Report 99-202

passenger and freight ferry *Aratere*

power failure

Wellington Harbour

24 February 1999

Abstract

On Wednesday, 24 February 1999 at about 0640, the passenger and freight ferry *Aratere*, with 221 passengers and 33 crew on board, was proceeding past Point Halswell in Wellington Harbour at the beginning of a scheduled service to Picton, when the vessel suffered a series of power failures that eventually left it adrift without power. The emergency generator that was designed to supply power to essential services also failed.

Aratere was taken under tow at 0815 and with a harbour pilot on board was towed back to the ferry terminal. After another ferry cleared the terminal *Aratere* was berthed, its passengers disembarked and cargo discharged. The crew were able to restore electrical power shortly before berthing at about 1000.

Safety issues identified included:

- the incomplete failure mode effect analysis of on-board systems at design and installation stage
- the standard of quality control of essential component installation before the vessel entered service
- the standard of crew familiarisation with the vessel before it entered service.

A number of safety actions were taken by the operator to address the safety issues. A safety recommendation was made to the operator.

The Transport Accident Investigation Commission is an independent Crown entity established to determine the circumstances and causes of accidents and incidents with a view to avoiding similar occurrences in the future. Accordingly it is inappropriate that reports should be used to assign fault or blame or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

The Commission may make recommendations to improve transport safety. The cost of implementing any recommendation must always be balanced against its benefits. Such analysis is a matter for the regulator and the industry.

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Photograph courtesy of Tranz Rail

Aratere

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List of Abbreviations

ABB	Asea Brown Boveri
AC	alternating current
AC110	ABB programmable controller for the power management system
DC	direct current
DG	diesel generator (suffixed with a number to identify machine)
DNV	Det Norske Veritas classification society
DO	diesel oil
FO	fuel oil
kV	kilo volt(s)
kVA	kilo volt ampere(s)
m	metre(s)
MSA	New Zealand Maritime Safety Authority
Q1E	name given to the emergency distribution board isolator at the 400 V switchboard
QCP	name given to the interconnector circuit breaker in the emergency distribution board to isolate the supply to or from the 400 V switchboard
QSB	name given to the busbar tie-breaker at the 400 V switchboard
SOLAS	International Convention for Safety of Life at Sea
t	tonne(s)
UTC	universal time (co-ordinated)
V	Volt

Glossary

bridge	structure from where a vessel is navigated and directed
cable	0.1 of a nautical mile
class	category in classification register
con	directing the course and speed of a ship
gross tonnage	a measure of the internal capacity of a ship; enclosed spaces are measured in cubic metres and the tonnage derived by formula
high voltage	any voltage above 1000 V AC or 1500 V DC
low voltage	any voltage between 32 and 1000 V AC or 115 and 1500 V DC
net tonnage	derived from gross tonnage by deducting spaces allowed for crew and propelling equipment
port	left-hand side when facing forward
starboard	right-hand side when facing forward

Data Summary

Vessel particulars:

Name:	*Aratere*
Type:	passenger and freight ferry
Registered:	Nassau, Bahamas
Classification:	Det Norske Veritas
Class:	SOLAS 1A1 car and train ferry A, general cargo carrier, Ro-Ro
IMO number:	9174828
Allowable passengers:	365
Length (overall):	150.00 m
Breadth:	20.25 m
Gross tonnage:	12 596 t
Net tonnage:	3779 t
Construction:	steel
Built:	in 1998 by Hijos de J. Barreras S.A. in Vigo, Spain
Power plant:	four 3680 kW Wartsila 8L32 diesel engines each coupled to a 50 Hz, 3300 V Asea Brown Boveri generator
Propulsion:	four 2600 kW electric motors coupled in pairs via reduction gearboxes to two 4-bladed fixed-pitch propellers
Normal operating speed:	19.5 knots
Owner:	Wilmington Trust Company
Operator:	Interisland Line, Tranz Rail

Location: Wellington Harbour

Date and time: 24 February 1999 at about 0640[1]

Persons on board: Crew: 33; Passengers: 221

Injuries: nil

Nature of damage: nil

Investigator-in-Charge: Captain John Mockett

[1] All times in this report refer to New Zealand Daylight Time (UTC +13 hours) and are expressed in the 24 hour mode.

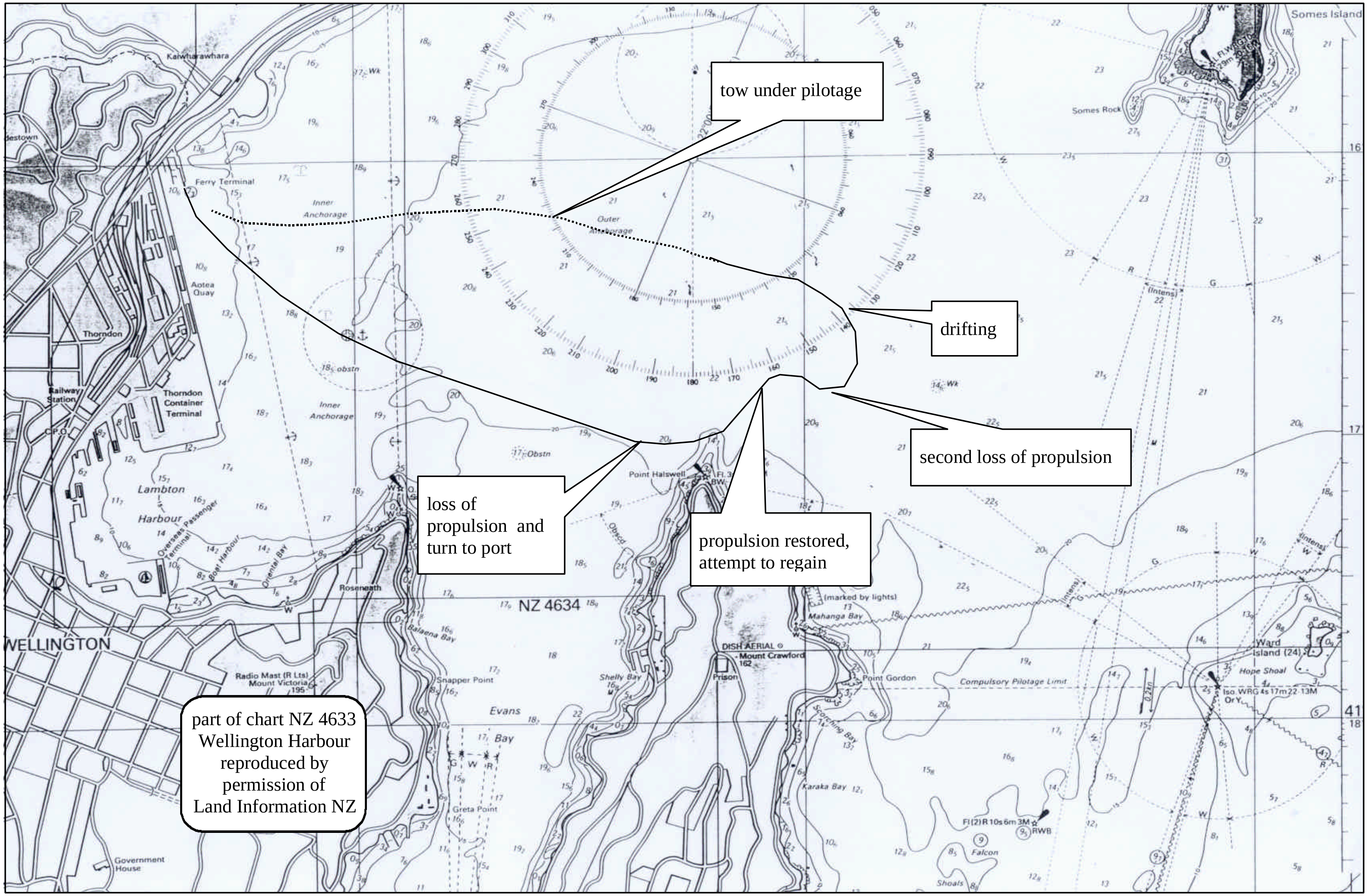

Figure 1
Part of chart NZ 4633 showing approximate track of *Aratere*

1. Factual Information

1.1 History of the trip, navigation

1.1.1 On Wednesday, 24 February 1999, the ferry *Aratere* was lying alongside number 5 berth at Aotea Quay in Wellington awaiting its place at the ferry terminal. The vessel had been out of service for a routine maintenance period. At about 0530 the vessel moved to the ferry terminal to embark passengers and load cargo. The vessel was secure at the terminal at about 0600 and had a scheduled departure time of 0630. There was no rail cargo to load, so both the rail and vehicle decks were used for road cargo to speed up the operation.

1.1.2 Cargo operations were completed by 0630 with 221 passengers, various cars and other vehicular cargo on board. The pre-departure checks were completed and the vessel let go from the terminal at 0635.

1.1.3 The master conned the vessel clear of the terminal and set the first course for the harbour transit. He then engaged the automatic navigational track system and began increasing speed as *Aratere* crossed the harbour.

1.1.4 As the vessel approached Point Halswell, about a cable and a half off and on a course of about 110 degrees, the electric propulsion motors stopped. The master still had steering available so he turned the vessel away from the immediate danger of Point Halswell and reduced the engine power control settings (see Figure 1).

