Chapter

A Review of Alternative Marine Fuels

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Abstract

Today, ships navigating all around the world are not allowed to emit SO_x more than 0.5%. Same regulation for nitrogen has already come into force. More and more nations are becoming aware and concerned about the negative effects of climate change, whereas many countries are already feeling the effects of harmful greenhouse gas emissions. Therefore, the world's fleet needs a new fuel types, which are alternative to conventional petroleum-based ship fuels. Benefits such as low sulphur standards accompany all alternative fuel options. As will be discussed further in Section 2, there are challenges and limitations associated with CO_2 emissions along with benefits. The review of the literature and field shows that the impact of these current choices on the management and environments is still not bright enough, although each alternative has consisted entirely different effects in their body and each alternative pose specific risks to the environment, crew, management and port states. This chapter gives a review on the impact of each alternative fuels on the environment. In addition, the chapter touches upon handling of risks associated with alternative fuels and technologies.

Keywords: Global Warming, Alternative fuels, Shipping, Emissions, LNG, HFO, Methanol, Greener Shipping

1. Introduction

An ocean-going vessel has been thought of as a critical factor in the transportation of the goods all around the world throughout the history. As a political goal of the regions, the financial growth has been maintained since the industrial revolution. However, these rapid changes are having a severe effect on the environment. The consumption of the combustible and flammable elements has significantly accelerated with the increase in international trade. Air pollution and its impact on the environment have been a subject of research since the 1850s. Emission from factories and transportation vessels is a significant area of interest within the field of climate. In the new global economy, the environment has become a central issue for human health. Previous studies have reported that the leading cause of some of diseases is industrialization and transportation. For example, respiratory tract diseases such as asthma, trachea, bronchioles, alveoli, pleura, apnea are increasingly recognized as a serious, worldwide public health concern [1]. Alternatives to current oils are becoming an instrument in the transportation sector. Recent evidence suggests that it is required an alteration from fuel oil to Liquefied Natural Gas (LNG) or Methanol due to the limited sources and the adverse effects of the emissions on the human health and environment [2]. Investigating zero emission is a continuing concern within environmental science. The sections below provide an understanding of each alternative fuels such as a LNG, a Liquefied Petroleum Gas (LPG), a methanol, a Heavy Fuel Oil (HFO) with scrubber technology based on the literature and Authors' technical visits some shipping companies.

2. Liquified Natural Gas (LNG)

In the management booklet of TarnTank, the significant information about LNG has been given. The information was given in the manual are listed below [3]:

LNG consists of methane (CH_4) and other substances. It's form can be changed by cooling down to −162°C at atmospheric pressure. By converting the gas form into the liquid form, the volume is reduced 600 times compare to gas form. This reduction makes it easier to transport and store. Typically, LNG tanks contain three times the capacity of an equivalent volume of heavy fuel oil. LNG also contains small quantities of nitrogen, ethane, propane, butane, and some other trace components, with the proportions varying according to the source of the LNG and how long it has been ageing. Cryogenic hazards could occur due to LNG, since it has a low temperature. Natural gas has a flammability range of between about 5% and 15% by volume when mixed with air. As an example, −187°C is a flashpoint. 530°C is autoignition degree means that natural gas is not readily ignited by hot surfaces – unlike marine gas and fuel oil, which can be readily ignited by hot surfaces such as unlagged exhaust systems, a primary cause of engine room fires. After the operations, some LNG can be trapped in the transfer line. If this amount meets with heat ingress, some local pressures can occur, and this high coefficient of volumetric expansion can cause pipe bursts as shown in **Figure 1**. This burst leads to the release of natural gas.

70 Bar (g) is the critical limit for the pipe structure. After one hour of the line, pressure reached 70 Bar, rupture of the pipework or equipment is highly likely. "Thermal relief valves" are being used to maintain release trapped gas or liquid. The first LNG fuel oil ship started to operate in 2000. Statistics dated first March 2018 showed that the number of LNG powered vessels reached to 121 whereas 127 new ship started to be built by shipyards [4]. In general, in a new ship construction, the highest cost of the investment belongs to engine compartments. Engines need to be modified or wholly renewed according to the fuel oils planning to be used onboard

Figure 1.
Pipe burst due to the high coefficient of volumetric expansion.

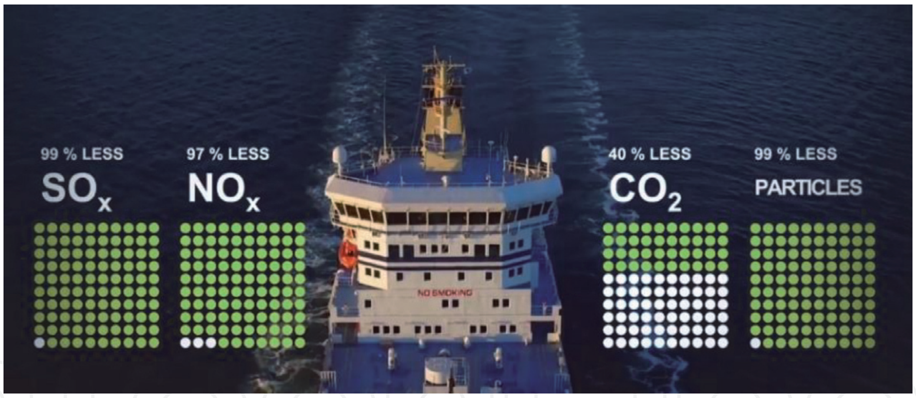

Figure 2.
Emission Decrements.

the vessels. A few former companies find the solution to use the hybrid fuel-powered engine. For instance, the MT TarnTank, which is LNG powered vessel, fuel gas supply system is designed for both the gas-fuelled engine and conventional type fuel engine. LNG powered engines are one of the most widely used groups of alternative fuel oil engines in Nordic countries. As the emissions shown in **Figure 2**., liquefied natural gas is very clean source. The releasing of SO_x is %99, NO_x %97 less than heavy fuel oils whereas CO_2 emission is high.

The energy density of liquefied natural gas is higher than heavy fuel oil. Despite its environment-friendly and efficacy, ship-owners suffer from several significant drawbacks: time loss to invest, spare parts, bunker supply, cost, educated crew to run this engine. By the help of IMO's regulations checklist shows the proper way for the bunkering operations of LNG. The main questions in the TarnTank Company checklist are about [3]; communication between the regulating authority, bunker deliverer and receiving vessel about safety and emergency response plans. Risk assessment forms are filled and discussed by each side, physical situation of the manifolds must be in operational range, LNG transfer profile (ratio/time) and vapour management schedule has been agreed upon, the receiving tank volume and temperature before bunkering must be within acceptable limits, temperature, pressure, methane number properties of the LNG must be acceptable, handling trapped volumes after an Emergency shutdown system for LNG bunkering – Electrostatic discharge (ESD) must be agreed upon, freeboards and the tidal and operational effects of the draft must be agreed, the ship must be ready for any shifting because of weather conditions, wavelength, wave height, wind speed, lightning is another critical point, the ships or other obstacles are essential in the Swinging Circle, cryogenic protection systems such as water curtains and insulated hose saddles must be compatible?, Safety zone should be established, Ship-Shore Connection box must be checked and ready to use. In the booklet, they call it as "Grounding and hose connection - a grounding cable from ship to quay must be connected and followed by bunker hose connection.", visual check must be done, stripping and purging, hoses must be drained before disconnection, disconnection of hoses and grounding.

