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Optimizing and implementing Vessel arrival system for Coal vessels at Port of Paradip

by

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Abstract

The objective of this paper is to implement a Vessel arrival system for a major Indian port "Paradip" for minimizing waiting time of Coal vessels and reduce vessel operation and demurrage costs. As a result this will improve supply chain efficiency of coal transport.

This study is carried out due to recent huge congestions observed at Port of Paradip due to surge in coal demand particularly for Power sector in India and due to lack of adequate handling facilities & productivity of ports in India. Moreover congestion in port attributes to fleet of vessels being held in port which means less utilization of vessels and as a result loss of earnings & demurrage costs. The method applied here requires adjustment of vessel's speed to most economical speed for a targeted ETA in agreement with all concerned parties, matched with a berthing time of the vessel so as to minimize waiting period at anchorage prior berthing and cargo operations. While proceeding at slow speeds vessel save a lot in terms of fuel consumption and demurrage costs incurred.

The factors which influence the decision of adjusting speed have been taken as independent variable with respect to speed and a multiple regression model is developed to see positive correlation of these factors with speed. For evaluation of cost saved another model under optimization process gives a function of speed. Results of cost savings is shown with economical speeds applied on actual case scenarios of vessels called at Paradip port. Apart from this analysis other inefficiencies and causes of demurrage costs incurred in supply chain have been discussed with possible solutions. However these solutions have been noted to be of long term planning and execution hence Vessel arrival system can be contributed as an only immediate solution to reduce waiting times and resulting cost savings which improve efficiency as well as profitability of supply chain of coal transport in Indian port of Paradip.

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List of abbreviations

AMWELSH	Americanised Welsh Coal Charter Party Form (BIMCO-1993)
BARECON	General Bareboat Charter Party Form (BIMCO-1974)
BDI	Baltic Dry Index
BIMCO	The Baltic & International Maritime Council
BOT	Built-Operate-Transfer
C/P	Charter Party
CEC	Central Electricity Company
DSOL	Distributed Simulation Object Library (A Java based library)
DWT	Dead Weight Tonne
ECI	East Coast India
ETA	Estimated Time of Arrival
GENCON	General Charter Party Form (BIMCO)
GENTIME	General Time Charter Party Form (BIMCO-1999)
HVCCLT	Hunter Valley Coal Chain Logistics Team (Australia)
IEA	International Energy Agency
IFO	Intermediate heavy Fuel Oil
IMF	International Monetary Fund
INMAR SAT-C	International Maritime Satellite Aided Tracking- Standard C
KPMG	Klynveld Peat Marwick Goerdeler (A Global audit, Tax service & Advisory company)
LP	Linear Programming
MCR	Maximum Continuous Rating
MDO	Marine Diesel Oil
MEL	Centre for Maritime Economics and Logistics
MIP	Mixed Integer Programming

MT	Metric Tonne
Mt	Million tonnes
OECD	Organisation for Economic Co-operation and Development
OR	Operational Research
PDPR	Per Day Pro Rata
POLCOAL-VOY	Polish Coal Voyage Charter Form (BIMCO-1997)
PPT	Paradip Port Trust
PWCS	Port Waratah Coal Services
PWWD	Per Weather Working Day
UNCTAD	United Nations Conference on trade & Development
WW SHEX	Weather Working days Sundays & Holidays Excepted

Chapter 1 Introduction to Thesis

1.1 Introduction

The current growth of India's Power sector and requirement of power generation has driven a huge demand of coal in past 4-5 years but due to shortfalls to fulfil this surge in demand there is a great challenge posed by this growing trend of coal demand.

Coal demand is projected to keep growing for next 15-20 years with fast pace of country wide development projects. However due to shortage in domestic coal supply this demand cannot be met hence there is increased imports of coal cargoes but unfortunately there are hindrances for efficient flow of coal supply chain due to poor infrastructure in ports and road/rail networks resulting in delays in cargo handling at ports and lack of capacities disrupting the whole supply chain of coal for use in power generation, steel production and cement production which are the major sectors for development of country and consuming most of the coal. In this view there is need for streamlining the scheduling of coal from producing countries or coal mines transported through ocean going vessels in order to synchronise the coal supply chain in cooperation from producers to users. As infrastructure capacity is limited to handle the increased demand and infrastructure development takes time so optimization or optimal scheduling is the most effective solution for current situation, and optimal scheduling of vessels in port is the major link of this chain, there have been various studies for different supply chains in past on vessel scheduling and berth allocation to minimize waiting times or delays which have been able to get lot of advantage using such approach, This resolution approach is of utmost importance as these supply chain inefficiencies are resulting in reduced throughput, queues of ships giving rise to additional huge amounts of operational costs and increased demurrage leaving dissatisfied coal buyers.

This has prompted lot of new ideas being implemented in supply chains involving various schemes to manage berth allocations & reduce queues using many day-to-day operational decisions making and logistical tools for an optimal solution. In this study also it is intended to apply a similar platform for reducing waiting times using a proposed vessel arrival system in port which can have optimal results for coal supply chain at port of Paradip reducing port and vessel operational costs. The operational models used in the study can be applied in a port operation system to improve these inefficiencies in supply chain of coal while all concerned stakeholders will remain focused in their core business with their necessary contribution.

1.2 Paradip at a Glance

Paradip port is among twelve major ports in India and when it was commissioned and opened in 1966 was first major port on east coast of India. Paradip port is regarded as deepest port particularly for Coal handling in India which is its core strength and makes it a preferred port by deep draught vessels. By virtue of its being a deep water port instead of Kolkata, Haldia, Vishakhapatnam for loading and unloading operations of larger Bulk carrier coal carrying vessels are preferred here. However due to inefficiencies in supply chain, berth allocation and transportation the port productivity is effected which is coupled with the lack of infrastructure and surprisingly shortage of adequate manpower also with respect to traffic flow has resulted and delayed to particularly unload the Coal cargo vessels causing congestion for Coal vessels in Paradip. According to news report by reporter *Amarnath Parida* (2009), who gave in Orissa diary of Business news, due to these congestions during last year Paradip experienced more than 50 ships waiting at anchorage, which incurred berthing delays of more than 10-15 days on an average.

There are two dedicated berths for coal in Paradip and eight general cargo berths which are also used for coal loading / unloading from time to time and due to growing coal demand in India there is tremendous increase in coal vessels calling India. In past year according to traffic data of Paradip port trust (2009-10) and as per report by *Amarnath Parida* (2009), the Congestion at the Paradip Port had increased to all time high, with average waiting time of almost 10 to 15 days to get berth. Although current situation of congestion is not so grim but with expected revival of economy, the growth of energy and steel sector is also likely to reach new heights and in view of that Paradip there are major ongoing projects which involves further deepening of existing entrance and approach channel to handle Cape size vessels of 1,25000 MT DWT on completion of these projects the estimated depth of Port entry channel and harbour approach channel will increase from existing depth of 13.0 meters and 15.0 meters to 17.0 meters and 18.7 meters respectively. Apart from this a concession agreement has been made to construct a deep draught coal vessel berth which is underway and awaiting clearances, The agreement is on BOT (Built-operate-transfer) basis of capacity 10 Million tons per annum, Paradip Port Trust (2009). Therefore in view of above with increased trade and number of vessels calling at Paradip the berth congestion may arise due to lack of capacity and inefficiency of supply chain of coal in the region.

It is evident from the following figure of congestion index that Coal vessels in Paradip on average had to wait about 2.5 days as per data obtained in a period of about two years.