1.1.5 The master informed Wellington Harbour Radio and an inbound vessel of the situation. The inbound vessel agreed to stay clear of *Aratere*.

1.1.6 Within a few minutes, *Aratere* was heading about 050 degrees towards Somes Island when the master became aware that propulsion had been restored, so he started to steer back to starboard to regain the required track.

1.1.7 *Aratere* had swung back to starboard to a course of about 120 degrees when the propulsion motors stopped again. The master aborted the starboard turn and put the rudders hard to port. Again the vessel swung to port until heading towards Somes Island.

1.1.8 The effect of the large rudder angles and the turning of the vessel had reduced the speed considerably and the vessel was soon stopped in the water and drifting towards the centre of the harbour. The master updated Wellington Harbour Radio and the inbound vessel of the situation.

1.1.9 At that time the propulsion motors were stopped but electrical power to the bridge remained. However, within a few minutes the main electrical power failed also. The emergency generator did not start automatically, leaving *Aratere* totally without power.

1.1.10 While the engineering staff were working to restore electrical power, *Aratere* continued to drift in the middle of Wellington Harbour. The weather was good with light winds and good visibility. The position of the vessel was monitored using visual bearings. The master did not anchor the vessel, but the option was available to him had the need arisen.

1.1.11 As time went on, the master liaised with the port to establish what options were open to him. The harbour tugs were assisting the berthing of an inbound passenger vessel and an outbound car carrier. At any time one or both of the tugs could have been called at short notice.

1.1.12 At about 0800, when the other port movements had been completed, *Aratere* was still drifting without power so the decision was made to use the harbour tugs to berth the vessel. Because no engines were available and 2 tugs would be needed, harbour regulations stipulated that a harbour pilot had to be employed.

1.1.13 At 0812 a harbour pilot boarded *Aratere* and by 0815 the tugs were made fast and the tow back to the ferry terminal commenced. *Aratere* was towed slowly as the terminal was occupied by another ferry. The vessel was "dead ship" and the rudders remained hard to port, making the control of the tow demanding.

1.1.14 During the tow, electrical power was restored and as the vessel approached the terminal at about 1000, propulsion was restored. *Aratere* was secure alongside the terminal by 1005. Passengers were disembarked and cargo unloaded to be re-allocated to other vessels.

1.2 Power supply system

(see Figure 2)

High voltage switchboard (3.3 kV)

1.2.1 Four 3900 kVA diesel generator sets were arranged to load share in parallel as a single power management system. The number of generators required on line was determined by a combination of the load requirement and the position of the mode selection switch on the bridge. The sequential order in which each generator was brought on line was determined by a manual priority selection setting in the engine control room. Once started, the generators automatically synchronised and then connected in parallel onto a high voltage 3.3 kV busbar[2]. This busbar was split into two sections but could be connected together as required with a manually operated busbar tie-breaker. The busbar tie-breaker was normally left in the closed position.

1.2.2 The main electric propulsion motors were fed through variable speed drives directly from the high voltage switchboard. General 400 V electrical power was fed via two 1000 kVA, 3.3 kV/400 V transformers, one connected from each side of the high voltage busbar to the 400 V switchboard. The automatic operation of the high voltage switchboard was controlled by the Asea Brown Boveri (ABB) automatic control system called the power management system.

400 V switchboard

1.2.3 All the vessel's electrical services were fed from the 400 V switchboard. Input power for distribution could be supplied from one of the following sources:

- one or both 1000kVA transformers from the high voltage switchboard
- emergency generator
- shore power.

1.2.4 The 400 V busbar was split into 2 sections that could be connected with a manually operated busbar tie-breaker, but was normally left in the split mode. The left-hand side of the busbar was fed from either transformer number 2 or shore power while the right-hand side was fed from either transformer number 1 or the emergency generator.

1.2.5 Two feeds, one from each side of the 400 V switchboard, supplied a 230 V switchboard via two 200kVA, 400/230 V transformers for services such as lights and standard power outlets. The feeders were interlocked so that only one of these transformers could be connected at a time. The 230 V switchboard was adjacent to the 400 V switchboard in the engine control room.

[2] A system of conductors in a generating or receiving station on which the power is concentrated for distribution.

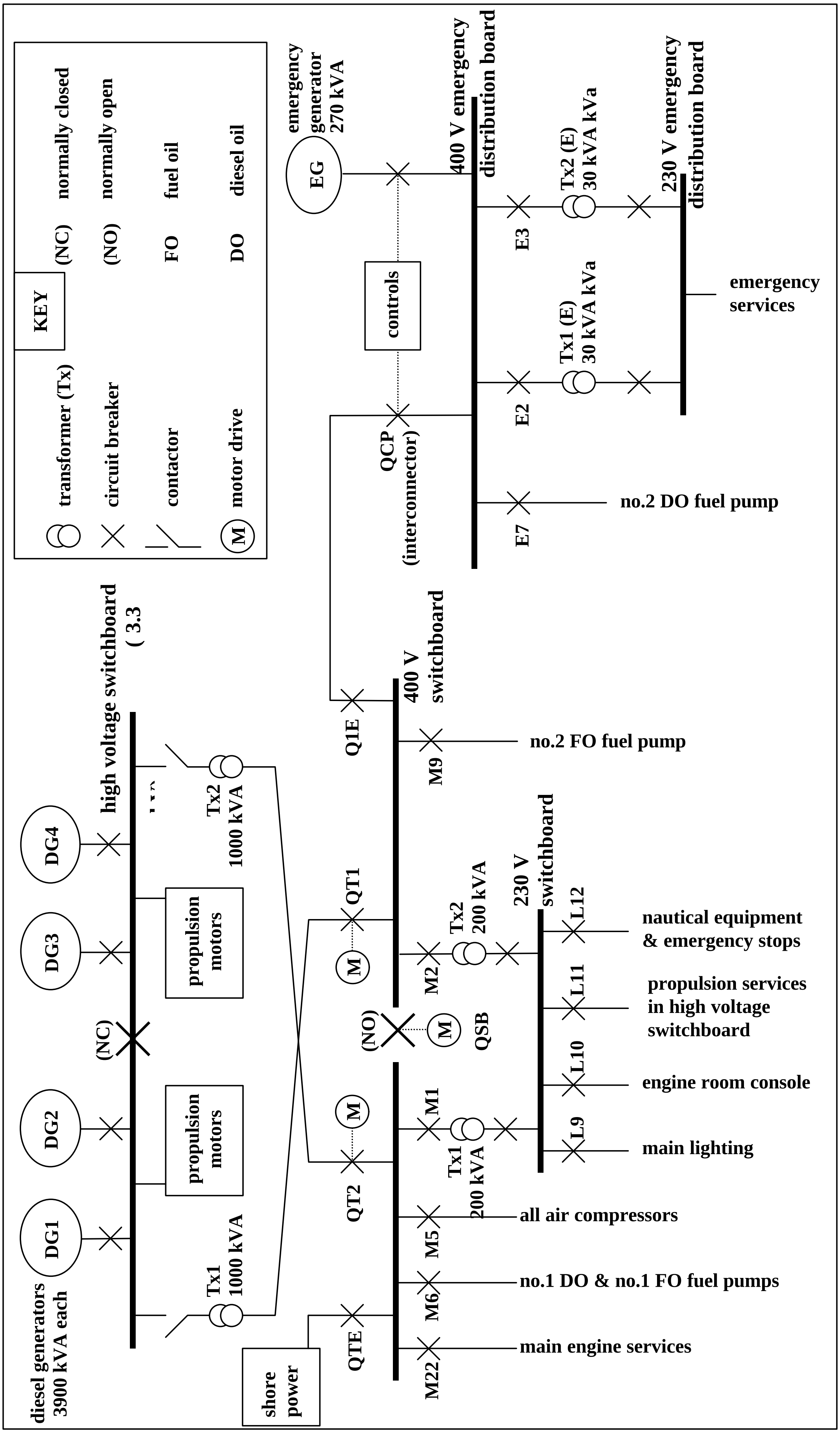

Figure 2
Voltage distribution system on board *Aratere*

Emergency distribution boards

1.2.6 A 400 V emergency distribution board was situated outside the engine-room in the emergency generator room. It was normally fed from the right-hand side of the 400 V switchboard. Two 30 kVA, 400/230 V transformers were fed from the emergency distribution board and supplied an adjacent 230 V emergency distribution board. Only one of these transformers could be connected at a time. The 400 V and 230 V emergency distribution boards distributed power to all "essential" services throughout the vessel.

1.2.7 If the supply from the 400 V switchboard to the emergency distribution board failed for more than 3 seconds, and the failure was detected on the live side of the emergency distribution board isolator (QCP), then the emergency generator would start automatically. The controls would then automatically isolate the 400 V switchboard and re-supply all services connected to the 400 V emergency distribution board from the emergency generator.

1.2.8 If power was subsequently restored to the 400 V switchboard, the emergency generator was automatically disconnected from the emergency distribution board. The emergency generator diesel engine did not however automatically shut down. This had to be done manually.

