The study focuses on minimizing fuel consumption and greenhouse gas (GHG) emissions of cargo vessels (tankers, bulk carriers , containers etc..). The main contributor is the vessel speed:
There is a nonlinear relationship between the SWS (Still water speed) - the speed that the engine produces, and the overall fuel consumption. It means that small changes in engine speed result in an increase in the power (between 2.7 and 3.3). If the only target during a vessel voyage is to reduce fuel consumption, the answer will be to sail at the lowest speed possible. Adhering to desired time of arrival (DTA), is the place where a vessel must increase engine speed, and consume additional fuel. Another consideration of speed control, is the actual SOG (speed over ground), this is the linear speed that combines the speed gained from the engine (SWS) and weather and sea conditions (wind, wave , currents ..) . Using physical formulas that translate weather and sea conditions, combined with naval architecture standards, the calculation of speed consumption and SOG, in the case of different engine power (SWS) is fairly feasible.

As a graduate student in machine learning and operation research, I want this thesis to contribute to the following question:
For a fixed ship route divided into n segments between departure port A and destination port B where the bearing of the ship in each segment is fixed, determine the optimal Still Water Speed (SWS) for each segment to minimize the total fuel consumption over the voyage while ensuring arrival at port B is not later than a desired time of arrival (DTA). Each segment has fixed and known weather and sea conditions (wind, waves, and ocean currents) affecting the vessel's speed.
The first step of the research is to proove that by modeling the problem as a linear optimization problem, can produce an optimal solution, superior to a heuristic approach.
The benchmark for heuristic solution, is a journal article named " Ship Speed Optimization Considering Ocean Currents to Enhance Environmental Sustainability in Maritime Shipping ". the article provides 2 main important factors:

1. Detailed formulation of maritime parameters calculation (SOG, Fuel consumption..)
2. Detailed use case of a 12 segment voyage , with weather and sea condition data

The article provides the solution approach, and the minimal fuel consumption that the algorithm achieved.
The first part of the thesis \ journal article, is to provide:

1. Literature review
2. Research approach
3. Problem definition and mathematical formulation
4. Results and comparison against heuristic approach baseline

In order to "level the playing field" , I've first implemented all the equations from the article, into a python code. The target was to use the same baseline of parameters calculations (SOG, FCR) in order to create a valid .DATA file. The file with all the necessary calculation, was then used in a linear programing model, that produced a new set of optimised results.
The first step of validation was to take the article's SWS input, SOG output, and compare it with the results of the same inputs through my utility functions implementation. The goal was

to see minimum discrepancies between article SOG and calculated SOG. results below:

Segment	SWS	Article SOG	Calculated Sog	sog diff	percent diff
1	12.7	12.36	12.356215	0.003785	0.03%
2	12.2	11.72	11.738374	0.018374	0.16%
3	12.2	12.59	12.635041	0.045041	0.36%
4	12.1	12.11	12.132424	0.022424	0.19%
5	12.5	12.04	12.03888	0.00112	0.01%
6	12.3	12.1	12.165201	0.065201	0.54%
7	12.4	11.85	11.852915	0.002915	0.02%
8	12.7	10.98	10.809994	0.170006	1.55%
9	12.3	12.05	12.007468	0.042532	0.35%
10	12	12.67	12.660112	0.009888	0.08%
11	12.4	12.21	12.222302	0.012302	0.10%
12	12.5	12.72	12.672564	0.047436	0.37%

The next step was to compare optimization results between the article Genetic algorithm and linear programing method. Results below:

Optimization results - genetic algorithm (Article):

Segment	SWS	SOG	Travel_Time	Distance	FCR	Fuel_Consumption
1	12.7	12.36	18.1	223.716	1.44	26.06
2	12.2	11.72	24.1	282.452	1.29	31.09
3	12.2	12.59	24.1	303.419	1.29	31.09
4	12.1	12.11	24.6	297.906	1.25	30.75
5	12.5	12.04	23.3	280.532	1.38	32.15
6	12.3	12.1	23.8	287.98	1.32	31.42
7	12.4	11.85	24	284.4	1.35	32.4
8	12.7	10.98	21.2	232.776	1.44	30.53
9	12.3	12.05	25.1	302.455	1.32	33.13
10	12	12.67	24.9	315.483	1.21	30.13
11	12.4	12.21	24.1	294.261	1.35	32.54
12	12.5	12.72	22.7	288.744	1.38	31.33
			280	3394.124		372.62

Optimization results - Linear programing :

