Can Autonomous Ships revive Domestic Coastal Shipping for Non-Bulk Freight in Australia?

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Master thesis

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Abstract

Australia being an island with most population concentrated in a few large coastal cities, one might expect coastal shipping to play an important role in the domestic freight task. However, in 2014 road and rail accounted for 78% and 18% of the non-bulk domestic freight task, respectively, leaving coastal shipping with only 4%. Why? First, "door-to-wharf-to-wharf-to-door" shipping, as with rail, is more complex and time-consuming than "door-to-door" by road. Second, the 2012 cabotage reforms imposed onerous conditions on foreign-flagged ships, decreasing their participation in coastal trades drastically. With the development of new technologies, ships are gaining greater autonomy and current research projects suggest the arrival of unmanned coastal vessels between 2020 and 2025. Compared to their conventional counterparts, autonomous ships have the potential to reduce fixed costs and increase productivity.

Keywords

Autonomous ships, Australia, Non-Bulk Freight, Coastal shipping

Preferred citation style

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1 Introduction

This report explores the possibility of a revival of Australian coastal shipping by autonomous vessels. Coastal shipping does not play an important role in the freight transportation landscape of Australia, particularly the non-bulk freight. Why? First, "door-to-wharf-to-wharf-to-door" shipping, as with rail, is more complex, expensive ands time-consuming than "door-to-door" by road. Second, the 2012 cabotage reforms imposed onerous conditions on foreign-flagged ships, decreasing their participation in coastal trades. With the development of new technologies, ships are gaining greater autonomy. Current research projects in the Baltic and North Sea suggest the arrival of unmanned coastal vessels between 2020 and 2025. Compared to their conventional counterparts, autonomous ships have the potential to reduce fixed costs, particularly related to crewing and fuel, and increase productivity.

This research is divided into two parts. The first one introducing the current research projects looking into autonomous ships, their challenges and advantages, with a detailed view of the legal aspects and further the current situation in the maritime industry and how autonomy could shape it in the future.

The second part focusses on an implementation of coastal shipping for non-bulk freight. Potential shipping routes were identified based on the freight distances and the current and future freight movements. Once determined, the conceivable routes were further investigated, with regards to the nature of the freight moved, its potential shift and the availability of important rail competition. Finally, by analysing the modes' transit times an attempt was made, to quantify the necessary reduction in freight rates autonomous ships would have to achieve, in order to be successfully implemented.

Part I

Autonomous Ships

2 Introduction to Autonomous Ships

2.1 Autonomy versus Automation

The definitions of autonomy and automation given by the Oxford Dictionary Online (2017a) are:

Automation: The use or introduction of automatic equipment in manufacturing or other process or facility

Autonomy: The right or condition of self-government

Autonomy is not possible without automation, and the path going from automation towards autonomy starts at manual control to fully automatic control and subsequently leading to autonomous navigation. The following sections will explore the path towards autonomy.

2.2 Autonomous vehicles

2.2.1 Cars

In the car industry, the Society of Automative Engineers developed the levels of automation depicted in figure 1.

The SAE levels from 0 to 3 consider that the human driver is present in the car and must do the driving. Without any help (SAE level 0), with help of driver assistance tools such as adaptive cruise control or parking assistance (SAE level 1 - "hands on"), with a system taking control over the vehicle (accelerating, breaking and steering) (SAE level 2 - "hands off"), and then over to a level where the vehicle can drive on its own in a specific situation (e.g. motorways), still needing the driver to intervene when necessary (SAE level 3 - "eyes off"). From SAE level 4 ("mind off") on, the driver does not need to be „ready to take over the driving“in certain defined surroundings and in all surroundings in SAE level 5 ("steering wheel optional"),

Figure 1: Levels of Driving Automation

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
Human driver **monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
Automated driving system **("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Source: SAE International (2014)

2.2.2 Trains and Trucks

Self-driving trains have been in use on metro systems since the 1960s, and can now be found in cities all over the world. In Sydney, the first driverless metro train should be operative by 2019. The use of autonomous technology for trains is operated in controlled underground settings, like RioTinto currently experimenting driverless mining trains, as well as driverless trucks(Stewart, 2017), however the future area of development explores overground settings.

Self-driving intralogistic vehicles are also standard as for example on modern container terminals as at the *Patrick Terminal* in Brisbane.

2.2.3 Ships

The ship industry has experienced automation for some years. Most vessels are already fitted with electronic navigation instruments, informing of the ship's position, the distance to other ships, their course and speed as well as their predicted trajectory (ARPA [1], radar and AIS[2]). Large ships are steered by an autopilot keeping the ship on his predefined track. Manual control of the rudder and main engine is used for manoeuvring or for handling error events. The technology needed for an implementation of autonomous ships, therefore is already mainly in application, but the challenge is to find the optimal way to combine them reliably and cost effectively.

Levels of autonomy for ships: Similar to the levels of driving automation Lloyd's Register (2017) developed a classification for ships presented in figure 2. The goal being to propose a framework for the assurance of safety and operational requirements for unmanned ships:

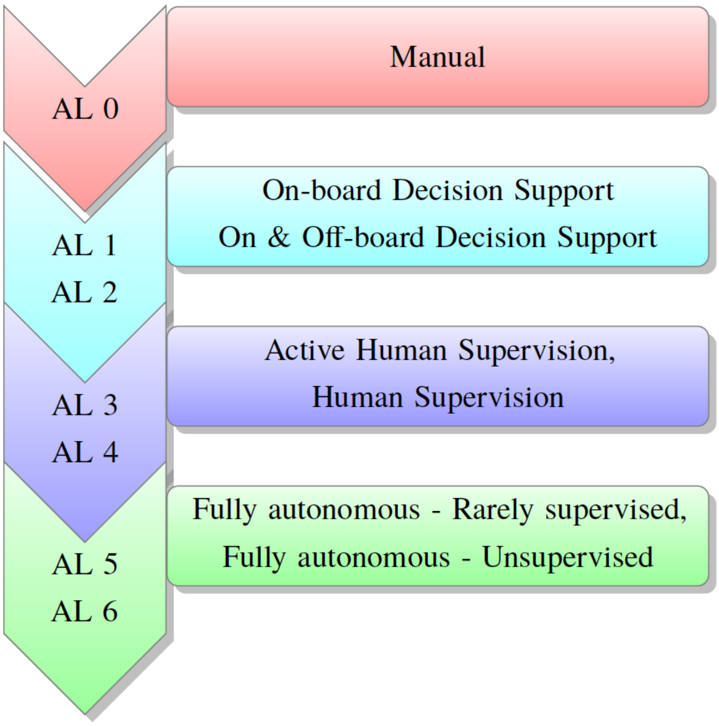
- At level AL 0, the human completely controls all actions on the ship.
- At AL 1, the human is in control, but decision support tools can present options. Data is provided by systems on board. Additionally for AL 2, data may be provided by systems off-board.
- At AL 3, Decisions and actions are performed with human supervision. Whereas AL 4, decisions and actions are performed autonomously with human supervision. High impact decisions are implemented in a way to give human Operators the opportunity to intercede and over-ride.
- At AL 5 the ship system is rarely supervised. It makes decisions and operates autonomously. AL 6, the autonomous ship, the system makes decisions and operates, without supervision.

The current overall autonomy is, dependant on various situations (as entering a port or cruising on the ocean) and the ship, between autonomy levels 2 and 4.

[1]Automatic Radar Plotting Aid calculated other ships' course and speed, and transmits a warning if there is a risk of collision

[2]Automatic Identification System: transmits information about the ship's identification, its position, course and speed

Figure 2: Autonomy Levels for Ships based on Lloyd's Register (2017)



2.3 Why autonomous ships ?

2.3.1 Benefits of autonomous shipping

Autonomous and unmanned ships would contribute to the aim of a more sustainable maritime transport industry, as it bears the potential to:

- **Reduce Crewing Costs**, by first reducing the crew, then in a second step remotely controlling the ship and eventually to autonomous shipping.
- With reducing the crew comes also the **Omission of the Crew Accommodation**, meaning less (uneconomical) weight on the ship thus fuel and energy savings and more benefit bringing cargo space.
- **Better Operation Efficiency**, by combining and improving the various navigation and management systems (e.g. Energy management systems, improved routine and navigation). Further a better reliability of the engine and other systems is expected.

- **Greening of Shipping** is trivial following the benefits mentioned before. Fuel savings, a better energy management system and then the use of alternative fuels and/or alternative propulsion systems will significantly reduce exhaust gas emissions.

- **Safety Benefits:** human error being a dominant factor in maritime casualties. The European Maritime Safety Agency identified in 62% of accidental events human erroneous actions as the main reason. This is followed by equipment failure, in 20% of the events. In 71% of the accidental events, shipboard operation appeared to be the most significant contributing factor. Automated look-out, navigation and collision avoidance will therefore provide significant benefits and a decrease of collision is expected.(EMSA, 2016)

- Attract seagoing professionals by having **better working conditions** (since there is an important recruiting problem)

- **Reduction of Piracy Acts**: Piracy acts often target the crew as hostage and ask for a ransom. Without any crew on-board piracy acts could be reduced.

- **Redefinition of Shipping as a Logistics Provider:** By reducing the operational costs of ships, autonomous ships will increase the attractiveness of small vessels at sea and inland. The access to urban areas at waterways could develop new logistical, last-mile segments, and transportation possibilities with high flexibility. Seabubbles concept introducing a river taxi in Paris (Seabubbles, 2017). Additionally it would also reduce road congestion and therefore contribute to the greening of logistics.

- **Economic Benefit**, will depend very much on technical solutions, propulsion system, fuel prices and the type of trade the ship is involved in, including the ideal size of the ship.

2.3.2 Limitations and Challenges

Autonomous ships can and will only be applied where they will be safer and especially more cost-effective. But a lot of challenges are to be assessed before autonomous ships become reality:

- **Reducing/Eliminating a whole crew** of a ship, means to reduce a skill range of 20-30 collaborating crew members and combine these with there specialities in one central element.

- **Maintenance and repair issues**: The biggest part of the crew is responsible for the ongoing maintenance and repair of the machinery. One of the biggest challenges, will therefore be to make machinery more long-term reliable, since support to autonomous ships will be only limited on sea. Key learnings are expected from the implementation of autonomous ships in coastal areas.

- **Legal issues**: Especially concerning the Seaworthiness of ships, the shipmaster's responsibilities and duties, the pilotage areas as well as the hierarchical position in the COLREG regulations avoiding collisions. These issues are explained more thoroughly in section 4

- **Cyber-Security** as in the previous section mentioned the usual piracy acts would be reduced, but a new way of piracy could emerge.

- **Situational Awareness:** Autonomous ships will be operated in very harsh natural environments, subject to sudden changes, along with other maritime traffic. The bigger these vessels the more difficult they are to manoeuvre and therefore to stop.

- **New ship design / New Propulsion system / Technical and Operational Infrastructure at Ports**: Autonomous ships will give the incentive to new ship designs, new propulsion systems and new infrastructures at ports, which will need to be flexible and adaptable to current situations. Current infrastructure will be rethought and standards will have to be revised, representing a major turnaround in the industry.

- **High capacity communication / Data-Sharing** Autonomous ships will still be monitored and their systems will refer back to a central system. In first steps, autonomous ships are expected to be remotely operated, which engages high capacity of communication and data-sharing issues.

These challenges will become less important and others will rise, when remote operating coastal ships will be launched. From this first step a lot of additional data, experience and learnings can be gathered and flow into the consideration of the challenges.

2.4 Research projects about autonomous ships

2.4.1 Waterborne^{TP}

Waterborne^{TP}, a technology platform in the EU, striving to regularly update R& D requirements for European competitiveness in the maritime industry published in 2005, their vision of an autonomous ship and so kicking in, the beginning of research on autonomous ships:

Next generation modular control systems and communications technology will enable wireless monitoring and control functions both on and off board. These will include advanced decision support systems to provide a capability to operate ships remotely under semi or fully autonomous control. Waterborne TP (2017)

2.4.2 Maritime Unmanned Navigation through Intelligence in Networks (MUNIN)

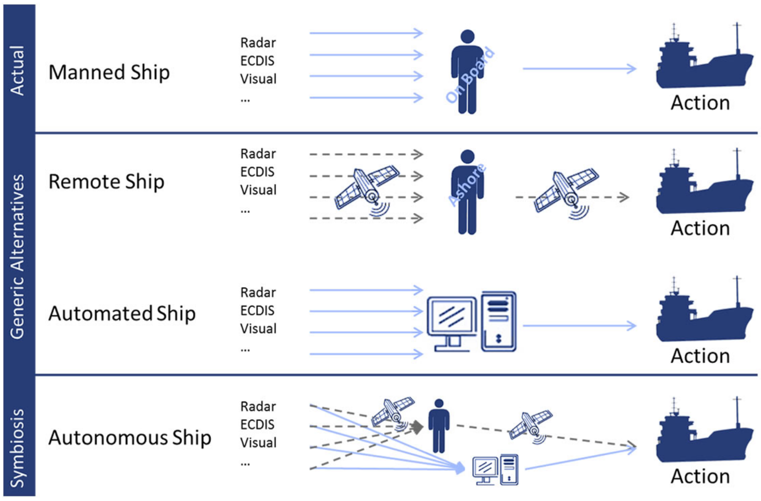
The MUNIN research project, based upon the Waterborne^{TP} strategic research agenda, assessed a feasibility study of autonomous vessels, with regards to technical, economic and legal background. The case used was the one of a dry bulk carrier operating in intercontinental tramp trades, thus not being affected by congested or restricted waters. Figure 3 illustrates the MUNIN concept and its understanding of the „autonomous ship ", as the symbiosis of a „remote "and an „automated ship ".

Departing from the current **„manned ship "**, which uses decision supporting tools and can therefore be associated up to level of autonomy *AL3* depending on the situation and the ship. Two generic notions are developed:

- The **„remote ship "**, with operating tasks being performed exclusively via a remote control mechanism (e.g. by a shore based human operator). By remote monitoring it is understood the concept of measuring and fully monitoring values from sensors on the ship (e.g. course and speed) and shown in real time in an operation centre ashore or on-board another vessel. The transmission of sufficient information and data about the ship and its surrounding space,is crucial to be able to perform remotely-operated navigation.

- The **„automated ship "** has advanced decision support systems on board and undertakes all the operational decisions *independently* without intervention of a human operator.

Figure 3: Autonmous Ship as understood by the MUNIN Concept



Source: MUNIN (2017)

The **„autonomous ship "** is then the symbiosis of the two notions above and corresponding to the autonomy levels *AL 3* and *AL 4*. The ship is *autonomously operated, but monitoring and controlling* functionalities are executed by an operator ashore in the *Shore Control Centre*.

Decisive systems and entities: With regards to the technical feasibility, MUNIN defined the systems and entities, considered as being decisive to a successful implementation of autonomous ships. These systems were already broadly defined in the section 2.3.2 considering the upcoming challenges of autonomous ships.

1. **Advanced Sensor Module:** The sensors and sensor data processing are supposed to replace in the best possible way the perceptions of the officer. Thus the aim is to reduce overall uncertainty and improve the quality and integrity of the „perception model "in order to determine appropriate actions under the prevailing conditions. The module would be responsible for the detection of objects and their classification, with regards to potential dangers to the ship. Further, to represent the overall environment, with collecting and assessing data from navigational, meteorological and safety sensors to build a local map of objects and potential hazards.

2. **Autonomous Navigation System:**

   - The **Deep Sea Navigation System (DSNS)** should ensure that the ship follows the predefined voyage plan within its action range or adjusting the route in case of changes in weather and traffic situations.

- The **Remote Manoeuvring Support System** is seen as an auxiliary for the DSNS and the shore control center. It aids carrying out manoeuvres for collision avoidance, while navigating in constrained waterways in ports.

3. **Autonomous Engine and Monitoring Control system:**

   - **Engine and Monitoring Control system** would be continuously monitoring the critical technical systems in order to prevent malfunctions and breakdowns during the voyage and better maintenance planning.
   - With an **Energy Efficiency System** the increased degree of instrumentation and automated control would simplify the implementation of energy efficient optimisation.

4. **Shore Control Centre:**

   - In the first steps of autonomous ships, the **shore control centre** acts as a continuously manned supervisory station for monitoring and controlling a fleet of autonomous ships.

Further the project did a cost-benefit analysis showing that compared to a conventional bulker, the autonomous ship would be commercially viable.

2.4.3 Advanced Autonomous Waterborne Applications Initiative

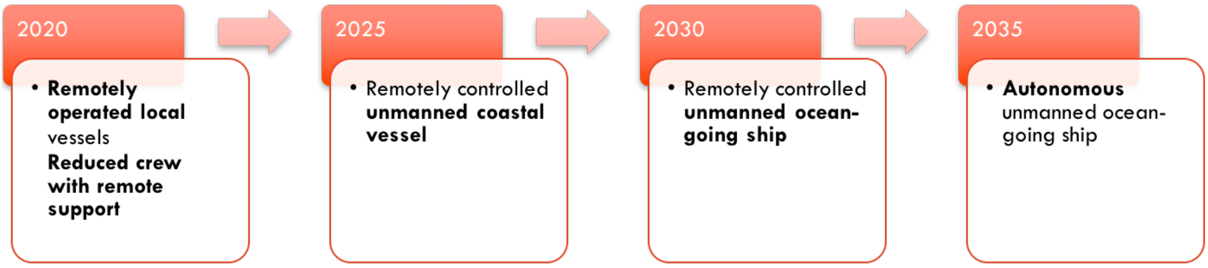
The AAWA initiative project aims to produce the specification and preliminary designs for the next generation of advanced ship solutions. The research consortium is funded by TEKES (Finnish funding agency for technology and innovation) and brings together partners across the maritime industry.

The timeline of AAWA's understanding for a future implementation of autonomous ships is shown in figure 4.

The objectives of the AAWA initiative being:

- To create competence for remote controlled vessels in commercial use and a hotspot for Waterborne remote control technology

Figure 4: Timeline of AAWA Project based on AAWA (2016a)



- To develop commercially viable short to medium- term solutions

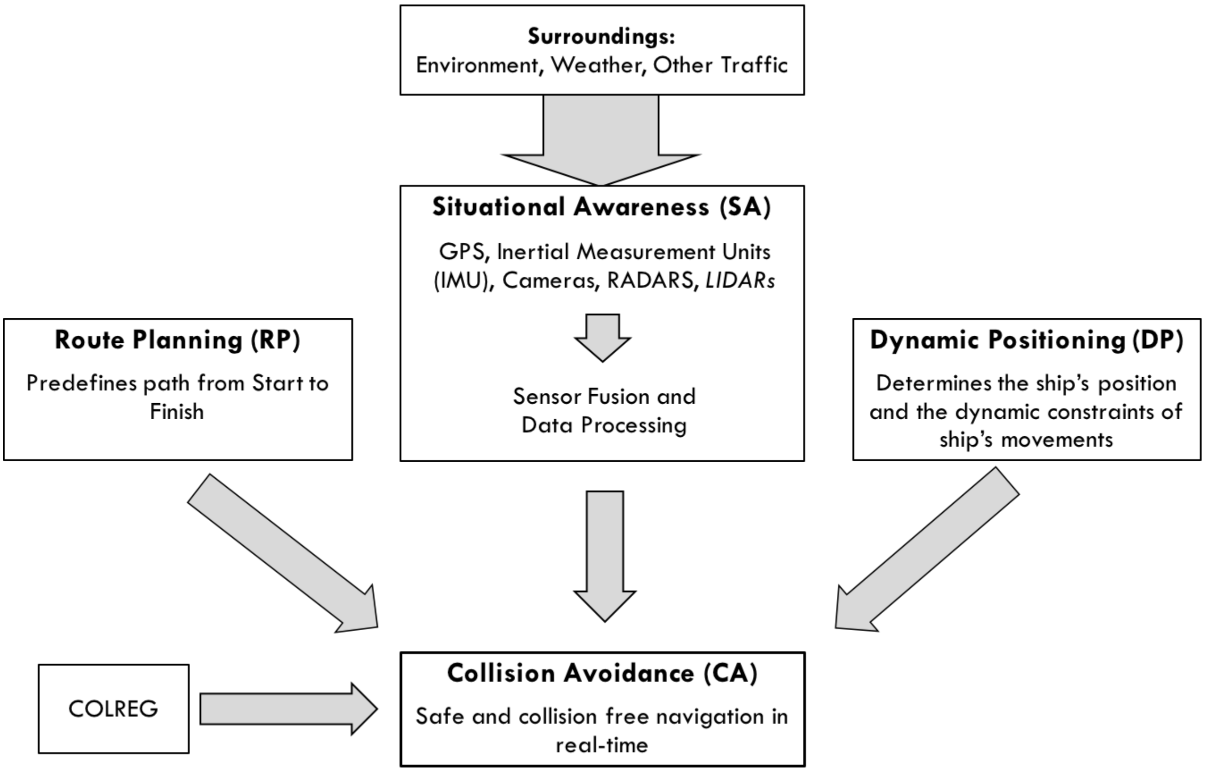
In the first part of the project, AAWA examined the current state of understanding of autonomous ships, especially focussing on the technology, safety, legal and economical aspects. By the end of 2017, the second part would develop these aspects in order to demonstrate the concept.

- Technology: What technology is needed and how can it be best combined to allow a vessel to operate autonomously and miles from shore?
- Safety: How can an autonomous vessel be made at least as safe as existing ships, what new risks will it face and how can they be mitigated? Safety and security implications of designing.
- Legal and Regulatory implications: Are autonomous ships legal and who is liable in the event of an accident?
- Economical: What will be the incentive for ship owners and operators to invest in autonomous vessels? How is the existence and readiness of a supplier network able to deliver commercially applicable products in the short to medium term?

AAWA's understanding of the autonomous navigation system (ANS) is shown in figure 5. There are four main components of the ANS:

1. Route Planning (RP), which predefines the path from Start to Finish and is already in use.
2. Situational Awareness (SA), which extracts the relevant information of the surroundings (environment, weather, other ships, etc...) through the various tools like GPS and RADARS and then fusions and processes the data to the shore-based center. This then involves high data communications. Challenges here are the unknown environments and events. The situational awareness needs a tolerance to extreme weather conditions as well.
3. Dynamic Positioning (DP), which determines the area where the ship is able to manoeuvre in future. The speed of a ship is fairly slow and the environment in which it moves is not

Figure 5: Autonomous Navigation System based on AAWA (2016b)



confined (vs. narrow road) but no quick or sharp manoeuvres are possible.

4. The three components are combined together and give information to the Collision Avoidance (CA) system, which provides safe and collision free navigation in real-time, following the COLREG rules.