1.2.9 Under strictly controlled circumstances it was possible to power the 400 V switchboard from the 400 V emergency distribution board, but this was not the normal mode of operation. The emergency generator did not have sufficient capacity to power the emergency loads at the same time as all the services connected to the 400 V switchboard.

1.3 Electrical modes of operation

1.3.1 The various switchboards and distribution boards of the low voltage power system could be mode selected to suit operational requirements. A number of safety interlocks were incorporated to protect each board from connecting unsynchronised power supplies.

400 V switchboard mode selection

1.3.2 The position of a mode selection switch determined the operational mode of the 400 V switchboard. For normal operation at sea and in port, "emergency" mode was selected. In this mode the 400 V switchboard could only be powered from the main diesel generators via either or both of the 1000 kVA transformers. In port, one diesel generator was sufficient to supply all the electrical needs of the vessel. At sea the number of diesel generators used was dependent on required load, the biggest loads being the propulsion motors.

1.3.3 When "harbour" mode was selected, power could be supplied to the 400 V switchboard from either a shore power source or the emergency generator, but not from the main diesel generators. This mode would only normally be used when shore power was required, such as during dry-docking, or possibly during reinstatement of normal operations after a blackout.

400 V switchboard power input

1.3.4 The position of an input selection switch determined the normal source of power to the 400 V switchboard. For normal operation at sea and in port, "main transformers" was selected. In this mode the switchboard could only be powered from the main diesel generators via one or both of the 1000 kVA transformers.

1.3.5 When "shore connection" was selected, power could be supplied to the 400 V switchboard only from a shore power source.

400 V switchboard - emergency distribution board isolator (Q1E)

1.3.6 Supply from the 400 V switchboard to the emergency distribution board could be isolated using the isolator switch Q1E. The isolator was normally left in the closed position but could be opened to isolate the emergency distribution board for maintenance, or to test the automatic response of the emergency generator. Two status lights were situated above the isolator switch to indicate whether it was open or closed. A third light indicated whether or not the emergency distribution board was in harbour mode.

1.3.7 During a maintenance period some 9 months after the incident, the Q1E status lights were found to have been installed in the opposite position to other circuit breaker status lights on the 400 V switchboard.

Emergency distribution board - mains isolator (QCP)

1.3.8 There was a second isolator, QCP, known as the interconnector, at the emergency distribution board. Whereas the isolator Q1E at the 400 V switchboard could only be operated manually, the interconnector could be operated manually or automatically, the mode being selected at the emergency distribution board.

1.3.9 For normal operations the mode was selected as "QCP-Auto". In this mode the emergency generator control system opened or closed the interconnector automatically to enable the generator to supply power to the essential services that were connected to the emergency distribution boards in the event of a power failure.

1.3.10 The mode could also be selected as "QCP-Manual". In this mode the interconnector still opened automatically in the event of a power failure to the emergency distribution board, but could also be opened or closed by the local manual pushbuttons. This mode facilitated the supply of limited power to the 400 V switchboard from the emergency distribution board. Interlocks were fitted to ensure that any power supply from the 400 V switchboard and emergency generator power supplies could not be connected together.

Emergency generator - harbour mode key switch

1.3.11 The option was provided to allow, under exceptional circumstances, the supply of limited power to the 400 V switchboard from the emergency generator.

1.3.12 The emergency generator was rated at 240 kW, which was more than sufficient for its potential fully connected emergency load of 187 kW. When in harbour mode, the total 400 V switchboard connected load was 464 kW, which was more than the available excess emergency generator capacity of 53 kW. In order to retain the emergency generator backup, some of the 400 V switchboard loads would have to be shed manually, or not used.

1.3.13 After the emergency generator was running and connected to the 400 V emergency distribution board, it could be connected to the 400 V switchboard using the harbour mode key switch at the emergency distribution board. In order for the connection to be made, the key switch had to be manually changed from its normal "off" position to the "on" position, and the 400 V switchboard had to be isolated from all other power sources by selecting "harbour" mode and "main transformers" power input at the 400 V switchboard. The status of the emergency generator harbour mode key switch was indicated on the 400 V switchboard.

1.3.14 While feeding the 400 V switchboard, the emergency generator output current was continuously monitored and if it exceeded a pre-set limit, the 400 V switchboard load was automatically disconnected to retain power supply to the essential services connected to the emergency distribution boards. Alternatively, the 400 V switchboard could be manually disconnected by pressing a dedicated emergency stop button.

Emergency stop

1.3.15 The emergency stop systems were powered from either a 24 V DC battery system or the 230 V AC emergency distribution board. The emergency stop shunt trip[3] coils on circuit breakers, M6, M9 and M22, that were noted to have tripped during the blackout sequence, were controlled by a 230 V relay that was normally energised from the emergency 230 V distribution board.

1.3.16 The final control power for these particular circuit breakers was supplied from the live side of the local circuit breaker. Upon activation of the appropriate emergency stop button, the 230 V relay was de-energised. This then supplied 230 V from the circuit breaker control circuit through an interface relay to energise the shunt trip coil of the breaker.

1.3.17 This configuration set up a race condition[4] that tripped circuit breakers M5, M6 and M22, or M9 whenever the relevant side of the 400 V switchboard was powered up before the emergency 230 V distribution board and the relay were energised. Therefore, these breakers would always trip when the 400 V switchboard was first powered up from either the main diesel generators or the shore power. The breakers would also trip when the emergency generator was shut down after power had been restored to the 400 V switchboard.

1.3.18 It appeared to be a design condition that tripped these circuit breakers, which effectively disabled the fuel oil supply system for the diesel generators and stopped all the air compressors and other main engine services until the breakers were manually reset.

1.4 Control systems

1.4.1 The Wartsila electronic control system provided an automatic controller dedicated to each main diesel generator engine to monitor, control and protect it. The controllers were interconnected with the power management system to which signals were sent should alarm conditions require the operating parameters of an engine to be changed.

1.4.2 The power management system was an ABB system which controlled and optimised the power flow between the diesel generators and the loads connected to the high voltage switchboard. The system included an independent AC110 controller for each of the 2 frequency converters and a Synpol-D automatic controller for each diesel generator.

1.4.3 The 2 AC110 controllers were modular units for logic and sequential control of speed and power limitation of the propulsion power according to required or requested load and the available power from the diesel generators. The AC110 controllers arranged to minimise the number of diesel generators on load while still providing sufficient power for the operation in hand.

1.4.4 The Synpol-D automatic controllers monitored and controlled the electrical output from each generator driven by a diesel engine. The Synpol-D units were connected together and created an integrated power management system. The controllers had a protection function in that operating limits of the electrical output were monitored, and the units also received out-of-limit signals from the Wartsila electronic control system at the diesel generators. Out-of-limit parameters might require the Synpol-D controllers to either warn engineering staff, reduce the output power of a diesel generator, or stop an engine for more serious events.

[3] A relay-type device provided as part of a circuit breaker that, when energised, will trip (or open) the circuit breaker.
[4] A situation where more than one device, such as a relay and a contactor, are energised at the same time but the resulting sequence of events is dependent upon the time that each device takes to activate.

1.4.5 The automation system incorporated all vessel machinery and process supervision and alarm monitoring. It provided a dynamically responsive single line system display of the vessel services to the computer screens at the engineer stations on the bridge and in the engine control room. It also provided the alarm printouts.

1.4.6 A monitoring control unit was fitted in the emergency generator room to monitor the power supply between the 400 V switchboard and the emergency distribution board. The unit controlled the automatic starting of the emergency generator and power supply to emergency services when it detected a loss of power for more than 3 seconds.

1.5 The fuel change-over system

General arrangement

1.5.1 The fuel supply to each diesel generator engine was fed from a common fuel line switched from either a fuel oil or a diesel oil supply line via a 3-way valve. The position of these fuel valves was monitored and automatically controlled by the automation system. They could be manually operated from the computer screens if required.

Valve control

1.5.2 Each valve was normally set to "sequence" but could be set to "central". When set to "sequence", the supply valves were automatically controlled to the diesel oil position if the high voltage switchboard registered a blackout situation. When set to "central", the supply valves were manually controlled from the automation system computer.

Valve operation

1.5.3. The 3-way valves were kept in the fuel oil position by a spring. Control air pressure was switched on or off with a 24 V DC solenoid valve controlled by the automation system. If the solenoid was energised, air pressure switched the valve to the diesel oil position, holding it there against the spring. When the solenoid was de-energised the air pressure at the valve was vented and the valve returned to the fuel oil position under spring pressure.

1.5.4 In the event of a loss or a reduction of air pressure, the spring overcame the holding air pressure and the valve returned to the fuel oil position.

Number 2 diesel oil forwarding pump

1.5.5 The automation system controlled number 2 diesel oil forwarding pump to supply diesel fuel to the diesel generators under emergency conditions. If any 3-way fuel valve was in the diesel oil position, the automation system would run the number 2 diesel oil forwarding pump, providing it had power and was in the Auto mode at the local pump control station. The automation system would continue to present the run signal to the pump until all the 3-way valves had returned to the fuel oil position.

1.6 Events in the engine-room

1.6.1 The shift of *Aratere* from Aotea Quay to the ferry terminal was accomplished without incident or any mechanical or electrical problems. During the shift, diesel generator numbers 3 and 4 were used.