3. Heavy Fuel Oil (HFO)

After the decisions of IMO, the debates and preparations for the new world combustion system had already started for decades. The industry intends to make investment decisions by the lights of the expert's predictions, but the experts do not have any specific clue about the future. Since ships were operating around the world, thus exploitation of the resources has been continuing making the prices of oil increase. However, what happened in 2015? The prices of oil fall dramatically from 120 USD/ton to 30 USD/ton against the market predictions [5]. In 2018, it was raising to 100USD/ton again, and the predictions were to reach 400 USD/ton. However, the other experts are expecting that the prices are going to fall again since the consumption of oil is decreasing.

The price of HFO is directly affected by the ship's operational costs since an average Panama Size ship consumes 24 ton in a voyage day. So, for the shipowners who are entirely in debt to banks with loans, this kind of investments are critically important. One prediction for the future is evident that half of the today's ship owners are going to bankrupt after 2020. HFO is still an option when the ship-owners and operators are concerned about the price increase and availability of complaint fuels but to be an alternative. HFO price graph is given in **Figure 3**. Scrubber technology makes HFO reasonable for managements which is installed by shipyards. To install this unit shown in **Figure 4**, significant investments must be paid [6]. An average Handymax ships conversion cost calculated as 6 million USD.

Current operational expenses such as sludge handlings, chemical consumables will go up by increased power consumption. In **Figure 5** the types of the scrubber technologies can be seen.

This scrubber technology, which is shown in **Figures 4** and **5**, can be adapted to new building vessels as well as currently navigating vessels.

In MS Fryken, a scrubber laboratory is carrying out experiments for Chalmers University. Obtained test results indicated so far that the scrubber technology has a potential to meet both 0.5% and 0.1% emission regulations. In **Figure 6**, we can see a closed-loop scrubber system. If in an open-loop system, the sea water is used to

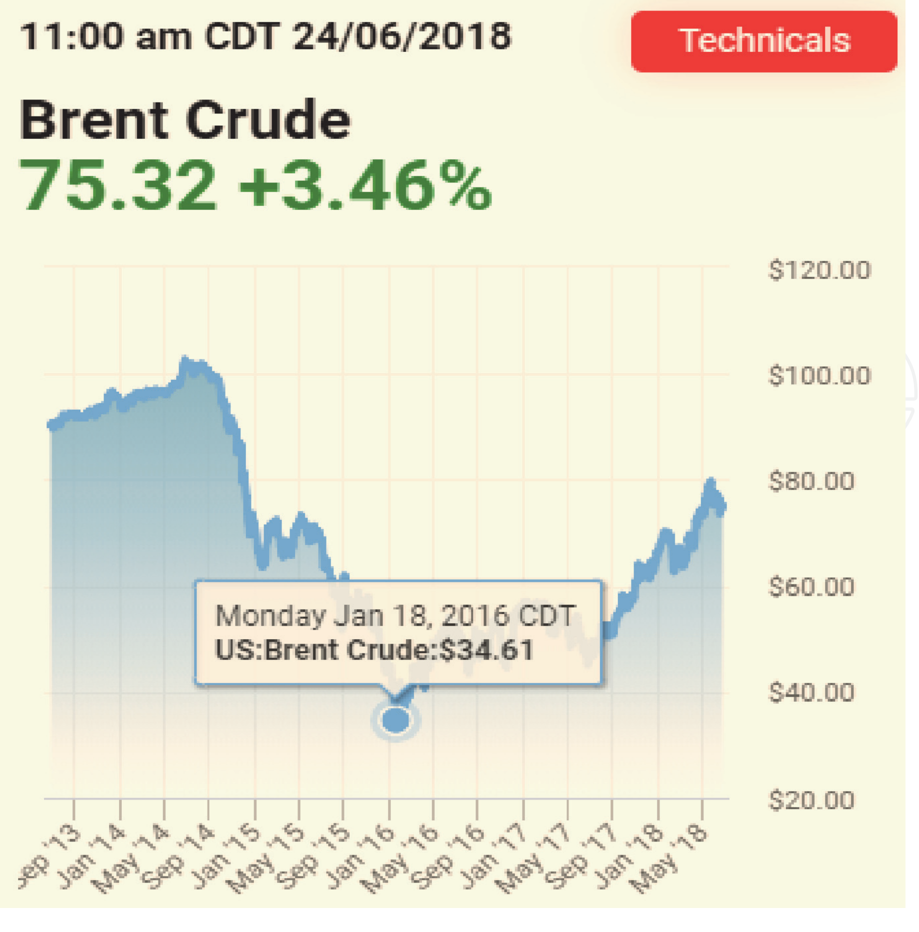

Figure 3.
Fuel Oil Prices last 15 years [5].

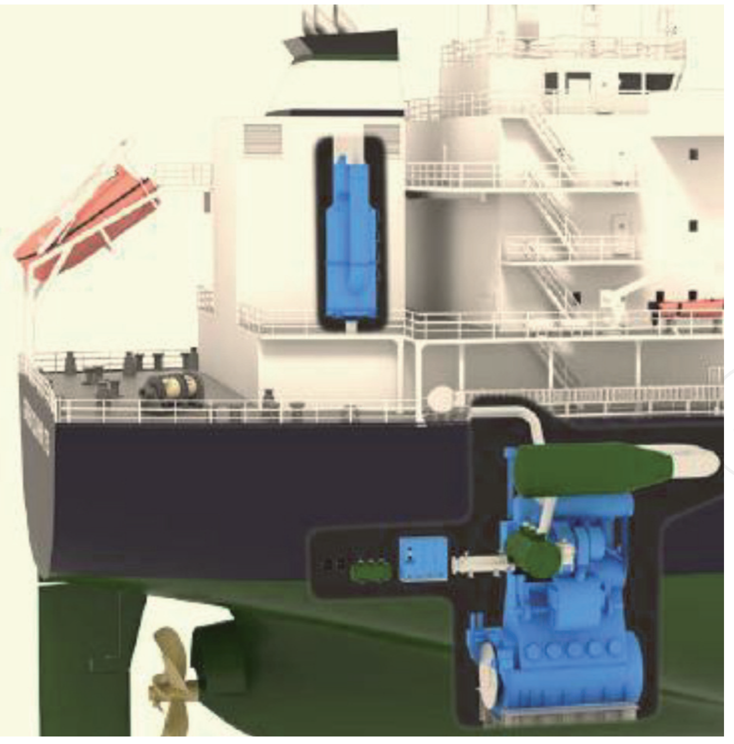

Figure 4.
Scrubber Unit [6].