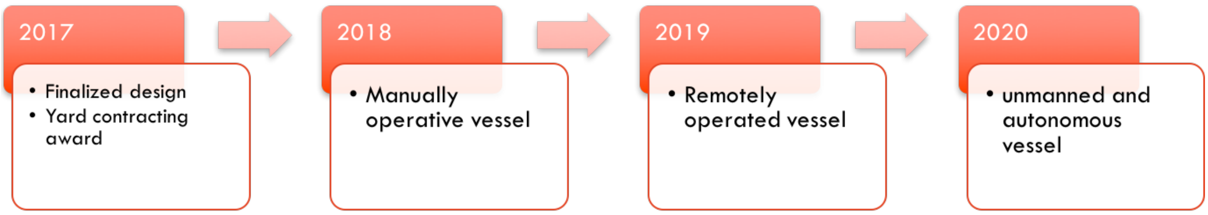
2.4.4 One Sea Ecosystem

One Sea is a Finnish-led collaboration and a high-profile ecosystem with a primary aim to create the world's first autonomous maritime ecosystem by 2025 in the Baltic Sea, on the Finnish coastal area.

2.4.5 NOVIMAR Project

NOVIMAR introduces a different concept than MUNIN, called „platooning ", but also building on the Waterborne strategy. The concept rather than having remote controlling the ship, proposes a vessel train version. This would in essence be a number of unmanned „Follower Ships"with

Figure 6: Timeline of Yara-Birkeland Project based on Kongsberg (2017)



own sailing/manoeuvring capabilities being temporarily led by a manned „Leader Ship“. The vessels will be able to join and leave the trains at places close to their origin and destination seaside or inland. Opposed to the MUNIN concept, this brings the additional benefit of no sizeable investment in infrastructures like control centres. The concept would focus on small vessels at sea and inland and therefore increase the access to urban areas located at small waterways.

2.4.6 Kongsberg - Yara Cooperation

The global fertilizer company Yara, based in Norway developed with shipbuilder Kongsberg a 120 TEU [3] open top container ship „Birkeland “, fully battery powered and prepared for remote control and autonomous operation. The operational area is within 12 nautical miles from the coast and would link 3 ports in southern Norway, completely covered by the Norwegian Coastal Administrations' VTS system at Brevik. Shown in the timeline of the project in figure 6, the first phase is to implement a containerised bridge with crew facilities (2018). When the ship is ready for autonomous operation this module will be lifted off (2019-2020). Loading and unloading will be done automatically using electric cranes and equipment. The ship will not have ballast tanks, but will use the battery pack as a permanent ballast.

2.4.7 Japanese Shipping Company - Nippon Yusen

The Japanese shipping company *Nippon Yusen* plans to send a remote-controlled vessel across the Pacific Ocean in 2019, thus still crewed to ensure safety and proper monitoring. Two other big Japanese shipping companies Mitsui O.S.K. Lines Ltd. and Kawasaki Kisen Kaisha Ltd. state to be also currently involved in autonomous ships research.

[3]Twenty-foot Equivalent Units

2.4.8 Australia - BHP

BHP being one of the biggest mining companies in the world and active in Australia, is hence, one of the largest dry-bulk carriers in the world. Their vision for the future of dry bulk shipping is „Safe and efficient autonomous vessels carrying BHP cargo, powered by BHP gas“this vision could, relating to them, be realized within a decade. As a large company their short-term focus is on lowering costs, and one of the domains they are focusing on are autonomous vessels, since it could improve safety and have better efficiency for the marine supply chain.

2.4.9 Others

- **Rolls Royce** is collaborating with MacGregor (cargo-handling machinery) to investigate the impact of developments in autonomy for cargo ship navigation and cargo systems on-board container ships. They are also collaborating with Google developing the intelligence awareness system. Furthermore Rolls-Royce is also highly implicated in the AAWA and the OneSea Projects.

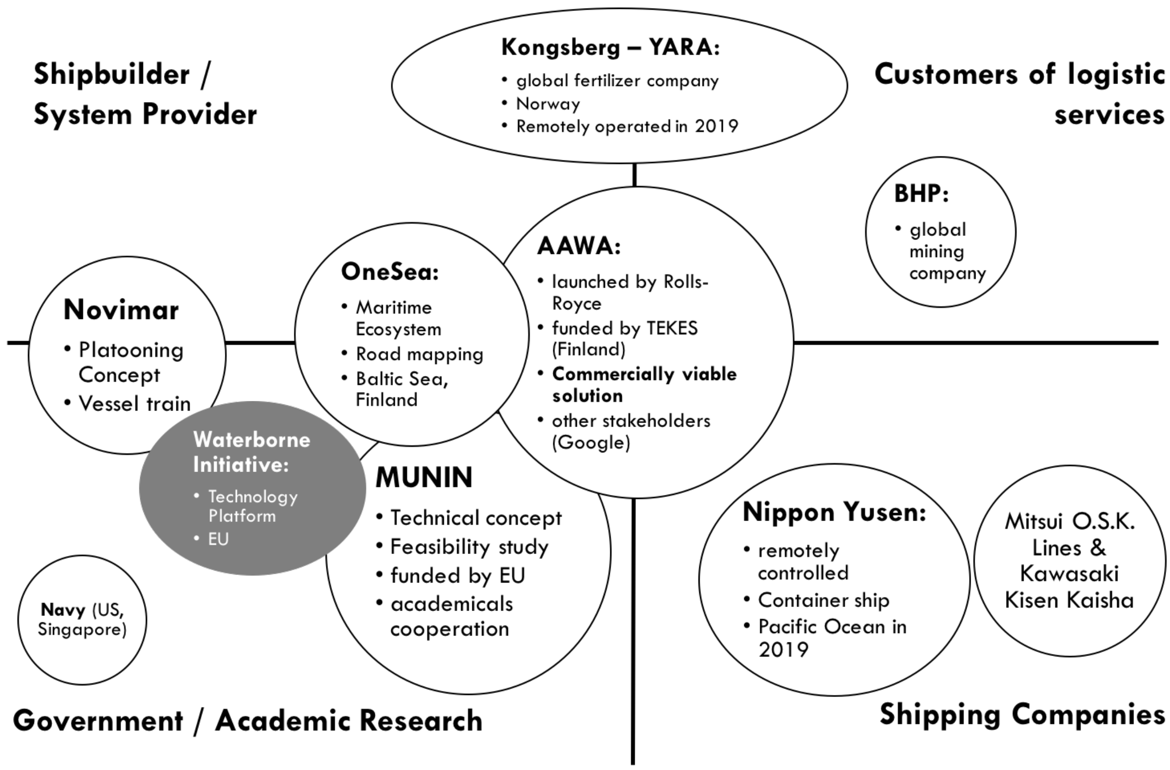
- **Det Norske Veritas Germanischer Lloyd (DNV GL) - ReVolt:** The DNV GL also initiated a research project in August 2013 before participating in the AAWA research consortium, with a concept for an unmanned, zero-emission, shortsea vessel in Norway: the „ReVolt “, fully battery powered and with a cargo capacity of 100 TEU.

- **RAmora Vessel:** The Robert Allan Ltd. introduced an autonomous tug concept, that will be used remotely with a hybrid propulsion system and substantial battery storage capacity to enable extended operation even in potentially hazardous environments such as LNG terminals or firefighting situations.

2.5 Conclusion

The current research projects as summarized in figure 7 show, how implicated various maritime industry players are into the development of autonomous ships. The research is done, independently and in groups: as shipbuilder / system providers (Rolls Royce, Robert Allan Ltd., Kongsberg), freight shipping lines (Nippon Yusen, Mitsui O.S.K. Lines Ltd and Kawasaki Kisen Kaisha Ltd., ESL Shipping), ferry lines (Finferries), classification societies (DNV GL, Lloyd) as

Figure 7: Summary of the current research projects



well as the „important current users“of freight services (YARA, BHP). This illustrates that the revolution of autonomous shipping is taken very seriously and the „first mover advantage “could completely disrupt the maritime industry. The MUNIN and the NOVIMAR projects introduce two different concepts leading towards autonomous ships. The MUNIN projects considers autonomous ships as a symbiosis of a remote and an automated ship and developed the concept of a shore-based operator (SBO) operating and supervising the ships. The NOVIMAR concepts sees the implementation of autonomous vessels through „platooning“, having a manned ship leading temporarily a train of unmanned smaller ships and focussing more on inland waterways.

3 Maritime Industry

3.1 Current situation

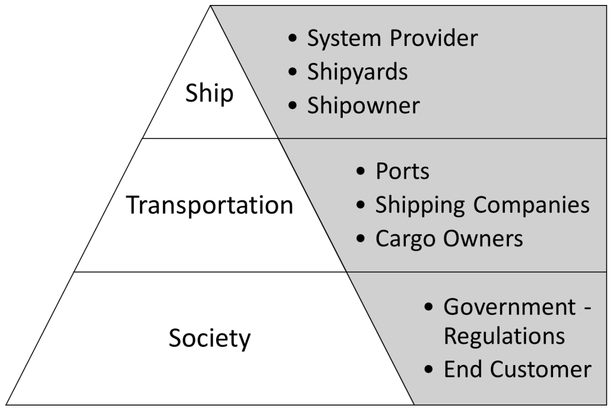
The current shipping industry can be divided into three main areas: first the ships, then the actual transportation task and the society. The ships, being the vehicle capable of accomplishing the transport task, are built in a strong collaboration between the shipyards, the different system providers (e.g. engine) and the shipowner. The cargo owners require shipment, performed by shipping companies or operators passing through ports. The shipping companies can be the shipowners but are not necessarily, and can therefore bond between the ships and the transportation task. Last but not least, the society plays the roles of the government and its regulations on the shipping business on one side, and more importantly on the other side of the population demanding products and hence logistics.

Autonomous ships seem to have a bright future, and bring the expected benefits of fuel saving and crew costs, and also savings on emissions by new engine configuration. The business implementation or taking an active part in the fore coming of this technology, seem to be more difficult at present, since it is a high investment, a lengthy endeavour for regulations to be settled and until the technology is ready-for-use, with reliable and sustainable equipment.

What is expected to hinder autonomous ships to take off is mainly the regulatory and legal level. Social acceptance is crucial to adopt innovations and starts with the recognition of the technology and its possible close future.

Additionally, potential shipping areas face strong competition from other industries, where autonomy is more advanced and where the market entry is likely to be lower (autonomous trucks and trains). This chapter tries to understand the different possible actions and reactions, of decisive stakeholders in the maritime industry and thus their renewed set of roles.

Figure 8: Current Maritime Industry



3.2 Possible business implementation

3.2.1 Private Global Company

Large private companies have high logistical needs and invest important resources every year to reduce their transportation costs and have a better control of their supply chain. Therefore they could be keen investigating autonomous shipping. Currently they are either important customers of shipping companies or have the logistical task in-sourced as it is the case for instance for the large mining companies active in Australia BHP and Rio Tinto or the example of the Yara-Birkeland research project introduced earlier.

Those companies would invest into tailored autonomous ships leading to a strong cooperation with shipbuilders and system providers, testing them on a national basis and then expanding the ships and their know-how to their global network.

If concentrating on Australia, some large mining companies, which already have private rail, ports infrastructure and logistical services, are in a strong economical and negotiating position. They could therefore be the key player, shaping regulations with the government to their needs and ensuring of a fast implementation.

3.2.2 Shipping Company

Shipping companies seem to have two options, when it comes to the implementation of autonomous ships, being either active or passive.

- **Active** (e.g. Nippon Yusen): Shipping companies that take an active part in autonomous ships, seek for direct benefits in reducing crewing and fuel costs, increasing cargo capacity, but more importantly to have the first mover advantage in the technology and thus to be more competitive in the future. Engaging with autonomous ships, also means that they will have an impact on the technology development on the ships and regulations.

- **Passive**: Passive shipping companies, are the ones, that do not take an active part. They are either not ready or capable to invest resources and time, or simply do not see the near future of the technology. Once the advancements show a clearer picture, they will eventually buy and use the ships and the technology. But this will likely result on the basis of a market competition against the active, first-mover, all-taker shipping companies. A question remaining is whether the passive shipping companies would wait until ships are fully autonomous or whereas they would engage earlier and consider remotely controlled ships. This implies an understanding concerning control center infrastructure with the government and/or the ports. Shipping companies, that engage too late, are likely to face strong established competitions and will have to rapidly diversify and specialize in order to keep up.

3.2.3 Private Partnerships

Private companies and shipping companies, might both not have enough resources to play an active part in the implementation of autonomous ships, could collaborate. That way resources could be mitigated between them. For private companies, the advantages are, that they would have a service tailored to their needs and a dedicated business partner. Shipping companies on the other hand, could examine the future technology, while having their business as usual. They would be more competitive once autonomous ships are established, since they would have first a long-term customer/partner and compared to other shipping companies, a first-mover advantage.

In Australia, this could be particularly interesting for the not so global mining companies, having large bulk logistical needs and their shipping provider.

3.2.4 New entrants

There are various „new entrant“possibilities, with a step in technology, comes also a change in the required skills. New entrants are hence expected in the suppliers area. An important need for data and software related services will emerge, as shows the collaboration between Rolls-Royce and Google (Rolls Royce, 2017). New entrants are therefore, new entrants in the maritime industry coming from various other sectors and thus enhancing cross-sectoral cooperation.

In terms of shipping companies, no new entrants are expected, since the market entry cost is very high, but more a consolidation of global players, that have the resources to play an active part or that can react based on their market size.

3.3 Transport Costs

Autonomous ships are expected to greatly reduce the ship costs. This chapter gives a structure of the cost breakdown of vessels. The determinants of maritime transport cost in figure 9 are divided into seven categories, which are directly related to the transportation (operating costs of ship, shipped product and the Ports), the industry (Structure of the industry) and the specific countries (Position within the global network, Trade flows, Trade Facilitation).

Autonomous ships will have a direct impact on the ship's operating costs and the port costs explained later in section 3.3.1. Indirectly autonomous vessels will, through expected simplifications and developments of official documents (such as the landing bill), reduce customs formalities and thus reduce the waiting times for ships. UNCTAD (2015), states that 10% less time is expected to lower the cost by 0.5%. The structure of the industry, will also be impacted by autonomous ships, as explained earlier in section 3.2.

3.3.1 Ship's Costs:

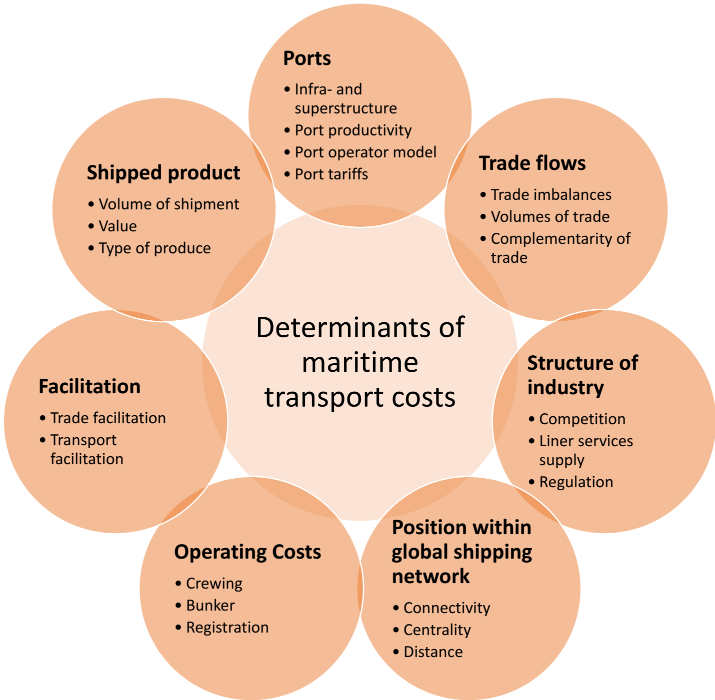
The ship's operating costs vary depending on the ship type and age. Through economy of scales, shipper tend to bigger vessels, which currently in the industry leads towards oversupply.

The cost of operating, maintaining and financing a fleet are shown in figure 10 and can be divided into:

1. **Operating costs:**

    - **Crewing cost** depending on the size of the crew and the employment policies adopted by the owner and the ship's flag state. The minimum number of crew depends on

Figure 9: Determinants of international maritime transport costs based on UNCTAD (2015)



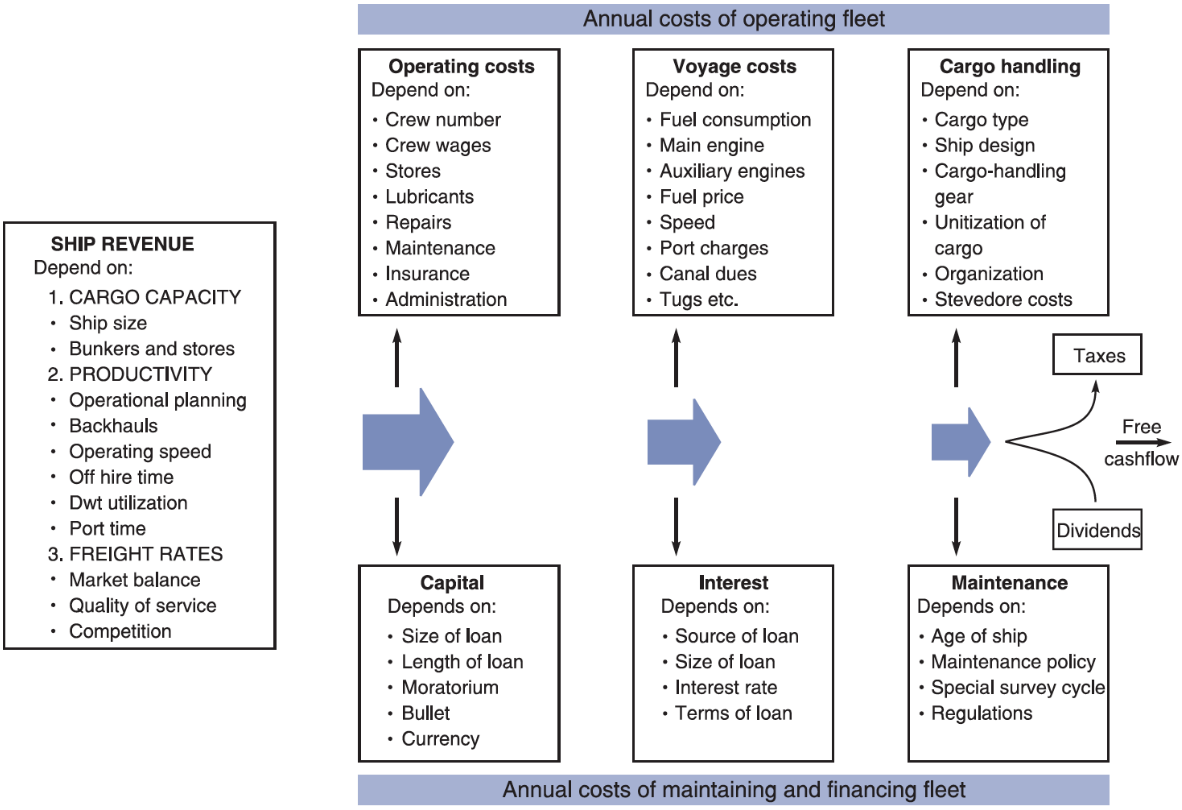
flag state regulation, degree of automation, the skill of the crew and the amount of on-board maintenance undertaken.

- **Stores** are the expenditure on consumable supplies (cabin stores and various domestic items used on board ships) and **lubricating oil**.
- **Repair and maintenance** of the main engine and auxiliary equipment.
- **Insurance** varies form ship to ship. Two-thirds of the cost is to insure the hull and machinery, which protects the owner of the vessel against physical loss or damage, and the other third is a third party insurance, which provides cover against third party liabilities such as injury or death of crew members, passengers or third parties, pilferage or damage to cargo, collision damage, pollution and other matters that cannot be covered in the open insurance market.
- **General costs** such as the registration fee, which is to be paid to the flag state and the general administration.

2. **Voyage costs:**

- **Fuel costs** are the most important item. The fuel consumption depends on the ship, the hull condition and the speed at which it is operated. Fuel prices vary over time.
- **Port charges** include the use of facilities and services provided by the port. These depend on the time spent in the port, the size of the vessel and the type of cargo

Figure 10: Shipping Cash-flow Model



Source: Stopford (2009)

loaded or discharged.

3. **Cargo-handling costs**, include the cost of loading and discharging the cargo and the stevedore costs, which are particularly important in the liner business

4. **Capital and Interest costs**, which finance the fleet. Included is also the taxation cost of the ships, which depends on the flag states registration.

5. **Periodic maintenance costs**, refer in particular to dry-docking, which should happen on a regular basis, depending on the age and the condition of the ship. During the dry-dockings, the seaworthiness of the ship is assessed too.

3.3.2 Cost comparison conventional carrier vs. autonomous ship

Table 1 compares quantitatively the costs of an autonomous vessel towards the ones of a conventional carrier. The range going from ⇊, meaning a great reduction towards ⇈, which means much higher costs. The ⇔ expects no important changes related to autonomous vessels. The comparison provides expectations of change, but the symbols are not relatable in between them. A great reduction in fuel costs is not comparable with a great reduction in general costs for instance.

Table 1: Cost comparison autonomous ship vs. conventional carrier

Cost elements	Change	Comments
1. Operating Costs		
Crewing costs	⇊	Unmanned ship in the long-term
Stores	↓	No crew, thus no domestic items on-board
Repairs & Maintenance	↓	Through monitoring control systems, maintenance should be kept to a minimum. If there is a breakdown at sea, the cost would be much higher since nobody is on-board.
Insurance	↓	Claiming that 70% of accidents are human errors, insurance cost should therefore decrease with less crew members.
General costs	↓	Less crew members to administrate
2. Periodic Maintenance Costs		
Periodic Maintenance Costs	↓	Dry docking process would be optimized through monitoring systems
3. Voyage Costs		
Fuel costs	⇊	Depends on engine type, but reduction through weight reduction of the ship
Port Charges	↓	Cargo-handling should be more efficient, thus less time spent in port. Ports will need to upgrade their infrastructure
4. Cargo-handling Costs		
Cargo-handling Costs	↓	Reduced by improved ship design and advanced ship-board cargo handling gear.
5. Capital Costs		
Capital Cost	⇔	Ships will use less steel and hence cheaper, but navigational systems might be more expensive

4 Legal Challenges in autonomous shipping

This chapter tries to understand as laid out in section 2.3.2, one of the main challenges of autonomous ships, the regulatory environment. First by introducing the current international regulations and their structure, and then by assessing the issues related to an implementation of autonomous vessels internationally and nationally.

4.1 Introduction to International Maritime Law

In the international context, the United Nations are, through their „convention on the law of the sea "(UNCLOS) responsible for the coordination of the interests and gaining agreements for a consistent body of jurisdictional rules. The UNCLOS, therefore lays down the states' rights and obligations to take measures with respect to ships, and so define the fundamental issues of the ownership of the sea, the right of passage through it and the ownership of the sea bed. The latter is determined by the division of the maritime zones as illustrated in figure 11:

- The **territorial sea (3-12 nm [4]):** Ships have the right of innocent passage. Coastal states only have the right to enforce their own laws relating to specific topics such as navigation and pollution.

- The **contiguous zone (12 nm):** A strip of water, where coastal states have limited powers to enforce customs, fiscal, sanitary and immigration laws.