1.6.2 Having berthed at the ferry terminal, the electrical load requirement meant that only one diesel generator was needed and number 4 remained running on load. The starting priority for the engines was set in the order 4, 3, 1 and then 2.

1.6.3 As loading was nearing completion, the duty engineer was in the engine room and conducted pre-departure checks in conjunction with the master on the bridge at about 0630. Nothing untoward was noted.

1.6.4 When the master selected stand-by mode for departure, number 3 diesel generator started and came on load with number 4 to provide the required power. *Aratere* left the terminal at 0635 and once clear of the berth, the power requirement increased as the harbour passage progressed, but not to the extent that number 1 was required to start.

1.6.5 At 0640 number 2 frequency converter unit detected a fault on number 1 engine, resulting in a power failure alarm. The engine was therefore no longer available so number 2 engine became the next priority engine, if required.

1.6.6 At 0642 an oil mist detector alarm was activated on number 3 engine. The initial alarm was of a level that required attention by an engineer. However, the first alarm was followed only 9 seconds later by an alarm of a higher level. Such an alarm activated a programmed shutdown of the engine and the fluctuation caused a loss of power to the general electrical services; the immediate effect being the loss of main lighting.

1.6.7 When number 3 engine shut down, the power management system started number 2 engine which, because of the power failure alarm on number 1 engine, had become the next priority engine. The initial loss of power also meant that excess load had to be shed and the power management system shut down the propulsion motors.

1.6.8 The duty engineer was in the engine control room and telephoned the chief and first engineers and also pressed the immediate assistance alarm to summon the other engineering staff. He then went into the engine-room to check around.

1.6.9 On his return to the control room after only a few minutes, the electrical and propulsion power appeared to him to have been restored by the power management system.

1.6.10 When the chief engineer received the call for assistance from the duty engineer, he proceeded immediately to the engine-room. On his way, he noticed that smoke was coming from 3 of the exhaust risers in the funnels and from that deduced that 3 engines must still have been running.

1.6.11 The chief engineer first went to the high voltage switchboard, where he found that 3 engines were running and connected to the switchboard but the propulsion motors had tripped off. He reset the frequency converters which fed the propulsion units to ensure that they could be restarted.

1.6.12 The chief engineer went to the control room where he met the duty engineer. He stated later that 3 engines were still running. The first engineer arrived shortly afterwards. The chief engineer noted that the circuit breakers, M6 and M9, feeding the fuel oil forwarding pumps and breaker, M22, feeding the main engine services had tripped and he sent the duty engineer to check that the pumps were running after the first engineer had reset the breakers.

1.6.13 At this time there was power to the 400 V switchboard, but the chief engineer saw that only half of the board was live. Each side of the switchboard was fed from a transformer controlled by a contactor, but only one of them had re-set. In order to supply power to both sides of the switchboard, he closed the busbar tie-breaker, which was normally in the open position.

1.6.14 The chief engineer then heard the engines beginning to starve of fuel so he followed the duty engineer to the fuel oil forwarding pumps. When he got there the pumps had stopped. The only fuel then available for the engines was that already in the fuel lines feeding by gravity to the engines.

1.6.15 The chief engineer returned to the engine control room and had intended to feed power to the 400 V switchboard from the emergency generator by selecting harbour mode. However, the emergency generator had not started. The second engineer, who was also an electrical engineer, proceeded to the emergency generator room to investigate why the generator had not started.

1.6.16 Meanwhile attempts were being made to restart the main diesel generators. Start failure alarms for the engines were recorded by the automation system between 0654 and 0658.

1.6.17 The chief engineer went to the emergency generator room to assist the second engineer with the investigation and attempts to start that generator. When he arrived he found that the engine would not start as there was an overspeed alarm indicated in the monitoring control box each time an attempt was made.

1.6.18 There were no drawings immediately to hand in the emergency generator room so, at about 0700, the chief engineer used his mobile telephone to call a technician from a shore-based company that had recently carried out some maintenance work on the control box. At that time the technician was driving to work and suggested that the reset button should be pressed but the second and chief engineers had already tried that without success. The technician agreed to check the drawings at his office and call back as soon as possible.

1.6.19 While waiting for the technician to return the call, several more attempts were made to start the engine. The engine was started each time but would not continue running.

1.6.20 The technician returned the chief engineer's call a short while later and with the assistance of the drawings held at his office was able to make further suggestions. Various components in the control box were bridged and, after some 2 hours, the engineers were able to start the emergency generator and keep it running, supplying power to the emergency distribution board.

1.6.21 At some stage during that period when the chief engineer was in the engine control room he noticed that the indicators for the position of the 3-way fuel supply valves were flashing on the computer screen of the alarm monitoring system. The flashing lights indicated to him that the valves had changed position, were not fully open or closed or there had been a loss of air pressure holding the valves in position. The automation system recorded valve position errors between 0730 and 0800.

1.6.22 The chief engineer had decided that he would attempt to feed power from the emergency distribution board via the interconnector, QCP, in order to run the priming pumps when the main diesel generators were started. However, he was unable to do so because the interconnector closing mechanism was jammed. It was discovered later that a shear pin was broken within the interconnector.

1.6.23 The chief engineer decided not to spend any more time trying to feed power to the 400 V switchboard. With the emergency generator running, the emergency distribution board was live and one of the feeds from it was to the number 2 diesel oil forwarding pump. He returned to the engine-room and started the pump manually.

1.6.24 Before the chief engineer could start a diesel generator he had to change the 3-way fuel valves back to the diesel position. This was achieved by reinstating the air pressure via cross-over valves from the main air bottles to feed the control air system. Once the diesel generators were running on diesel oil, the engineers were able to restore power to the 400 V switchboard and eventually, at about 1000, power to the propulsion motors.

1.7 Post incident investigations

1.7.1 The oil mist detector alarm that had caused number 3 diesel generator to shut down had a previous history of activating spurious alarms. It was determined that this current event was also spurious. Because of this history and while the problem was being investigated, the chief engineer had normally sequenced number 3 diesel generator as the last priority engine to start. Under normal operating conditions it would be unusual for 4 diesel generators to be running at any one time.

1.7.2 At some time during the maintenance period alongside Aotea Quay, the priority sequence had been altered to make number 3 diesel generator the second engine to start. Under sailing conditions the second priority engine was always running.

1.7.3 When the Wartsila electronic control system sensed the oil mist detector alarm that required the shutdown of the engine, it would have sent an electrical signal to the Synpol-D controller to open the breaker at the high voltage switchboard to disconnect the generator from the busbar.

1.7.4 The shutdown signal was wired between the 2 controllers but it was discovered after the incident that the wiring at the Synpol-D end had been disconnected. The shutdown wiring for the other engines was found to be disconnected also. During various shipyard and sea trials those wiring runs would have to have been fully connected for system proving. There was no record of why, when or by whom the wiring had been disconnected.

1.7.5 The compressors which fed the control air system tripped off during the initial power disturbance. It was discovered they would not restart automatically when normal power was restored. It was the control air that held the 3-way fuel valves in the diesel oil position for emergency operation.

1.7.6 The control system that monitors and protects the emergency generator engine was found to have been falsely indicating an overspeed alarm for the engine. The control box, which was of Spanish design and manufacture, had failed during the delivery voyage and been replaced on arrival in New Zealand. The replacement had also failed and the control box in place during the incident was the third unit to be installed in the short life of the vessel.

1.7.7 The closing mechanism of the interconnector, QCP, between the 400 V switchboard and the emergency distribution board was jammed. A shear pin within the mechanism was found to be broken.

1.7.8 During tests after the power failure, the automatic voltage regulators of the diesel generators and the Synpol-D reverse power alarm limits were adjusted by ABB after they were found to be outside design parameters.

1.7.9 During checks after the incident, the mode switches for the fuel forwarding pump starters were found in the “remote” position. The pumps could only be started manually with the mode switch in that position.

1.8 Vessel history

1.8.1 The specifications for building *Aratere* were formulated by Tranz Rail in April 1997. The shipbuilding contract was awarded to Hijos de J. Barreras S.A. of Vigo in Spain and the keel was laid in November 1997. The expected completion date was November 1998.

1.8.2 Throughout the planning and building periods, Tranz Rail held discussions with the New Zealand Maritime Safety Authority (MSA) regarding the vessel’s plans, ownership, operations, charter, crewing and accommodation.

1.8.3 *Aratere* was launched on 8 September 1998 and remained in the shipyard being fitted out. The building and outfitting were monitored throughout by the classification society, Det Norske Veritas (DNV).

1.8.4 The vessel was nearing completion in December 1998 and sea trials were conducted. On 15 December 1998, DNV issued the necessary statutory and trading certificates to enable the vessel to sail to New Zealand. Some conditions of class were attached to the certificates which meant that various items had to be completed or modified before full certification would be granted. The certificates issued in Spain were short term and intended to be sufficient only for the delivery trip to Wellington, where the vessel would be surveyed and certificated appropriate for the intended inter-island operation. The passenger and cargo certificates were valid until 15 January 1999.