Segment	SWS	SOG	Travel_Time	Distance	FCR	Fuel_Consumption
1	12.5	12.154758	18.41747898	223.86	1.38	25.40
2	12.4	11.939477	23.66435314	282.54	1.35	31.85
3	12	12.431751	24.38755409	303.18	1.22	29.75
4	12.2	12.234161	24.39398991	298.44	1.28	31.27
5	12.6	12.143079	23.10040147	280.51	1.41	32.62
6	12.5	12.374831	23.21971104	287.34	1.38	32.02
7	12.5	11.953601	23.79199373	284.4	1.38	32.81
8	13.2	11.313922	20.61619304	233.25	1.62	33.48
9	12.3	12.007468	25.13435805	301.8	1.31	33.02
10	11.8	12.45893	25.33925466	315.7	1.16	29.39
11	12.3	12.121203	24.23851824	293.8	1.31	31.84
12	12	12.171735	23.6958823	288.42	1.22	28.91
			279.9996887	3393.24		372.37

The next step of the research is to solve the optimization problem, but this time in a situation where the sea conditions are not constant during the voyage. It means that the weather/ sea conditions are changing over time. It means that a speed change decision is dependent on actual changeable conditions.

I want to construct a directed graph.
every node represent a square in a matrix of mile (distance from start point) and time (time passed from start time)

there is a finite numbers of miles (should be an input parameter) and finite number of hours to complete the voyage (should be an input parameter)

every node has an attribute of "environmental and sea conditions".
the condition for every node, should be managed in an external table to the graph.

the cost of transitioning between nodes, is a function of two decision variables:
- SWS (steal water speed), the natural speed an engine is producing
- sail time of a desired segment , how long do the speed sail in a SWS speed

A dedicated formula, that uses the external condition table,transposes the sws decision into a SOG (speed over ground) result. The multiplication of SOG and sail time, should produce two outcomes:
- the next node in the graph (miles from start point, time from start point)
- cost of transition, a formula that takes the SWS and computes the FCR (fuel consumption rate). The multiplication of FCR and Sail time, is the “fuel consumption cost” of sailing between the nodes, AKA graph weight.

The method of constructing the graph is as follows:
Input parameters:

- Segment length - the distance needed to cover in the same bearing, regardless of the sea conditions. Every segment starts exactly where a previous segment ends.
- Sea conditions for every segment - the sea and weather conditions, for every segment, in a constant time window
- Time window (weather forecast granularity) - the time elapse between weather forecasts
- SOG formula - SOG calculation that derives from a combination of SWS decision, and pre defined weather conditions for the segment
- FCR formula- FCR calculation that derives from a combination of SWS decision
- SWS range (knots)
- Speed granularity (knots)

Graph entities:

- Node: defined by two points (distance from start point, time elapsed from start point)
- Edge:defined by two points (exit node , destination node)
    - Attribute: fuel consumption of sailing between exit and destination nodes

Graph construction algorithm:
1. Create one data structure to log the nodes and a different data structure to log the edges
1. Start at the beginning of the first segment , and construct the depot node (0,0)

2. For the input speed range and speed granularity (after transitioning to SOG):
   - If (remaining distance until next segment / SOG) < time until next time window)
     Than: create new destination_node
     Else: create new time_node

Speed_information = {Min_speed : 11,
Max_speed:13,
Speed_granularity: 0.1}

Segments_table:

Segment_ID	Wind_Direction (œÜ·µ¢)	Beaufort	Wave_Heigh	Current_Direction (Œ≥·µ¢)	Current_Speed (m/s)	Ship_Heading (Œ≤·µ¢)	Segment_Distance (nm)
1	139	3	1	245	0.3	61.25	223.86
2	207	3	1	248	0.72	121.53	282.54
3	9	4	1.5	158	0.73	117.61	303.18
4	201	4	1.5	178	0.21	139.03	298.44
5	88	5	2.5	135	0.49	143.63	280.51
6	86	4	1.5	113	0.22	140.84	287.34
7	353	3	1	338	0.54	136.42	284.4
8	35	5	2.5	290	1.25	110.37	233.25
9	269	4	1.5	270	0.28	102.57	301.8
10	174	3	1	93	0.72	82.83	315.7
11	60	1	0.1	185	0.62	84.87	293.8
12	315	3	1	90	0.3	142.39	288.42

Optimize_route:

Segment	SWS	SOG	Travel_Time	Distance	FCR	Fuel_Consumption
1	12.7	12.36	18.1	223.716	1.44	26.06
2	12.2	11.72	24.1	282.452	1.29	31.09
3	12.2	12.59	24.1	303.419	1.29	31.09
4	12.1	12.11	24.6	297.906	1.25	30.75
5	12.5	12.04	23.3	280.532	1.38	32.15
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12	12.5	12.72	22.7	288.744	1.38	31.33
			280	3394.124		372.62

```
Class optimize_route: (segments_table, speed_constraints,DTA):



        Def load_model(self)
                Return model


        Def solve(self):
                Return (optimize_route)
```