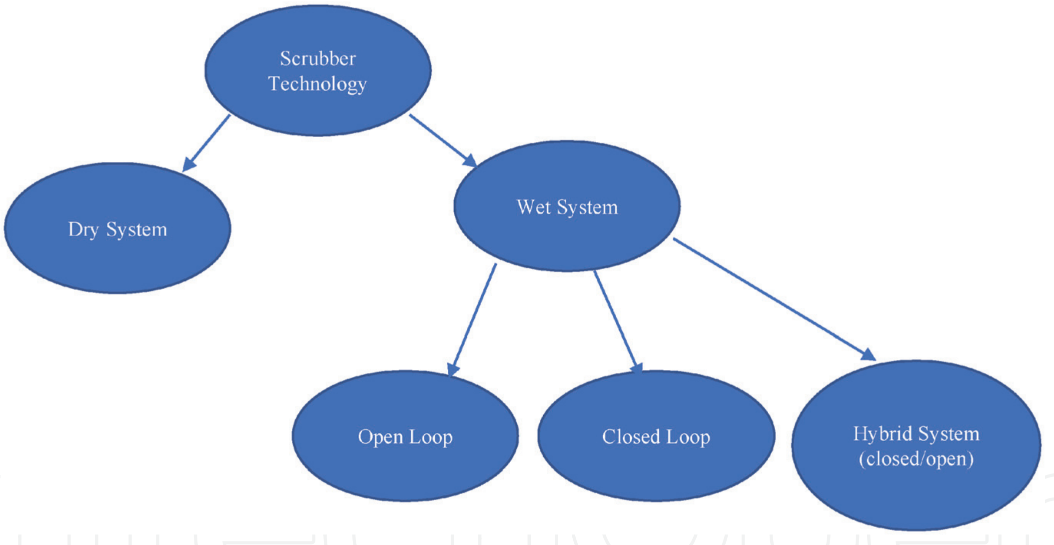

Figure 5.
Scrubber technology types.

wash out the SO_x in the exhaust, then in the closed-loop system uses chemicals such as caustic soda [8]. Closed loop scrubbers are installed on ships which are sailing in freshwaters [6].

In the open loop system, the used seawater discharge back to the sea. Discharging to the water in some locations is prohibited according to the MARPOL. Since the other ports will force the same regulations in the next years, a hybrid type of scrubbers is most likely to be used in many ships.

Current fuel type HFO has an extensive distribution network, and the engineers onboard are familiar with handling and operating the current fuel oil. The technical departments of the shipping companies work as an advisory team and technical problems in an average aged ship happen quite often. This advisory team is familiar with HFO and they can respond to any problems very promtly. Primarily by the

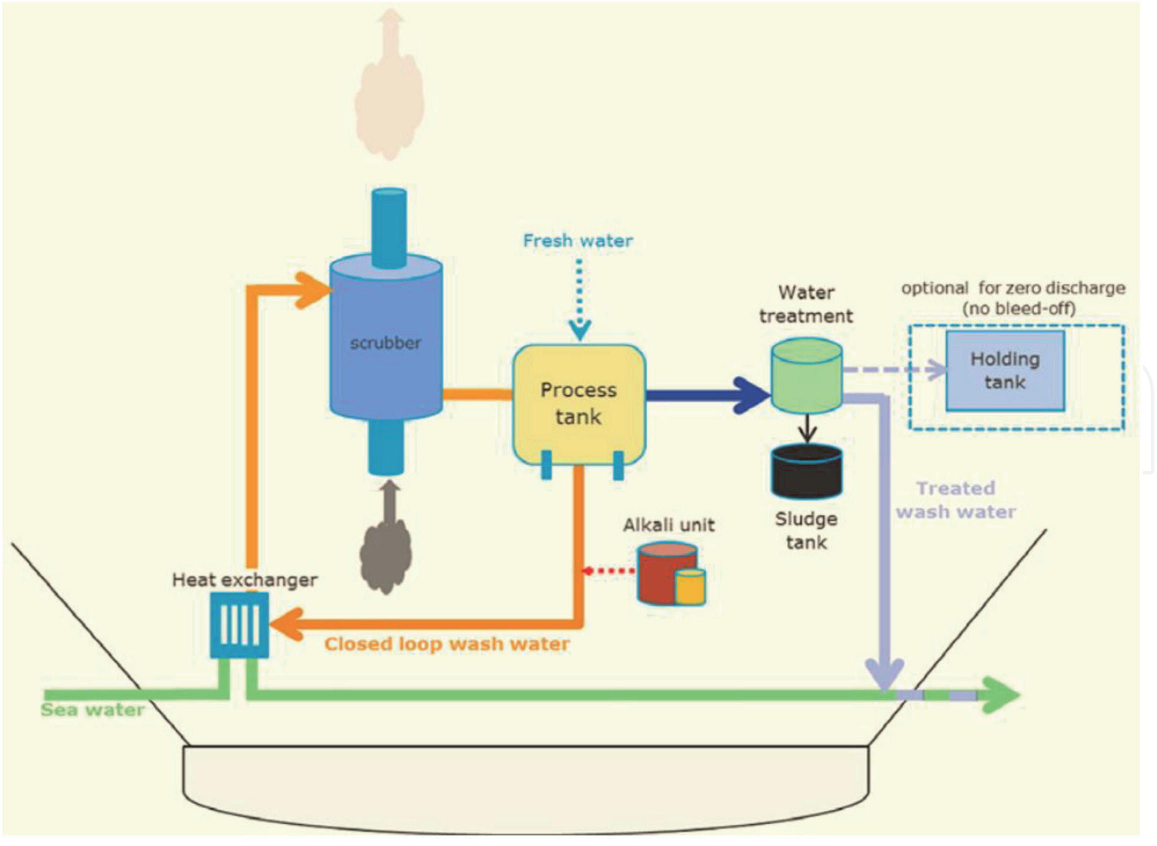

Figure 6.
Closed-Loop Scrubber [7].

influence of the technical department which consist of chief engineers, the shipping companies will insist on using HFO until it will disappear from the market. This prediction shows that the ships yards are going to be entirely busy with handling scrubber installations to meet the rising demand for scrubber technology.