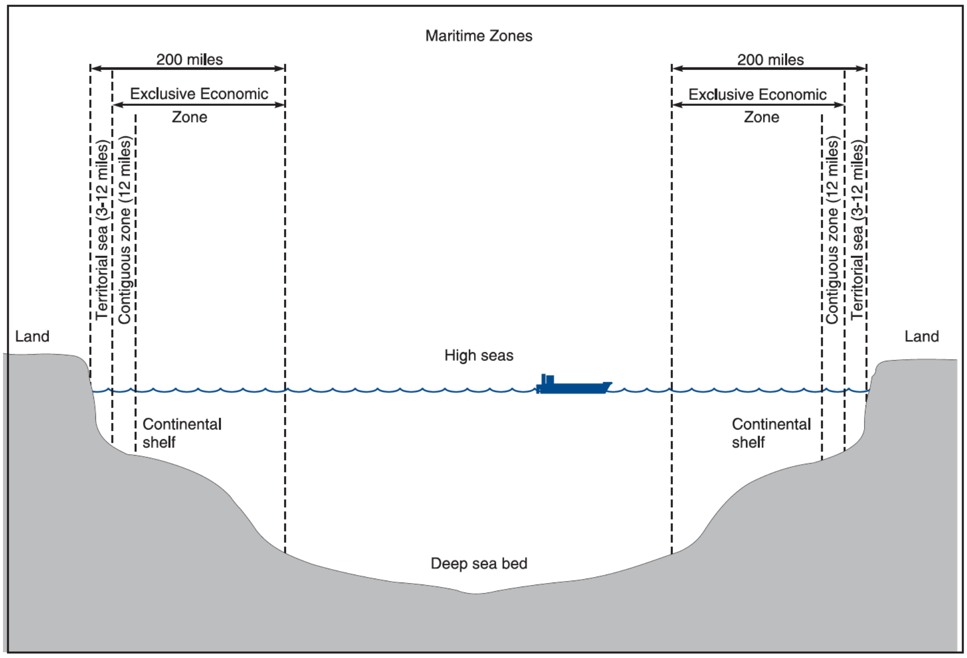
- The **exclusive economic zone „EEZ"(from 12 nm up to 200nm):** belt of sea extending up to 200 miles from the baseline. Freedom of navigation and the laying of cables and pipelines.

- The **high seas:** where vessels flying a particular flag may proceed without interference from other vessels.

Further the UNCLOS delegates the task of developing and maintaining workable regulations „the technical rules"to the:

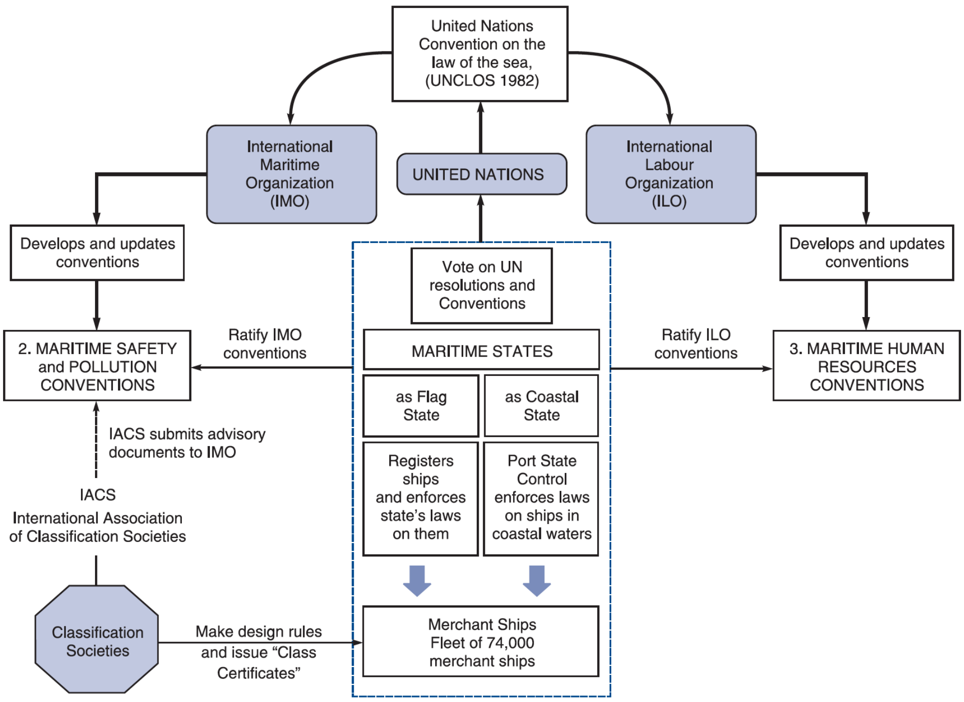
[4]nautical mile

Figure 11: Maritime zones



Source: Stopford (2009)

Figure 12: The maritime regulatory system showing the role of the 166 maritime states



Source: Stopford (2009)

- **International Maritime Organization (IMO):** responsible for regulations covering ship safety, environment, prevention, liability, security and compensation. The most important conventions relating to maritime safety and pollution prevention for merchant shipping, being SOLAS (Safety), MARPOL (Pollution), COLREG (Collisions) and STCW (Training).

- **International Labour Organization (ILO):** responsible for the laws governing the people on board ships.

These two organizations produce conventions, which become laws, when they are enacted by each maritime state (not all 166 states sign up to every convention).

Each maritime state has two different roles:

1. As a **flag state:** A ship needs a „nationality "for legal and commercial purposes. The ship then undergoes a registration process for a national, international or open register. The flag state therefore makes and enforces laws governing ships registered under its flag, such as:

    a) Tax and commercial and financial law.
    b) Compliance with enacted maritime safety conventions
    c) Crewing and terms of employment
    d) Naval protection and political acceptability

2. As a **coastal state** the maritime state enforces the maritime laws on ships in the states' territorial waters.

The **classification societies:** (such as Lloyd's Register (LR), Nippon Kaji Kyokei, DNV GL, etc...) are the shipping industry's internal regulatory system. They „enhance safety of life and property at sea by securing high technical standards of design, manufacture, construction and maintenance to mercantile and non-mercantile shipping ". In this way, classification societies set the industry standard for establishing that a vessel is properly constructed and in good condition, by issuing a class certificate. Without the class certificate, a ship cannot obtain insurance and has little commercial value. Additionally, the classification societies represent the largest technical expertise of the shipping industry. Additionally, when it comes to regulations, they play an important part in the role of technical advisers to the maritime regulations with two fundamental aspects: **developing rules** and **implementing them**.

Figure 13: Legal Challenges with regard to the autonomy levels

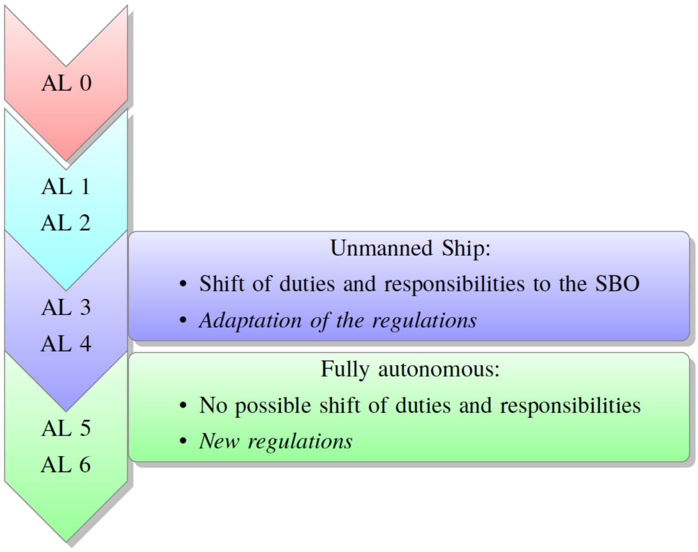


Figure 12 represents the maritime regulatory system as an interrelated schema.

4.2 Autonomous Ships in the International Context

The three principal areas of concern are navigation, crewing and liability, raising issues such as the seaworthiness of the ship, the ship master, his duties and the question of how autonomous ships should be considered hierarchically in the COLREG [5]. Only the issues considered as being decisive to a comprehensive understanding of autonomous ships are introduced in this chapter, it goes without stating that more minor issues will rise, once the regulations will be explored.

Figure 13 gives a brief look of the legal challenges relating to the autonomy levels of vessels.

4.2.1 Crewing Level

„An *insufficient* and *incompetent* crew can cause a vessel to be unseaworthy “[6] and expose shipowners to cargo claims [7] and even void a marine insurance policy [8] therefore at an UNCLOS

[5]Convention on the International Regulations for Preventing Collisions at Sea (1977)
[6]Hong Kong Fir Shipping Co v Kawasaki Kisen Kaisha [1962] 2 WLR 474, 481
[7]The Hague-Visby-Rules 1968
[8]Marine Insurance Act 1906

level a ship has to be „*properly* manned “[9] or as the SOLAS states „*sufficiently and efficiently* manned “. These three regulations do not produce a clear rule, whether the focus of properly crewing a ship, is on a certain numerical amount of crewing to be met or on its competency.

- If the **competence** is considered the decisive criteria, then the shore-based operator (SBO) or team can provide a safe navigation of the ship, and the ship could be unmanned. The future developments of autonomous shipping lead to think, that a SBO is the first step, in a long-term process, the ship should be completely autonomous and the SBO at most have a surveillance function. This shows how hard it will be to updated and adapt regulations sustainably, without having to reconsider them after every minor technological step.

- In the other case, where the **number** of the crew is decisive, the legalities would have to be completely revised.

Further the UNCLOS, requires that a flag state must ensure the safety at sea, and therefore its appropriate crew qualification and amount. Depending on the states, two different approaches were identified:

1. The owner of the ship needs to submit its proposal for safe crewing numbers according to the type of vessel and the nature of the voyage. In that case, autonomous ships could be applied. (UK, Australia, Canada, Hong Kong and Bermuda)

2. Regulations specify the minimum number of crew according to the type of vessel. Whereas in this case the legal situation for autonomous ships is more complex. (Singapore, United States, New Zealand and South Africa)

Further the STCW [10] UNCLOS regulation, which promotes safety of life and property at sea and the protection of marine environment applies primarily to seafarers serving on-board ships. This is expected to be expanded to shore-based personnel, since autonomous ships will be carrying property and could damage the environment.

Another criteria to the seaworthiness of a ship is its safety management system, representing only a minor issue here. Since it is considered, that through centralizing the operations in one shore-control centre, the cooperation is enhanced and therefore the shipowner would have a better control of the ship.

[9]Article III (1)(b) Hague-Visby Rules
[10]Standards of training certification and watchkeeping

4.2.2 Ship master duties

The traditional role of the ship master, being „a natural person who, is responsible for a vessel and all things and persons in it and is responsible for enforcing the maritime laws of the flag state "will disappear and the associated legal duties and liabilities will disperse to other factors.

The definition of a ship master fits to the SBO, since its a person having command or being in charge of the ship, but not all duties can be fully shifted. Therefore the responsibilities will have to be rethought and redistributed between the SBO, the owner and the ship's agent (on a long-term basis, only between the owner and the ship's agent). Two main roles can be identified for the ship master:

1. Duty to render assistance:

    - UNCLOS, SOLAS and the salvage conventions state that it's the ship master's personal duty to render assistance. If the SBO is legally the master, they may find themselves criminally liable for any failure to do so.

    - Further it is not practical for autonomous ships to render physical assistance beyond alerting other ships or coastal authorities, given that it is not designed to carry people and there are no lifeboats or food/water/first aid supplies.

    - Conforming, if the autonomous ship itself gets into difficulty, there is no obligation on coastal states or other vessels to render assistance as there are no lives on board.

2. The master as the agent of the shipowner:

    - The ship master's task is to accurately note the condition of cargo at the time of shipment, this role will have to be delegated by the owner to an agent in the relevant port, since the SBO, for obvious geographical reasons, cannot take this responsibility.

    - The master has the responsibility of its ship and therefore also has to know what is transported, and if it is in line with the bills of landing and has the right to refuse dangerous cargo. These responsibilities can surely be delegated, but risks of fraud are important and verification needs to be consequent. Also safety concerns might not be the same, for someone not being on-board.

4.2.3 Pilotage:

In sensitive areas, as ports and environmental sensitive waters, pilotage is compulsory, which means giving over the conduct of the ship, to a pilot, who has come on-board and is specialized in the particular area. These pilotage laws vary not only from country to country and from port to port.

This situation raises again a lot of questions, since the physical application would be difficult and therefore the liability issue is high.

Since the autonomous ship is not designed to carry people, the pilot can simply not board the ship. However if the pilot can board the ship and take over the control, there would be an important piracy risk. Further the question raised would be to whom the pilot is answerable, since no higher instance would be on-board and supervising.

Solutions there could be to:

- Grant an exemption to a person, here the SBO: What the AAWA project recommends and is the current legal procedure in Australia. The SBO could become a licensed pilot for the area and berth the autonomous ship by remote control, having a similar role of an air traffic controller. This shows to be difficult in the assessment of the SBO, since some kind of remote control examination needs to be done.

- Grant an exemption to the ship (as is current use in South Africa, Hong Kong and India): those law would allow be more easily applicable for autonomous ships.

4.2.4 Navigational compliance with COLREG

The COLREG implemented regulations to avoid collisions at sea, through traffic separation schemes and demands "a proper lookout by sight and hearing as well as by all available means appropriate in the prevailing circumstances". The autonomous ship, which will be equipped with multiple sensors in order to ensure the information on the ship's surroundings must be sufficiently accurate and the SBO could satisfy this requirement if the information is fed back properly. Also the autonomous vessel demands an appropriate position in the responsibility hierarchy of COLREG. It could be considered as „not being under command“, but in fact it is a ship that has exceptionally lost its ability to be controlled.

4.2.5 Liability

Following with the issues that are brought with unmanned ships and therefore the shifts or reiterations of in particular the ship master's responsibilities, comes the question of the liability. Who is liable for the conduct of an autonomous vessel ? The players between which it seems sensible are the SBO (short-term), the owner, the manufacturer of the ship or the manufacturer of the technology leading to the error ?

Future accidents will be caused by defected products and systems, while the role of human error is reduced or at least shifted elsewhere. When there is less human control, the reliability and problem- solving capacity of an autonomous system become crucial. The autonomous system must survive even when human intervention is not possible...

4.3 Autonomous Ships in the Australian Context

Autonomous and/or unmanned vessels, used for a commercial activity, that operate exclusively within Australia's EEZ will be considered as "domestic commercial vessels" (DCVs). The Australian National Law, a vessel is not excluded of being so, because it is unmanned or autonomous:

- *Vessel - means a craft for use, or that is capable of being used, in navigation by water, however propelled or moved, and includes an air-cushion vehicle, a barge, a lighter, a submersible, a ferry in chains and a wing-in-ground effect craft.* [11]

- *Domestic Commercial Vessel - [a vessel as above]... .conjunction with a commercial, research or government activity* [12]

4.3.1 Australian regulations:

Therefore the owners of an autonomous ship would be required to meet the requirements for a *regular* DCV of class 2A (Non-Passenger vessel), set out in the National Law Act, as listed below:

[11]section 8 of (Office of Parliamentary Counsel, 2016)
[12]section 7 of (Office of Parliamentary Counsel, 2016)

1. The vessel must have a **unique vessel identifier (UI)**.

2. Operation of the vessel must be authorised by a **National Law Certificate of Operation**, which describes the conditions under which a vessel must operate as how and where, and :

    - the crew required to operate a vessel safely. Part E of the National Standards for Commercial Vessels, sets the **crewing requirement**, considering that *A vessel must carry sufficient competent and trained crew at all times when operating, so that:*

        - *the vessel can safely navigate, berth and unberth; and*

        - *the vessel systems essential to safety can be effectively operated and monitored; and*

        - *immediate and appropriate emergency action can be taken when there is a failure of an essential system; and*

        - *the risk associated with the nature of the activity conducted by the vessel is reduced to the extent that is reasonably practicable; and*

        - *a measured response to emergencies or risks that may threaten the vessel or persons on-board during normal or abnormal conditions, when considering all facets of the vessel's operation, can be provided; and*

        - *rapid and safe evacuation of all persons on-board the vessel can be facilitated.*

      These requirements therefore, as explained before in section 4.2.1 do not imply that a crew has necessarily to be on-board, since the crew of the vessel must be *sufficiently competent and trained*. If the unmanned and autonomous ship is considered sufficiently safe, then autonomous ships have a future, without considering specific changes in that regulation.

    - For *not existing* vessels, as are unmanned vessels:

        – a **Risk Assessment** including measures to control identified risks, has to be conducted and

        – a **Safety Management System** is required, complying with Part E of the National Standards for Commercial Vessels.

3. The vessel must be the subject of a **National Law Certificate of Survey**, which certifies that the vessel has been surveyed and meets standards for design, construction, stability and safety equipment. It has to be shown that the vessel is suitable for its intended use and area of operation and will comply with the standard applying for vessels. [13] These standards will presumably need adaptation for autonomous ships, considering certain changes in the design of the vessel. Probably, a standard will have to be met with regards to the autonomous technology used too.

4. The vessel must be crewed by persons holding the required **National Law Certificate of Competency**, prescribing the standard for qualifications of crew and masters of domestic commercial vessels. In the case of an unmanned vessel, an additional certificate could be defined for a shore-based operator (SBO). Considering an unmanned and fully autonomous vessel more research will need to be made in order to define the necessary „competency"of crewing this vessel would need.

5. **General Safety Duties** apply to persons in relation to DCVs. The safety duties, as introduced in section 4.2.2, will need to be reassigned, particularly those mentioned below:

   - Ensuring the safety of the vessel, marine safety equipment, and the operation of the vessel.

   - To not operate, or cause the vessel to be operated, if it is an unsafe vessel.

   - To implement and comply with the Safety Management System (SMS) for the vessel and its operations

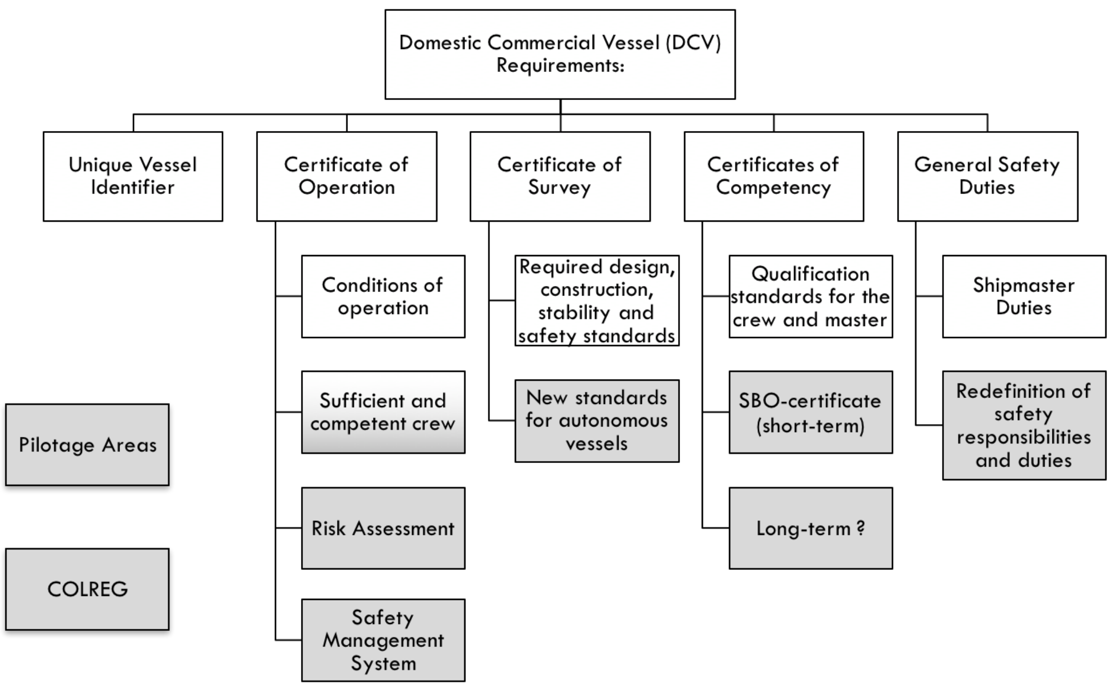
     – the owner of a DCV should implement and maintain a SMS, and

     – the master of a DCV should maintain and comply with the SMS, so far as reasonably practicable.

The requirements of a DCV and the legal challenges autonomous ships would face are summarised in figure 14, with in red the critical points.

[13] section 8 of (AMSA, 2016c)

Figure 14: Legal Challenges of Autonomous Shipping in Australia



4.3.2 Exemptions

A first step towards a fast implementation of autonomous ships in Australia, and therefore bypassing the various and time-consuming legal and regulatory changes and adaptations to be made, would be the granting of exemptions. Two type of exemptions can be made:

- **General Exemptions:** AMSA has implemented a number of „general exemptions"in order to address situations where it is considered unnecessary to impose the entirety of the National Law Act on a vessel due to its size, operational area and category, and general risk factors, or where transitional arrangements are required. These general exemptions are provided to specific people or vessels. For now, there is no tailored exemption for an Autonomous or Unmanned vessel, however this may be considered by AMSA for a future implementation. (Judson, 2017)

- Owners can apply for **specific exemptions** from any particular requirement related to the vessel. A specific exemption being an exemption that is granted to a specific vessel based on specific circumstance. The exemption may only be granted if it is satisfied that the exemption concerned, taken together with the conditions to which it is subject, will not jeopardise the safety of a vessel or a person on board a vessel.(Judson, 2017)

4.3.3 Commonwealth state and territory regulations

Additionally to the Australian regulations, Commonwealth State regulations may be required for unmanned and autonomous vessels. Especially relating to marine pollution, waterways management and environmental protection.

4.3.4 Australian Pilotage areas

As explained in section 4.2.3 specific pilotage areas prove to be an additional legal difficulty. In Australia, there are four coastal pilotage areas subjected to environmental restrictions, shown in figure 15, which are located in the state of Queensland in the North-East:

- The Inner Route (from Cape York to Cairns)
- The Great North East Channel
- Hydrographers Passage
- Whitsundays (Whitsunday Passage, Whitsunday Group and Lindeman Group)

These pilotage areas will make a fast implementation of autonomous shipping difficult, and therefore do not seem suited for a first implementation, and should be considered only once the legal aspects are fully clarified.