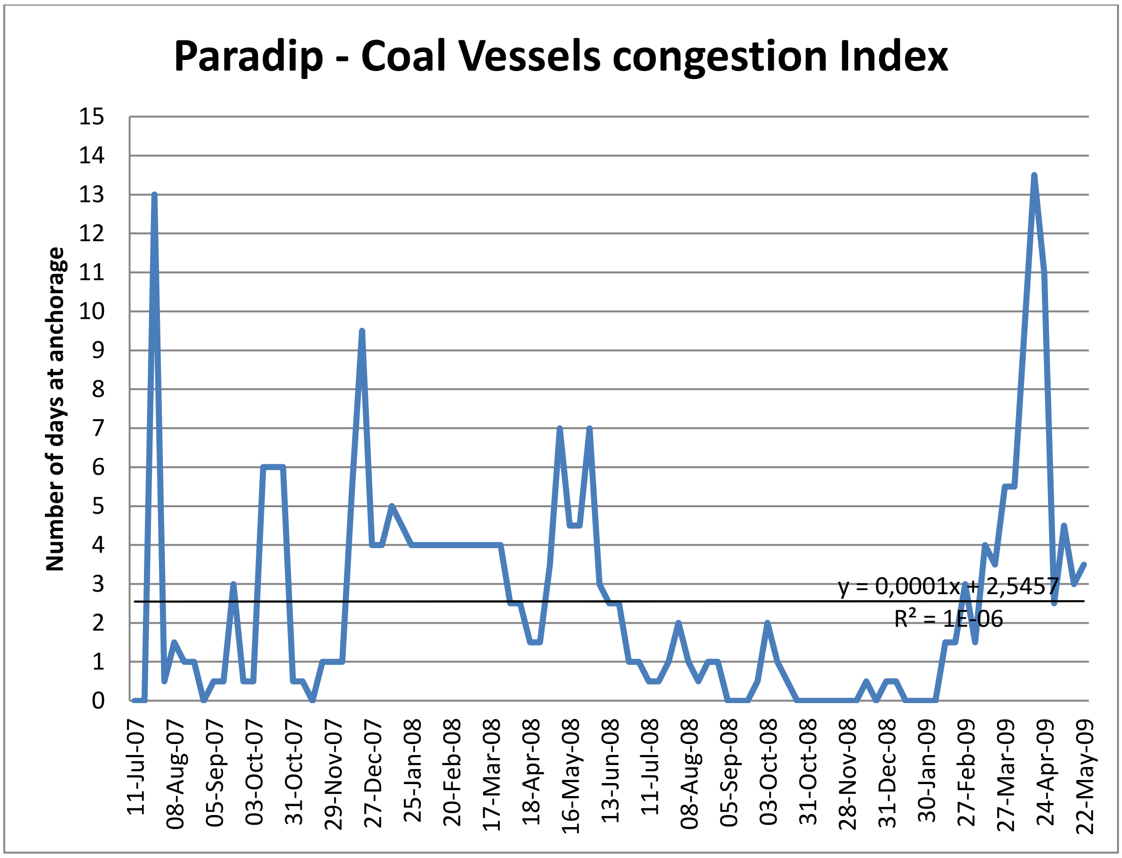


Figure 1: Paradip - Coal Vessels Congestion Index

(Source: Global Ports in association with Simpson Spence & Young Ship brokers**)**

1.3 Research Questions

The thesis investigates how congestion and resulting berth allocation problem in port attributes to long waiting time for Coal carrying vessels at port of Paradip and how the long waiting time leads to fleet of vessels being held in port which means less utilization of vessels and as a result loss of earnings & demurrage costs. The objective of this study reveals implementation of a vessel arrival system in which vessel is tracked and adjusts to an agreed speed en route in order to minimize waiting time and resulting costs as demurrage and at the same time also minimize substantial fuel costs & this is not only a cost effective measure but also improves port productivity and reduces inefficiencies of overall supply chain.

Basis of this study is chosen from a concept from Newcastle Port, which is considered to be world's largest Coal export port in Australia. The concept is aimed to limit numbers of vessels at anchor waiting to enter port of Newcastle and reduce queue of vessels (Vessel arrival system Trial- Policy paper, 2008). Using this concept a further optimization of vessel arrival time as a function of speed is carried out with objective of minimizing the overall costs in terms of bunker fuel costs, demurrages costs and costs resulting from supply chain inefficiencies. Earlier studies also explain advantages of optimization of arrival time for better berth allocation or scheduling. Part of basis in this study is also made from literature on decision for Optimum capacity of a port by El-Naggar (2010), describes application of queuing theory to support decision making process which is integrated in this thesis with a Mixed-integer programming models study by Ronconi & Birgin (2010) for scheduling problems and optimizing. Reference for the basis of study is also made to a study by Golias *et al*, 2009, details optimized arrival time of vessels with minimum waiting times & minimum delayed departures which subsequently help in minimized emissions from vessels in port. The study by Imai *et al*, 2007, evaluated berth allocation problems and developed model to minimize departure delay & total service time. Also there is attempted study on demurrage reduction in coal transportation which is basically due to inefficiencies in supply chain from port to the user end.

Combination of above studies makes the basis for the objective of reducing costs which generates the basic research question of this thesis, which is as follows:

"How optimization of vessel arrival time will achieve a positive impact on waiting times and resultant costs? "

This research question also gives rise to other research questions with regard to better utilization and port or berth productivity and also reducing inefficiencies of supply chain, which are as follows:

"How vessel arrival system will help to improve utilization and productivity?"

"How inefficiencies of supply chain will be affected with controlled Vessel arrival time?"

As thesis progresses in the starting phase effectiveness of implementation of a Vessel arrival system will be checked for Coal Vessels arriving at Port of Paradip, followed by relationship of all cost variables with respect to speed with multiple regression analysis model, a further evaluation of effect on cost with adjustment of speed will be done which will progress into optimization concept and then followed by queuing model managing rate of arrivals of vessels.

1.4 Status of Study

Previously studies have been conducted for berth allocation and scheduling problems with the objective of minimizing delays and terminal operators costs (Golias *et al*, 2009) and minimising delayed departure of vessels & involving maximum berth utilization expressed by reduced total service time (Imai *et al*, 2007).

Apart from these studies there are numerous studies dealing with efficient berth scheduling minimizing waiting time and utilization of fleet and terminal have been done also using the concept of optimization of vessel arrival time with optimal speed & rate of arrival. Solutions obtained from such studies are considered to be quite beneficial in terms of reducing operating cost, fuel cost & minimising emissions produced by vessels.

However there are very few studies which are measuring reduction in costs also on application of these solutions of berth allocation and optimization and also establishing the effects of controlled vessel arrival on supply chain of coal, particularly for an Indian port & cargo specific regional supply chain.

In this study it is intended to specifically see the relative cost effectiveness of solutions implemented under controlled vessel arrival by speed adjustment in agreement with all concerned and how it minimizes the waiting time in port & resulting reduction in operations, bunker and demurrage costs for commercial gains of all concerned parties. At the same time it ensures improvement in utilization and productivity with regard to least delayed departures of vessels and coordinated supply chain.

1.5 Thesis Structure

There are six chapters in this dissertation which are carefully structured. First chapter is Introduction which gives overview of situation at Port of Paradip and elaborates the research questions and their applications in the study. Chapter 2 illustrates the role of Coal and its supply chain from Global and India's prospective and also explains Supply chain of coal for port of Paradip. Chapter 3 discusses all previous related literature referred for this study. Chapter 4 details research methodology and models used for solutions to obtain results for minimizing delays for coal vessels calling at Paradip and evaluating profitability of the chain. Models use multiple regression analysis, optimization model and queuing theory for respective evaluations. Chapter 5 gives results and analysis. Last Chapter 6 is conclusions of the study mentioning all findings of this research and further recommendations.