Related to the safety domain, current HFO has its own risk inside. Currently, most of the ships in the market are using HFO and MGO as consumption. During the voyage in open seas, the engines use HFO, in the ports the generator runs by MGO, in the Sulphur Emission Control Area (SECA) areas they run with LSFO. Since the operating temperature is different (for example MGO is usually operated at 35C, and HFO is mostly at 135C), the risk of thermal shocks is highly possible during the oil change over. This shock may damage the structure of the pipeline and fuel systems [9].

4. Methanol

Methanol (CH_3OH) is the purest alcohol, consisting of a methyl group (CH_3) linked with a hydroxy group (OH). It boils at 65°C and solidifies at -94°C [10]. It has no colour and has an odour that is similar to ethyl alcohol. It consists of low carbon and high hydrogen contents. Methanol is the primary material of the derivatives of which is used to produce various compounds for daily living needs. For example, in building materials, perfumes, plastic bags, pharmaceuticals, paints, coatings. It is produced by natural gas, coal, biomass, bio-reshaping. Methanol can also be produced through gasification of coal and a cheap method with the widely available resource. The design and processing conditions may vary depending on the composition of the coal used as a feedstock. Methanol produced from coal has twice as high GHG (Green House Gas) as from natural gas. It can also be produced from virtually all biomass such as wood, algae, municipal and agricultural waste through gasification. As an example, black liquor from pulp industry can be gasified and used for methanol synthesis. The chemicals are recovered and reused. A plant at the Smurfit Kappa paper mill in Piteå, Sweden started to produce dimethyl ether in 2010. Diesel engines can be operated by dimethyl alcohol. With a volume of methanol, it is easy to reached the same energy level with 2,5 times larger volume of fuel oil. The flash point is low (11°C, 12°C) and guidelines are currently in the draft for incorporation into the International Maritime Organization's recently adopted International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code). The risk and safety analysis carried out for the SPIRETH Project (Alcohol Spirits and Ethers as Marine Fuel), which was co-coordinated by SSPA and ScandiNAOS and tested methanol and DME as ship fuels, contributed to the development of the IGF code [11]. Pilot Methanol was initiated by JIP 6–7 to prove and showcase that methanol is an innovative, safe, and sustainable fuel for shipping. EU project aims to demonstrate methanol as a cost-effective, clean, and comfortable fuel alternative with an easy infrastructure implementation [12]. The Zero Vision Tool (ZVT) platform was focusing on the research of methanol usage, converting the MF Stena Germanica to be capable of running on methanol fuel, It is possible that more ships in the Stena Line Fleet would be converted to methanol ships to be operated in the Baltic and the North Sea.

5. Research results

HFO with scrubber, LNG and Methanol are the most excellent alternatives for the transformation of the industry. These three options are compared in the **Table 1**. According to todays and future expectations of price, infrastructure, regulation, availability, environmental impact, technology, capital and operational expenditures [13].

The technology used in the maritime industry has been bringing innovation to maintain safety and efficiency [14]. By this development, the data transfer between ship and shore became more available. More information onboard the vessels would help us to establish a higher degree of accuracy models.

Some machine learning tools were tested with real sample data from a ship which navigated from Norfolk to El Dekheila. The sample data used in the calculations are presented in **Table 5**.

In the pre-processing term for data cleaning, the columns "average speed, wind force, RPM, slip, swell" were selected to prevent overfittings of algorithms. Consequently, data science algorithms suit very well with these current sample data.

CRISP-DM "Cross-industry standard process for data mining" methodology which is given in **Figure 7** is one of the most common data science methodology [16]. When the procedure applied according to the CRISP-DM figure with the sample data, the model learned and predicted the columns successfully.

This model is based on correlations. Isabelle et al. (2013), draw our attention to the differences between correlation and causality, and difficulties of "Cause and Effect Experiment" [17].

By analysing data collected continuous data from onboard, it is possible to find causes of the events and prevent disasters as well as preventing climate changes, economic changes, epidemics, cancer. Ships are real-life laboratories for this methodology. Besides this, it proposes an evaluation methodology to take the right decision for company perspective.

Qualitative methods are mainly basing on expert's experience. However, when it comes to alternative fuel oils, the industry has not got enough experiences yet. We can say that; these qualitative methods are suitable for pre-AI shipping industry

	HFO- Scrubber	LNG	Methanol
Price	The price is expected to drop significantly due to low global demand.	The price level is competitive. With MGO and expected to be competitive with low-sulphur HFO. It is predicted that the competitiveness of LNG with scrubber high-sulphur HFO is also possible.	Since methanol is produced mainly from natural gas, its price is dependent on natural gas prices. The price of methanol can be lower in case of production from coal. However, the latter may have an adverse effect such as increased Green House Gas emissions. The production costs of methanol from hydrogen and CO_2 are higher than the costs of methanol synthesis methane.
Infrastructure	Well-developed infrastructure. It is uncertain whether in the future bunker suppliers will still be available at all geographical locations.	LNG in principle is available worldwide, and investments are underway to make LNG available to ships. LNG bunkering vessels, bunker truck and permanent bunker depot will continue to grow.	Truck or bunker vessels can accomplish the supply of methanol to ships. Stena Lines has developed a dedicated bunkering area in the port of Goteborg which includes a safety barrier to avoid problems associated with methanol leakage.
Regulation	The IMO MEPC limited the sulphur content of ship fuels to 0.5% worldwide and 0.1% in sulphur emission-controlled area. However, it is permissible to continue burning HFO and use scrubbers to clean the exhaust gas to achieve an equivalent level of sulphur emissions.	The IMO IGF came into force for the design and construction of LNG fuelled ships. Bunkering LNG fuelled ships are subject to national regulations. Some ports have established local rules for bunkering. Organisations such as ISO, IASC, SGMF developed requirements and guidelines for LNG bunkering.	The chapter for methanol in the IGF Code which is for all gas and other low flash point fuel ships is currently under development. Some other projects (i.e. SEDNA) are running to establish guidance for three bunkering processes; Truck to Ship, Shore to Ship and Ship to Ship. Also, class companies such as DNV GL has released rules for low flash point fuels that also includes methanol.
Availability	Available.	The production capacities of LNG have no limitations and are expected to increase.	In 2016 the global methanol demand was around 80 million tonnes.
Environmental Impact	Oil-based ship fuel has a more significant environmental effect than alternative fuels. The sulphur content, particle emissions, NO_x, CO_2 of even low sulphur ship fuels is much higher than of alternatives.	Natural gas from LNG is the cleanest fossil fuel available today. There are almost no SO_x emissions to it; particle emissions are very low, the NO_x emissions are lower than those of Marine Gas Oil (MGO) or Heavy Fuel Oil (HFO). Methane release must be considered.	With clean-burning methanol qualities as a marine fuel, methanol can reduce emissions of sulphur oxide by 99%, nitrogen oxide by up to 60%, particulate matter by 95%.