1.8.5 Tranz Rail took delivery of *Aratere* from the shipyard on 16 December 1998 and the vessel left Vigo bound for Wellington on the same day. The estimated date of arrival in Wellington was 15 January 1999.

1.8.6 The delivery voyage took longer than anticipated. On 20 December 1998, problems were experienced with the starboard propulsion motors. The fuses on the motors blew and when new fuses were installed, they blew also. As there were then no further spare fuses on board, the starboard propulsion was no longer available and *Aratere* continued with port propulsion only.

1.8.7 On 21 December 1998, the Vulcan couplings between the port propulsion motors and gearboxes failed, leaving *Aratere* adrift with no propulsion available on either side. The couplings from the starboard side were removed and used as replacements for the failed couplings on the port side, allowing the vessel to continue to Panama, again with propulsion on the port side only.

1.8.8 Replacement fuses for the propulsion motors and spare Vulcan couplings were placed on board *Aratere* at Panama. The vessel spent a total of 3 days in Panama, during which time the starboard propulsion was reinstated and the vessel transited the canal. Having cleared Panama *Aratere* proceeded, via Tahiti for fuel, to Wellington where the new estimated date of arrival was 19 January 1999.

1.8.9 On 18 January 1999, the engineering staff observed movement in the port side Vulcan coupling and the speed of *Aratere* was reduced.

1.8.10 *Aratere* arrived in Wellington on 19 January 1999. The MSA conducted a Port State Control inspection that day, noting that the SOLAS certificates had expired. There were further MSA inspections the next day, mainly regarding the accommodation and its conformance with local legislation.

1.8.11 *Aratere* remained alongside in Wellington to progress work involved in removing the conditions of class imposed by DNV, conducting surveys for the re-issue of the expired certificates and completing changes to the accommodation required by the MSA.

1.8.12 *Aratere* was to replace the ferry *Aratika.* Because of the delays to the arrival of *Aratere*, *Aratika* continued in service while the commissioning of *Aratere* was completed. In order to cover the full ferry schedule, Tranz Rail postponed the dry-docking of another ferry, *Arahanga*. *Aratere* was expected to enter full passenger and freight service at the end of January 1999. Staff who were assigned to *Aratere* worked on board the vessel for training and familiarisation but at times were needed to crew the *Aratika* and *Arahanga* as they continued in service.

1.8.13 On 28 January 1999, DNV issued short term SOLAS certificates for *Aratere* which were valid to 15 March 1999. Those certificates were formally recognised by the MSA on 29 January 1999. On 29 January 1999, trial voyages to Picton and back were carried out without passengers or cargo.

1.8.14 *Aratere* commenced passenger and cargo services on 1 February 1999 but the port side Vulcan coupling failed again during that first day. The vessel returned to Wellington and was withdrawn from service by Tranz Rail to allow investigations to be conducted by the manufacturer of the couplings while awaiting delivery of spare couplings.

1.8.15 Investigation and repair work continued until 12 February 1999 although *Aratere* made a cargo-only return crossing on 7 February 1999, running with only the starboard propeller engaged.

1.8.16 Following an inspection on 9 February 1999, the MSA imposed conditions on the vessel requiring that, despite being built under International Load Line Convention rules, some of the railings on the vessel had to be modified. The required modifications were completed by 12 February 1999 and the conditions lifted.

1.8.17 *Aratere* resumed service on 13 February 1999, and continued without problem until the power failure on 24 February 1999.

1.8.18 There had been considerable positive publicity preceding the delivery and arrival of Aratere, but both local and national media attention soon focused on the delays, the mechanical problems, the withdrawal from service, the modifications and repairs and the power failure.

1.9 Crew rosters and conditions

1.9.1 The crew of *Aratere* worked on 2 separate roster systems. Seven senior crew members worked and lived on board for a full week and were then relieved by another group of staff for a week. Other crew members worked on board each day for an 8-hour shift only and worked on a walk-on walk-off arrangement.

1.9.2 The personnel involved in the week-on and week-off roster were the master, relief master, chief officer, second mate, chief engineer, first engineer, second engineer, the on-board services manager, boatswain and assistant boatswain.

1.9.3 All remaining officers and crew were rostered on an 8-hour shift for a period of 6 days. The shift times were 0530 to 1330, 1330 to 2130 and 2130 to 0530. The shift periods were nominated to coincide with the sailing timetable of the ferry.

1.9.4 There were no galley facilities to produce on-board catering for the crew. Meals were prepared ashore in Wellington and delivered to the vessel during the one-hour turnaround in port. The food was either kept hot in the pantry adjacent to the messroom or microwaved as required. The messroom was communal for officers and crew but the space was not sufficient to allow the whole crew to be seated at one time. It was designed as such on the presumption that meal times would be staggered to suit individual working schedules.

1.9.5 Cabin accommodation was provided for the live-on crew. The walk-on walk-off crew were provided with changing room facilities only. The standard of the accommodation and messing was the subject of much debate between Tranz Rail management, the crew, the maritime unions and the MSA. Several modifications were made before the vessel entered service.

1.10 Personnel information

1.10.1 The master held a foreign-going masters certificate. He had started his career at sea in 1960 and spent a year as midshipman at the Royal Australian Naval College. In 1961 he joined the Union Steam Ship Company as an apprentice cadet. He stayed with that company for 10 years ending up as chief officer serving on the rail ferries. When New Zealand Railways took over the management of the rail ferries in 1971, he transferred to remain working on the inter-island trade.

1.10.2 He gained his command in November 1973 and in the ensuing 26 years has commanded each of the ferries run by New Zealand Railways, now known as Tranz Rail.

1.10.3 Together with another master, he was appointed to *Aratere* while it was still in the building yard in Vigo and stood by the building for the last 2 months. He sailed as a watchkeeping officer on the vessel when it left Vigo on 16 December 1998 and went as far as Panama on the delivery trip to New Zealand. He rejoined the vessel as master when it arrived in Wellington in January 1999 and had been working on a week-on week-off roster since that time. During his week on duty, the master lived on board the vessel.

1.10.4 The chief engineer joined an overseas shipping company as junior engineer in 1967 and remained with that company until 1972, by which time he had reached the rank of second engineer. In 1972 he joined New Zealand Railways as third engineer. He gained his Chief Engineers certificate in 1974 and became first engineer at that time. He was promoted to chief engineer in 1990 and had served on all of the rail ferries.

1.10.5 The chief engineer was appointed to *Aratere* while it was still in the building yard in Vigo. He stood by the building for the last 4 months in the shipyard and sailed as far as Panama on the delivery trip to New Zealand. He rejoined the vessel when it arrived in Wellington in January 1999 and had been working on a week-on week-off roster since that time. During his week on duty the chief engineer lived on board the vessel.

1.10.6 The duty engineer was engaged on *Aratere* as third engineer. After serving an engineering apprenticeship in Wellington he went to sea in 1965 with the Union Steam Ship Company where he stayed until about 1969 when he gained his Second Engineers certificate. He then worked for various overseas shipping companies as third or second engineer. He gained his Class 1 Motor certificate in 1973 and then sailed as second engineer with another overseas shipping company for about 15 months to gain steam engine experience before returning to a New Zealand coastal company, where he served as chief engineer for about 12 years.

1.10.7 After another period with overseas shipping companies, the duty engineer joined New Zealand Railways in 1990. He served on the rail ferries for about 5 years, mostly as third engineer but also as second, first and chief engineer for a while. He returned to other overseas shipping companies for another 2 years and then rejoined Tranz Rail in 1997. Since rejoining he had served as third engineer.

1.10.8 The duty engineer had no involvement with *Aratere* during the building period nor during the delivery trip to New Zealand. He joined the vessel in Wellington on 21 January 1999 and was part of the walk-on walk-off crew. He worked an 8-hour shift timed to cover one return trip to Picton from Wellington. In common with other day crew members he worked one shift for 6 days and then had 4 days off before rotating to the next shift. At the time of the incident he was working the 0530 to 1330 shift and was on his fifth rostered day on.

1.10.9 The second engineer served an apprenticeship as electrical fitter in Wellington before joining New Zealand Railways in 1978 as second electrical officer. He was promoted to first electrician in 1982 and had served on all of the inter-island ferries. He remained with the company through the transition to Tranz Rail. When Tranz Rail decided to discontinue carrying dedicated electrical officers, he gained an engineer watchkeeping certificate and was employed as second engineer as part of the watchkeeping staff, although the bulk of his time was spent working on the electrical plant.

1.10.10 The second engineer was appointed to *Aratere* while it was still in the building yard in Vigo. He stood by the building, concentrating on the electrical plant, for the last 4 months in the shipyard, but did not sail on the delivery trip to New Zealand. He rejoined the vessel when it arrived in Wellington in January 1999 and had been working on a week-on week-off roster since that time.

1.11 Crew familiarisation

1.11.1 Tranz Rail assigned staff to *Aratere* at an early stage. Those senior crew members assigned to the vessel spent time in the shipbuilding yard in Vigo overseeing and supervising the construction and fitting out periods. Both groups of the intended live-on crew spent some time in Vigo.

1.11.2 During their time in Spain, the masters and deck officers did a simulator course to help prepare them for the technology of the new bridge. Four of the company electrical engineers went on a power management course run by ABB in Finland.

