotive complies with US Tier 2 emissions. An interesting note is that when US emission regulations were being determined it was considered that the two-stroke engine's days were numbered. However, EMD's development work with the two-stroke engine has so far made it possible to meet the increasingly onerous emission regulations without requiring after-treatment of the exhaust gases.

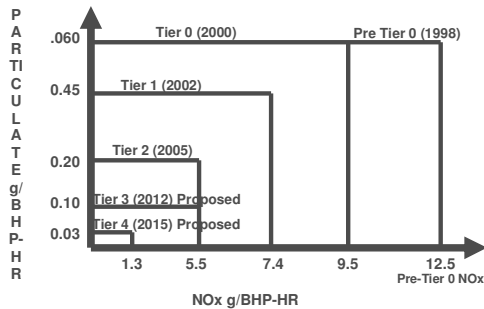


Figure 12: EPA Locomotive Emission Standards from 1998

To meet the US emission standards, engines are required to comply with stringent NOx and particulates (soot) emissions as detailed in Figure 12. To meet the particulate requirement, new piston rings were introduced which halve the lubricant oil consumption. To meet the NOx requirements, the after-coolers were substantially increased in size, which further cools the charge air as it passes from the turbo-charger to the air box, refer to Figure 13. The radiators were also increased in size, with 4 of the ten rows devoted to the after-cooler circuit. To meet the Tier 2 emission levels it was also necessary to retard the fuel injection timing. The SCT locomotive however does not have retarded timing, which allows improved fuel consumption. The engine in this arrangement is still better than the Tier 1 requirements. The trade-off is a little more NOx for less CO₂.

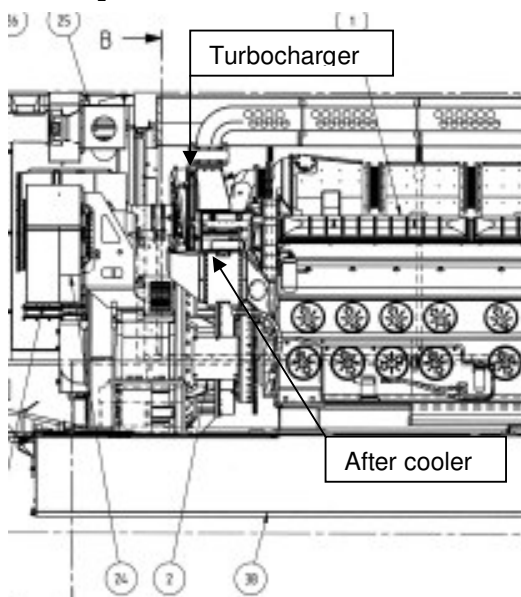


Figure 13: Turbocharger and After Cooler.

12. CAB LAYOUT AND DESIGN

The SCT locomotive cab is based on the current cabs manufactured by DEDIR for its V and FQ class locomotives incorporating key design improvements. To meet SCT's requirements, including the ability for the locomotive to be used readily for shunting and long end operation, the cab is bi-directional in layout with two driving positions. The cab was designed in-conjunction with driver representatives from Adelaide and the layout for the cab was determined by working with a virtual 3D model. The advantages of working with a 3D model was that a mock up cab was not required, saving considerable design time. It also allowed the cab working party to work with the designers in altering the layout of cab equipment while checking for the ergonomics and functionality aspects. Figure 14 shows one of the 3D concept cab drawings used by the cab working party. The resultant cab layout is very clean and user friendly considering the amount of communication systems that are required by a locomotive that operates across five states of Australia. It should also be highlighted that the locomotive is fitted with CCTV which enables the driver an improved field of view when operating the locomotive with its long end leading.



Figure 14: 3 D Working Layout of Cab

13. ON – TRAIN REFUELLING

A principal requirement for any locomotive consist operating efficiently between the East and West coast is the ability to haul the maximum loads without stopping between major fuelling locations. The distance between Adelaide and Perth is approximately 2650 kms and typical SCT trains require up to 50,000 litres of fuel for this journey. The major fuelling locations between the East and West coast being at Melbourne, Adelaide, Perth and Cook the SCT trains are consistently suffering delays due to having to rely on fuelling at Cook. Also with only two SCT locomotives now required to haul the SCT trains, each having a fuel

capacity of 10,000 litres, the total amount of fuel being carried on the SCT trains is less than that carried by the three locomotives that previously operated these services. To ensure the SCT trains are not operating close to their minimum fuel levels and to minimise delays at certain fuelling locations the SCT locomotives are fitted with an in-line fuelling system that allows them to be continuously fuelled from rail tankers. The in-line fuelling system was originally developed for SCT trains in conjunction with Freight Australia and Liquip International. Figure 15 shows the on-train refuelling tank container system.



Figure 15: On Train Refuelling System

14. THE CUSTOMER PERSPECTIVE

The first SCT GT46 ACe locomotives entered service in February 2008. Apart from some initial reliability and commissioning issues they are successfully demonstrating all the benefits and capabilities that were anticipated from AC traction. The locomotives are hauling the SCT trains with one less locomotive in each consist through the Adelaide Hills and through the desert to Perth. The locomotives have also gained a rating to each haul in excess of the originally specified 1600 trailing tonnes up to 1 in 45 grades with tight curves against existing DC traction locomotives that are rated to haul up to 1250 trailing tonnes. SCT's previous trains operating through the Adelaide Hills were up to 4400 tonnes however SCT are now regularly dispatching trains of up to 4800 tonnes. It should also be noted that during June 2008 three SCT locomotives hauled what was believed to be the biggest train load hauled through the Adelaide Hills that was in excess of 4900 tonnes.

SCT are already appreciating the cost savings by virtue of reduced maintenance due to having fewer locomotives performing the same tasks whilst achieving quicker servicing turnaround times due to the adoption of AC traction motors. An added advantage is also that an extra wagon can also be included in each train due to one less locomotive being required for each consist, noting

the train length restrictions across the DIRN. Cost savings through greater fuel efficiencies and reliability have also been recognised but at the time of writing this paper are yet to be quantified.

DEDIR have demonstrated their confidence in the SCT GT46 ACe locomotive by building a further nine locomotives for lease. Refer to Figure 16 showing DEDIR's Production Line



Figure 16: The DEDIR Production Line

CONCLUSION

Australia's first mainline AC traction locomotive, the SCT GT46Ace was developed because a privately owned freight company SCT, that had always prided themselves as being innovative, and an established and successful Australian rolling stock manufacturer Downer EDI Rail, were both seeking an opportunity to gain an advantage in the competitive rail industry.

SCT commissioned Halcrow to undertake a series of reviews to determine the most appropriate course of action in order to remain competitive when faced with the threat of relying on their major competitor for hook and pull services.

After detailed studies the answer was to develop and utilise AC traction locomotives. DEDIR successfully demonstrated their engineering capabilities by packaging the equipment from EMD's SD70ACe, a US 190 tonne locomotive into a locomotive that could operate across Australia's Mainline Network.

The resultant locomotive, the SCT GT46Ace, is proving to haul up to 30% more loading and is more cost effective, due to its greater fuel efficiency and maintenance savings, than the most advanced DC locomotive currently operating across the DIRN, making it the first of Australia's next generation of locomotives.

Acknowledgements

The Authors would like to thank Ron Bury (SCT), Ulo Kasepuu (DEDIR) and all the Production, Engineering and Staff at Downer EDI Rail for their tireless efforts in producing the SCT GT46c ACe locomotives and ensuring their success.