	HFO- Scrubber	LNG	Methanol
Technology	Scrubber technology is readily available to clean exhaust gases of oil-based ship fuels. In addition to scrubbers, selective catalytic reduction and exhaust gas system will be required to comply with NO_x emission limits.	Gas engines, gas turbines, LNG storage and processing systems have been available for land installations for decades. All above necessary process equipment are also commercially available.	There are two main engine options for the methanol-powered vessel: two-stroke diesel-cycle engine and four-stroke lean-burn Otto-cycle engine. The only single two-stroke diesel engine is currently commercially available.
CAPEX	The investment costs for scrubbers' range between $650/kW (5000 kW engine) and $100–$150/kW (40,000 kW and larger engines)	The CAPEX is decreasing, as LNG technology is developing quite rapidly and the competition between suppliers is increasing. Compared to scrubber system with HFO the CAPEX cost for LNG is and continue to be higher.	The cost for installation of methanol systems onboards the vessels (e.g. internal combustion engine, fuel tanks, piping) is three times cheaper than the costs associated with LNG systems. No need for cryogenic temperatures and pressurized fuel tanks as in LNG.
OPEX	The operational costs of scrubbers are composed of the cost of maintenance and energy consumption (pumps, scrubbing unit to remove the SO_x from exhaust gases).	The OPEX cost for LNG systems onboard ships are almost the same as for conventionally fuelled system. However, the maintenance of gas burning engine in case of LNG used may be less expensive owing to its cleanliness.	The cost of OPEX is expected to be similar to that of oil-fuelled systems without scrubber technology. Also, the benefit can be gained, since some ports offer discounts to alternative fuelled ships.

Table 1.
Comparison of HFO - LNG- Methanol.

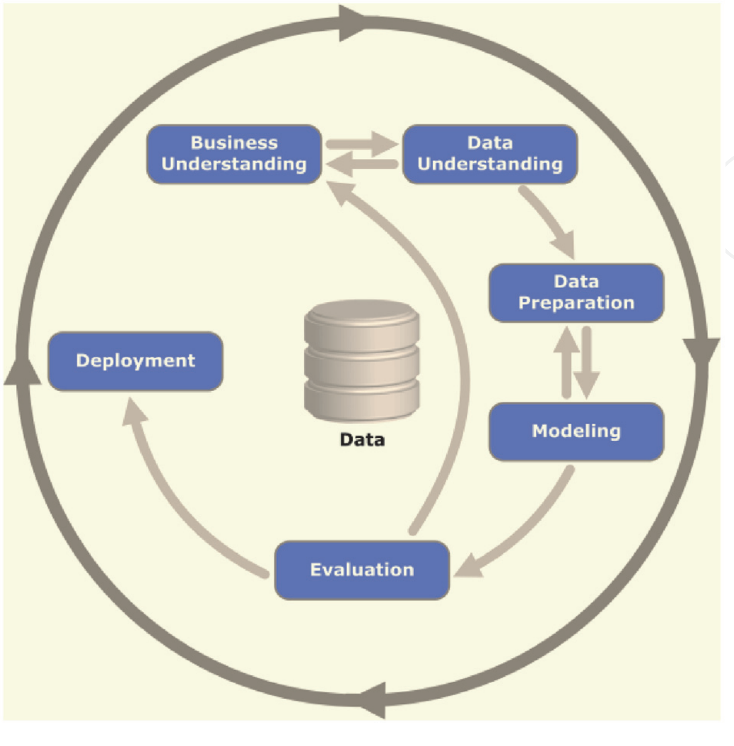

Figure 7.
CRISP-DM Process [15].

conditions. Today the shipping industry is living its technological age. The most significant benefit of this age is "being available of data transfers from ship to shore". With these advantages, we are going to find the opportunity to develop autonomous ships.

While the shipping industry is talking about autonomous ships, the rest of the industry has already started to use robots and artificial intelligence in the industrial activities. However, before the autonomous ships get into forced, we should find answers to these questions:

- Is it possible to collect any data for data mining application onboard the vessels?
- What can we use this data for?
- Is it possible to use these data to evaluate the risks of each type of oil?
- Is it possible to teach a machine by supplying the flowing data?
- Is it possible to develop a machine learning system which prevents accidents by prediction?
- We learn that to set a laboratory for "Cause and Effect Studies" is costly and has many other problems. How about onboard the ships?

In the current study, an empiric data mining and machine learning was applied to the real sample data from a vessel which is given in **Tables 2** and **3**.

Av. Speed	Wind Force	RPM	Slip	Swells
13.52	4	105.00	10.8	E
13.2696	6	104.80	12.3	E
13.4958	6	105.20	11.09	E
12.8652	5	106.50	14.69	W
12.75	6	107.56	17.85	W
13.0087	5	107.75	16.34	W
12.7958	7	107.88	17.82	W
12.2167	6	108.07	19.42	W
12.5609	6	107.55	19.07	W
13.1583	5	106.57	14.45	W
13.3042	3	105.21	14.00	W
13.4261	4	105.02	13.04	E
13.8917	4	106.19	9.38	E
13.3652	4	105.35	13.72	E
13.3792	1	105.35	12.84	E
13.3957	5	105.28	13.46	E
13.7125	4	105.43	12.38	E

Table 2.
*Extracted Voyage Data From **Table 5**.*

Correct classified: 2	Wrong classified: 4
Accuracy: 33,333%	Error: 66,667%
Cohen's kappa (κ) 0,2	

Table 3.
Accuracy rate.

When we look at the literature on data science methodology, we come across with different kind of analytics. Autonomous ships must use descriptive analytics that recognise the data, predict the data based on the description, then prescript the data and take action according to the traffic congestion found and predict the current condition from the history of the data. Prescriptive Analytic uses the results of the descriptive and predictive analytics. While descriptive analytics are evaluating the current data, Prescriptive Analytics examine the data and gives suggestion and takes the actions without a human. All the prescriptive systems are managed and run by machine without a human.

As an empirical application, the author used the data given in **Table 5** in order to predict the data shown in **Table 4**. The data in **Table 5** represents the real ship data collected from a voyage between Port of Norfolk to Port of El Dekheila during authors previous work experience with a largest shipping company in Turkey.

After performing following six-steps, the data presented in **Table 3** was achieved.

1. Excel reader
2. Statistics
3. Scatter Plot
4. Partitioning
5. Decision Tree Learner
6. Decision Tree Predictor Scorer

With the scorer node, the author checked the accuracy of the learner by prediction results.

Depending on the data's properties, the accuracy rate has been changing. In this data sets, the learner can predict the results with %33 accuracy. Healthier data and different partitioning tools can decrease this rate.

As we understand from the tree in **Figure 8** when the swell direction is from "N or north", the slip is going to be more than %14,5 which means that the consumption of the fuel oil and greenhouse gas emissions are going to increase.