1.11.3 When building was completed the vessel underwent commissioning trials and surveys. The crew that were on board were involved with those trials to approve the operation of individual items and ultimately the overall operation of the vessel in full sea trials together with the DNV surveyors.

1.11.4 Tranz Rail accepted *Aratere* and took delivery of the vessel on 16 December 1998. Two separate delivery crews manned the vessel for the voyage to Wellington. One crew took the vessel as far as Panama and the second crew from Panama to Wellington. The crews comprised staff who were to become the regular crews when the vessel went into operation.

1.11.5 The delivery voyage gave the crews an opportunity to get to know their vessel in operational conditions without the demands of a ferry schedule to follow. On the way to Wellington they carried out various trial manoeuvres and practised emergency procedures, although only a minimum number of crew was on board. Neither of the assigned electrical engineers were on board for the delivery voyage.

1.11.6 The problems with the starboard propulsion motors and the port Vulcan coupling during the voyage took up a lot of time and reduced the time available for drills and familiarisation. The problems delayed the vessel and resulted in added commercial demands to get the vessel to Wellington as soon as possible to enter service.

1.11.7 Tranz Rail had in place a familiarisation procedure under which a crew member joining one of its vessels was given a familiarisation package. The package gave new crew a description of the vessel with particular reference to safety and emergency equipment and procedures. The familiarisation package was specific to the vessel and also to the rank of the new crew member. Thus a new engineer would receive a different package from that given to a new deck officer.

1.11.8 *Aratere* was substantially different from the other ships in the fleet and at the time of the incident the familiarisation package for the vessel had not been finalised. New crew had to learn about their vessel through on-the-job training given by others who had been involved in the building and delivery.

1.11.9 There were many manuals and plans on board for the equipment and systems but they had not been catalogued by the time of the incident. Dedicated plans and system drawings had not been copied and placed in the vicinity of specific systems. For example, there were no drawings in the emergency generator room to assist the engineers when they needed to diagnose the problems with which they were faced. This made diagnosis of any problem difficult.

1.11.10 Tranz Rail had set aside a period of 12 days from the vessel's arrival in Wellington for remedial work to remove conditions of class, inspections and surveys by both DNV and MSA and new crew training. *Aratere* entered service on 1 February 1999 but was withdrawn on the same day due to mechanical problems. The vessel did not resume service until 13 February 1999. The second period alongside was essentially taken up with investigation and repairs but did afford some additional training time, although some crew were also needed to keep *Aratika* in service.

1.11.11 Those crew members spoken to after the incident expressed varying degrees of uncertainty with regard to the correct operation of the equipment on the vessel.

2. Analysis

2.1 The power failures

2.1.1 The alarm printouts from the automation system presented an accurate sequential record of failure events and have been used as the predominant diagnostic tool for the investigation of the incident. Additionally the course recorder printout and engine load record have been used to support the timing. Comparisons of times recalled by those involved have been considered together with the alarm list to present the fullest possible recreation of events. Inevitably there were discrepancies but those involved in the incident were more focused on the remedial action than recording accurate times.

The initial problem

2.1.2 As *Aratere* was building up speed across Wellington Harbour, an oil mist detection alarm activated on number 3 diesel generator. The alarm condition triggered the automatic immediate shutdown of the diesel engine. Whether or not the alarm was genuine, the Wartsila electronic control system detected the problem and acted upon it as a real event. The control system sent a signal to the Synpol-D controlling number 3 diesel generator to advise it that the diesel engine was shutting down and that it should disconnect the generator from the high voltage switchboard.

2.1.3 Because the wiring between the controllers was not connected at the Synpol-D, the Synpol-D received no signal to open the breaker and the generator remained connected to the high voltage switchboard while its diesel engine shut down.

2.1.4 The power management system monitored the availability of power from each generator by observing the status of the breaker at the high voltage switchboard. Because the breaker remained closed the power management system was effectively deceived into believing that number 3 generator was fully connected and capable of providing its full capacity of 3900 kVA to the propulsion load.

2.1.5 Number 3 diesel generator would then have actually been drawing power from the busbar as the diesel engine was being driven by its generator, which was effectively operating as a motor. The power management system eventually disconnected number 3 diesel generator from the high voltage busbar when the excessive reverse power flow was detected by the Synpol-D. These events would have caused an abnormal voltage fluctuation on the high voltage switchboard.

The first power failure

2.1.6 When number 3 diesel generator was shut down at 0642 because of the oil mist detection alarm, the resulting voltage disturbance at the high voltage switchboard caused numerous alarms over the following 50 seconds.

2.1.7 The 2 transformers feeding the 400 V switchboard were connected to the high voltage switchboard with contactors, which required continuous power on their control coil to remain closed. The high voltage switchboard control interlocks detected a low voltage at the busbar and tripped the 2 contactors feeding the 400 V switchboard transformers. As a result, all of the general electrical services lost power. It was at this stage that the duty engineer called for assistance.

2.1.8 As number 4 diesel generator was still running and number 2 had started but was in the process of coming on line, the power management system automatically restored power to the general electrical services within one minute by re-closing the 2 contactors feeding power to the 400 V switchboard transformers. A race condition was set up between the 400 V switchboard circuit breakers and their emergency stop trip circuits, causing the circuit breakers M5, M6, M9 and M22 to trip at the 400 V switchboard. This stopped the fuel oil forwarding pumps for the diesel generators together with all of the engine pumps that were fed from the main engine services breaker and all of the air compressors.

2.1.9 The voltage on the high voltage busbar had dropped but the high voltage switchboard remained alive. It was the voltage drop that caused the temporary loss of 400 V power at the 400 V switchboard.

2.1.10 The circuit breakers M6 and M9 for the fuel oil forwarding pumps were reset but this action would have been taken several minutes after the power failure.

2.1.11 Because failure of the general electrical services had been only for a short time, the master had been able to steer away from the planned course. Over the following 6 minutes and 30 seconds no further alarm conditions were recorded as the power had appeared to have returned to normal. The master was able to commence steering back to the planned course. The chief engineer had observed that 3 engines were running and connected to the high voltage switchboard.

The second power failure

2.1.12 The automation system reported a power failure on number 4 diesel generator at 0652 and the Synpol-D appears to have opened its circuit breaker at the high voltage switchboard in the next minute. The cause of the power failure was not clear but was probably associated with fuel starvation to the diesel engine after the fuel oil forwarding pumps had lost power during the first power failure. The Wartsila electronic control system would have detected the fuel loss but was unable to isolate the generator from the busbar because of the wires being disconnected at the Synpol-D, the same as for number 3 diesel generator.

2.1.13 Number 4 diesel engine shut down and its generator started to draw power from the high voltage switchboard as it motored the diesel engine in the same way as number 3 had during the initial power failure. The busbar voltage at the high voltage switchboard was disturbed again, but this time all of the diesel generators tripped off line, with the busbar reporting a blackout alarm at 0653.

2.1.14 The power management system automatically restored power to the high voltage switchboard but connected only one transformer to the 400 V switchboard. As both number 3 and number 4 diesel generators had tripped off, it is possible that the power management system determined that power was available only from the side of the high voltage switchboard fed by number 2 diesel generator and energised only the transformer on that side. The chief engineer, who was by this time in the engine control room, noted that the 400 V switchboard was alive only on the side fed by transformer Tx1. In order to supply power to both sides of the 400 V switchboard he closed the busbar tie-breaker, QSB.

2.1.15 The busbar tie-breaker was normally open in operational circumstances. When it was closed, electrical interlocks prevented the transformer Tx2 from being connected between the high voltage switchboard and the 400 V switchboard as the power management system continued attempts to automatically restore normal operation.

2.1.16 When the busbar tie-breaker was closed, power was supplied from the right-hand side of the 400 V switchboard to the left-hand side. The circuit breakers M5, M6 and M22, which had previously been reset, would have tripped again when power was restored to that side of the switchboard due to the race condition.

2.1.17 Apparently the supply feed to the 230 V switchboard in the engine control room was from breaker M1 which was situated on the side of the 400 V switchboard that had been without power. Interlocks prevented breaker M2 being closed at the same time, so until the busbar tie-breaker was closed there would have been no main lighting. Battery-operated lighting in the engine-room was confined to exit lights, which were not placed to enable machinery inspection. None of the engineering staff spoken to reported any difficulty in moving around the machinery spaces so probably the emergency lighting was on, giving the impression of a power failure.

2.1.18 The emergency lighting was powered from the emergency distribution board, which therefore must have had power at this stage. The side of the 400 V switchboard that was still alive supplied power to the emergency distribution board via the interconnector and circuit breakers.

2.1.19 The time at this stage was about 0655 and the lack of main lighting and the stopped fuel forwarding pumps gave the engineers an impression of a power failure. The chief engineer considered powering the 400 V switchboard from the emergency distribution board by selecting harbour mode. However, seeing that the emergency generator was not running, he and the other engineers proceeded to the emergency generator room to investigate.

2.1.20 The circuit breakers, M6 and M9, feeding the fuel forwarding pumps, and M22 feeding the engine services had been reset after the first power failure but appear not to have been reset after the second. At some stage the mode selection on the pump starters were set to "remote". This was probably done during attempts to reset the pumps. Having the pump starters set to "remote" rather than "auto" would have by-passed the automation system, which meant that the pumps would not start automatically when power was restored.