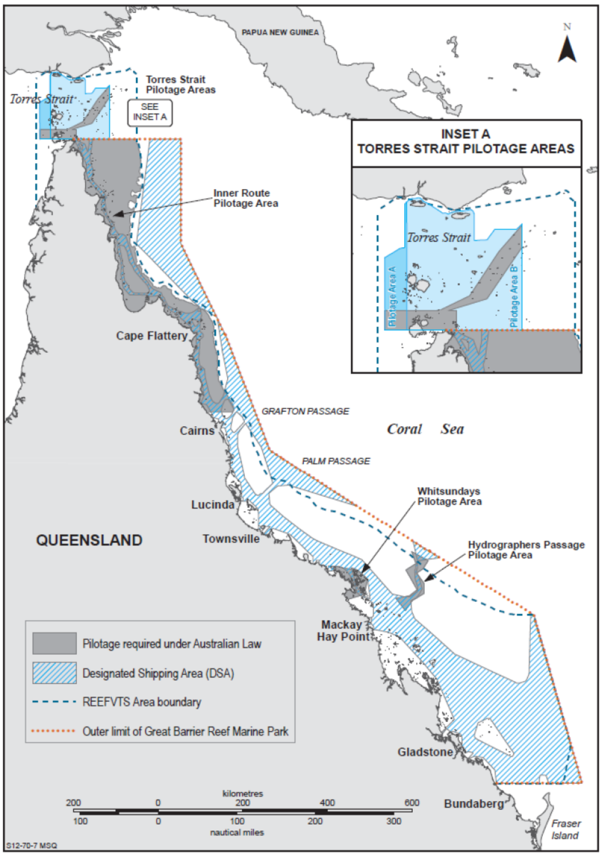
4.4 Australian Coastal Shipping regulations

4.4.1 Cabotage

This part focuses on the maritime legal situation on Australia's coast. Autonomous ships are not likely to make an important impact in these regulations, but the Australian cabotage reforms have an important influence on ship transportation and their prices, thus leading to a potential interest for autonomous ships.

In 2012 cabotage reforms were engaged in Australia. Before the 2012 reform, coastal shipping was subjected to the Navigational Act (1912), which considered two regulatory categories, the AUS-flagged and the foreign-flagged ships. The details are explained in table 2:

Figure 15: Australian Pilotage Areas



Source: AMSA (2017)

The 2012 reform, replaced the precedent system by a three-tier licensing regime divided into General, Temporary and Emergency licences (and a transitional general licence). The details are explained in table 3.

Following the 2012 reform, foreign-flagged ships had to deal with a lot of complicated procedures and comply with Australian employment conditions. Subsequently their participation in coastal trade has decreased dramatically, eliminating also their specialised services. Hence there is less competition and the freight rates augmented to a rate that is not competitive with road and rail any more. It is currently cheaper for Australian manufacturers to import commodities, then to have them shipped around the continent for local manufacture.

In march 2017, a push towards coastal shipping reforms was made by the government through the release of a discussion paper for stakeholders of the maritime sector. The discussion paper proposes retaining the basic structure of the current regulatory regime, with amendments to remove the aspects reported as unreasonably limiting, inflexible or onerous for stakeholders

Table 2: Navigation Act before the 2012 reform based on Thompson and Cockerell (2015)

Licence	**Details**
AUS-flagged ships operating under licence	- permanent - unrestricted - to carry cargo and passengers - subject to conditions such as labour law requirements
Foreign-flagged ships operating under a single voyage permit (SVP) or a continuing voyage permit (CVP)	- temporary permit - to carry nominated cargo, - subject to a lesser range of conditions than ships operating under licence.

and allow a path forward for coastal shipping reform to be agreed by all relevant parties. The objective of these proposed amendments is to ensure safe, secure and efficient coastal shipping as part of Australia's national transport system. (DIRD, 2017)

4.5 Conclusion and summary

The Australian and International legal situations do not differ much, when considering autonomous ships. In both cases, the important regulatory challenges are the crewing level, the shipmaster's duties redefinition and reassignment with the relevant safety management system, the pilotage areas as well as the position of autonomous ships in the maritime traffic hierarchy.

In the Australian case, temporary exemptions could be made in order to implement and test the technology, while in a legal transitional phase. With an early implication in the matter, Australia could not only be a pioneer in the legal field and therefore have a close future cooperation with the international regulations IMO, but also be implicated in the important technological changes in the industry. On the other hand, once the IMO has recognised and authorised unmanned shipping operations, regulatory challenges will be greatly reduced.

Autonomous ships could open a breach in current and future cabotage regulations, in relation to

Table 3: Coastal Trading Act under 2012 reform based on Thompson and Cockerell (2015) and BITRE (2017b)

Licence	Available to	Obliged to	Restrictions
General Licence (GL)	- AUS flagged ships - foreign flagged ships, intending transition to AUS flag within 5 years	- employ AUS residents - crew wages at AUS rates - comply with annual mandatory reporting requirements	- none (up to 5 years)
Transitional General Licence (TGL)	- foreign flagged ships - held a licence issued under the previous system - no longer accepted	- Same as GL	- Same as GL
Temporary Licence (TL)	- foreign-flagged ships - ships entered on the AUS International Shipping Register	- able to hire foreign crew - comply with some AUS employment conditions - other onerous requirements	- nominated coastal trade - specified number of authorised voyages - 12 month period
Emergency Licence (EL)	- response to national emergencies (cyclones, earthquakes and bushfires)	- able to hire foreign crew - comply with some AUS employment conditions	- no more than 30 days

the freight rates. Australian flagged autonomous vessels would be less penalized compared to international ships and alternative transportation modes, by labour and employment conditions making their fixed costs substantially lower. This could lead to more domestic consumption and less importation. Hence more job opportunities for local manufacturing.

Part II

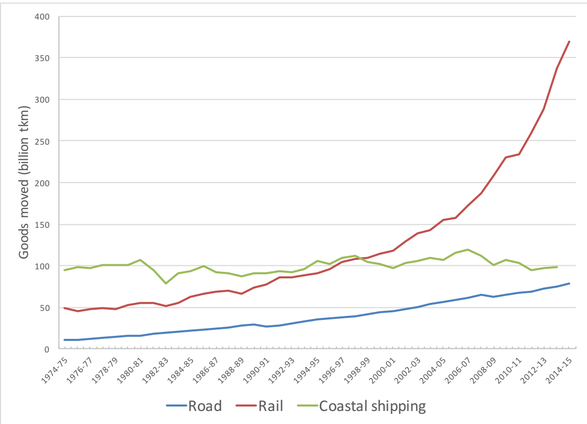
Non-Bulk Coastal Shipping in Australia

5 Freight situation in Australia

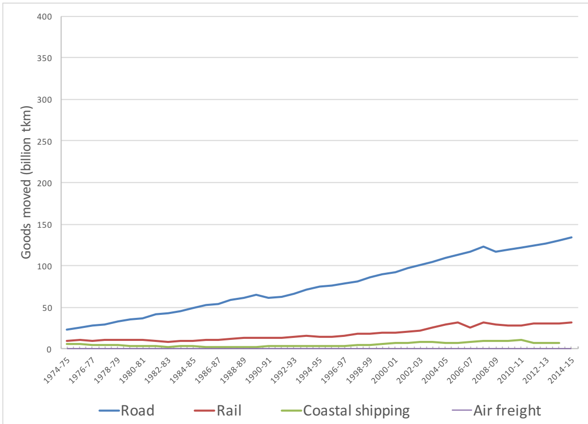
Freight is transported by four different modes in Australia: Rail, Road, Air and Shipping. Domestic freight uses all the modes and international freight is, for obvious geographical reasons restrained to air freight and shipping. The total freight volumes have quadrupled over the past forty years, especially due to a significant growth in road freight and, since the early 2000's in rail freight related to a strong increase in mining activities.

Figure 16: Evolution of the Australian domestic freight by transport mode 1974-75 - 2040

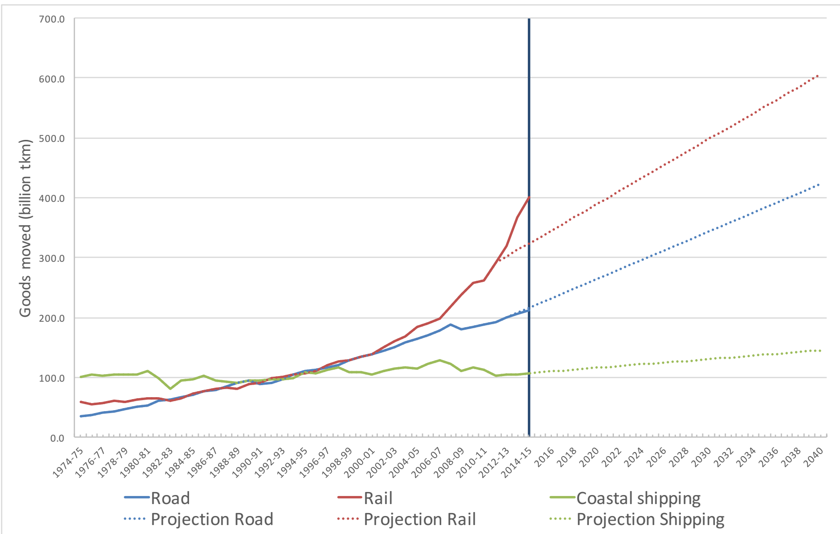
(a) Bulk Freight Task



(b) Non-Bulk Freight Task



(c) Total Freight Task and Projections until 2040



Source: BITRE (2016c) and BITRE (2014b)

Figure 16 illustrates the evolution of the amount of goods moved from 1974-75 until 2014-15 detailed for bulk (figure 16(a), non-bulk (figure 16(b) and total (figure 16(c). Bulk freight has more than tripled over the last 40 years (from 155 billion tkm in 1974-75 to 511 billion tkm in

2013-14) and non-bulk freight more then quadrupled (from 40 billion tkm in 1974-75 to 168.2 billion tkm in 2013-14).

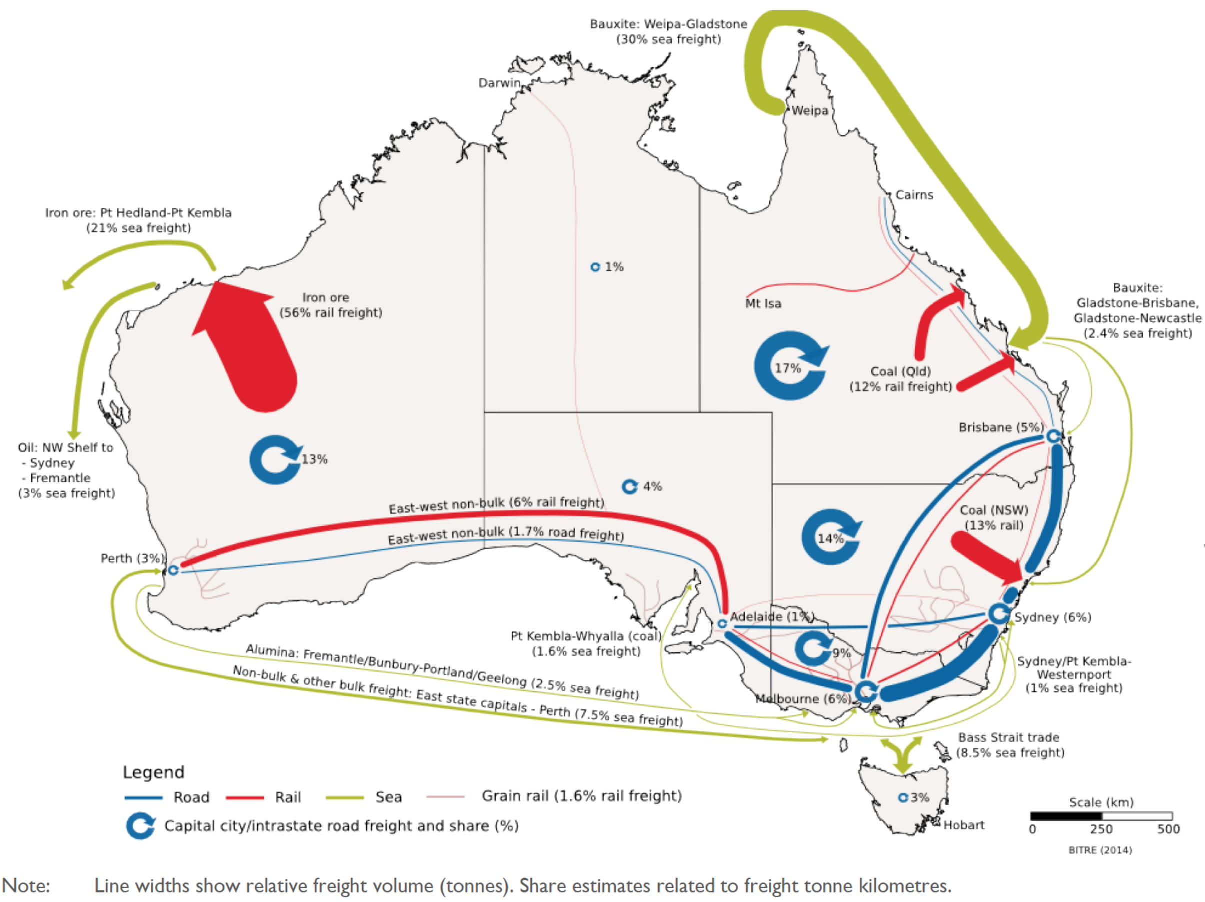
Table 4: Freight Modal Split in 2013-14

	Road	Rail	Coastal Shipping	Air Freight
Bulk	14.8%	66.1%	19.1%	-
Non-Bulk	77.5%	17.9%	4.5%	0.2%
Total	30.3%	54.1%	15.5%	0.0%

Source: BITRE (2016c) based upon Tables T2.1a, b and c for goods moved [billion tkm]

Table 4 shows the freight modal split in 2013-14. And figure 17 depicts the major freight volume flows through Australia, considering road, rail and sea modes.

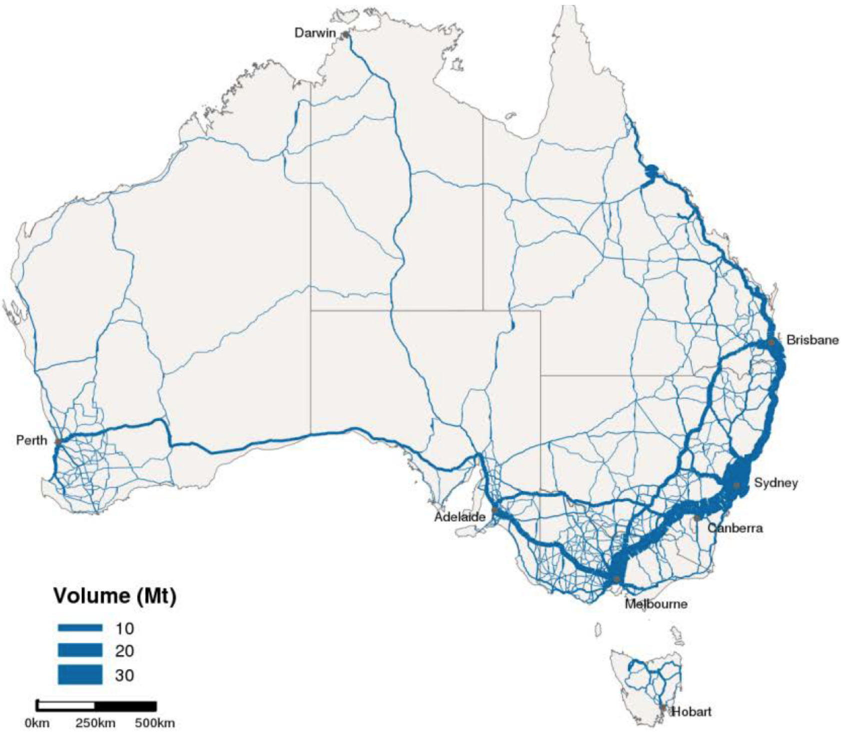
Figure 17: Major freight flows in Australia 2011-12



Source: BITRE (2014b)

5.1 Road

Figure 18: Inter-regional road freight task, 2000-01



Source: BITRE (2014b)

Currently road freight accounts for nearly 15% of the domestic bulk freight and dominates the non-bulk freight task with 78%, as shown in table 4. In the capital cities, road takes even over 20% of the total road freight in Australia (2011-12) and therefore the highway triangle Melbourne - Sydney - Brisbane is very loaded in road freight as shown in figure 18. These major flows are illustrated in blue in figure 17.

5.2 Rail

Rail dominates the bulk freight task, with a modal share of 66.1%, transporting in particular iron ore and coal (80% of total rail freight task). Non-bulk rail freight has a non negligible modal share of about 18%, its main freight routes being the Eastern states - Perth and the Melbourne-Brisbane corridors. The rail freight flows are illustrated in red in figure 17.

5.3 Coastal shipping

Coastal shipping is specialized in bulk commodities such as aluminium ores, iron ore and petroleum. For non-bulk freight coastal shipping has very little impact (4.5% modal share), but shipping and ports are an important interface with the land freight task between major domestic centres and gateways for international trade. Figure 16(a) illustrates, that coastal shipping freight has remained about the same absolute level of 100 billion tkm, for nearly 40 years, but the modal split decreased from 61.6% in 1974-75 to only 19.1% in 2013-14, due to the heavy cabotage regulations since 2012 and the strong competition with international carriers taking additional cargo to a marginal price. High differences in transit time between coastal shipping and road or rail, make the domestic competition more difficult.

The current coastal shipping freight flows are depicted in green in figure 17. Coastal shipping being particularly developed in Queensland, on the North-Eastern Coast, transporting bulk freight (bauxite) from Weipa to Brisbane. However the Great Barrier Reef located there is an environmental sensitive area subjected to pilotage as was explained in section 4.2.3, and would therefore slow an implementation of autonomous vessel down. Western Australia, has also a coastal shipping route transporting bulk freight from operating mines to Perth.

In terms of non-bulk freight, three corridors retain the attention, for a potential autonomous ships implementation:

1. The South-Coast Corridor from the Eastern States to Perth, which is already an implemented coastal shipping route.

2. The Bass Strait Corridor, between Melbourne and Tasmania, also an existing coastal shipping route.

3. The North-South Corridor (between Brisbane, Sydney, Melbourne and Adelaide), shows an important volume of freight moved and could open an opportunity to autonomous ships.

5.4 Air freight

Although not considered further in this work, air freight transports highly valuable freight and therefore shows to have a very high impact with regards to the value of the freight. Air freight is suited for low density and/or high value commodities and therefore comprises a small share of the freight volumes. It is only used for non-bulk freight and accounts for less than 0.01% of total domestic freight movements (mainly newspapers, parcels and other light goods). International air freight represents less than 0.1% of Australia's total international air freight, but produces over 21% of total trade value. Sydney is the largest import/export airport, whereas Perth is the largest Australian export airport by value because of the important amount of gold.

5.5 Freight Projections

The total domestic freight task is projected to grow 80 % by 2030, particularly through growth in bulk commodities and road freight. Demand for freight on the East Coast will increase, as population growth is expected to particularly concentrate around the cities of Melbourne, Sydney and Brisbane (ABS, 2013).

Figure 16(c) shows the total domestic freight evolution with a projection until 2040, based on (BITRE, 2014b) numbers from 2011-12. By 2030, road freight is projected to be 1.8 times its 2010 level. Rail freight is expected to be 1.9 times the 2010 level, due to growth in iron ore exports whereas domestic coastal shipping would grow only 15 per cent, over the 2010 level.

The comparison of projections and current situation for the years 2010-11 to 2014-15 seem to fit well, with road and coastal freight, whereas rail freight was underestimated.

5.6 Conclusion

The domestic freight situation in Australia is dominated by road and rail freight. In order to revive coastal shipping, autonomous shipping should focus on the North-South corridor, the East-West (to Perth) corridor and the Bass Strait corridor as illustrated in figure 19. On the North-South corridor, the demand for freight transport is high and with population growth projections of over 60% until 2040, demand for freight transport is going to increase too. The East-West corridor is an existing shipping route, with rail as a main competitor. the Bass Strait, a well-established shipping corridor, transports currently 99% (Aurecon, 2013c) of freight moved through Melbourne and Tasmania.

6 Methodology

6.1 Introduction

Following the conclusions from the precedent chapter the freight corridors were divided into North-South corridor, East-West corridor and the Bass Strait corridor, as illustrated in figure 19, to examine a possible implementation of autonomous ships in Australia. Possible shipping routes were identified considering the road distance as well as current and projected freight movements.

This chapter introduces the methodology of the analysis.

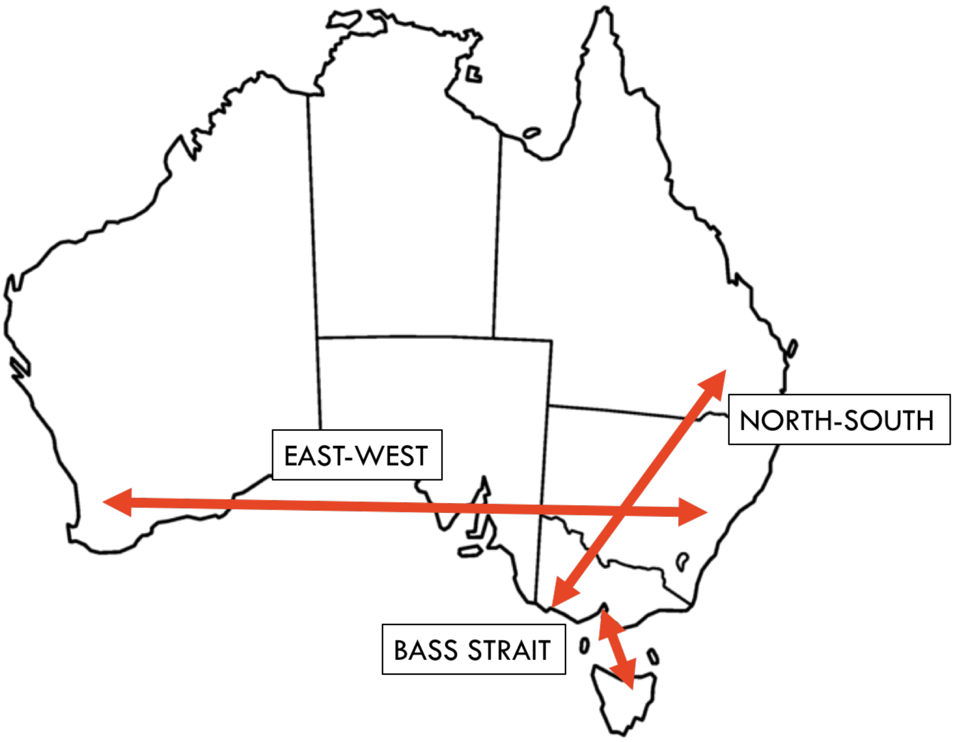
Coastal shipping being usually neither price nor time-competitive over shorter distances, because of terminal lifts at both ends requiring relatively high loading and unloading costs (port handling charges), expensive pre- and post-transports processes and considerable document handling. Road distances, which can be undertaken in one day are hence considered not flexible enough and too short.Bendall and Brooks (2011) suggests therefore a minimum corridor distance threshold of 1,000 road km.

Current freight movements having less than 500’000 TEU per direction were considered as low and not further investigated.

Based on this, the chosen routes were further investigated particularly on the potential shift of freight towards coastal shipping and the rail competition. In a next step, the current freight rates between the available modes were compared. In order to understand how much cheaper coastal shipping should be, to make up for the longer transit time and therefore autonomous ships, an analysis of freight travel times was done.

Finally it was concluded whether the route presents a potentially viable option or not.