By the help of this simple prediction model, the company can easily predict the engine slips from the up-to-date data getting from the ships. The distance of the

Row ID	RPM	Av. Sp	Wind F	Predicted slips
Row0	100	12	2	16.477
Row1	110	14	3	11.833
Row2	120	13	4	26.531

Table 4.
Predicted Slips.

DATE	NOON POSITION		SEA MILE	VOY TIME	AV SP	REST DIST	COURE	WIND		SWELL	SEA		TEMP	SEA TEMP	RPM	slip %	TIME ZONE	DAILY FUEL OIL CONSUMPTION			REST OIL			ENGINE DISTANCE	FRESH WATER		
				Steam																							
	LAT	LON	Nm.	h.m	Knt	Nm.		DIR	FORCE	DIR&FOR	DIR	FORCE						IFO	MDO	L/O	oil1	oil2	oil3		REST	Eva	CONSUMP
5/31/2013	**COSP 1600 LT**					**5269.4**											GMT-4	**1293.2**	**130.1**	**55560**	**14600**	**39560**	**1400**		**380**		
01.06.2013	36 04N	070 42 W	270.40	20.00	13.52	4999.00	067	SW-6	4	E-2M	E	3	22	21	105.00	10.76	GMT-4	31.2	1.5	**250**	14600	39310	1400	303.0	370	0	10.00
02.06.2013	38 48 N	064 19 W	305.20	23.00	13.27	4693.80	090	WSW - 2	6	SE-3M	E	5	23	18	104.80	12.30	GMT-3	35.0	1.7	**295**	14600	39015	1400	348.0	372	19.1	17.10
03.06.2013	38 48 N	057 23 W	323.90	24.00	13.50	4369.90	090	WSW - 2	6	SE-2M	SE	5	25	23	105.20	11.09	GMT-3	36.5	1.8	**310**	14600	38705	1400	364.3	384	22	10.00
04.06.2013	38 48 N	051 03 W	295.90	23.00	12.87	4074.00	090	ENE-8	5	W-2M	NW	4	18	20	106.50	14.69	GMT-2	35.0	1.7	**295**	14600	38410	1400	346.8	390	23	17.00
05.06.2013	37 50 N	044 43 W	306.00	24.00	12.75	3768.00	103	ENE-8	6	WNW-2/ 3M	WNW	5	19	20	107.56	17.85	GMT-2	36.5	1.8	**315**	14600	38095	1400	372.5	400	20	10.00
06.06.2013	36 40 N	038 39 W	299.20	23.00	13.01	3468.80	103	NE-8	5	W-2/3M	W	5	20	21	107.75	16.34	GMT-1	35.0	1.7	**305**	14600	37790	1400	357.7	416	20	4.00
07.06.2013	35 29 N	032 31 W	307.10	24.00	12.80	3161.70	103	NNE-6	7	W-3M	W	6	18	20	107.88	17.82	GMT-1	36.5	1.8	**315**	14600	37475	1400	373.7	427	21	10.00
08.06.2013	34 17 N	026 56 W	293.20	24.00	12.22	2868.50	085	NE-6	6	W-4/5M	W	5	23	20	108.07	19.42	GMT-1	36.5	1.8	**308**	14600	37167	1400	363.8	440	20	7.00
09.06.2013	34 44 N	021 07 W	288.90	23.00	12.56	2579.60	085	NNE-6	6	WNW- 2/3 M	NW	5	23	20	107.55	19.07	GMT 0	35.0	1.7	**300**	14600	36867	1400	357.0	456	19	3.00
10.06.2013	35 14 N	014 45 W	315.80	24.00	13.16	2263.80	085	NNE	5	NNW - 1M	NW	4	21	20	106.57	14.45	GMT 0	36.5	1.8	**312**	14600	36555	1400	369.1	460	21	17.00
11.06.2013	35 44 N	008 20 W	319.30	24.00	13.30	1944.50	085	NNW-6	3	WNW-1M	WNW	2	20	20	105.21	14.00	GMT 0	36.5	1.8	**313**	14600	36242	1400	371.3	460	20	20.00
12.06.2013	36 23 N	002 00 W	308.80	23.00	13.43	1635.70	081	W-5	4	E - 0.5M	E	3	22	21	105.02	13.04	GMT 1	35.0	1.7	**298**	14600	35944	1400	355.1	450	4	14.00
13.06.2013	37 05 N	004 51 E	333.40	24.00	13.89	1302.30	086	SW - 4	4	E-1M	E	4	25	22	106.19	9.38	GMT 1	36.5	1.8	**311**	14600	35633	1400	367.9	431	0	19.00
14.06.2013	37 08 N	011 10 E	307.40	23.00	13.37	994.90	109	E-8	4	E-1M	E	3	24	22	105.35	13.72	GMT 2	35.0	1.7	**298**	14600	35335	1400	356.3	424	0	7.00
15.06.2013	35 14 N	017 23 E	321.10	24.00	13.38	673.80	111	CALM	CALM	E-1M	E	CALM	25	22	105.35	12.84	GMT 2	36.5	1.8	**310**	14600	35025	1400	368.4	414	0	10.00

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DATE	NOON POSITION		SEA MILE	VOY TIME Steam	AV SP	REST DIST	COURE	WIND		SWELL	SEA		TEMP	SEA TEMP	RPM	slip %	TIME ZONE	DAILY FUEL OIL CONSUMPTION			REST OIL			ENGINE DISTANCE	FRESH WATER		
	LAT	LON	Nm.	h.m	Knt	Nm.		DIR	FORCE	DIR&FOR	DIR	FORCE						IFO	MDO	L/O	oil1	oil2	oil3		REST	Eva	CONSUMP
16.06.2013	33 30 N	023 10 E	308.10	23.00	13.40	365.70	111	NW-6	5	E-1M	E	4	28	23	105.28	13.46	GMT 3	35.0	1.7	**299**	14600	34726	1400	356.0	405	0	9.00
17.06.2013	31 25 N	029 12 E	329.10	24.00	13.71	36.60	111	NW-6	4	E-1M	E	3	26.5	23	105.43	12.38	GMT 3	36.5	1.8	**316**	14600	34410	1400	375.6	393	0	12.00
TOTAL VALUE			5232.80	397.00	13.18	36.60									106.16	14.27		604.70	29.60	5150				6106.5		209.10	196.10
																		688.50	100.500	50410.0				359.2		12.30	11.54
																		36.56	1.79	311.34							

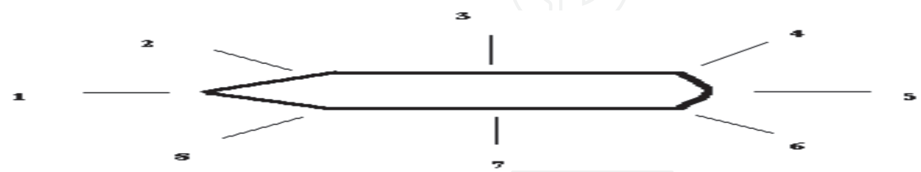

Table 5.
Navigation Data from Norfolk to El Dekheila.