2.1.21 The second power failure was initially a full power failure which prompted the power management system to change the 3-way fuel valves to the diesel oil position using control air. Those diesel generators still running should normally have been running on diesel oil within 30 seconds. However, there would have been no power at the emergency distribution board to run the number 2 diesel oil forwarding pump. At this stage number 3 diesel generator was still shut down due to the oil mist detector alarm, number 1 could not be brought on line due to an alarm condition and number 4 had been struggling from what appeared to have been fuel starvation. Number 2 diesel generator appeared to have been the only one still operating unhindered.

2.1.22 The power management system appears to have been able to put number 2 diesel generator back on line to restore power, via Tx1, to the 400 V switchboard and therefore to the 400 V emergency distribution board. The automation system, sensing that the 3-way fuel valves were in the diesel oil position, was then able to start number 2 diesel oil forwarding pump to get diesel oil to number 2 diesel generator before it too starved of fuel oil.

2.1.23 When the power was restored to the left-hand side of the 400 V switchboard via the busbar tie-breaker, the 230 V switchboard would have become live. The initial outcome of this would have been an increase of engine-room lighting from emergency to mains and the return of power to the nautical equipment on the bridge. The emergency lighting in the control room was fairly good and the change to mains lighting appears to have gone unnoticed by the engine-room staff. Had they realised that mains power had been restored they probably would not have focused on trying to get the emergency generator running.

The emergency generator failure

2.1.24 The emergency generator was designed to start automatically after detecting a power loss on the supply side of the circuit breaker QCP, the interconnector between the 400 V switchboard and the 400 V emergency distribution board. The power graphs from the automation system showed number 2 diesel generator was still on line until about 0710.

2.1.25 The automation system reported a number of overspeed alarms on the emergency generator from 0700 to about 0745. These alarms were probably the result of manual attempts to start the emergency generator.

2.1.26 The fact that at about 0655 the emergency generator was not running was perceived by the crew as a failure of the automatic system to start it. However, with power still available at the 400 V switchboard the emergency generator would have had no signal to start.

2.1.27 Electrical interlocks would have prevented the emergency generator from being connected to the 400 V switchboard if there was a supply from any other source, because the 400 V switchboard must be completely without power before the emergency generator can feed power to it.

2.1.28 While the 400 V switchboard was in emergency mode, the diesel generators were able to provide power to it so the emergency generator interconnector was also interlocked to prevent 2 unsynchronised supplies being connected together. The 400 V switchboard was still in emergency mode when initial attempts were made in vain to start the emergency generator manually against electrical interlocks. This action may have led to the breaking of the shear pin in the interconnector.

2.1.29 At the first and second power failures, power was temporarily lost at the 400 V switchboard and therefore at the emergency distribution boards. No alarm conditions were recorded for the emergency generator at those times, even though the loss of power had been of sufficient duration to require the emergency generator to start. The generator had not started on these occasions so it is probable that the fault, later found in the monitoring control box that prevented the emergency generator starting, had existed before the first power failure. This suggests that even if power from the 400 V switchboard had not been present at the interconnector, the emergency generator probably would not have started automatically.

The third power failure

2.1.30 The 3-way fuel valves had defaulted to the diesel oil position after the high voltage switchboard blackout at 0653. Therefore, after the second power failure and partial restoration of power, number 2 diesel oil forwarding pump would have been operating and the diesel generators running on diesel oil.

2.1.31 The fuel oil forwarding pumps had shut down when the circuit breakers tripped again under the race condition at the second power failure. Although the circuit breakers had been reset after the first power failure, it seems likely that they were not reset after the second.

2.1.32 Number 2 diesel oil forwarding pump was powered from the emergency distribution board which was being fed via the 400 V switchboard and would have tripped off when the emergency distribution board temporarily lost power at the second power failure. The automation system would have restarted the diesel oil pump when power was restored.

2.1.33 The engineers began working on the emergency generator shortly before 0700 and continued to attempt to bring it on line and supply some power to the 400 V switchboard. At some stage during the initial attempts, the emergency distribution board probably lost power again and the number 2 diesel oil forwarding pump tripped off again, causing the diesel generators to shut down from fuel starvation.

2.1.34 When the control air pressure eventually dropped to a point where the 3-way fuel valves could no longer be held in the diesel position, the valves would have returned under spring pressure to the fuel oil position. Once the valves were in the fuel oil position, diesel oil would not have been able to reach the diesel generators, even if number 2 diesel oil forwarding pump had been running. However, once all the 3-way valves had returned to the fuel oil position, the automation system would stop the diesel oil forwarding pump, but it could still have been operated manually.

2.1.35 Without the availability of fuel oil because those pumps were shut down, and diesel oil because it was unable to reach the engines due to the position of the 3-way valves, the diesel generators ran out of fuel and stopped. All power would have been lost at this point.

2.2 Crew familiarisation and morale

2.2.1 The personnel assigned to *Aratere* during building in Vigo were those intended to be regular members of the operational crew when the vessel was put into service. Two persons of each senior rank were assigned to the vessel and spent some time in the shipyard. While this time afforded some opportunity for familiarisation, the work involved a lot of supervising the installation of equipment. It was not until the end of the building period that those crew would be able to begin to build an overall picture of the operating systems of the new vessel.

2.2.2 The busiest period in the building of a vessel is inevitably at the end when individual items are commissioned within the overall operating system and then the overall system function tested and commissioned. The number of items required to be checked is always large and is at a time when pressure of work increases for all concerned to complete the building, pass the vessel to its new owners and get it into service.

2.2.3 Before a new vessel is accepted by and delivered to its owner, full sea trials are conducted. This is usually when operating crew observe their new vessel as a single entity for the first time. While the crew may have been involved in the commissioning of individual items or isolated systems, the sea trials are probably the most meaningful familiarisation procedure in the building process. Nevertheless, the trials are a busy time and involve equipment designers, manufacturers, installers, shipyard staff, classification society surveyors and owner’s superintendents. Although the crew are involved in the process, they are generally either observers or involved with specific tasks.

2.2.4 Tranz Rail accepted *Aratere* after the completion of trials and the vessel left Vigo for the voyage to Wellington. The delivery voyage was probably the best familiarisation opportunity for the operating crews and it was appropriate that the vessel was manned by different crew before and after Panama.

2.2.5 *Aratere* was a complex vessel that was substantially different from the other ships operated by Tranz Rail. The control and automation systems were complex and involved much electronic control. Neither of the electrical officers that were to be appointed to the vessel was involved with the delivery voyage. This valuable opportunity for key staff to familiarise themselves with the vessel was lost.

2.2.6 The crews involved in the delivery voyage did continue their familiarisation through drills and trials on the equipment and systems. However, there were problems with propulsion motors and gearbox couplings that occupied considerable time in repairs and also delayed the vessel.

2.2.7 The delays meant that there was added pressure to get the vessel to Wellington and into service and the crews were not able to undertake any drills that might create further delays.

2.2.8 The vessel arrived in Wellington later than the originally planned date and then had to undergo surveys by the MSA and the classification society. The short term certificates that had been issued in Spain had expired because of the delays and had to be re-issued. The MSA inspections found faults that had to be rectified before the vessel could be put into service.

2.2.9 The time spent on surveys, inspections and remedial work afforded some time for further familiarisation and training of newly appointed crew. The vessel was put into service but soon suffered further breakdowns of the propulsion gearboxes and was again withdrawn.

2.2.10 There had been a lot of publicity surrounding the arrival of the new vessel and media reports on its progress. The breakdowns on passage, the initial detention period and the further breakdowns all attracted considerable media attention. The company was supportive of the crew but the media attention placed an additional pressure on the crew who already had a high workload.

2.2.11 When seafarers are content with a vessel and the conditions under which they serve, they describe it as being a “happy ship”. In the early days of its operating life *Aratere* was not a “happy ship”. The media attention focusing on failings rather than any positives, the issues surrounding crew accommodation, and the catering arrangement and standard of fare were all factors that adversely affected the morale of the crew on board. This, together with the work demands on them to get the vessel into service made for a crew that was not fully prepared and sufficiently familiar with their vessel.

2.2.12 The manning concept of some people living on board while others worked a shift each day was new and did little to form the whole crew into a properly functional unit. The handover for the walk-on walk-off members was carried out during the short turnaround of the vessel. This gave little opportunity for camaraderie that is usual among crews living together on their vessel, creating instead a group of individuals. Those individuals rarely spent much time together for the exchange of information and knowledge.

2.3 Summary

2.3.1 The mechanical problems experienced on the delivery voyage and when first entering service had no direct bearing on the causes of the power failure but had created delays and meant that at the time of the power failure the vessel had actually been in service for 11 days only.

2.3.2 A number of factors contributed to the eventual total failure of the power plant and its management system on board *Aratere*. The isolated faults that had developed in the system, such as the faulty oil mist detector on number 3 diesel generator, can be considered normal events in the day-to-day running of a vessel; events that the system should have been able to cope with.