Figure 19: Division of Freight Corridors



6.2 Determination of Potential Coastal Shipping Routes

6.2.1 Current Freight Movements

The road, rail and sea freight flows were assessed, with published and unpublished data from the Bureau of Infrastructure Transport and Regional Economics (BITRE) and the Australian Bureau of Statistics (ABS).

Road Freight Movements To assess the non-bulk road freight movements for the year 2013-2014, two datasets (covering the same period) were used:

1. The ABS published the „Road Freight Movements "(ABS, 2015) considering **State-OD-pairs**.

    - Table 5.1: *Total tonnes carried by commodity, by method* was used, in order to determine the ratio for each commodity of transportation method. E.g. 15% of *cereals* transported by road freight are „general "freight (general consisting of „containerized "and „other") and 85% bulk (general consisting of „solid bulk "and „liquid bulk ")

2. **City-OD-pairs** were additionally requested from BITRE (2017c), which were only available as *total* road freight movements by commodity. These can be found in appendix A.1 With the commodity transportation ratio from above, the non-bulk city-OD-pair of freight movements could be determined.

Rail Freight Movements The rail freight movements were taken from BITRE (2010a), which published the *Origin/destination for interstate and intrastate rail freight, 2007–08 (million net tonne kilometres)* and can be found in appendix A.2.

1. Because rail freight is expected to be loaded on the train at the main freight station, the state-OD were considered as city-OD numbers (e.g. NSW-VIC was assumed as Sydney-Melbourne).

2. The data was adapted to million net tonnes, by dividing each OD-pair by their distance.

3. The data was then adapted to 2014 in order to be consistent with Road and Sea freight, with the non-bulk growth rate, between 2007-08 to 2014-15 of 3 % (BITRE, 2016c).

4. Rail freight is not considered as being *non-bulk* but as *intermodal* [14], although in this work intermodal freight is considered as non-bulk, in order to simplify, but non-bulk rail freight could be slightly overstated.

Sea Freight Movements The sea freight data was taken from (BITRE, 2017b) providing the freight movements for most routes considered in this work, additional routes were requested from BITRE (2017c) and can be found in appendix A.2. TEUs under *temporary licence* was used as a measure for containerised freight as very little containerised freight is transported between the mainland capitals except under Temporary Licence. This means that sea freight could be slightly understated.

[14]Intermodal designated trains include mixed trains that carry both intermodal and steel products. These mixed trains complicate measuring tonnages for ARTC as they weight whole trains and not only components (BITRE, 2010a)

Since container are measured in TEUs (Twenty-foot equivalent), the number of containers were converted into tonnes using an average weight of 12.22 tonnes per TEU (BITRE, 2017b).

6.2.2 Freight Movement Projections

The official BITRE 2030 freight projections are based on the year 1999, and seem to be very optimistic when compared to 2014 numbers. The actual 2014-15 data does not vary much from the 1999 base year numbers. Therefore two 2030-projections were considered:

1. The official BITRE projections for the year 2030 from BITRE (2009), based on the year 1999.

2. The *adapted one*, based on the actual 2014-15 freight movements and the growth rate from BITRE (2009) for each route and mode according to equation 1:

$$Freight_{Projection} = Freight_{Base} * (1 + GrowthRate)^{Year_{Projection} - Year_{Base}} \quad (1)$$

   The equation was cross-validated with the 1999 and 2030 numbers. The referenced table can be found in Appendix B. The growth rates are not considered to be up-to-date, but this approximation seem to be the best.

6.3 Potential Freight Shift

The next step for each route chosen to be further investigated, was to assess how high the potential freight shift towards sea freight could be. Only freight from road was considered, for the following reasons:

- Road has the highest share and is therefore the biggest competitor
- Reducing road freight presents the highest possible external cost reduction (emissions, congestion) and therefore a greater incentive for governmental support
- Rail freight has a similar shipping system, but is often faster. Additionally government invests a lot into rail infrastructure and is therefore unlikely to support a mode competing directly with rail.

Furthermore only city-to-city flows were examined in order to reduce inter-modal local deliveries and thus the cost and travel time of the voyage. The potential freight shift was therefore calculated, based on the road freight movements obtained in section 6.2.1. Since coastal shipping freight is taking a longer total travel time, not all freight products will likely to be shifted. Certain commodities were therefore considered as perishables or not suited (e.g. food, animals, concrete) and were thus removed.

Projections of freight shifts were done in depending on the commodity type.

1. BITRE (2009) published freight growth rates for road, rail & sea modes for specific routes.

2. Certain commodities such as wood, iron and other manufactured articles had different growth rates defined in BITRE (2009).

Both tables and the validation can be found in appendix B. The potential shift, simply assess freight that could be moved from Road towards another mode, may that be rail or coastal shipping. Further there are no considerations of changes in growth due to rail network changes.

6.4 Freight Rates

6.4.1 Travel Time Value

Autonomous ships could lower the fixed costs and therefore represent an incentive for enhancing coastal shipping freight. The decisive disadvantage of coastal shipping being the total transit time, the question is by how much the freight rates should be lowered so that coastal shipping would be price-competitive in particular towards road freight. This was done by assessing and comparing the transit times differences for each routes and modes. With road freight travel time values published by ATAP (2016), a range of freight rate differences could be estimated.

Total Transit Times of different Modes Article 13.5 (c) from the Fair Work Commission (2017) states the total agreed driving hours for specific road journeys. Additionally article 20.2 specifies the hours of work and fatigue management, defining that for every 5.5 hours of drive there must be a break of 30 minutes, and for every work day of 12 hours the employee must have 10 hours off duty. Meaning that 11 hours of driving result in a total of 22 hours time for the driver. The paid break time was valued at 100% of the non-urban hourly value and the unpaid break time at 25%. From the driving hours, the assumption was made that 1 hour at both ends would be in an urban environment. For the loading/unloading time an additional 1 hour at both ends of the voyage was added.

The average transit times for rail were taken from table TA.2 from BITRE (2016b), and considered as being *Non-Urban* travel times. an additional 15 hours were supposed to be reasonable allowing for loading/unloading and local deliveries at an *Urban* rate.

For sea an average speed of 14 knots (1 knot = 1.852 km/hr) was taken. The average ship turnaround time in 2016 was 29 hours (BITRE, 2017d), therefore considering 15 hours at both ends seems reasonable. Again the vessels travel time was valued at a non-urban value and the turnaround time/local delivery at an urban rate.

Value of Road Freight Travel Time In order to have an understanding of the impact of the additional travel time between the modes, the value of travel time was assessed.

The road freight values of travel time are based on resource costs expressed in 2013 values from (ATAP, 2016), which can be found in appendix D. The average of the *Rigid and Articulated Trucks* was considered, as road freight is mainly moved by trucks. Since a percentage difference is assessed, the 2013 values are not adapted to the current values. The averaged values are stated in table 5.

Table 5: Average of Road Freight Travel Time Values based on ATAP (2016)

	[Unit]	Average 2013
Non-Urban		
Occupancy Rate	[PAX/vh]	1.08
Value per Occupant	[AUD$/vh/hr]	26.29
Freight Travel Time	[AUD$/vh/hr]	11.13
Urban		
Occupancy Rate	[PAX/vh]	1.10
Value per Occupant	[AUD$/vh/hr]	26.29
Freight Travel Time	[AUD$/vh/hr]	21.92

Two different methods were considered for the analysis of the price differences:

1. **Total value of transit time** The values of road, rail and sea travel time where calculated

with the road freight travel time values, using equation 2, considering the loading/unloading time as urban and non-urban otherwise. The values were then compared.

A variation was added, in order to consider the differences of resource costs between road and rail. The occupancy rate for rail containers was calculated based on an hourly crew rate of 150 AUD (Northern Territory, 2016) and a train capacity of 76 containers (based on dimensions from ARTC (2011)) giving a value of 1.96 AUD per hour, crew and container. This value was, in the variation, also used for the coastal shipping.

2. **Hourly rate**: The total freight travel time value was calculated only for road and then divided by the travel times of each mode to get an hourly rate per mode.

$$TTTV = TT_{nu} * (OR_{nu} * VO_{nu} + FTT_{nu}) + TT_u * (OR_u * VO_u + FTT_u) \quad (2)$$

where:

$TTTV$	Total Travel Time Value [2013 AUD$]
TT	Travel Time [hr]
OR	Occupancy Rate [PAX/vh]
VO	Value per Occupant [2013 AUD$/PAX/hr]
FTT	Freight Travel Time [2013 AUD$/vh/hr]
nu	Non-Urban
u	Urban

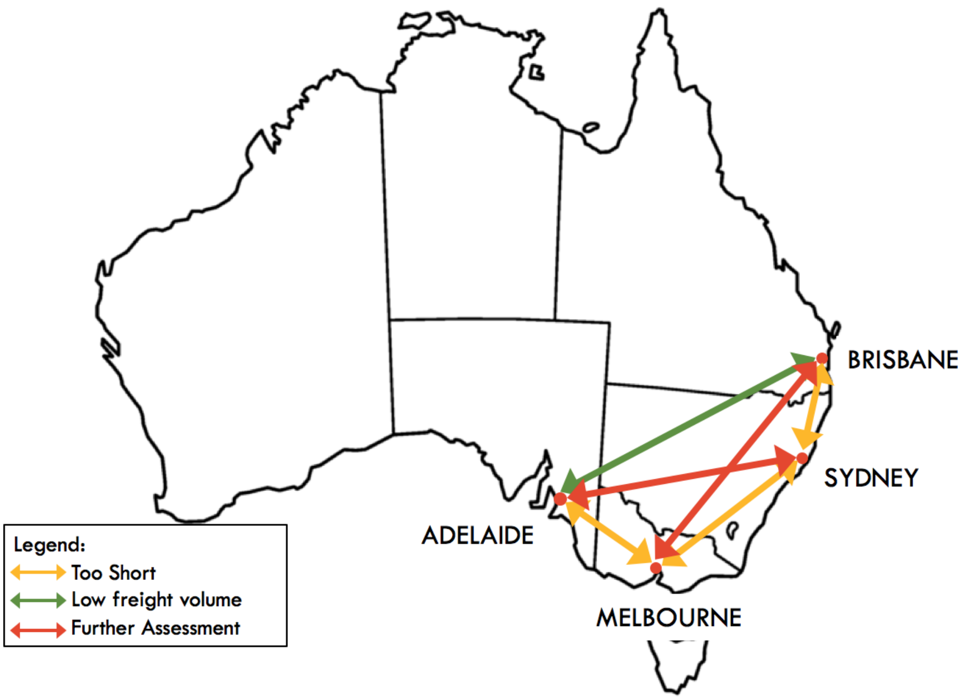
Limitations The results of these calculations are quite limited, since they are related mainly to road freight value. Further, this gives a price range for coastal shipping based on the total transit time, but does not consider the necessary range for other main mode deciding factors as reliability and availability of road, rail and coastal shippin5.

7 North-South Corridor

7.1 Determination of Potential Coastal Shipping Routes

The freight routes considered as being in the „North-South Corridor "are linking the major cities Sydney, Melbourne, Brisbane and Adelaide, as illustrated in figure 20. The northern cities of Australia, Cairns and Darwin, were not investigated, because enhanced pilotage restrictions are believed to make an implementation more difficult there. The relevant links and their distances by mode are shown in table 6.

Figure 20: Routes investigated in the North-South Corridor



7.1.1 Road Distance

As explained in section 6.1, the routes with a road distance under 1000 km were identified as being too short and are highlighted in yellow in figure 20. These are Sydney-Melbourne, Sydney-Brisbane and Melbourne-Adelaide.

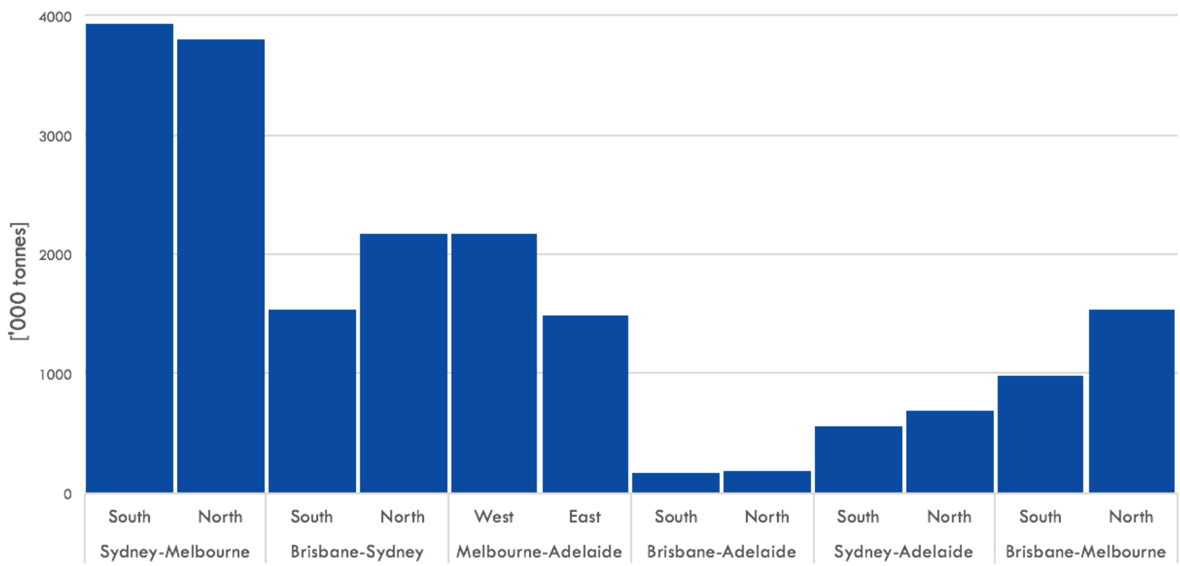
Table 6: Distances of North-South Routes based on BITRE (2016c)

Distance	**Road [km]**	**Rail [km]**	**Sea [km]**
Melbourne-Adelaide	726	832	988
Sydney-Melbourne	875	929	1114
Sydney-Brisbane	922	965	977
Sydney-Adelaide	1405	1868	1833
Brisbane-Melbourne	1677	1901	2042
Brisbane-Adelaide	2051	2816	2761

7.1.2 Current Freight Movement

In figure 21 the total non-bulk freight movements are represented per direction. The „long-haul "routes have, especially compared to the *Sydney-Melbourne* route, less freight movements. The *Brisbane-Adelaide* route, shows to have very low amount of current freight and suggests not being further investigated. Sydney-Adelaide has a balanced freight movement, whereas more traffic is moved from Melbourne to Brisbane.

Figure 21: Non-bulk Freight Movements per direction on the North-South Corridor, *South* meaning freight movements towards the south (e.g. *from Sydney to Melbourne*, respectively North meaning *from Melbourne to Sydney*)



7.1.3 Freight Movement Projections

Figure 22 compares the 1999 base year numbers, the current freight movements, the BITRE projection for 2030 and the adapted projections for 2030. One can clearly see that the BITRE projections overestimates the freight movements since it is often expected to more than double in the next 15 years. On certain routes the current numbers are lower than the 1999 base year data. The freight projections confirm, that the Brisbane-Adelaide route should not be further investigated.

Figure 22: Non-bulk Freight Movements and 2030 Projections on the North-South Corridor

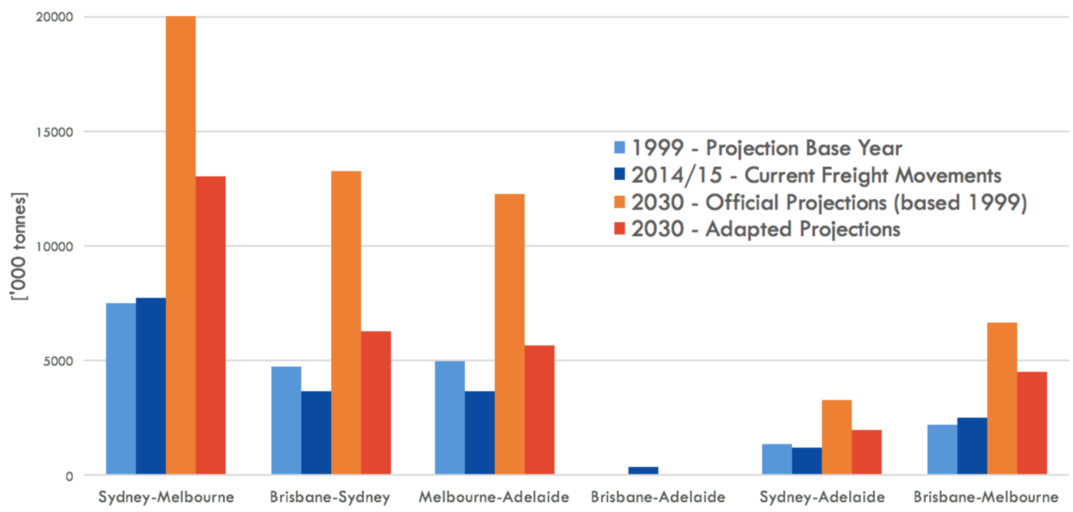


Table 7 summarizes the north-south corridor routes investigated. Three of them are deemed to short to be competitive against road. Brisbane-Adelaide has too low freight movements. Sydney-Adelaide and Brisbane-Melbourne are the routes, which are further investigated.

Table 7: Summary of the potential North-South Autonomous Coastal Shipping Corridors

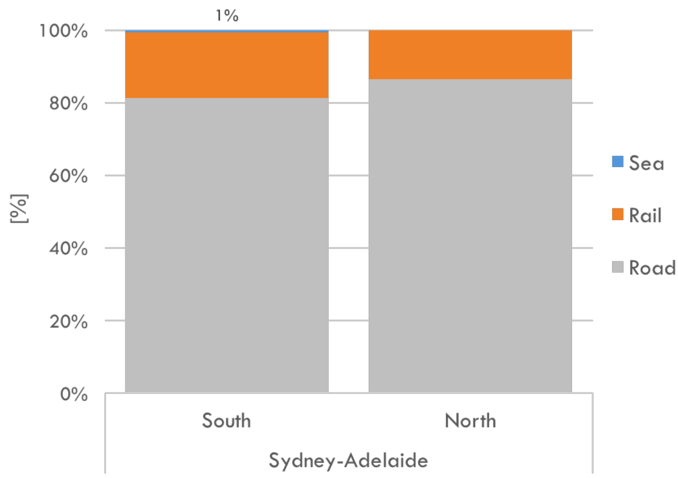
North-South Corridors	**Conclusion**
Sydney-Melbourne Brisbane-Sydney Melbourne-Adelaide	Too short to be road competitive in terms of delivery time and price
Brisbane-Adelaide	Low current volume of freight and 2030-projections
Sydney-Adelaide Brisbane-Melbourne	Further Assessment

7.2 Potential Freight Shift

7.2.1 Sydney-Adelaide Route

Figure 23 shows the current freight modal split in each direction of the Sydney-Adelaide route. Road has the biggest share between 81% - 86% followed by Rail 14%-18%. Coastal Shipping appears to have a minimal share of 1% in the southern direction. This suggests that some freight is moved by international cargo vessels for a marginal cost.

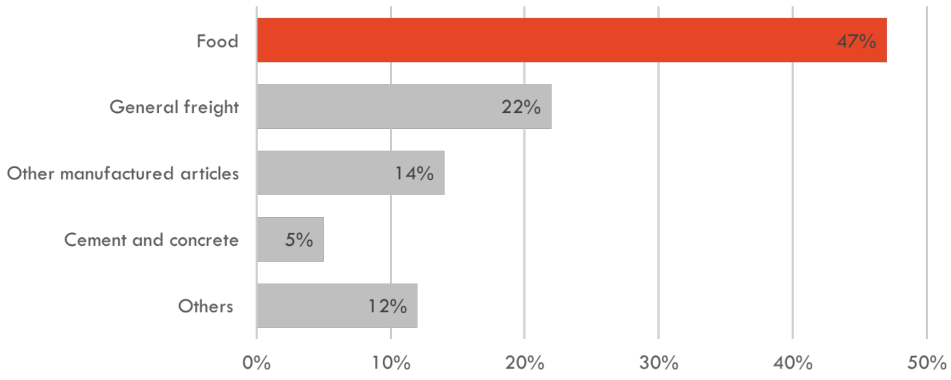
Figure 23: Non-Bulk Freight Traffic Modal Split for Sydney-Adelaide 2014-2015



Commodities Moved: The non-bulk freight commodities transported between Sydney and Adelaide are shown in figure 24. Food is with 47% the main commodity transported on the route followed by General Freight, Other manufactured articles, Cement & concrete and others summed up. Food is not considered suitable for coastal shipping, as no closer details are available with regards to the perishability as explained earlier in section 6.3. It is therefore identified in red in figure 24, whereas the other categories are treated as suitable for a freight shift.

The potential for coastal shipping freight, represents currently around 500'000 tonnes and in 2030: 834'000 tonnes, or 42% of the total non-bulk freight in 2030. However, this potential is a rough approximation of how much *could* be shifted towards rail or coastal shipping from road. It is not clear how time- and other factors sensitive, the different commodities are. Additionally, if coastal shipping was implemented with the governments' motivation to reduce road freight, the assumption would be that, the total 42% would rather distribute between the rail and the sea mode.

Figure 24: Sydney-Adelaide 2014 Non-bulk Road Freight Commodities based on (ABS, 2015)



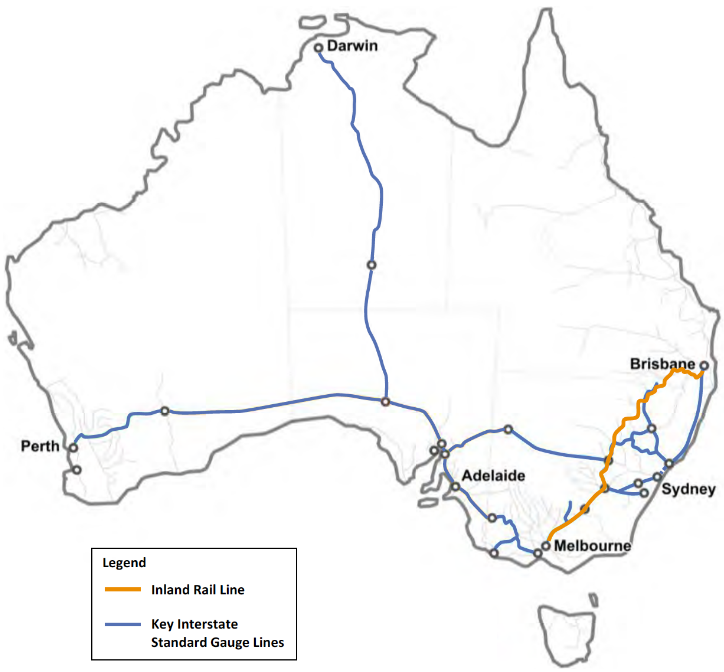
7.2.2 Brisbane-Melbourne Route

Figure 25 shows the current freight modal split in each direction of the Brisbane-Melbourne route. The road and rail share are balanced. Coastal Shipping appears to have a minimal share of 4% in the southern direction. This suggests as is already the case for Sydney-Adelaide that freight is moved by international cargo vessels for a marginal cost.