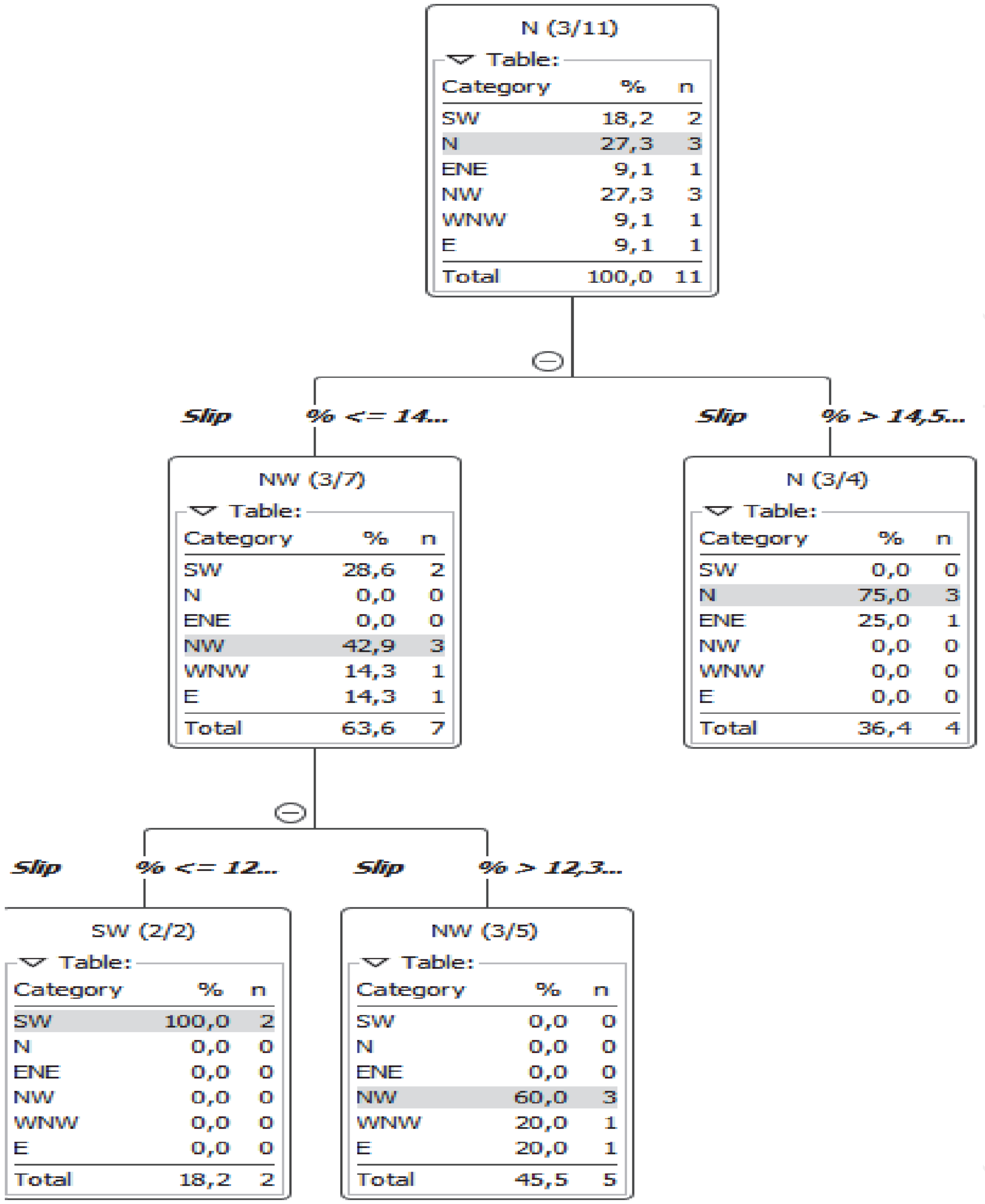

Figure 8.
Decision Tree Results.

ship movement by one complete rotation of the propeller or the propeller pitch is calculated by shipyard and written in the "ship's manual". Engine distance is calculated by multiplying the propeller pitch to propeller distances. For a certain time period the ship movement distance can be calculated by engine distance. But in reality, engine distance can vary due to weather conditions such as wind, current and swells directions, fouling on the ship's hull, etc. Therefore, the observed distance might be less or more than engine distance.

Slip is a rate of the difference between the engine distance and observed distance. The simple formulation showed below:

$$\text{Slip} = 100 \times \frac{\text{Engine Distance} - \text{Observed Distance}}{\text{Engine Distance}} \tag{1}$$

If this machine learning model can be fed by long term data, the engine performance under the same sea conditions can be predicted. In **Table 4**, the actual slip rates predicted by the model. The daily slip, from the noon reports which is daily given by ship captain, can be compared with the actual slip. In that way, by comparing the daily slip with actual slip, potential problems associated with ship performance could be spotted. Since there is not enough chief engineers who have experiences with alternative fuel powered vessels, this kind of machine learning algorithms is going to accelerate the experience accumulation in the technical department of the companies. Shipping market could be ready for an engine evolution, but the industry has not enough well-experienced engineers for this conversion.

If we can use the algorithms efficiently and feed the machine learning by real ship data, the developing models can be trained and after be used to give predictions and suggestion in a short time as well as well-experienced engineers working at ocean-going vessels. By intensive use of algorithms, the market can close the gap of the well-experienced engineers on alternative fuel powered engine.

Table 6 was generated to demonstrate what kind of element can affect the bunkering operations. From the study visit to industry, some parameters were found. During the fuel transfer, there are many parameters which can affect the soundness of the operation;

- Illumination of the work area
- Sea condition
- Wind Force
- Tank pressure of
  - Ship Tank
  - Bunker Tank
  - Line
  - Manifold
- Density
- Temperature of
  - Weather
  - Ship Tank
  - Bunker Tank
  - Line
  - Manifold
- Capacity
  - Ship tank
  - Bunker tank (rest)

Sea Condition	Work day of assigned Crew	Wind Force	Illumination	Ship Tank Temperature °C	Ship Tank Pressure MPa (abs)	Density t/m3	Bunker Tank Temperature °C	Bunker Tank Pressure bar (abs)	Ship tank available (rest) capacity	Bunker Tank rest capacity	Rest M3/ 315 M3 capacity *100	Line Pressure MPa (abs)	Line Temperature °C	The temperature at manifold ° C	The pressure at the manifold bar (rel)	Transfer rate M3 (per hour)	Leakage
6		4	enough		0.1												Y
2		2	not enough	−187.0	0.4		−187.0						−187.0	−187.0			N
6		6			0.48												Y
3		2		−163	0.5												N
6		6		−162.5								7.00					
5		5															
7		7			0.75												
6		6															
6		6		530.00			530.00						530.00	530.00			
5		5															
3		3				0.5											
4		4															
4		4															
4		4															
1		1															
5		5															
4		4															

Table 6.
ML Alternative Fuel Powered Vessels Data Table for ML Applications.