Chapter 2 A Global Overview of Coal & its supply chain at Paradip

2.1 Coal Situation Overview - World

Coal is one of the Non renewable fossil fuel & energy sources which is in most abundant form than other fuels and Coal reserves are much widely spread. As per "*World coal institute"* records the coal reserves with recoverable reserves exist in 70 countries worldwide and coal reserves are likely to last more than other fossil fuels. It is estimated that Coal reserves will last 122 years whereas oil and gas reserves will last about 42 and 60 years respectively at current level of production. Oil & gas reserves are mostly concentrated in regions of Middle East & Russia which is almost 67% of oil and 66% of gas. (World Coal Institute, 2008).

There has been a steady growth of seaborne trade of coal, the estimated data indicate the seaborne trade of Thermal Coal has shown a growth rate of 7.5% per annum and average growth rate of coking coal is about 1.8% per annum as we can see in the following table.

Table 1: Growth of seaborne trade of Coal

	Steam Coal		**Coking Coal**	
	Atlantic	**Pacific**	**Atlantic**	**Pacific**
1986	74Mt	59Mt	61Mt	81Mt
1996	125Mt	139Mt	70Mt	103Mt
2006	240Mt	330Mt	72Mt	129Mt

(Source: Simpson Spence & Young Ship brokers**)**

If we look at the supply of energy source the Coal is the primary source and in most abundant form as compared to all other non renewable or renewable energy sources. It is also most widely used source in power generation. The current trend also estimates the coal as the major source of energy worldwide even though there are environmental concerns are there as new technologies will come in force in due course such as carbon capture system which will reduce its environmental impacts.

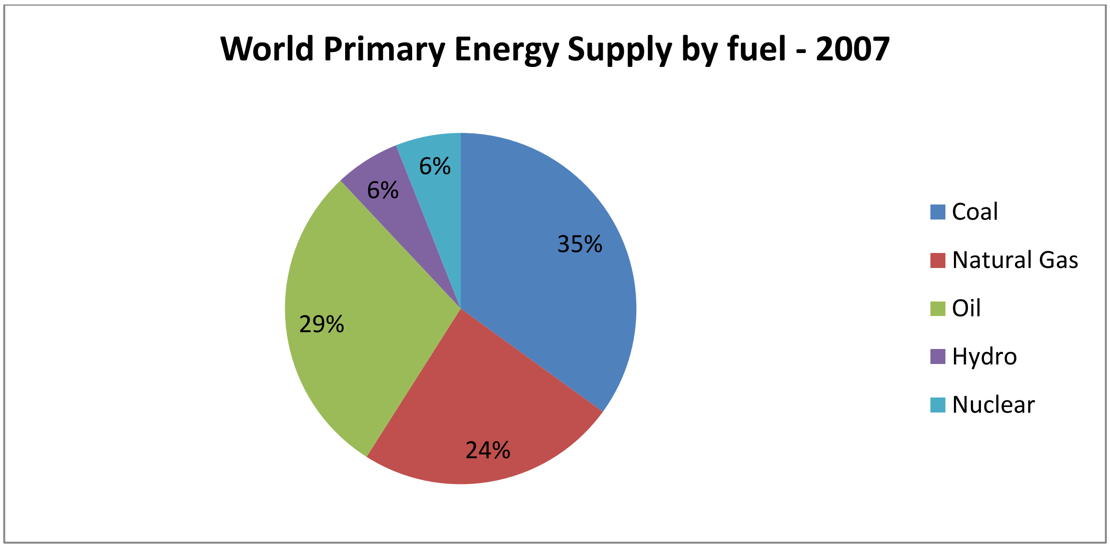
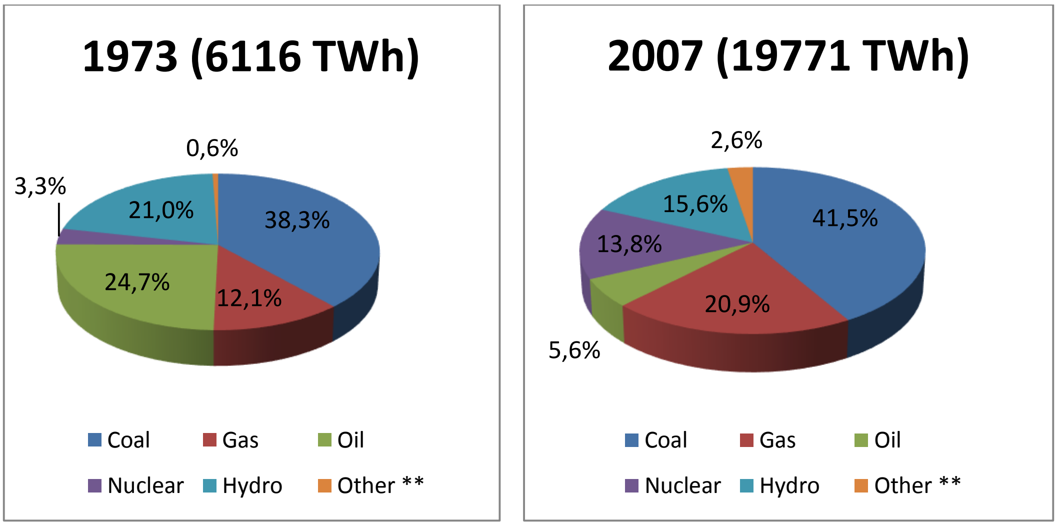


Figure 2: World Primary Energy Supply by fuel - 2007

(Source: BP statistical review of world energy 2008 / 2nd India Coal Summit Oct 5, 2009**)**

Worlds 41.5 % of electricity (2007) is produced by coal fired power plants only(International Energy Agency statistics- 2009) and the major consumer countries being China, USA, India, Japan and Russia which amount to 72% of total generated electricity by coal alone (World Coal Institute / 2nd India Coal summit, 2009). Steel production is other large sector which depends on coal, almost 70 % of worlds steel production depends on Coal (World Coal institute / 2nd India Coal summit, 2009). If we see evolution of world electricity generation from 1973 to 2007, by fuel Coal is predominantly the major source of electricity generation as shown in following figure.



** Other includes geothermal, solar, wind, combustible renewable, waste and heat

Figure 3: Electricity Generations by Fuel 1973 & 2007

(Source: International energy agency – key world energy statistics 2009**)**

Coal demand until 2030 is expected to grow at average rate of 2% per annum which is comparatively faster than overall energy demand. It is estimated that 97% of the global increase in demand is in Non OECD countries alone with China and India being major demand centres of which China accounts for two third of the increase and India about 19%. This rising demand means India will double its production (International energy agency – World energy Outlook, 2008 p-125). In following table we can see reference figures for coal demand worldwide.

Table 2: World Coal Demand (Million tonnes of coal equivalent)

	1980	2000	2006	2015	2030	2006-2030
OECD	**1373**	**1566**	**1627**	**1728**	**1703**	**0.2%**
North America	571	832	839	895	959	0.6%
United States	537	777	787	829	905	0.6%
Europe	657	467	472	491	418	–0.5%
Pacific	145	267	316	342	326	0.1%
Japan	85	140	161	164	153	–0.2%
Non-OECD	**1181**	**1714**	**2735**	**4019**	**5308**	**2.8%**
E. Europe/Eurasia	517	295	307	356	386	1.0%
Russia	n.a	158	152	201	233	1.8%
Asia	572	1249	2238	3415	4634	3.1%
China	446	899	1734	2712	3487	3.0%
India	**75**	**235**	**318**	**451**	**827**	**4.1%**
Middle East	2	12	13	20	36	4.4%
Africa	74	129	147	174	175	0.8%
Latin America	16	29	31	55	77	3.8%
World	**2554**	**3279**	**4362**	**5746**	**7011**	**2.0%**
European Union	n.a	459	463	460	372	–0.9%

(**Source:** International energy agency – World energy outlook, 2008, p-127)

2.2 Coal Situation Overview - India

Coal is very important source of energy in India and main driving source of Power generation, although in terms capacity of power generation which stands to be of about 152 GW (as on 30th September 2009 – Power sector, India KPMG India report) India is fifth largest country in the world but average production to its demand ratio is very low as compared to developed and emerging nations & it is essential for growth of India to increase capacity by producing and importing huge amount of coal in order to meet rapidly growing demand for Power and steel sector. There are lot of projects in pipeline but there is need expediting their execution which is definitely not an easy task due to long investment decisions & policy making process, delays in approvals, signing of agreements, release of funds, equipment shortage, adequate manpower shortages and so on all these factors have always been a major hindrance for development in India. The government system in itself is very complex for expediting the projects. Apart from the projects the transport / supply chain of Coal is also very inefficient which makes it difficult to even handle the current production and imports so the first solution that comes to mind is optimizing this supply chain as first task because even if projects execution is expedited but supply chain is still inefficient then it does not solve the purpose and will become a big hurdle for utilizing the available sources also. The most practicable approach in this stage is to minimize delays and disruptions in the processes of the coal supply chain. This can be achieved by better schedule management & procurement by involving all concerned parties (all Stakeholders) with their clear understanding and a common goal of optimizing the whole supply chain by minimizing delays with due regard to profitability & growth of supply chain.