Figure 25: Non-bulk Freight Traffic Modal Split for Melbourne-Brisbane 2014-2015

Competing rail corridor: In 2017, the Australian Government announced its commitment to the full delivery of the Inland Rail project with an additional $8.4 billion equity investment in the Australian Rail Track Corporation (ARTC) (The Hon Darren Chester MP, 2017b). The Government has previously committed nearly $900 million towards planning and land acquisition (The Hon Darren Chester MP, 2017a). The Inland Rail, with first trains expected by 2024, will provide a high-capacity dedicated freight link between Melbourne and Brisbane. The project is a mix of upgrading and new railway and foresees at least 50 operational years to a total construction cost of approx. $11 billion. Figure 26 shows the Inland Rail connection, within the Australian rail network.

Figure 26: Australia's Standard Gauge Network - Inland Rail connection



Source: PwC and ARTC (2015)

The expected key benefits towards the existing coastal line are the reduction of rail congestion (in Sydney), the reduction of emissions, the reduction of transit time: InlandRail expecting to have a transit time of less than 24 hours, a better reliability, higher availability and a cheaper price (57-65% of the road price) than the current rail connection.

Governmental support for the implementation of autonomous ships is not very likely unless, there is enough freight, capable of supporting the InlandRail and coastal shipping, with a reasonable cheap price so that road freight is kept to a minimum.

Demand Forecast for InlandRail: PwC and ARTC (2015) states that in 2013-14 4.7 million tonnes of non-bulk freight were transported between Melbourne and Brisbane, whereas in the current numbers for 2014-15 only 2.5 million tonnes were transported on the route. This is due to the fact that, the inland rail figures were estimated in 2015 but using old and incomplete data (the previous ABS freight movement survey being in 2001) (BITRE, 2017c).

The assumption for the Inland Rail projections were (PwC and ARTC, 2015):

1. Non-bulk freight growth rate per year on the Brisbane-Melbourne route of 2.9%.

2. All freight from the coastal route is expected to shift towards the InlandRail.

3. Freight will be generated on the Perth/Adelaide - Brisbane routes and from North-Queensland. However, this is not relevant for a coastal shipping implementation.

The projected freight demand from PwC and ARTC (2015), was adapted to the current numbers, using the freight growth rate of 2.9 %, and considering the share of InlandRail (IR) to be the same for both projections. Table 8 shows the adapted non-bulk freight projections.

Table 8: InlandRail Demand Projections based on PwC and ARTC (2015)

year	**Non-Bulk Freight [Mio. tonnes]**	**Transported by IR [Mio. tonnes]**	**Share of IR [%]**	**Rest [Mio. tonnes]**
2014	2.5			
2024-25	3.4	1.7	50%	1.7
2029-30	3.9	2.1	54%	1.8
2049-50	6.9	4.1	60%	2.7

According to table 8 the non-bulk freight InlandRail share in 2024-25 will remaining at a share of about 50% and is expected to increase to 60% until 2049-50. There is a remaining non-bulk freight share of 50% in 2024-25 to 60% in 2049-50, not moved by the InlandRail. The rail competition, although will become stronger and as suggested by Bendall and Brooks (2011), coastal shipping is not likely to be able to compete.

7.3 Freight Rates

7.3.1 Comparison of Freight Rate Data

SKM (2013) published rail, road and sea (if available) freight rate data from 1996 to 2012. The rates are in AUD cents per net tonne kilometre ($ / ntk), which expresses the rate paid to move one tonne of freight one kilometre. There are no adjustments made for inflation or changes in values of currency. The evolution of the freight rates can be found in appendix C.1.BITRE (2017a) published nominal average freight rate from 2016, which are also shown, as an indication.

Table 9: Summary of Freight Rates on the North-South Corridor

North-South Corridor	**Road Freight Rate [c/ntk]**	**Rail Freight Rate [c/ntk]**	**Difference Road to Rail [%]**
Sydney-Adelaide	10.5	6.7	- 36%
Adelaide-Sydney	10.5	5.3	- 50%
Brisbane-Melbourne	7.0	3.8	- 46%
Melbourne-Brisbane	12.5	7.9	- 37%
BITRE (2016)	9.1	(4.3)	- 52%

Source: (SKM, 2013) and (BITRE, 2017a)

Table 9 summarizes the 2012 published freight rates for the two routes of highest interest and the BITRE average freight rate from 2016. The BITRE road freight rates are an average for non-bulk freight on interstate freight routes whereas rail rates are for non-bulk freight on the Eastern States to Perth route, thus not representative in this case.

Sydney-Adelaide has a balanced road freight rate and a slightly higher rail freight rate for the route Sydney-Adelaide. The Melbourne-Brisbane road and rail freight rate are higher than Brisbane-Melbourne, due to the higher demand in this direction.

The difference between road and rail rates vary with the direction and appear to be between 36% and 50%. The BITRE average freight rate 2016 shows a difference of 52% between road and rail. Sea freight rates were not available.

Since rail rates are significantly lower than road freight rates, but road freight still takes the majors share of freight traffic, it is suggested, that (1) the freight movements are not directly from city OD- pairs and therefore local deliveries have an important impact on the rates, (2) the flexibility and availability of trucks is better than the one of trains, tied to a certain schedule (3) the reliability is higher for road than for rail.

7.3.2 Travel Time Value Assessment

As introduced earlier, the transit times of the different modes were evaluated with road freight travel time values in order to understand the impact of higher transit time on the price.

Table 10 estimates the total road transit time according to section 6.4.1.

Table 10: Sydney-Adelaide Travel Time Breakdown based on section 6.4.1

Road Travel Time Breakdown	**[hrs]**
Scheduled Non-Urban Driving Time	14.7
Scheduled Urban Driving Time	2.0
Break Time (100% valued)	1.5
Break Time (25% valued)	10.0
Loading/Unloading/Transit	2.0
Total estimated travel time	30.2

Table 11 compares the total transit times for the different modes between Sydney and Adelaide. And summarizes the different methods used to determine how much cheaper rail and sea should be in order to make up for the additional transit time.

Road freight would therefore only need roughly 30 hours, rail freight (at least) 42 and sea more than three times more. The *Freight Rate Compared to Road*, represents how much cheaper the rail or sea rate should be, in order to be price competitive. For example: for the *Total Value of Transit Time* rail should be 51% cheaper to reach the same *Transit Time Value* than road. When compared to the freight rate data, the *adjusted method* seems to be out of range, whereas the range given by the *total value of transit time* and the *hourly rate* fit quite well, with a range for the rail freight rate between 32% and 51% cheaper than road. The sea freight rate should therefore be between 70% and 78% cheaper than road to make up for the longer transit time.

Table 11: Sydney-Adelaide Travel Time Value Analysis

	Road	Rail	Sea
Est. Total Transit Time [hr]	30.2	44.7	99.7
Total Value of Transit Time			
Transit Time Value [2013 AUD]	944.2	1937.3	4286.4
Freight Rate Compared to Road [%]		-51%	-78%
Total Value of Transit Time Adjusted for Rail and Sea			
Transit Time Value [2013 AUD]	944.2	1209.1	2574.8
Freight Rate Compared to Road [%]		-22%	-63%
Hourly Rate			
Transit Time Value [2013 AUD]	944.2		
Hourly Rate [2013 AUD]	31.3	21.2	9.5
Freight Rate Compared to Road [%]		-32%	-70%

7.4 Conclusion

On the North-South corridor, two routes were identified as potential routes for domestic coastal shipping, Sydney-Adelaide and Melbourne-Brisbane, which were further investigated. Sydney-Adelaide appears to have a freight potential for coastal shipping. Melbourne-Brisbane also has important freight movements, but with the construction of the InlandRail and the governmental support of the project, an implementation of autonomous ships as a potential for coastal shipping, is unlikely. Further the freight rates differences resulting from the travel time value analysis, seem difficult to reach.

8 East-Western Corridor

8.1 Determination of Potential Coastal Shipping Routes

The freight routes considered in the „East-West Corridor “are linking Perth to the eastern cities Sydney, Melbourne, Brisbane and Adelaide, as illustrated in figure 27. The relevant links and their distances by mode are shown in table 13.

Figure 27: Routes investigated in the East-West Corridor

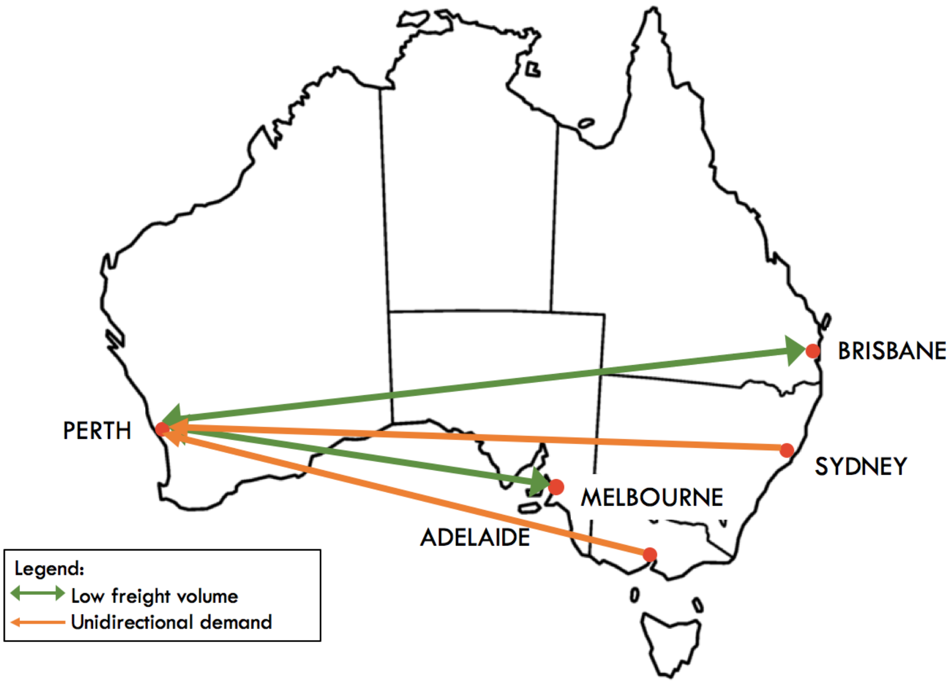


Table 12: Distances of East-West Routes based on BITRE (2016c)

Distance	Road [km]	Rail [km]	Sea [km]
Brisbane-Perth	4682	5101	4920
Sydney-Perth	4036	4137	3991
Melbourne-Perth	3416	3468	3111
Adelaide-Perth	2690	2637	2509

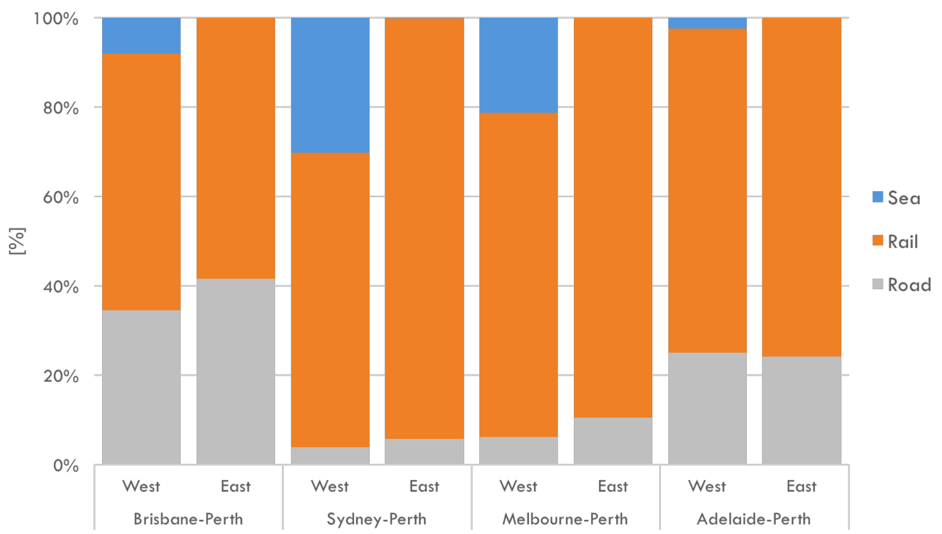
8.1.1 Road Distance

On the East-Western corridor, the length of the route is not an issue, since all are longer than the threshold of 1,000 km.

8.1.2 Rail Competitor

The main competitor is rail, as can be seen in the current freight modal split in figure 28. The Brisbane-Perth route has an important road share, because it is more direct (does not pass through Adelaide, but Port Augusta). In the western direction coastal shipping is an important competitor for Sydney- and Melbourne- Perth with 30% respectively 21% of share. In the Eastern direction Rail has the highest share with 76% - 94% (Brisbane-Perth excepted). On the Adelaide-Perth route, road takes about one fourth of share, maybe because of the shorter distance, compared to the three other corridors. Rail has a balanced share and it is unlikely that freight would move towards coastal shipping. It is striking that, coastal shipping is no an important mode on the Adelaide to Perth route. This is due to a lower volume of containers exchanged at the Port of Adelaide compared with Melbourne, Sydney, Brisbane and Perth, hence the stop is not interesting economically. Additionally, Adelaide being the last port on the way to Perth, international cargo will already have stopped at either Brisbane, Sydney or Melbourne and would probably have loaded enough additional cargo.

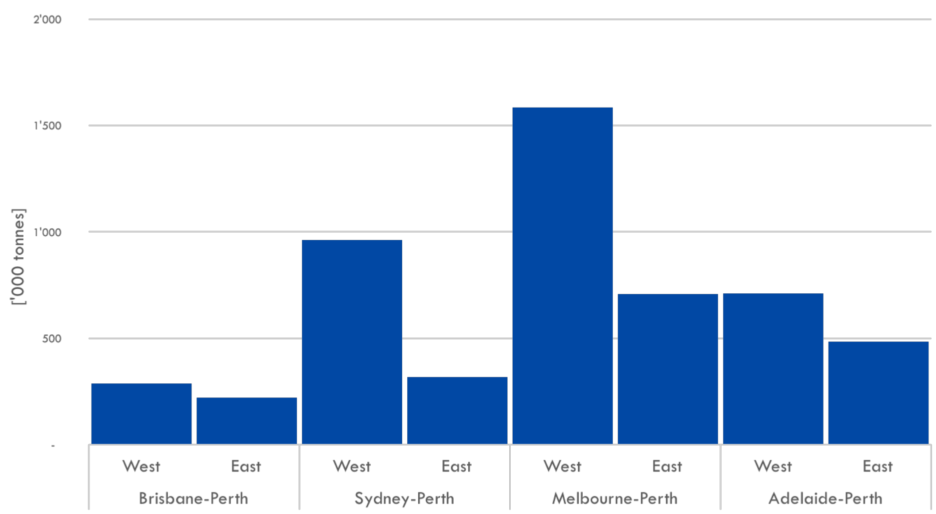
Figure 28: Freight Modal Split on the East-West Corridor



8.1.3 Current Freight Movement

Figure 29 represents the total non-bulk freight movements per direction. Brisbane-Perth and Adelaide-Perth have more or less balanced freight movements. Brisbane-Perth has the lowest amount of freight, with less than 500'000 tonnes in each direction and therefore can be excluded from further assessment. Adelaide-Perth has a medium to low volume of freight and together with the high rail share, it seems not possible for coastal shipping to compete particularly with rail. Sydney-Perth and Melbourne-Perth show an important number of freight moved, but there is an imbalance between the West and the East, with more freight being moved towards Perth. In total about 3'500'000 tonnes are moved from East to Western Australia and only half of it from West to East.

Figure 29: Non-bulk Freight Movements per direction on the East-West Corridor, *West* meaning freight movements towards the west (e.g. *from Sydney to Perth*, respectively East meaning *from Perth to Sydney*)



8.1.4 Freight Movement Projections

Figure 30 compares the 1999 base year numbers (in light blue), the current freight movements (in dark blue), the official BITRE projection for 2030 (in orange) and the adapted projections for 2030 (in red).

For Brisbane-Perth no projections were published, leading to the conclusion, that it is not a relevant direct freight route, which confirms the decision taken earlier of not further investigating the route. For Sydney-Perth, the official projections for 2030 are below the current situation, and therefore the adapted projections seem to better represent the situation. While for Melbourne-Perth and Adelaide-Perth the BITRE-2030 and the adapted 2030 projections, are closer and therefore considered being representative.

Figure 30: Non-bulk Freight Movements and 2030 Projections on the East-West Corridor

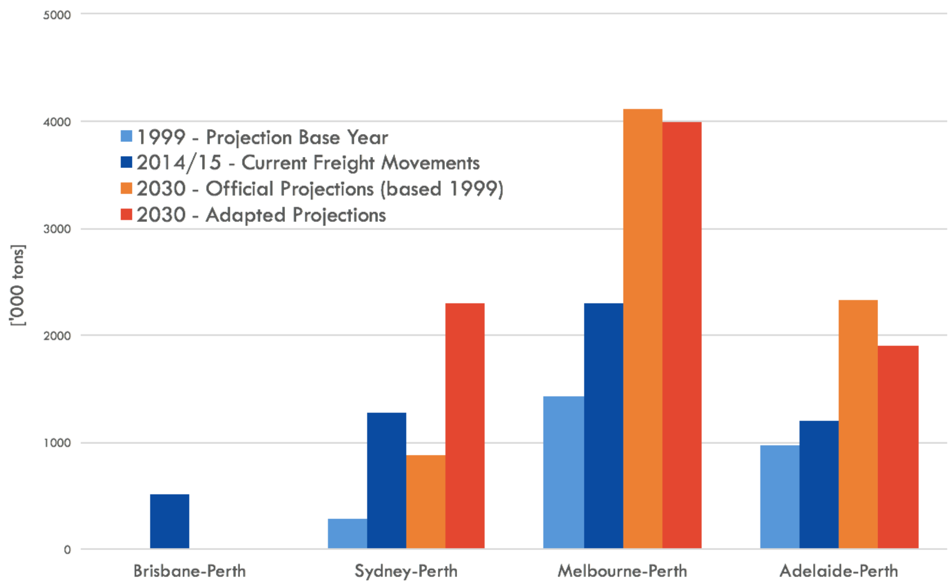


Table 13 gives a summary of the east-west corridor routes investigated. Brisbane-Perth has not enough freight movements. Sydney-Perth and Melbourne-Perth have a unidirectional flow making a dedicated coastal shipping route difficult.

Table 13: Summary of the potential East-West Autonomous Coastal Shipping Corridors

East-West Corridors	**Conclusion**
Brisbane-Perth	Low current volume of freight
Sydney-Perth	Unidirectional Flow (25% of total goes to the East)
Melbourne-Perth	Unidirectional Flow (30% of total goes to the East)
Adelaide-Perth	Middle to low current volume of freight and high rail competition

8.2 Freight Rates

Coastal shipping to Western Australia is mainly serviced by foreign or Australian flagged vessels that provide international services for import and exports to and from Australia. They ship around Australia from East to West and carry domestic cargo between Australian ports as a way of supplementing their income. Sea freight rates on those routes are therefore only marginal costs of the coastal service and cannot be representative of a dedicated coastal shipping service.

8.2.1 Comparison of Freight Rate Data

SKM (2013) published rail, road and sea (if available) freight rate data from 1996 to 2012. The rates here are expressed in AUD cents per net tonne kilometre ($ / ntk), which expresses the rate paid to move one tonne of freight one kilometre. There are no adjustments made for inflation or changes in values of currency. The evolution of the freight rates can be found in appendix C.2. Table 14 summarizes the 2012 freight rates from 36 and the difference between Eastern and Western rates. BITRE (2017a) published nominal average freight rate from 2016, which are also shown, as an indication. Road freight rates are an average for non-bulk freight on interstate freight routes whereas rail and sea rates are for non-bulk freight on the Eastern States to Perth route.

Table 14: Summary of Freight Rates based on (SKM, 2013) and (BITRE, 2017a)

East-West Corridor	**Road Freight Rate [c/ntk]**	**Rail Freight Rate [c/ntk]**	**Sea Freight Rate [c/ntk]**	**Δ Road to Sea [%]**	**Δ Rail to Sea [%]**
Brisbane-Perth	10.0	5.0	3.0	-70%	-40%
Perth-Brisbane	6.0	3.0	n.a.		
Sydney-Perth	11.0	6.5	4.2	-62%	-35%
Perth-Sydney	4.0	2.0	n.a.		
Melbourne-Perth	10.0	6.5	5.2	-48%	-20%
Perth-Melbourne	4.0	n.a.	n.a.		
Adelaide-Perth	10.5	6.0	n.a.		
Perth-Adelaide	4.0	2.5	n.a.		
BITRE (2016)	9.1	4.3	3.1	-52%	-27%

Rail and Road freight rates towards Perth are between 60% and 70% more expensive than towards the East, when not considering the Brisbane-Perth route. Sea freight rates are available only for the routes Melbourne-Perth, Brisbane-Perth and Sydney-Perth and depends on the distance: an increase of about 900 km distance results in a decrease of 1 c/ntk in price.

For the route Sydney-Perth, coastal shipping is about 60% cheaper than road and 35% cheaper than rail. For Melbourne-Perth, sea is 48% cheaper than road and only 20% cheaper than rail.

If there was to be a dedicated coastal shipping freight line, the one-way trip to Perth rates would have to cover at least 160-170% of the total round trip cost, while being still, in the Melbourne-Perth case, 20% cheaper than rail. This seems difficult to achieve, even for autonomous ships and thus the corridor was not further examined.

8.3 Conclusion

An implementation of autonomous vessels as a way of reviving domestic coastal shipping in the East-West corridor appears to be difficult. Particularly due to the unidirectional flow, making dedicated coastal shipping services difficult to cover costs and further due to the important competition of international carriers, which ship cargo to a marginal price towards Perth. Additionally, the freight rates comparison illustrates also how difficult an implementation would be in the North-South corridor. Since it resulted that sea freight rates should be between 70% and 78% cheaper than road on the Sydney-Adelaide route and the international carrier marginal prices are in the best case (Brisbane-Perth) 70% cheaper.

9 Bass Strait: Tasmania - Melbourne Route

9.1 Current Situation

The freight route from Melbourne to Tasmania is the only domestic freight route in Australia, that can only be serviced by ship (99% of freight goes over sea (Aurecon, 2013c)). In 2014-15 12.7 million tonnes or 461.656 TEU were moved through tasmania's major publicly owned ports, of which 65% was bulk and 35% was container freight (Dept. of State Growth, 2015c). The Bass Strait line services domestic (89% of containers moved in 2013) and international (11% or 48'000 TEU of containers moved in 2013) markets, being a feeder service through the port of Melbourne (Aurecon, 2013c). Currently three shipping service provider are travelling between Melbourne and Burnie / Devonport. These are indicated in figure 31 and summarized further in table 15. *Toll-ANL* travels from Melbourne to Burnie and *SeaRoad Shipping* and *TT-Line* travel between Melbourne and Devonport. *TT-Line* is primarily a ferry service and prefers not to carry containers, additionnaly its main cargo customers are *Toll-ANL* and *SeaRoad* shifting their overlap of freight (Aurecon, 2013c). *Toll-ANL* accounts for 54%, *SeaRoad* for 25% and *TT-Line* for 21% of freight movements. The transport is done through overnight services, taking about 11 hrs. Because of freight task's high diversity, roll-on/roll-off vessels (stated as RoRo in the followings) are used. These vessels permit to simply drive on the ship and therefore enable fast loading and discharges, reducing the handling of containers and the immediate delivery to vessel.