- Transfer rate per hour
- Working day of the assigned crew since embarked onboard

These parameters are dynamic and thus frequently change due to inherent nature of the water. During the bunkering, assigned personnel observes the changes. Here, we should bear in mind the associated human errors. **Table 6** presents mentioned above main parameters that affect the bunkering operations.

By the use of ML algorithms, the shipping industry can learn about alternative fuels more and more in the future, and the **Table 6** is most likely to expand with new columns.

6. Conclusions

Notably, the sulphur limit for automotive diesel is much lower than that for ship fuel. Across Europe, it is at 0,001%, 100 to 500 times below the 2020 limit for shipping. Therefore, it is most likely that the shipping industry will still be under scrutiny regarding the sulphur limits in marine fuels. The International Maritime Organization (IMO) has already taken steps to limit the sulphur content of ship fuels to 0.5% worldwide from 1st January 2020. The IMO has recently adopted an ambitious target to reduce GHG emission by 50% or from 940 mton (in 2008) to 470 mton (in 2050). This will serve as a driving force in introducing a broader range of environmentally friendly fuels, propulsion solutions and energy efficiency measures. This study has reviewed selected alternative ship fuels such as LNG, methanol and compared these fuels against heavy fuels oil with scrubbers in **Table 1** in terms of risks, price, infrastructure, regulations, availability of fuels, their environmental impacts, technologies required, capital expenditure (CAPEX), Operational expenditure (OPEX).

According to available research and information, LNG is the cleanest of fossil fuels which can satisfy the demand of shipping industry for years to come. However, it is not totally carbon free. For example, the release of unburned methane (so-called methane slip) could reduce the benefit of LNG over HFO. The prices of LNG on the market are comparable to the process of HFO. The price of methanol production also depends on which type of resource (e.g. natural gas, coal, biomass) is used as a feedstock. However, the prices of methanol are higher when compared to LNG and HFO. Although this methanol is gaining interest in the market because of its sulphur free and it, therefore, has the potential to meet the current 0.1% SO_x emission in the Control Area requirements. Safety requirements for methanol as low flash point fuel must be followed according to existing rules, eg. IGF Code, which is still being expanded and developed by the IMO.

Being critical can also mean looking for reasons why we should not just accept big risk prediction as being binominal. By generating a prediction model which is fed by all aspects that leads to unwanted results such as fuel leakage, grounding, fire etc. a pre-notification system can be developed as in **Figure 9**. To establishing the similar model to the bunkering operations of alternative fuel oils, **Table 6** was generated. When we investigate the result of intended model what we are going to predict is binominal which means this model predicts the existence of leakage by answering "yes or no". However, it is highly possible that the methodology of the model can be extended toward answers which give possibility. By adding the possibility to the answers, the results are going to be more meaningful.

The wellness of the crew onboard is also another critical issue. Today's shipping industry is on the way to autonomous, and most of the inventions brought

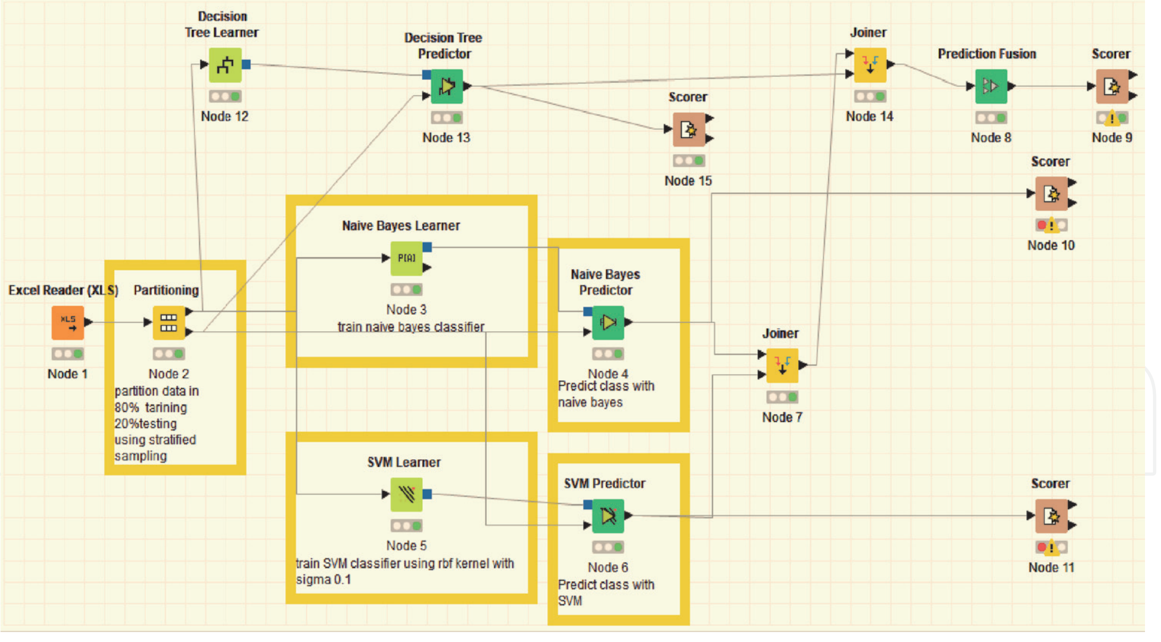

Figure 9.
Comparison with Decision Tree Naive Bayes and SVM Learner.

simplicity to onboard. By the time this easiness coming, most of the ship operators take advantages by reductions of the numbers of the crew onboard. While technological development has led to higher efficiency in maritime industry, some tasks, e.g. maintenance of the equipment or machinery, have not been affected by technical development and must still be handled manually in an often time-consuming manner [18]. Due to reduced staffing, these tasks must now be carried out by fewer employees. Lundh and her colleagues found that many engine room engineers reported using unauthorised shortcuts to be able to handle these tasks under time pressure [19]. These unauthorised shortcuts increase risks onboard the vessels. Briefly, the wellness of the crew must also be reflected in **Table 6** and algorithms.

Moreover, the ergonomy of the engine room is also essential for the shipping. For example, the study carried out by Lundh and her colleagues showed that the design of the engine control room and engine room is crucial for how different tasks are performed. According to this study, the design which does not support operational procedures, can induce an increased risk of exposure to hazardous substances and the engine crew members becoming injured [18].

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