Present situation of Coal supply chain is grim and situation is getting worse due to shortage in coal stocks for power sector, steel sector, cement sector and all other sector which use coal for production. Due to this fact there is need for effective management of transportation and production, the constraints in transportation have led to mismatch of demand and supply and demand is ever growing as we can see in the figure below.

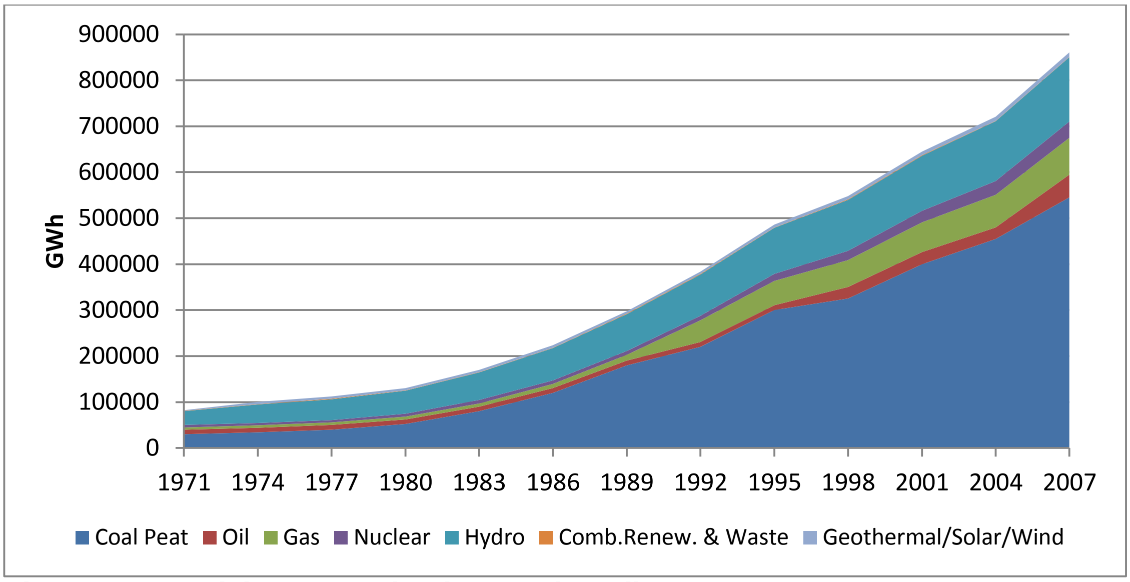


Figure 4: Electricity generation by Fuel in India

(**Source:** International Energy Agency, 2009)

2.3 Role of Coal supply chain in Paradip

As Paradip is in close proximity to Coal mines and there are number of steel plants in Orissa and neighbouring states of Jharkhand, Chhattisgarh, North West Andhra Pradesh and West Bengal etc. Due to this Hinterland and catchment area Paradip has a vital role in Coal supply chain and with its potential of deep draft and being a major port can play a significant role in Supply chain. However there are lot of missing links in transportation and its hinterland connectivity which need to be improved for Paradip to gain its competitive edge.

Thermal coal Supply chain of Paradip originates from Talcher & IB Valley Mines and this is very important coal supply chain corridor in India most of the Thermal coal from here is routed to State of Tamilnadu and Karnataka for their state electricity boards and Paradip is most economical port to route their cargo also Thermal coal imports are routed from Paradip with increasing demands. Cheapest route distribution of coal from Orissa to TN is Paradip-Ennore (Transcare-Business development plan Paradip p-125). The detail cost analysis is as follows:

The existing routes to TN (with landed cost)
- Talcher – Paradip – Tuticorin (Rs. 1450/t)
- IB valley – Vizag – Tuticorin (Rs. 1,874/t)
- Talcher – Paradip – Ennore (Rs. 1,350/t)
- IB Valley – Paradip – Ennore (Rs. 1750/t)

However due to transportation problems sometimes despite of being most economical route the other routes are also chosen which are mainly due to railway rakes problems. Hence in order to be competitive it is important for Paradip to improve their efficiency which as a starting point can be done by implementing a Vessel arrival system and utilizing capacities.

Similarly Paradip has vast potential for Coking and Non Coking Coal for steel industry as neighbouring states of Chhattisgarh and Jharkhand are major hub for steel plants and Paradip with its proximity and hinterland is also a competitive port in this sector. High handling capacity is the key element for Paradip to gain competitive edge in this sector and for which once again Vessel arrival system can be quite beneficial. Besides there are various ongoing projects to improve hinterland connectivity in rail links and road infrastructures, which needs to be expedited.

Paradip port has a major role in Coal supply chain in India and accounts for significant coal flows of Thermal, coking & Non Coking coal. According to data obtained for Coking coal imports we can see in the following table that Paradip accounts for maximum amount of coking coal transported through here.

Table 3: Coking coal imports for major Indian ports (Figures in MT)

Port	Coking Coal					
	August 2008	September 2008	October 2008	November 2008	December 2008	Port Total
Kolkata/Haldia	451,895	403,886	275,735	274,159	449,535	***1,855,210***
Paradip	325,918	652,156	799,165	352,244	443,542	***2,573,025***
Ennore	0	0	0	0	0	***0***
Chennai	111,650	50,766	0	0	27,766	***190,182***
Tuticorin	0	0	0	0	0	***0***
Mangalore	0	55,095	63,773	0	0	***118,868***
Goa	0	307,594	338,829	184,458	194,270	***1,025,151***
Mumbai	160,609	132,450	267,914	356,606	324,673	***1,242,252***
Vizag	724,974	595,743	467,282	469,308	715,406	***2,972,713***
Navlakhi	519,369	123,453	0	0	0	***642,822***
Porbander	36,595	35,193	0	25,000	19,372	***116,160***
Bhavnagar	0	0	0	0	0	***0***
Pipavav	0	123,147	0	0	14,187	***137,334***
Cochin	NA	0	0	0	0	***0***
Mundra	56,124	261,521	0	0	0	***317,645***
Bedi	NA	65,047	0	114,517	0	***179,564***
Kandla	NA	0	0	0	0	***0***
Magdalla	NA	0	0	0	0	***0***
Dahej	NA	0	0	0	0	***0***
Total	***2,387,134***	***2,806,051***	***2,212,698***	***1,776,292***	***2,236,169***	***11,418,344***

(**Source:** Coal Insights, India Coal Market Watch issue 30 Dec 2008, mjunction services limited)

In recent past even the trend of overall growth of Paradip as compared to other major ports in India also remains quite significant including other commodities as reflected commodity wise traffic in Appendix 1.