2.3.3 The reason why it did not cope on the day of the incident was twofold:

- there were design faults in the system which indicated a less than adequate failure mode effect analysis had been carried out on the system at the design and testing stage; and
- there were serious defects in the installation of the plant that indicated a less than optimum standard of quality assurance at the installation and testing stage.

2.3.4 The concept of the power management system on board *Aratere* was not altogether new. The system was designed to operate with little intervention from the crew, as long as it was set up in the correct mode. For all intents and purposes, it appears that initially the crew did have the system set up correctly, albeit with the most unreliable generator further up the priority sequence than it should have been.

2.3.5 There was evidence however, that in the heat of the moment, rather than stand back and let the automation do its job, the crew reverted to their natural instinct of going out into the engine-room and operating the various components manually. In a correctly set up plant, this can lead to a poor result. As it turned out with the plant on *Aratere*, some crew intervention was required due to the design and installation of the plant being fundamentally flawed. Unfortunately though, the crew were not sufficiently familiar with the operation of the plant to use its diagnostic tools to good effect and solve the problem in good time. It was fortunate that the weather conditions were favourable and that *Aratere* was not in more difficult waters. The master handled the situation well and at no time was the safety of the vessel compromised.

2.3.6 A vessel such as *Aratere* that carries a large number of passengers on a route that in places leaves little margin for error, needs a high level of reliability and redundancy of critical components, and correspondingly, needs a crew that is fully familiar with, and confident in, their vessel before it enters service. There is no place for on-the-job training for an entire crew in such circumstances. It appears that in this case *Aratere* entered service before it was technically fit to do so, and with a crew that was not adequately familiar with it.

3. Findings

Findings and safety recommendations are listed in order of development and not in order of priority.

3.1 The sequence of events that resulted in the power failure was initiated by a spurious oil mist detector alarm that required number 3 diesel generator engine to be shut down. The Wartsila electronic control system appropriately treated the alarm as a real event and initiated the shutting down of the engine.

3.2 The Wartsila electronic control system sent a signal to the ABB power management system that the engine was being shut down and that the generator should be disconnected from the high voltage switchboard.

3.3 The power management system had been designed to manage the loss of a diesel generator without causing a major disruption at the high voltage switchboard; however, it did not receive the signal to disconnect the generator from the high voltage switchboard because the wiring for that alarm condition had been disconnected at the interface between the Wartsila electronic control system and the power management system.

3.4 The power management system was unaware that number 3 diesel engine was shutting down and presumed that its full electrical load was still available.

3.5 As number 3 diesel engine shut down, it started to draw power from the high voltage switchboard. The power management system then detected the reverse power flow and disconnected the generator from the busbar and started number 2 diesel generator to compensate for the loss, but not before a disruptive voltage drop had occurred.

3.6 Because of the voltage drop at the high voltage switchboard, the power management system disconnected the propulsion motors from the load. At the same time the voltage drop resulted in the transformers feeding the 400 V switchboard tripping, causing a loss of power at the 400 V switchboard.

3.7 The power management system began to recover and reinstated power to the 400 V switchboard, which resulted in the circuit breakers for the fuel oil forwarding pumps, air compressors and main engine services tripping off the board due to a design fault in the system. The circuit breakers for the fuel oil forwarding pumps were manually reset a few minutes after the first blackout but the others were not.

3.8 Number 4 diesel generator began to starve of fuel because the fuel oil forwarding pumps had tripped off and there was a delay of a few minutes before they were reset by the crew. The Wartsila electronic control system would have detected the fuel loss but the wiring fault at the Synpol-D prevented the alarm signal reaching the power management system.

3.9 Number 4 diesel generator began to draw power from the high voltage switchboard in the same way that number 3 had done in the first power failure. The power management system detected the reverse power flow and disconnected the generator from the busbar.

3.10 The loss of number 4 diesel generator caused another severe voltage disturbance at the high voltage switchboard and all the diesel generators tripped off the high voltage switchboard, causing a full blackout. Number 2 diesel generator was still running at that stage.

3.11 The blackout resulted in the automation system changing the fuel supply from fuel oil to diesel oil. Number 2 diesel oil forwarding pump was automatically started once the power management system used number 2 diesel generator to begin restoring power to the 400 V switchboard.

3.12 The power management system automatically restored power to the high voltage switchboard but was only able to connect one transformer to the 400 V switchboard before the crew intervened by closing the busbar tie-breaker, preventing the other transformer from being connected. It was not clear if the power management system would have connected the other transformer if the crew had not connected both sides of the switchboard together.

3.13 The circuit breakers for the fuel oil forwarding pumps would have tripped again at the restoration of power after the second failure and were not reset, but by this time a diesel oil forwarding pump was running.

3.14 The 3-way supply valves were in the diesel oil position and held there against a spring by control air pressure. The air system began to lose pressure because the air compressor had stopped when its circuit breaker tripped. The springs overcame the reduced air pressure and returned the 3-way valves to the fuel oil position against the flow of diesel oil from the diesel oil forwarding pump.

3.15 As the 3-way valves on each engine returned to the fuel oil position, each engine starved of fuel and stopped. Once all the 3-way valves returned to the fuel oil position the automation system would have stopped the diesel oil forwarding pump. Thus neither fuel oil nor diesel oil was available and all the diesel generators starved of fuel and stopped, producing a complete blackout.

3.16 The emergency generator did not start automatically as it should have done at the first and second power failures due to a fault in its controller.

3.17 Initial attempts to start the emergency generator manually were made while limited power was still available at the 400 V switchboard. Electrical interlocks prevented the emergency generator starting at that time.

3.18 Faults in the design of the power management system on board *Aratere* were indicative of incomplete failure mode effect analysis at design stage.

3.19 Faults in the installation of the power management system were indicative of less than adequate quality assurance at installation and testing stage.

3.20 The faults in the design and installation of the power management system prevented it managing the loss of a diesel generator as it should have been capable of doing.

3.21 At the time of the power failures, *Aratere* was new in service and its crew still gaining experience in the operation of the power management system.

4. Safety Actions

4.1 Immediately after the incident, function tests were carried out by ABB on the power management system; by Wartsila on the Wartsila electronic control system and by Caterpillar on the emergency generator system.

4.2 The disconnected alarm wiring at the Synpol-D interface between the power management system and the Wartsila electronic control system was discovered and rectified.

4.3 The faulty oil mist detector on number 3 diesel generator engine and those on the other diesel generator engines were replaced with modified detectors.

4.4 Standing orders were introduced which stated that the chief engineer was to be the only person to set or change the engine starting priority selection.

4.5 The fractured shear pin in the closing mechanism of the interconnector between the 400 V switchboard and the emergency distribution board was replaced.

4.6 The faulty overspeed alarm in the monitoring control system for the emergency generator was temporarily bridged to allow normal operation while waiting for a permanent repair.

4.7 A new monitoring control system for the emergency generator was designed, manufactured and fitted by Caterpiller.

4.8 The design of the 400 V switchboard was altered so that the circuit breakers for the fuel forwarding pumps, air compressors and main engine services no longer trip off the board when power is lost or restored.

4.9 Running lights were installed at the 400 V switchboard to indicate the running status of all essential pumps.

4.10 A permanent sign has been placed near the fuel forwarding pumps describing correct procedures and settings of the pump mode switches.

4.11 Procedures were introduced to provide air to the control air system from the main air bottles in the event of a blackout to maintain the 3-way valves in the diesel oil position.

4.12 Consideration is being given to changing the automatic change-over of the fuel system to diesel oil on loss of power to become a manual operation.

4.13 A power supply for one of the fuel oil pumps was provided at the emergency distribution board.

4.14 Two additional electrical officers were assigned to the vessel to catalogue and index the operational drawings and manuals.

4.15 The additional electrical officers also made copies of plans for specific areas of operation and those plans were placed at the operational locations. This task is ongoing.

4.16 The company has encouraged a greater use of the automation system as a diagnostic tool for the engineering staff.

4.17 The company negotiated with the manufacturer of the automation system to provide a training programme that will be included in the familiarisation for new crew and be part of ongoing training for current crew.

4.18 The 3 watch-keeping engineers and one of the additional electricians have become part of the weekly rostered crew, resulting in a greater degree of networking and knowledge sharing between the officers.

4.19 Although catering for the live-on crew is still supplied from ashore, the standard of the fare has been improved and the catering arrangement has gained greater acceptance among the crew.

4.20 A documented familiarisation package for new crew has been prepared specific to *Aratere* and familiarisation procedures have been put in place for the ongoing training of all crew.

4.21 In the aftermath of any accident or incident, the resulting internal and external investigations into causes and contributing factors become valuable educational exercises. Coupled with scheduled periods of maintenance the operating crews have built a sound knowledge of the vessel's operating systems.

5. Safety Recommendations

5.1 On 8 June 2000 it was recommended to the Managing Director of Tranz Rail Limited that he:

5.1.1 Critically review the designing, building and commissioning into service of Aratere, with a view to developing procedures and guidelines for use with future new buildings. (036/00)

5.2 On 14 June 2000 the Managing Director of Tranz Rail Limited responded as follows:

5.2.1 The Company has already reviewed the process of designing, building and commissioning Aratere and the deficiencies noted.

Approval for publication 13 June 2000

Hon. W P Jeffries
Chief Commissioner