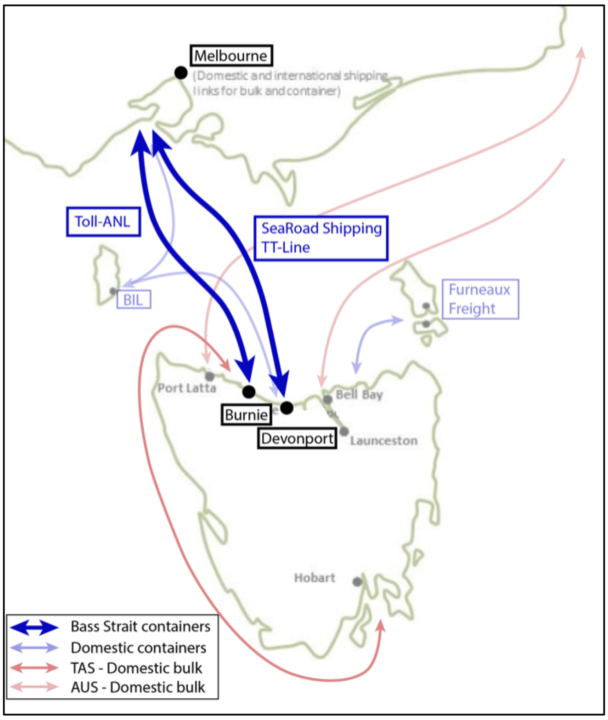
Table 15: Bass Strait - Current Situation based on (Aurecon, 2013c)

	Toll ANL	**SeaRoad Shipping**	**TT-Line**
Tas. Port	Burnie	Devonport	Devonport
Frequency	6 nights per week	6 nights per week	7 nights per week
Market Share [%]	54%	25%	21%
Market Share [15] [TEU/year]	240'000	105'000	95'000
Annual Capacity [TEU/year]	275'000	before 2017: 135'000 from 2017: 220'000	120'000

The total and one-way annual capacity is from 2017 on approximately 615'000 TEU / year respectively around 310'000 TEU/year.

[15] 2013 numbers

Figure 31: Current Domestic Freight Movements Bass Strait



Source: (Dept. of State Growth, 2015c) modified

SeaRoad Shipping replaced its vessel SeaRoad Mersey I in early 2017 and expects to replace the vessel SeaRoad Tamar I in 4 to 5 years at a capital expenditure cost of $ 100 Mio. Toll ANL will be replacing both of its vessels in 2018/19. The new vessels will have a lifetime of 30+ years. The Spirit of Tasmania I and II from TT-Line are currently about 20 years old and no replacement is planed in the next years.

Freight Costs The freight costs on the Bass Strait are considered as being about 23% higher than European costs according to Aurecon (2013c). These are due to the following reasons:

1. Mode of transportation
    - Short-haul shipping
    - Inter-modal costs resulting from the combination of land and sea transport, leading to additional transit time and an increased likelihood of damage to goods.
2. Freight

- High variety of freight: significant operational issues and inefficiencies with receival, handling and storage at terminals and stowage on board.
- Subject to seasonality: significantly more demand for freight movements to Tasmania from July to January.
- Imbalance in trade: more import than export, leading to a large number of empty containers that need to be repositioned. (Aurecon, 2013b)

3. RoRo-vessels

   - Require higher crew number (since two times loading and unloading every 24hour period): 14 crew per voyage + trainees, represents 19% of total vessel cost
   - Compared to international lines it is a high service frequency line, with small delivery windows.
   - Very efficient terminal throughput.

4. Government policies and regulations:

   - government ownership, degree of compliance with competitive neutrality by government owned transport service businesses (TT-Line).
   - Australian labour costs (Aurecon, 2013c) The impact on the cost of freight is that the wages and costs for Australian crews are 3 to 6 times higher than rates of international flagged vessels.
   - Australian fuel prices (Aurecon, 2013c) Bunker fuel prices on the coast of Australia are substantially higher than prices in the main bunkering ports in the Asian region such as Singapore.

Table 16 gives estimated ship cost breakdowns, published by Aurecon (2013c) and received from SeaRoad Shipping. The percentages from Aurecon (2013c) are voyage cost breakdown, and linking the cost directly to the voyage. Whereas the percentages from SeaRoad Shipping are in % of the revenue and therefore apply for both ships. The ship MV SeaRoad Mersey II, is LNG-powered explaining the smaller bunker cost when comparing to Aurecon (2013c).

Rolls-Royce introduced a concept of a *lean* RORO-vessel representing a very close step to autonomous and unmanned ships. Crew costs are expected to be saved by more than 50% and LNG power saving anticipated to halve fuel costs.

From table 16, it can be concluded that, autonomous ships (LNG-powered) in the Bass Strait could reduce total cost by about 20-30%, when considering only crewing and bunker costs.

Table 16: Estimated Ship Cost Breakdown for Bass Strait based on (Aurecon, 2013c) and (SeaRoad Shipping, 2017)

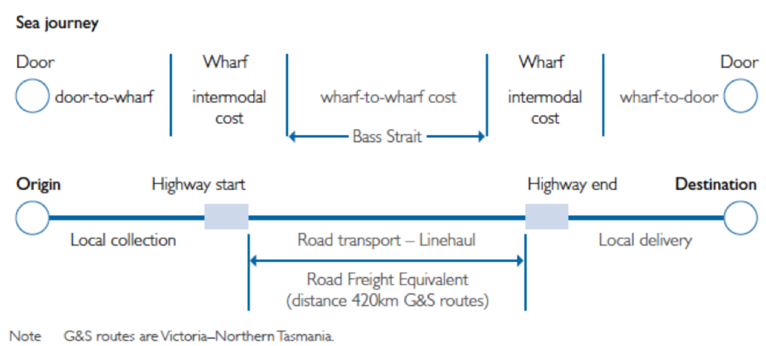
Estimated Ship Cost Breakdown	**Aurecon (2013c)**	**SeaRoad Shipping**	**Autonomous Ship**
Operating Costs (OPEX)	30.0%	37.8%	⇓
Crewing	*15.0%*	*19.0%*	⇓
Repairs, Maintenance (incl. Dry Docks)	*15.0%*	*5.3%*	
Capital Cost (CAPEX)	35.0%	18.7%	↓
Interests, Debt repayment			
Total Fixed Cost	**65.0%**	**56.5%**	⇓
Bunker Costs	30.0%	25.0%	⇓
Cargo-handling / port costs	5.0%	18.5%	↔
Total Variable Cost	**35.0%**	**43.5%**	⇓
Total	100.0%	100.0%	

CAPEX are expected to be lower because of the ships will be using less steel, but the installation of the LNG storage system would mean additional spend.

9.2 Tasmanian Freight Equalization Scheme (TFES)

The high cost of freight is seen as an obstacle for the Tasmanian industry. Therefore the transport is subsidized by the government through the Tasmanian Freight Equalization Scheme (TFES), introduced in July 1976. It is based on the concept of sea freight cost disadvantage, establishing the financial gap between the actual cost of the trans-Bass Strait freight task and a comparable land freight equivalent.

Figure 32: TFES



Source: (BITRE, 2013)

Figure 32 is a schema of the sea freight cost disadvantage concept, which subtracts the road freight equivalent from the notional wharf-to-wharf sea freight rate of the Bass Strait. Additionally transfer costs are considered for inter-modal movements.

The TFES parameters are reviewed regularly. With road freight rates becoming more expensive, the sea freight cost disadvantage is reduced.

In 2011-12, 90'64 Mio. $ were paid for 128'000 TEUs, giving an average of 710 $ per TEU (BITRE, 2013). In 2016-17, the total TFES assistance amounted to $146.5 Mio. (DIRD, 2017). showing that there is a willingness-to-reduce the subsidies from the government and therefore to invest into autonomous ships.

9.3 Future situation

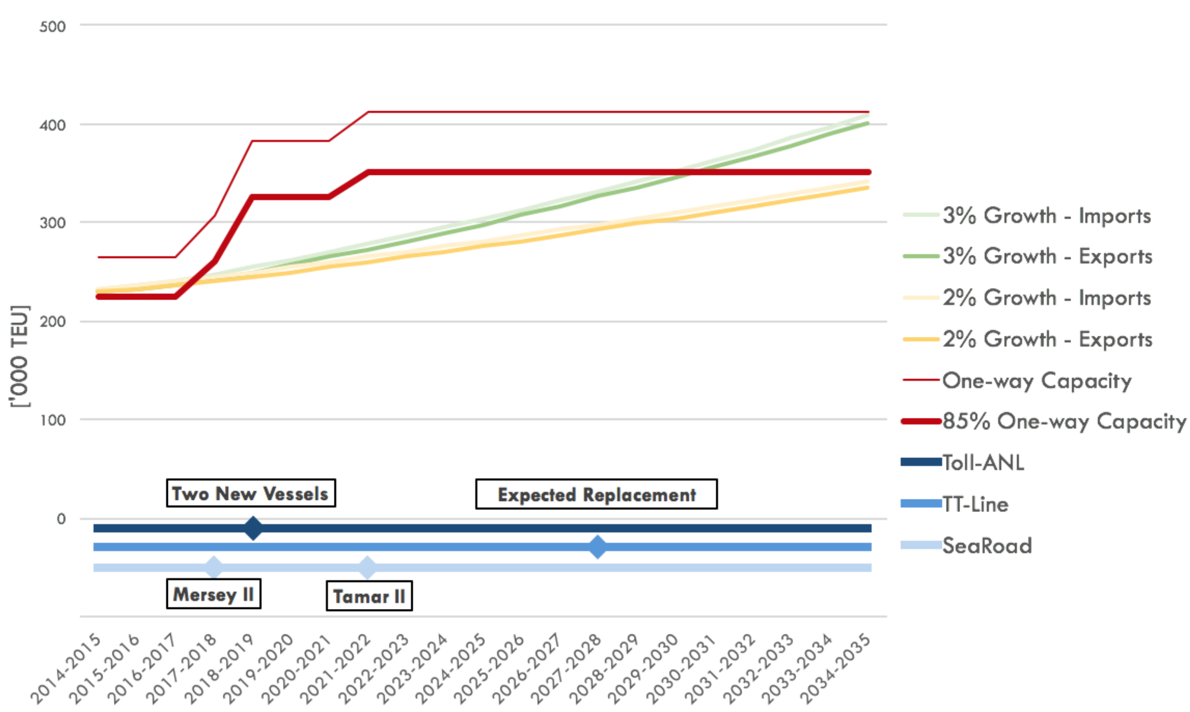
The growth rates of freight vary 1.5 % to 3 %. It is generally accepted that container volumes grow at a higher rate than GSP, which has been forecasted to be 2 % (Parliament of Tasmania, 2017) by 2018/19. Container growth over recent years has been low, with largely negative growth. Between 2013-14 and 2014-15 container growth reached 2.3%, but has fallen to 1.4% between 2015-16 and 2016-17 (TasPorts, 2017). The industry-led FLCT adopted a growth rate of 3 percent (FLCT, 2013). Dept. of State Growth (2015a) considered various future scenarios with a high growth rate of 3% and a low growth rate of 2%, which are also used here.

The 2-3 % container growth is a limitation and the future projections are to handled with care, since growth varied a lot in recent years, therefore a clear trend is difficult to predict.

The current projections estimate, that with a container growth of 3% the 85% capacity would be reached in 2028-29, respectively in 2033-34 with a growth of 2%. The analysis adopts the industry standard of 85% utilisation in determining effective operating capacity. This refers to the level at which a logistics chain can recover from unplanned outages or unexpected peaks (Aurecon, 2013c). This is without taking into account a possible replacement of the TT-Line ferries with additional cargo space, which could postpone this capacity bottleneck. Figure 33 illustrates the demand and capacity projections of freight movements until 2034-35 and the respective ship replacements by the shipping service providers.

TasPorts' 30 year plan (TasPorts, 2015) foresees to concentrate consumer goods primarily in Burnie and Devonport, whereas Hobart would remain the home of cruise and Antarctic logistics operations, but could still support commodities such as forestry and general cargo.

Figure 33: Timeline for Bass Strait, Future Supply and Demand based on Dept. of State Growth (2015a)



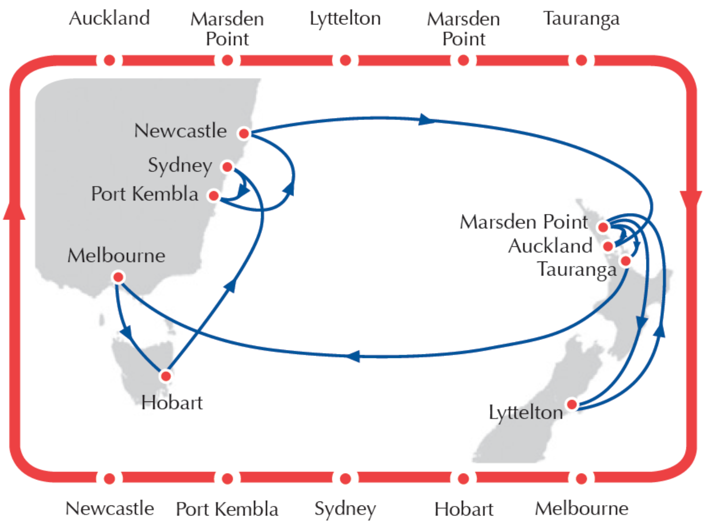
This suggests that autonomous ships could be implemented in the time frame between 2028-29 and 2033-34. There would be a capacity need and a willingness to pay. Additionally the technology is then considered to be in place if the research project expectations are met, see 4.

International Freight Movements In 2013 Swire Shipping announced the launch of a direct monthly link between Tasmania, Asia, New Zealand and the Pacific. The link is scheduled for 2018 as published in the schedule (Swire Shipping, 2017b). In november 2015, a new connection was added from Tasmania to the Australian Mainland, connecting Melbourne-Hobart-Sydney-Brisbane (Swire Shipping, 2015). As of early 2016, the service was only one third full (Chambers, 2016) and therefore has been updated to a *Trans Tasman Service* linking New Zealand and Australia every 14 days as shown in figure 34.

Even these are not exactly *Bass Strait* freight movements, the international line is a *domestic* concurrence, since it

1. links Melbourne with Tasmania unidirectionally, therefore taking advantage of the higher import flow, and not having to deal with the empty container problem.

Figure 34: Trans Tasman Service



Source: (Swire Shipping, 2017b)

2. links Tasmania with Australia's East Coast, New Zealand and Asia, relieving the Bass Strait from the transshipment freight movements to Melbourne.

3. freight rates are estimated to be lower than those of the Bass Strait, for the reasons explained earlier in section 9.1.

9.4 Conclusion

Autonomous ships in the Bass Strait would be a natural development of the shipping technology. There is a willingness to invest from government in order to lower the freight costs and thus the subsidies. A few options are possible starting with the replacement of the SeaRoad and Toll vessels from 2047 on. This bears the potential to see how the technology and the legal issues evolve. Investments would coincide with the upgrading of infrastructure. Or an investment when the 85% capacity is reached (between 2028-29 and 2034-35) with an additional autonomous ship. Both these options give a lot of time for the technology and the freight situation to evolve. The international competition could also move in, when the 85% capacity is reached, with an autonomous vessel or not.

10 Conclusion

This report explored the possibility of a revival of Australian coastal shipping by autonomous vessels. The current research projects are expecting, despite the challenges, remotely operated unmanned coastal vessels from 2025 on. The IMO (International Maritime Organization) included autonomous ships on their agenda and started to establish a new international legal framework. The AMSA (Australian Maritime Safety Agency) also investigates the adaptation of the legal framework, but opens through the granting of exemptions a gap for an early implementation of autonomous vessels.

The investigation of potential coastal shipping routes in Australia proved to be somewhat deceiving. The North-South corridor, although having a freight potential, has freight rates targets, which seem difficult to reach, even with unmanned autonomous vessels. Additionally, the operation of the InlandRail project will shake up the freight movement landscape and strengthen the position of the rail mode, with the government's support. The East-West corridor, having some very long-distance routes, proved to be also difficult in particular because of the unidirectional freight movements towards Perth.

The Bass Strait corridor, although not really „reviving "coastal shipping, seems to be the most reasonable implementation possibility for autonomous vessels. Unmanned and autonomous ships being a technology evolution of the system in place. Additionally, through possible reductions of TFES subsidizes, the government would have an interest in taking the matter upwards. The implementation of autonomous vessels could take place, when the 85% capacity is expected to be reached in 2028. Reason for that is the replacements of the Bass Strait fleet in the next few years with each a lifetime of about 30 years, but international concurrence is not to be underestimated.

The report identified some freight potential for autonomous shift, but did not consider other decisive key factors for mode choice, especially reliability and availability of the autonomous vessels. Further the current freight network was analysed, not considering the fact, that autonomous vessels would most probably decrease the optimal economical size of a vessel and therefore result in smaller ships. These would then be more flexible and could introduce new routes leading to new ports, which would be closer to the origin and destination of the freight. When comparing the road travel time value, no particular consideration of the technology improvements in trucks were considered. Electrical and autonomous trucks are also expected for the near future, and would first reduce road freight rates by a considerable amount, leading to the supposition that the freight rates gap between sea and road would not evolve very much.

Second electric road freight, will reduce its environmental impact, making the societal incentive of reducing road freight because of emission lowering debatable. In line with a reduction of road freight rates, the disadvantage of the Bass Strait freight would remain, therefore requestioning the potential of subsidies reduction.

It seems that the impact of autonomous ships, will revolutionizing the maritime industry more through the way to get there than the actual implementation of autonomous ships. The introduction of *intelligent* ships, meaning interconnected and communicative ships, into a connected logistic chain seems far more essential and decisive, than the technological evolution of the transportation mode.

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A Freight Movements

A.1 Road Freight Movements 2014 from BITRE (2017c)

		Destination				
Origin	Commodity	Sydney	Melbourne	Brisbane	Perth	Adelaide
Sydney	Empty	0	0	0	0	0
Sydney	Cereal grains	1735	26	0	0	0
Sydney	Food (animal or human consumption)	19986	1058	512	0	245
Sydney	Live animals	316	5	0	0	0
Sydney	Beverages and tobacco	7956	85	35	0	0
Sydney	Crude materials	4462	15	48	0	0
Sydney	Metalliferous ores and metal scrap	1109	37	0	0	0
Sydney	Sand, stone and gravel	42758	0	0	0	0
Sydney	Cork and wood	1097	0	0	0	42
Sydney	Coal	71	0	0	0	0
Sydney	Gases, natural and manufactured	3811	0	0	0	0
Sydney	Tools of trade	9512	0	0	0	0
Sydney	Petroleum and petroleum products	4588	5	64	0	0
Sydney	Animal and vegetable oils, fats and waxes	79	0	0	0	0
Sydney	Chemicals	619	28	0	0	0
Sydney	Fertilisers, manufactured	17	0	29	0	0
Sydney	Cement and concrete	19359	0	0	0	88
Sydney	Iron and steel	4011	161	52	0	35
Sydney	Other manufactured articles	9808	258	485	0	60
Sydney	Machinery and transport equipment	6139	2	49	13	16
Sydney	Miscellaneous manufactured articles	2683	383	46	0	0
Sydney	General freight	23515	1845	936	34	143
Sydney	Other commodity (not elsewhere specified) (	32364	271	165	0	7
Sydney	Total	195995	4179	2422	46	635
Melbourne	Empty	0	0	0	0	0
Melbourne	Cereal grains	0	2112	0	0	0
Melbourne	Food (animal or human consumption)	1408	40257	326	0	435
Melbourne	Live animals	5	59	0	0	103
Melbourne	Beverages and tobacco	26	1713	0	0	0
Melbourne	Crude materials	0	3752	0	0	17
Melbourne	Metalliferous ores and metal scrap	0	326	0	0	0
Melbourne	Sand, stone and gravel	0	64623	0	0	0
Melbourne	Cork and wood	0	4616	21	0	0
Melbourne	Coal	0	0	0	0	0
Melbourne	Gases, natural and manufactured	35	1194	0	0	12
Melbourne	Tools of trade	0	6293	0	0	0
Melbourne	Petroleum and petroleum products	95	5398	0	0	96
Melbourne	Animal and vegetable oils, fats and waxes	14	488	0	0	11
Melbourne	Chemicals	26	7778	26	0	0
Melbourne	Fertilisers, manufactured	0	0	0	0	16
Melbourne	Cement and concrete	0	16838	0	0	0
Melbourne	Iron and steel	84	5200	0	0	105
Melbourne	Other manufactured articles	164	18561	88	0	280
Melbourne	Machinery and transport equipment	18	11332	0	27	72
Melbourne	Miscellaneous manufactured articles	325	4218	0	0	27
Melbourne	General freight	2055	45736	444	100	494

A.2 Rail Freight Movements 2007-08, Table 6 BITRE (2010a)

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TA.6 Origin/destination for interstate and intrastate rail freight, 2007–08 (million net tonne kilometres)

State/territory of origin	State/territory of destination								
	NSW	VIC	QLD	SA	WA	TAS	NT	ACT	Total
Intermodal									
NSW	205	568	248	186	2 556	–	–	–	3 763
VIC	234	128	1 443	691	3 885	–	–	–	6 381
QLD	224	860	4 071	145	820	–	–	–	6 120
SA	169	449	278	80	1 325	–	1 388	–	3 689
WA	1 202	2 140	637	938	1	–	–	–	4 918
TAS	–	–	–	–	–	337	–	–	337
NT	–	–	–	558	–	–	107	–	665
ACT	–	–	–	–	–	–	–	–	–
Subtotal	2 034	4 145	6 677	2 598	8 587	337	1 495		25 873
Bulk									
NSW	16 262	588	767	563	1 076	–	–	–	19 256
VIC	162	458	164	217	297	–	–	–	1 298
QLD	10	0	40 839	–	2	–	–	–	40 851
SA	1 752	486	241	1 819	136	–	0	–	4 434
WA	4	10	1	2	105 047	–	–	–	105 064
TAS	–	–	–	–	–	119	–	–	119
NT	–	–	–	–	–	–	673	–	673
ACT	–	–	–	–	–	–	–	–	–
Subtotal	18 190	1 542	42 012	2 601	106 558	119	673	–	171 695
Total Freight									
NSW	16 466	1 156	1 015	749	3 632	–	–	–	23 018
VIC	396	586	1 607	908	4 182	–	–	–	7 679
QLD	234	861	44 910	145	822	–	–	–	46 972
SA	1 922	935	519	1 899	1 461	–	1388	–	8 123
WA	1 206	2 150	637	940	105 048	–	–	–	109 981
TAS	–	–	–	–	–	456	–	–	456
NT	–	–	–	558	–	–	780	–	1 338
ACT	–	–	–	–	–	–	–	–	–
Total	20 224	5 687	48 688	5 199	115 145	456	2 168	–	197 567

Notes:

1. Row labels indicate origin states and territories and column labels indicate the destination states and territories for freight. The entries of '0' in the table mean that volumes are small and less than one million net tonne kilometres; entries of '-' denote nil volume.
2. Excludes freight carried by various smaller intrastate train operators.
3. The only regular freight between the ACT and other jurisdictions in 2007–08 was the transport of a small volume of oil to the territory; the train operator classed this train as operating to Queanbeyan, NSW (on the ACT border). This traffic therefore appears as part of the intra-NSW traffic.
4. This table should not be compared with the 2006–07 data presented in Table A6 (page 47) in BITRE 2008. The data in the current year are net of container weight whereas the 2006–07 data include the container weight in measuring payload. (See Box 2 for a further discussion of measuring net tonnage.) Also, some historical data have been revised by operators in order to obtain better estimates of freight origins and destinations. (Box 3 discusses the issues of estimating freight origins and destinations.)