Chapter 3 Literature Review

3.1 Literature on Vessel Arrival System Implementation

There are numerous studies on vessel arrival distribution which are attempted for Container terminals and Ports but very few studies for Coal cargo and specifically a port in Indian subcontinent. Hence this study will address the vessel arrival system for coal vessels at one of the major port on east coast of India, Paradip. This study is of vital importance for inefficiencies with regard to prolonged waiting times and as Coal being the most abundant source of energy for a country's growth specially India which is putting up a remarkable growth in recent years and has a huge demand for coal in coming years.

A concept of Vessel arrival system has been implemented at Newcastle Port, a largest coal export port for coal vessels to reduce waiting time at anchorage in order to improve safety and adverse environmental effects. This is also intended to optimize Hunter valley coal chain for efficient operation. This measure effectively controls the congestion and reduces the number of ships, waiting at anchor, in the queue also reduces the risks to the ships, the port and the environment (Vessel arrival system policy paper p-52- Newcastle Port Corporation). There are additional benefits from this system with regard to demurrage costs, which under agreement are paid by coal producers. Hence a reduction in the ship queue can benefit with reduced demurrage costs (Vessel arrival system policy paper p-60- Newcastle Port Corporation). The concept uses speed reduction where vessel transits to the Port of Newcastle at the optimal fuel efficient speed with positive benefits this arranges queue of vessels according to cargo & berth availability making supply chain efficient.

3.2 Literature on Berth Allocation and scheduling problem

Golias *et al* (2009) presented a model to optimize dynamic vessel arrival time using a berth scheduling policy with resolution algorithm for the discrete berthing space. The study was carried out with the objective of minimizing waiting time which will reduce consumption of fuel & emissions from vessels in port.

In berth scheduling problems there is random arrival of vessels at a port for loading or unloading of cargo and the berth allocation is done by Port or terminal taking several factors and considerations into account, Theofanis *et al* (2009). In vessel scheduling problems there are three main types of problems as follows :

(1) The continuous versus discrete berthing space

(2) The Vessel arrivals - dynamic versus static

(3) The Vessel handling or service time – dynamic versus static.

In case of discrete berth allocation, Imai *et al* (1997, 2001, 2003, 2007), Hansen *et al* (2008), berth is considered to be a finite set of berthing space, whereas in case of the continuous problem Kim and Moon (2003), Park and Kim (2003), Guan and Cheung (2004), Imai *et al* (2005), Moorthy and Teo (2006), vessels can be berthed anywhere along the berth, in case of static arrival problem all vessels are considered to be already in port, hence the dynamic arrival problem is more practical and adopted in most of the literature, the study considers to have all vessel which are to be assigned berths at a scheduled time, arrived at the time when scheduling begins, Vessels ETA's used in model are known well in advance. Finally, the vessel handling operation time in the static handling time problem is considered to be known, Imai *et al* (1997), Hansen *et al* (2008), whereas in the dynamic, Park and Kim (2003), Imai *et al,* (2008) the handling time is variable. Prior to this study by Golias *et al* (2009), environmental factor was not included in other scheduling and vessel arrival time studies. Hence using mixed integer optimization model total waiting time & delayed departure of vessel is minimized with variable arrival time. The complexities in the model is solved by using Genetic Algorithms (GA) based heuristic (Golias 2007) and results produced proved that where a vessel arrival time is decided it can be more beneficial.

3.3 Literature on service time and delay time objective

The literature of Imai *et al* (2007) discussed berth allocation problem with objectives of service time and delay time. The study addresses a berth allocation or scheduling problem for minimizing ship service time & delayed departure time. Berth utilization is expressed by minimization of total service time. The study used procedures of sub gradient optimisation and genetic algorithm for solving the problem. The study uses dynamic version of berth allocation problem discrete and referred to previous studies employing genetic algorithms to solve problem which extended in Imai *et al* (2003) order to treat vessels with different priorities & it examines how berth allocation or scheduling differentiates ship handling with regard to its service time. Later study by Imai *et al* (2007) applies multiple ship treatment, same as applied by Nishimura *et al* (2001).

For objective of customer satisfaction which relates to delay in departure time it refers to Park & Kim (2002) for the model and for the objective of terminal efficiency it refers top models on minimisation of service time. Both objectives are taken independently to avoid complexity this is proved by using weights based on ship size, type etc by checking relationship of total service time and delayed departure time. The study then approaches formulation using discrete Berth allocation problem with basis of Imai *et al* (2005a, b) using certain set of assumptions, however it is expected that the problem of the minimising weighted delayed departure & total service time may give non inferior & complex solutions, therefore for the single objective berth allocation problem this study implemented two heuristics based on existing procedures, sub gradient optimisation with the Lagrangian relaxation and the GA based heuristics, Imai *et al* (2007). the results provided in this study can be useful for terminal operators in decision making.

3.4 Literature on solving scheduling & Cargo routing problem simultaneously

Agarwal & Ergun (2008) came out with a concept in case of liner shipping which used simultaneous ship scheduling and cargo routing problem. Their study involves optimization based decision support system for fleet management for a demand of cargo to be transported within given set of ports efficiently and in cost effective manner. For the purpose of solving ship scheduling and cargo routing problem they used a mixed integer linear programming taking into account the relevant constraints. Reference in this study was made to Ronen (1983) for this type of work done prior to 1983 and for work done in decade 1982-1992 it referred to Ronen (1993) and finally for the latest literature reference is made to Christiansen et al. (2004). Reference for linear programming made to Rana & Vickson (1991) a non linear integer programming used for maximization of profit. Perakis (2002) provided a review of Linear programming models to minimize operating and lay up costs. The main constraints used in the model are weekly frequency in the network and transhipment cargoes between two or more service routes. This study implied to, a technique of column generation based algorithm and a two phase benders decomposition based algorithm for solving mixed integer program known as, Greedy heuristic. For generating schedules an efficient iterative search algorithm used. Results of the study gave high percentage of capacity & vessel utilization and also high amounts of transhipments.

3.5 Literature on Tanker Vessel scheduling problem

Brown *et al* (1987) solved scheduling problem using an elastic set portioning problem for transportation of crude oil. The primary objective of this study is to minimize the fleet operation costs including demurrage costs using scheduling decisions. First comprehensive review of ship scheduling and routing problem was given by Ronen (1983) which was used as basic. Discrete scheduling decisions for minimising costs were formulated by integer programming. Problem formulation done as elastic set partitioning problem.

3.6 Literature on Bulk carrier Vessel arrival & Queuing problem

Jagerman & Altiok (2003), carried out study on Vessel arrival process and queuing in ports handling bulk cargoes. Basis of study is queuing problem of bulk carriers waiting for their turn of loading or unloading at a bulk port or terminal. The study takes into account the factors on which vessel arrival patterns depend. First vessel arrival process is studied and then queuing behaviour using a SHIP/G/1 queue. Basis of computations and expressions used was as shown by Cox & Lewis (1966) for sequence of vessel arrivals and number of vessels in port or queue and it also uses Techebyscheff inequality Bucklew (1990).

3.7 Literature on Ship arrival time distribution & queuing theory applications

Kuo *et al* (2006), conducted a study of inter arrival time distribution of container ships. This study attempted to find flaws of applying queuing theory for ship arrival time distributions. This study emphasise that past studies have taken into account only a particular berth or a terminal etc. whereas for arrival time distribution whole port system should be taken into account which is identified in this study. As per this study, there is a common misunderstanding that the arrival time distribution of a periodical container ship liner is a deterministic distribution. The port system is segmented as single shipping line, single berth, single container terminal, and entire port, to implement the goodness-of-fit test and analyze the container ships arriving during a unit of time. This study also investigates the evolution of the ship arrival distribution pattern by observation systems. This study also implements tests for dedicated and public container berths by comparing the variance in the patterns and characteristics of their ship arrival distributions. Study uses probability distributions patterns of Gamma distribution, Erlang distribution and exponential distribution and for test approach it uses Chi squared goodness of fit test and Kolmogorov-smirnov test, test results are obtained for the all port subsystems and the entire port.

3.8 Literature Optimum capacity of a port applying queuing theory

El-Naggar (2010) study describes application of queuing theory to support decision making process for Alexandria port in Egypt. The objective of study is to have optimal port facilities without over or under building and achieve minimum port costs. Model uses Queuing theory for waiting times and vessel arrival time service times are obtained with distribution. The methodology determines the pattern of ships arrival by queuing theory basis findings optimum number of berths to be in port is determined so that port usage costs are minimised. Further development or investment strategy of port can be on the basis of this concept. Waiting line model is applied to analyse ships movement which involves arrival rate or pattern of ship in port and its service time which is also variable depending on quantity of cargo , size of ship and handling capacity. Queuing theory is used as an important tool for ships waiting in port as ship handling is multiple operation system (Branislav and Nam, 2006). First step in modelling involves the ship arrivals which are random as well as scheduled for which a Poisson function is used in next step modelling of service time is done using Erlang distribution, now queuing phenomenon is established as exponential distribution for arrival and service time and also with exponential arrivals and a constant service time but for multi berths and exponential arrivals and multiple exponential service mathematical solution is not feasible so only the established feasible queuing phenomenon is used as mentioned above. The method used is as per queuing model Wen-Chih *et al* , (2007). After queuing model result is obtained port capacity is analysed and optimum capacity with respect to port costs is determined. In order to apply the concept and models data of port is used and optimum numbers of berths are computed for a port.

3.9 Literature on Vessel arrival planning strategies using simulation

Lang & Veenstra, (2009) studied managing the variance in vessel arrival and handling taking into account different cost components and dynamics and came out with quantitative arrival planning strategies. Arrival scheduling simulation is used in this study to analyze arrival planning strategies. Delays in terminals have considerable cost component and for that purpose this study considered approach based on controlling speed of approaching vessels taking into account all financial consequences of speeding up and slowing down hence it integrates operations of ship arrivals and terminal using simulation where arrival pattern of vessels is controlled by optimization. The basic starting point of the study is from idea that terminals should not be planned in isolation but should take into accounts operational efficiency of their users, UNCTAD, (2005, p.9ff). The study refers to Stahlbock and Voß (2008) for an elaborate review of OR applications in container terminals. For a qualitative analysis of delays Notteboom (2006), but these past studies do not offer an integrated analysis. Kia et al. (2002) also offer one of simulation studies of terminals, but they only consider a standard ship arrival process. This study involves ship arriving at random, and the use of an optimizing control mechanism to improve arrivals at the terminal is a new contribution to the literature on container transport logistics basis of which was taken from a previous analysis by Veenstra and Lang (2005). In simulation model arrival pattern is taken of scheduled ships arriving with delays and then ships are communicated to adjust speeds either increase or decrease to arrive just in time for available berth. Which saves fuel costs and waiting time in port is reduced. Waiting time is also considered as an opportunity cost of carrying other cargo if that time is saved. The simulation model is a java based DSOL libraries, Jacobs *et al,* (2002). Study applies Arrival planning strategies minimising system costs using mixed integer program, Nemhauser and wolse, (1988) aspects of arrival planning, centralised & Decentralised are considered former being when there is exchange of information and later being when there is limited exchange. The study concludes approach by simulating ship arrivals and integrating with optimization model and explains coordination between lines and terminals for added benefit of flexibility.

3.10 Literature on Demurrage reduction in hinterland transport of Coal

Bhatnagar et al, (2004), conducted this study to reduce demurrage costs of a Thermal power plant in India which are incurred due to delays in the coal receipt process; these are demurrage costs to wagons of Indian railways as they cannot be released in time after unloading. The objective of study is to analyze the causes of demurrage in coal receipt process and reduce the demurrage costs. The study refers to branching and bounding processes by Yamakawa (1991), a finite queuing system by Chelsst *et al* (1981) and describes a simulation for optimal route by waters & Ash (1991). It concentrates on coal receipt process and determines causes of demurrage in the process. Modelling involves first establishing a correlation between factors causing demurrage using regression analysis. Factors which show a high correlation are considered as main cause, and then model applies queuing approach using arrival process of rakes, service rate, number of servers & waiting size. A simulation is carried out dealing with service capacity and arrival pattern and there effects are seen. The results showed the need for improving internal processes in coal receipt by distribution of arrivals of rakes and service time improvements.

3.11 Literature on congestion problems at Paradip

3.11.1 Lack of berthing capacity

The berth allocation problem at Paradip is contributed from congestion experienced at the other ports on east coast mainly Haldia; and coal vessels calling on east coast of India preferred to call at Paradip for cargo operations as being deep draft port and its proximity to related industry consuming coal. To avoid congestion of berths, there is requirement of constructing additional berths but process is quite slow. Shortage of staff also adds to the berth allocation problem like less number of Pilots & mooring staff available to expedite berthing / un berthing operations for vessels coming to load and unload which is also a cause of concern and requires steps to be taken to increase the number of pilots and other staff in Paradip port. Though Paradip port trust is known to have sent proposal to concerned ministry for expansion of this port but still waiting for concrete solutions in this matter.

From the reported sources and as interviewed Paradip port officials by *Amarnath Parida* (2009) it was expressed that due to growing demand of coal the port is of vital importance and large number of vessels are calling the port however due to limited capacity in port berth allocation problems exist and ships have to wait to get berth in this port

3.11.2 Shortage of manpower & Lack of mechanical equipments

During monsoon season with rains there is reduced output of cargo handling operations as manual labour is also involved and there is shortage of adequate man power hence installation of mechanical cranes is necessary to increase productivity. However, it is noticed that the costs of mechanical equipments used for loading or unloading of coal if compared to the neighbouring ports are also high which is also a cause of concern & a deterring factor for shippers or receivers to use equipments for their ships at high costs.

The other important factor is that port suffers from shortage of manpower. According to an interviewed report by Amarnath Parida (2010) as of beginning 2010 the strength is known to be about 2,800, By 2013 which is expected to decline up to 2,000. The Port statistics show a large number of people will be retiring in the next couple of years which entails need for immediate recruitment of about 1,000 people at various positions. But these openings cannot be filled immediately as there is a Government restriction on recruitment for time being.

3.11.3 Scarcity of Railway rakes

Due to scarcity of railway rakes the coal stocks are being piled up in Paradip port which is resulting in ships delays or at times even some of the ships are being diverted to other neighbouring ports as unable to accommodate them due to limited number of railway rakes available for clearing coal stockpiles in port, which creates accumulation of coal despite huge demands and then there is hardly any space left to store more coal cargo.

According to a news report of Dec. 30, 2009 reported by a correspondent *Santanu Sanyal (2010)* Paradip Port Trust is unable to accept any more coal ships in view of the huge built-up of coal stocks within port premises, which is estimated to be more than two million tonnes.

Looking at India's Rapid growth and huge thermal power demand, this is a matter of deep concern for development of country as Thermal power stations, steel industry and some other major sectors including coal trading companies who are dependent on coal imports through ports.

The main reason for railway rake shortage has been caused by late arrival of iron ore rakes at the ports as recently the government of Orissa followed a crackdown on illegal mining and pilferage of iron ore in the State's Keonjhar and Nayagarh districts, which halted mining, loading and transportation activity of iron ore from these districts. Subsequently this has lead to less number of iron ore rakes arriving at the ports. Generally same rakes which are arriving in ports with iron ore for exports are used for back-loading of imported cargo, mostly coal, and this gives rise to difficulty in evacuating of cargoes out of the ports.