Source: Asciano, FreightLink, QR, SCT Logistics, Fortescue and BHP Billiton and estimates of Rio Tinto's railways from publicly-available data.

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A.3 Sea Freight Movements 2014-15, Table 3.4 (BITRE, 2017b)

Table 3.4 Containerised freight carried on permits permits/ Temporary Licences: The top ten routes

Coastal Trade Permits (2002–03 to 2011–12)

Financial year	Melbourne to Fremantle	Sydney to Fremantle	Brisbane to Fremantle	Adelaide to Fremantle	Melbourne to Brisbane	Melbourne to Adelaide	Brisbane to Darwin	Darwin to Gove	Gove to Darwin	Bell Bay to Fremantle	All routes under permit [a]
Containerised freight						(TEUs)					
2007–08	14 257	6 667	894	350	9 860	1 254	1 034			3 303	44 354
2008–09	18 879	6 479	1 097	548	7 472	1 156	1 298			1 900	44 320
2009–10	26 618	15 479	3 310	1 405	9 511	625	1 373	2 038	1 682	2 701	68 920
2010–11	37 716	22 487	3 489	1 554	3 517	1 374	865	2 544	2 437		79 310
2011–12	37 116	24 924	7 445	4 261	3 501	459	435				79 741
Voyages on permits						(number)					
2007–08	104	45	34	40	165	60	14			13	770
2008–09	99	33	19	57	143	56	19	.	.	10	730
2009–10	113	99	53	68	178	50	17	15	14	14	887
2010–11	172	234	43	55	32	30	16	20	20	.	806
2011–12	230	227	113	95	27	29	10	.	.	.	826

Coastal Trading Licensing System (2012–13 to 2014–15)

Financial year	Melbourne to Fremantle	Sydney to Fremantle	Melbourne to Brisbane	Brisbane to Sydney	Brisbane to Fremantle	Melbourne to Adelaide	Adelaide to Fremantle	Gladstone to Esperance	Darwin to Gove	Gove to Darwin	All routes under Temporary Licence [a]
Containerised freight [b]						(TEUs)					
2012–13 [c]	21 187	11 791	2 926	.	3 450	1 016	1 386	194	2 607	2 051	48 270
2013–14	30 117	19 987	3 423	3 038	3 447	1 402	1 452	1 087	.	175	64 954
2014–15	27 523	23 814	5 569	3 692	1 864	1 598	1 378	773	.	.	67 929
Voyages under Temporary Licence where containers were carried						(number)					
2012–13 [c]	139	120	17	.	78	34	43	2	24	20	534
2013–14	189	147	28	42	60	49	51	10	.	1	630
2014–15	186	135	28	49	51	45	53	8	.	.	630

a "All routes" include the top ten routes under permit and Temporary Licence where containers were carried and other routes under permit or Temporary Licence not listed separately (where containers were carried).

b TEUs were estimated for container shipments where volume was recorded in tonnes but the data indicated the pack type was 'container'. TEU estimates were based on the average weight (in tonnes) per TEU recorded in 2011–12, under the Coastal Trade Licences and Permits (COTLAP) system.

c The CLTS and permits system both operated in 2012–13, meaning the 2012–13 CLTS figures may underestimate 2012–13 trade.

Note: The top ten routes for TEUs are the routes that carried the largest number of TEUs summed over five years for permits (2007–08 to 2011–12) and three years for Temporary Licences (2012–13 to 2014–15). The routes are sorted in descending order by TEU count for the most recent year with the route ranked the first on the left in the table.

The statistics of some ports include data for other associated ports, terminals or facilities. The full list of ports and grouped ports/terminals/facilities is in "Appendix A: Australian ports".

Source: DIT (2013) and DIRD (2016).

B From BITRE (2009)

B.1 Tables 2.17 from BITRE (2009)

Table 2.17 Actual and projected interregional road and rail freight movements by commodity, 1999 and 2030, ABS (2006)-based population projections

Commodity		*Road*			*Rail*			*Road & Rail*		
Code	*Description*	*1999 (Mt)*	*2030 (Mt)*	*Growth 1999–2030 (% pa)*	*1999 (Mt)*	*2030 (Mt)*	*Growth 1999–2030 (% pa)*	*1999 (Mt)*	*2030 (Mt)*	*Growth 1999–2030 (% pa)*
1	Manufactured products	49.5	158.0	4.6	12.9	21.3	1.9	62.4	179.3	4.1
2	Grains and oilseeds	7.2	11.8	1.9	14.4	18.5	1.0	21.6	30.2	1.3
3	Sheep live	1.0	1.2	1.0	0.0	0.0	NA	1.0	1.2	1.0
4	Cattle live	2.1	2.5	0.8	0.2	0.3	0.5	2.3	2.8	0.8
5	Meat	3.6	4.3	0.7	0.3	0.4	0.5	3.9	4.7	0.7
6	Agricultural products	31.9	44.8	1.3	4.5	7.3	1.9	36.4	52.1	1.4
7	Coal and coke	6.7	8.8	1.0	125.2	291.8	3.3	131.9	300.5	3.2
8	Metallic minerals	3.1	6.8	3.0	14.1	31.3	3.1	17.3	38.1	3.1
9	Non-metallic minerals	76.9	159.0	2.8	5.2	10.4	2.7	82.1	169.4	2.8
10	Oil and petroleum products	12.8	20.3	1.8	2.4	3.2	1.1	15.2	23.5	1.7
11	Gas	0.0	0.0	1.2	0.0	0.0	NA	0.0	0.0	0.6
12	Steel and metals	12.9	22.5	2.2	4.7	8.5	2.3	17.6	31.0	2.2
13	Fertilisers	2.4	3.9	1.9	1.0	1.1	0.3	3.4	4.9	1.5
14	Cement	3.5	6.9	2.6	2.6	3.6	1.2	6.2	10.5	2.1
15	Timber and timber products	17.2	31.8	2.4	2.1	2.8	1.1	19.3	34.5	2.3
16	Other bulk	1.0	1.7	2.0	2.0	3.5	2.3	3.0	5.2	2.2
	Total	231.9	484.3	2.9	191.6	403.9	2.9	423.5	888.2	2.9

na Not applicable.
Sources: ABS (2006) and BTRE (2006*a*).

B.2 Tables 2.20 from BITRE (2009)

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Table 2.20 Actual and projected origin–destination non-bulk freight movements by transport mode, NLTN interstate corridors, 1999 and 2030

Corridor	*Road*	*Rail*	*Sea*	*Air*	*All modes*
		1999 *(thousand tonnes)*			
Sydney–Melbourne	6 270.6	1 218.1	8.8	96.0	7 593.5
Sydney–Brisbane	3 845.5	848.0	19.9	53.0	4 766.3
Sydney–Adelaide	1 104.5	229.0	6.9	17.0	1 357.5
Sydney–Canberra	1 205.7	8.0	0.0	7.0	1 220.7
Melbourne–Brisbane	1 803.9	421.8	16.3	19.0	2 261.0
Melbourne–Adelaide	2 899.8	2 048.1	8.8	17.0	4 973.7
Brisbane–Darwin	26.4	0.0	32.7	4.0	63.1
Adelaide–Perth	339.2	617.5	14.2	6.0	976.9
Adelaide–Darwin	324.9	0.0	0.0	4.0	328.9
Perth–Darwin	70.2	0.0	19.9	0.0	90.0
Melbourne–Perth	204.2	1 117.9	100.5	21.0	1 443.7
Sydney–Perth	27.5	226.0	33.6	23.0	310.1
		2030 *(thousand tonnes)*			
Sydney–Melbourne	19 025.5	1 224.4	5.4	292.1	20 547.4
Sydney–Brisbane	12 351.3	917.3	12.0	167.4	13 447.9
Sydney–Adelaide	3 082.7	221.9	4.3	48.5	3 357.4
Sydney–Canberra	3 416.5	0.8	0.0	11.2	3 428.5
Melbourne–Brisbane	5 259.0	1 392.8	44.5	55.2	6 751.6
Melbourne–Adelaide	9 906.3	2 320.3	6.5	58.2	12 291.2
Brisbane–Darwin	79.8	0.0	125.1	11.5	216.5
Adelaide–Perth	611.3	1 687.3	34.7	10.0	2 343.4
Adelaide–Darwin	817.9	0.0	0.0	10.1	828.0
Perth–Darwin	224.4	0.0	87.2	0.0	311.5
Melbourne–Perth	415.9	3 445.3	257.3	42.5	4 161.0
Sydney–Perth	62.7	732.9	90.7	51.3	937.6
		Average annual growth *(per cent per annum)*			
Sydney–Melbourne	3.6	0.0	−1.6	3.7	3.3
Sydney–Brisbane	3.8	0.3	−1.6	3.8	3.4
Sydney–Adelaide	3.4	−0.1	−1.5	3.4	3.0
Sydney–Canberra	3.4	−7.1	na	1.5	3.4
Melbourne–Brisbane	3.5	3.9	3.3	3.5	3.6
Melbourne–Adelaide	4.0	0.4	−1.0	4.0	3.0
Brisbane–Darwin	3.6	na	4.4	3.5	4.1
Adelaide–Perth	1.9	3.3	2.9	1.7	2.9
Adelaide–Darwin	3.0	na	na	3.0	3.0
Perth–Darwin	3.8	na	4.9	na	4.1
Melbourne–Perth	2.3	3.7	3.1	2.3	3.5
Sydney–Perth	2.7	3.9	3.3	2.6	3.6

.. not applicable.
na not available.
a. The FreightSim Adelaide–Darwin rail freight projection is based on projecting from 1999 rail freight traffic levels, which was prior to the completion of the Adelaide–Darwin rail line. BITRE has assumed Adelaide–Darwin rail OD freight traffic will grow on average by 3.0 per cent per annum, between 2004 and 2030.
Sources: BTRE (2007*a*) and BITRE estimates.

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B.3 Validation of Projection Method

2030-1999: 31 years

	Validation of projection - method: 2030 from 1999 base year			
	Road	Rail	Sea	Total (2030)
Sydney-Melbourne	19'024.28	1'218.10	5.34	20'247.71
Brisbane-Sydney	12'219.99	930.52	12.07	13'162.58
Melbourne-Adelaide	9'781.41	2'317.91	6.44	12'105.76
Brisbane-Adelaide	-	-	-	-
Sydney-Adelaide	3'113.88	222.01	4.32	3'340.21
Brisbane-Melbourne	5'240.39	1'380.98	44.60	6'665.97
Adelaide-Perth	607.93	1'689.46	34.45	2'331.84
Melbourne-Perth	413.24	3'447.82	258.93	4'119.99
Sydney-Perth	62.81	739.93	91.93	894.67
Brisbane-Perth	-	-	-	-
	Difference towards 2030 Projections			
Sydney-Melbourne	0.01%	0.51%	1.16%	0.04%
Brisbane-Sydney	1.06%	-1.44%	-0.58%	0.89%
Melbourne-Adelaide	1.26%	0.10%	0.86%	1.04%
Brisbane-Adelaide	-	-	-	-
Sydney-Adelaide	-1.01%	-0.05%	-0.44%	-0.95%
Brisbane-Melbourne	0.35%	0.85%	-0.22%	0.45%
Adelaide-Perth	0.55%	-0.13%	0.73%	0.06%
Melbourne-Perth	0.64%	-0.07%	-0.63%	-0.04%
Sydney-Perth	-0.17%	-0.96%	-1.35%	-0.94%
Brisbane-Perth	-	-	-	-

2030-2014: 16 years

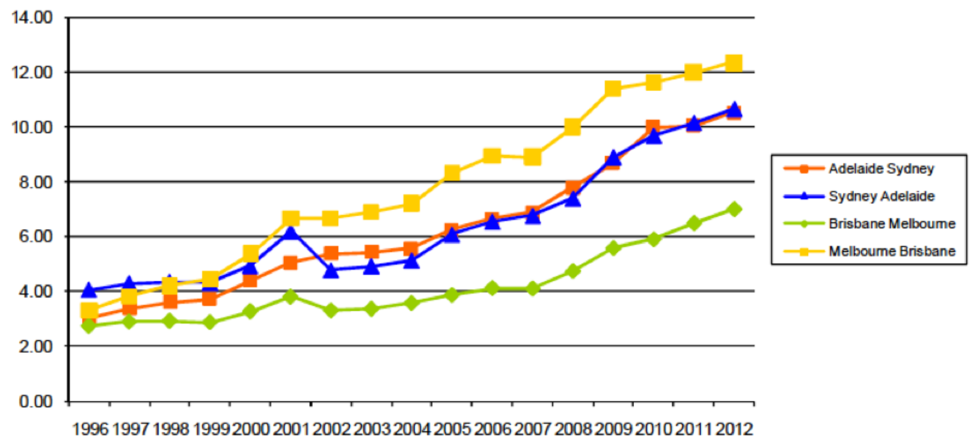
	ADAPTED freight projections 2030 to 2014 traffic ['000 tonnes]			
	Road	Rail	Sea	Total
Sydney-Melbourne	12'140.53	887.02	1.06	13'028.62
Brisbane-Sydney	5'735.05	527.24	35.62	6'297.90
Melbourne-Adelaide	4'186.49	1'500.71	16.63	5'703.84
Brisbane-Adelaide	-	-	-	-
Sydney-Adelaide	1'796.18	192.17	2.63	1'990.97
Brisbane-Melbourne	2'099.86	2'295.82	114.41	4'510.09
Adelaide-Perth	399.21	1'482.37	26.61	1'908.18
Melbourne-Perth	250.11	3'192.38	548.16	3'990.66
Sydney-Perth	84.15	1'721.46	489.31	2'294.92
Brisbane-Perth	-	-	-	-

C From SKM (2013)

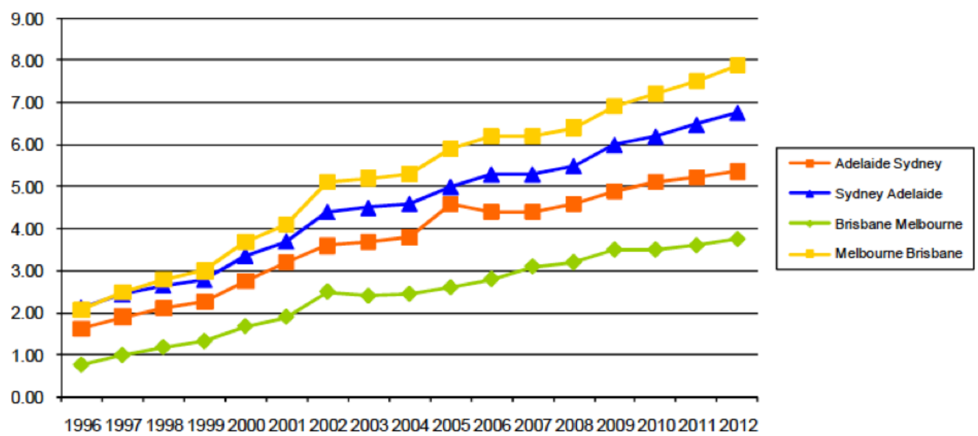
C.1 Evolution of Freight Rates on North-South Corridor [c/ntkm] 1996-2012

Figure 35

(a) Road Freight Rate c/ntk



(b) Rail Freight Rate c/ntk

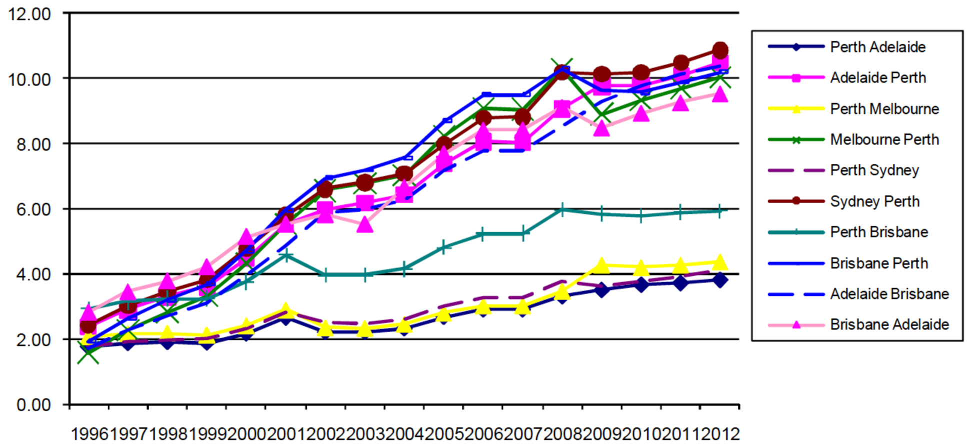


Source: SKM (2013)

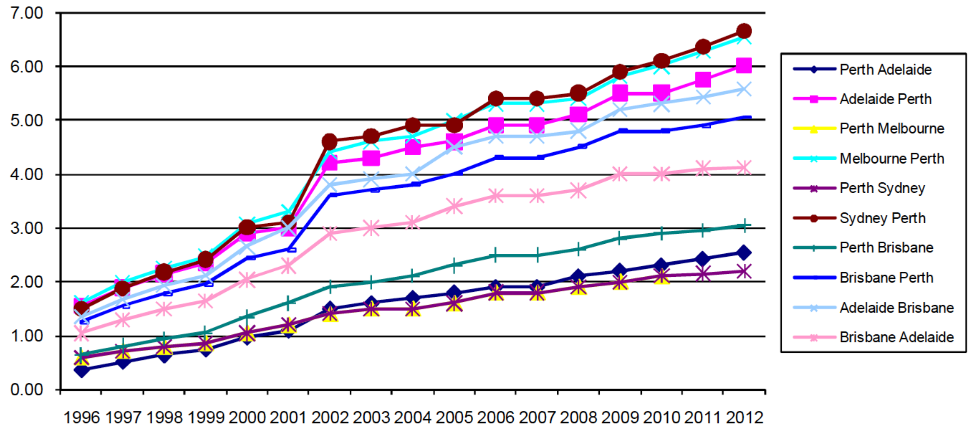
C.2 Evolution of Freight Rates on East-West Corridor [c/ntkm] 1996-2012

Figure 36

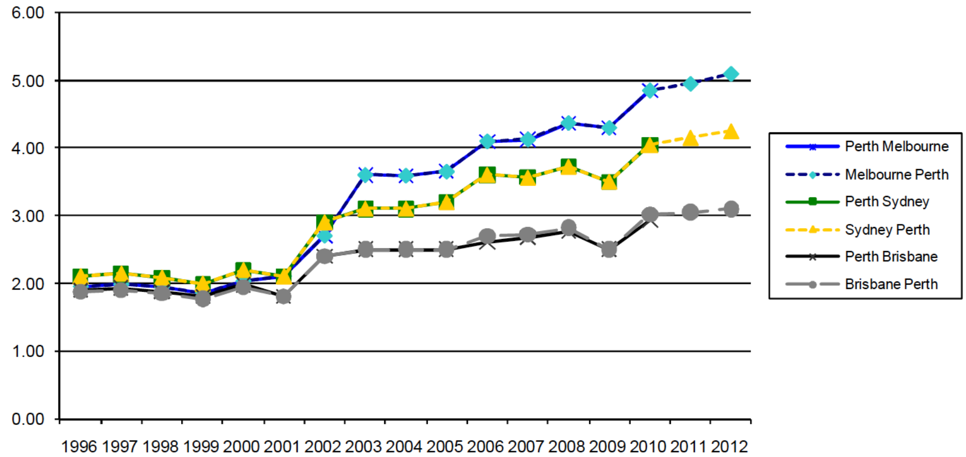
(a) Road Freight Rate c/ntkm



(b) Rail Freight Rate c/ntk



(c) Sea Freight Rate c/ntk



Source: SKM (2013)

D Estimated values of travel time for vehicle occupants and freight ATAP (2016)

Table 12 Estimated values of travel time (resource costs) – occupant and freight payload values, as at June 2013

Vehicle type	Non-urban Occupancy rate (persons/veh)	Non-urban Value per occupant ($/person-hour)	Urban Occupancy rate (persons/veh)	Urban Value per occupant ($/person-hour)	Freight travel time Non-urban ($ values per vehicle-hour)	Freight travel time Urban ($ values per vehicle-hour)
Cars (all types)						
Private	1.7	14.99	1.6	14.99	na	na
Business	1.3	48.63	1.4	48.63	na	na
Utility vehicles						
04. Courier Van-Utility	1.0	25.41	1.0	25.41	na	na
05. 4WD Mid Size Petrol	1.5	25.41	1.5	25.41	na	na
Rigid trucks						
06. Light Rigid	1.3	25.41	1.3	25.41	0.78	1.53
07. Medium Rigid	1.2	25.72	1.3	25.72	2.11	4.15
08. Heavy Rigid	1.0	26.19	1.0	26.19	7.22	14.20
Buses						
09. Heavy Bus (driver)	1.0	25.72	1.0	25.72	0.00	na
09. Heavy Bus (passenger)	20.0	14.99	20.0	14.99	0.00	na
Articulated trucks						
10. Artic 4 Axle	1.0	26.81	1.0	26.81	15.53	30.59
11. Artic 5 Axle	1.0	26.81	1.0	26.81	19.80	39.01
12. Artic 6 Axle	1.0	26.81	1.0	26.81	21.36	42.06
Combination vehicles						
13. Rigid + 5 Axle Dog	1.0	27.20	1.0	27.20	30.53	62.99
14. B-Double	1.0	27.20	1.0	27.20	31.46	64.91
15. Twin steer + 5 Axle Dog	1.0	27.20	1.0	27.20	29.50	60.89
16. A-Double	1.0	27.98	1.0	27.98	41.31	85.25
17. B Triple	1.0	27.98	1.0	27.98	42.17	87.01
18. A B Combination	1.0	27.98	1.0	27.98	50.79	104.80
19. A-Triple	1.0	28.45	1.0	28.45	60.89	125.64
20. Double B-Double	1.0	28.45	1.0	28.45	61.59	127.09

Note: na denotes not applicable.

Source: ARRB Group Ltd.