3.11.4 Accumulated stock

According to statistics of Paradip Port Trust (2009) & a correspondent *Santanu Sanyal (2010)*, there has been huge accumulation of Coal at Paradip, It was estimated to be almost about 1.5 million tonnes (Mt) of imported coal about 0.6

million tonnes (Mt) for power houses and approximately another 0.3 million tonnes for steel plants and the balance for traders. This accumulation mainly accounts Coal cargo of Steel Authority of India Ltd. and for various major companies such as Vedanta, Tata, Adhunik, Jaiswal Nicco and some other plants located in western Orissa.

If Railways ensures there is smooth & timely movement of railway rakes to ports for evacuation of accumulated coal stocks then to an extent this problem can be mitigated. But for that Railways need to move lot of empty rakes which according to railway officials if empty rakes are placed in ports very often on large scales then it is in their interest, particularly during such times when the demand for wagons is high. Due to such reasons there is need for implementation of systems like Vessel arrival system.

3.11.5 Delayed Projects

Essar, one of the major company in India has signed a deal with Paradip Port trust basis BOT concession agreement for about 8.7 million USD coal berth, this project will be named as Essar Paradip Terminals Ltd., as reported by Paradip Port trust (2009) & IANS (2009), to construct a deep draught coal berth, This coal berth will be developed by the concessionaire in 36 months as stated by the port authorities. The project is marked under a special purpose vehicle formed by Essar Shipping Ports and Logistics Ltd and Essar Shipping and Logistics Ltd, Paradip port trust (2009). Once this Coal berth project completes, the estimated capacity addition to the port will be 10 million tonnes per annum. In this venture Paradip Port Trust will be providing supporting facilities with regard to dredging of channel, railway connectivity and back up operations area at an estimated cost of 1.5 million USD. During it's term of 30 years the concession agreement also includes a revenue share of 31 percent to the port.

The dredging of the channel is already in progress, it is announced by Paradip port trust (2009) that depth of the proposed channel and berth will be 17.1 metres which will facilitate handling cape size vessels up to 1,25,000 DWT.

The port is also facing a challenging task of inefficiencies of coal supply chain. An estimated capacity of 20 Mt is created for handling coastal shipment at a huge cost, but the capacity utilisation presently is hardly 50 per cent.

These Coal chains are decided by jointly by Coal Ministry & Railway Ministry. Tamil Nadu Electricity Board has agreed to take 35 million tonnes of Telcher coal annually through port of Paradip, for which Paradip port trust approached both, but approval is taking long time.

3.11.6 Paradip port projects waiting for eco clearances

As of June 15, 2010 the above project Pending environment clearances has led to delays in the implementation of this BOT project at Paradip port. The work involves construction of deep draught berths for handling coal. The stipulated 180 days have elapsed but the necessary clearances are yet to be availed. The final approval is yet to come from the Union Ministry of Environment and Forests.

3.12 Summary on Application of Literature findings

Apart from all literature briefly explained above numerous studies on vessel scheduling and berth allocation problems have also been consulted. Based on above studies & research conducted previously as a first step this study incorporates and proposes a concept of implementation of Vessel arrival system at Port of Paradip, which is established with cooperation & agreement of all parties for a common goal of reducing operation costs which requires tracking and communicating with vessel to adjust speed according to the berth availability. Understanding of charter party important clauses, charter hire rates, freight of coal cargoes and demurrage costs etc is of utmost importance as it may involve legal implications if not addressed properly hence study elaborates important factors required to be considered for decision making process.

In second step which is decision making process for deciding reduction of speed to match targeted arrival time with minimum waiting time in port, It is intended to apply multiple regression analysis to find correlation of all cost factors with speed. Once a positive and large enough relationship is established Queuing theory is applied to calculate waiting times based on modelling of vessel arrival times and modelling of vessel service time distributions.

Next step involves optimization using mixed integer linear programming taking into account relevant cost and delay factors. This helps in determining optimum speed.

The optimum speed obtained is applied on actual case scenarios of different size bulk carriers carrying coal cargoes to Paradip are taken in consideration and reduction in their operation costs by adjusting speed is determined.

Chapter 4 Research Methodology & stages of Vessel arrival system

4.1 Paradip's market share

Paradip being one of the deepest ports in India has potential to accommodate expected growth of Coal and other bulk commodities, as we can see in the table below Port of Paradip has posted robust figures particularly for handling coal Paradip reflects largest volumes in India, this has been the trend in past 2-3 years and is expected to grow in future.

In coal supply chain Paradip has largest market share in India among 12 major ports as we can see in the figure below. Although projections show slight downfall over years which is due to development of new private ports within the region in coming years , however Paradip will still hold the largest share and quite significant amount of Coal flow and Paradip will retain the status of main coal handling port in India.

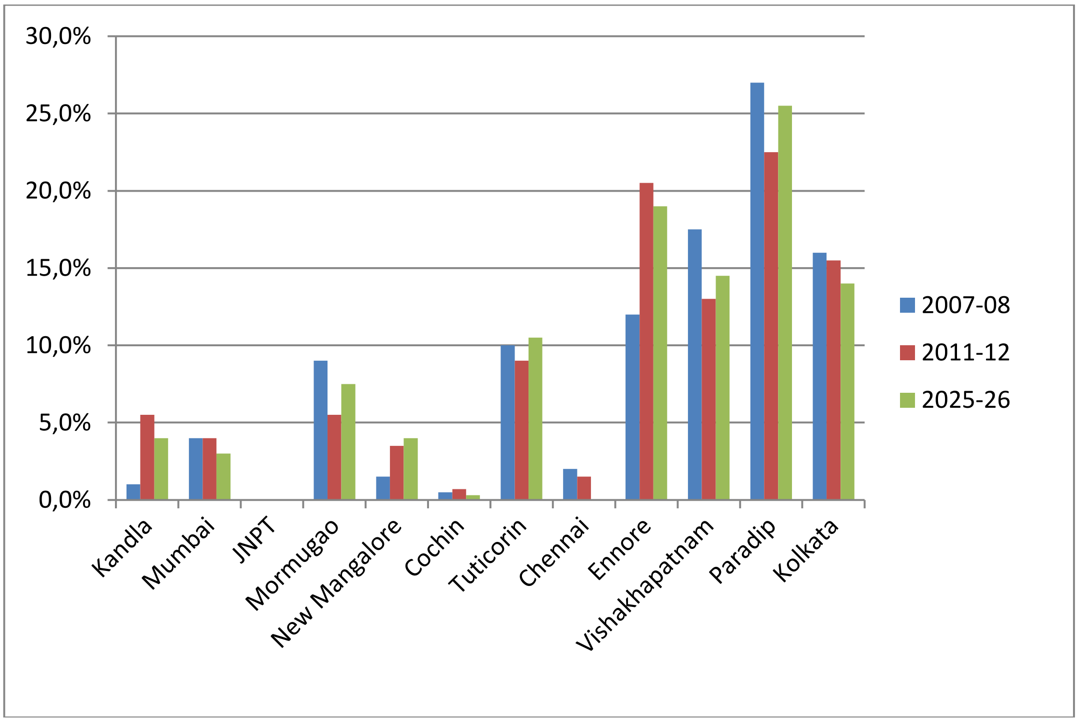


Figure 5: Market share per Major Port in handling Coal

(Source: Coordination of business plans for major ports in India Volume 1 Main Report, final version Prepared by Port of Rotterdam Authority, September 2007**)**

However there is challenge faced due to inadequate handling Coking, Non coking and Thermal coal flows, particularly for coking & Thermal coal as operational productivity is low and internal logistics system is not efficient for want of major constraints of inbound evacuation as customers are not able to evacuate the cargo with existing railway facility to clear the rakes this in turn delays vessels berthing and also there is not sufficient berthing capacity & Crane handling capacity to meet projected demand in future creating berth allocation problems leading to vessels long waiting and generating excessive demurrage costs which is borne by customers for waiting vessels and loaded railway wagons waiting to be cleared.

4.2 Projected Growth of Coal at Paradip & Challenges

The present situation of coal flows is posing capacity and berth allocation problems we can imagine what will happen in future when projected growth of coal chain during next 17 years in Paradip is increasing significantly as shown in figure below.

Figure 6: PPT Coking Coal - Demand Projection

(**Source:** Business Plan Development for the Paradip Port Trust – Final Report by Trans Care Logistics India Pvt. Ltd.)

In India long decision making process and expansion constraints are the key challenges for port to be efficient and competitive with minimum waiting for vessels.

Although there is business development plans of some existing projects targeted to meet the growing demand in coming future but there is no immediate solution as these projects are bound with Government decision making and clearances, the allocation of money for projects is time and phase linked and also have dependency on few major players or customers and hinterland connectivity of railway and road network & their operations.

Although in long term expansion projects can be beneficial with respect to expected growth however to solve present situation of vessels having berth allocation problems and reduction of long waiting at anchorage is only possible with proactive measures in cooperation with all parties of supply chain which can give optimal utilization of existing port facility and reducing total supply chain cost and also keep the port competitive enough.

The most effective method for immediate solution to the berth allocation problem and reducing anchorage time for coal vessels and subsequent demurrage costs for customers is based on concept of “Vessel Arrival System” which has been successfully implemented at Port of Newcastle in Australia. Vessel’s Arrival system Manages arrival time of vessels by slow steaming or proceeding at economical speed from origin port to destination port so it reduces the need for vessels to anchor and wait for turn or reduces anchorage time and it helps in reducing demurrage costs for vessel as well as rail wagons as ships berthing can also be coordinated and planned according to cargo in stock pile and possibility of clearing of railway rakes.

4.3 Implementation of Vessel Arrival System

For effective implementation it is important that all parties in supply chain or interest have agreement for commercial and contractual issues with regard to this.

In order to have clear understanding it can be implemented in phased manner so as to demonstrate and evaluate the proposed system.

Under existing system vessel are served at Paradip as first come first served basis according to their turn although queue of vessels guarantees high berth occupancy rate for any port but if queue is large it drops productivity and gives rise to berth allocation problems and generates demurrage costs with help of “Vessel Arrival System” It is intended to reduce ships queues and waiting times at anchorage which will benefit customers and total supply chain of coal while reducing fuel costs due to Vessel steaming to port at reduced or economical speed also enhancing maritime safety at the same time.

The “Vessel Arrival System” can be designed by Paradip port trust with necessary approvals at Government levels and in conjunction with all customers and stakeholders of the port.

The proposed system can be implemented in two stages as follows.
Stage 1 – Vessel tracking stage
Stage 2 – Slow steaming or optimal speed of Vessel transit

4.3.1 Stage 1

In this stage of "Vessel Arrival System" a coal vessel en route to Paradip for Loading or discharging will be tracked by Paradip port using INMAR SAT C (International Maritime Satellite aided tracking standard C) system equipped on all vessels which is mandatory under requirements of Global marine distress & safety system.

When vessel departs from previous port and is en route to Paradip will notify Paradip and all parties involved of its Estimated time of arrival at normal sea speed depending on vessel's estimated time of arrival at Paradip and berth situation at that time in cooperation with all parties Paradip port trust will inform vessel preferably 10 days prior arrival of deemed time of arrival to minimize the waiting time at anchorage and basis this deemed arrival time at Paradip vessel will adjust its speed with due regard to safety of navigation, weather conditions en route and keeping vessels main engine safety parameters in mind usually for most vessels they can reduce maximum up to 50-60% of MCR(Maximum Continuous Rating). In addition to optimal arrival time the vessel can save fuel also at this economical speed and reduction in green house gas emissions also. It is estimated most vessels at 20% speed reduction can save fuel up to 40%. We can note savings in this regard e.g. consider for a voyage from Gladstone, Australia east coast to Paradip a Panamax vessel proceeding at speed of 14 knots will burn at approximately 39 tonnes of heavy fuel oil daily and total passage will be of about 16 days consuming total of 624 tonnes of fuel oil during passage , If vessel is slowed by say 20% which gives speed of 11.2 knots at this speed voyage will become 20 days instead hence if there is long waiting at anchorage is expected it can be reduced by 4 days and thus demurrage costs and additionally there is fuel saving of up to 40% which means total consumption of about 468 tonnes i.e. a saving of 156 tonnes of fuel oil which amounts for a 380cst IFO at about 450 USD / MT, 70200 USD just for one voyage.

In order to track a vessel through its INMAR SAT-C the port must be registered user of INMAR SAT for which a licence needs to be acquired then Port traffic and information system can install the necessary equipments and software which can be used to track vessel, for this purpose port can obtain vessel's equipment type and access code numbers from vessels owner or agent and vessel is identified in the system and then Port traffic centre can access vessel position and other relevant data of arrival information by data polling on Sat-C, In INMAR SAT-C when polling response is active then registered users can poll a vessel at any time to obtain all required data such as vessel's position, course and speed at that time and intended track if that data is also incorporated in the vessels INMAR SAT-C system, using polling request to the system operators can obtain the relevant data automatically in this case port traffic centre can poll once daily, basis this vessel can be tracked in the ports traffic system network.

Initially the system can be used in trial phase for few months tracking vessels positions and speed and also vessels routes can be monitored to see transit routes and times from various ports to Paradip then these gathered information can be fed in the port's system to give ETA projections once fair amount of accuracy is obtained then the stage 1 can be implemented on vessels calling Paradip.

4.3.2 Stage 2

Stage 2 applies when vessel is tracked in Ports network and according to vessels estimated arrival time as per its tracked data in the system and vessels notices and with known vessels for coal loading and discharging operation in port at that time, berth availability can be calculated with average turnaround time of vessels in port, basis that vessel and all parties concerned will be advised its estimated turn of berthing to commence loading and discharging operations then in agreement for the purpose of any commercial arrangements vessel can adjust its speed to most optimal speed from that point on in order to arrive as close as possible to estimated turn of loading or discharging with due regard to safety of navigation, prevailing weather conditions and main engines safe parameters. It is important that this targeted date and time of arrival is agreed by all parties concerned for all commercial purposes and basis same vessels shall be deemed to be ready and tenders notice of readiness. In case there is change in turn of loading or discharging the vessel can increase or decrease speed further as practicable and in agreement with all parties concerned e.g. if any other vessel is unable to make the deemed arrival due to weather conditions or any technical breakdown the next vessel in line can be brought forward and port will communicate request to vessel and all parties concerned for vessel to increase speed to meet a revised berthing time.

However it is of utmost importance that all parties concerned should be in agreement and adequately shares all information with port and among themselves with regard to targeted ETA, savings in fuel costs, demurrage costs and all other commercial and operational matters which are necessary for smooth and successful functioning of Vessel Arrival system.

With implementation of Vessel arrival time it may be prudent for vessels to endeavour to arrive within 24 hrs to 48 hrs prior the agreed estimated berthing time not just in time of berthing as en route some time may be lost due to rough weather and variable current conditions experienced, with this some time will be in hand to adjust any delays whatsoever. Once time window of loading or discharging is allotted under Vessel arrival system then vessel must arrive prior this window any delays will disrupt the whole schedule of targeted berthing times for vessels and eventually may result in missing the berthing window any changes in ETA must be notified immediately to Port authority and all concerned parties for further planning and arrangements and accordingly Port may decide to fit another vessel arriving closer to that window and reschedule the berthing window for that particular vessel, vice versa Port will also notify vessels and concerned parties of any changes or update in allotted berthing times on daily basis or any subsequent change in berthing time through vessels agents. The changes in berthing time may be as a result of local factors in Port of Paradip for procedures and arrangements of transport, clearing of stockpiles, availability of railway rakes and their timely removal, documentations and due to any other resulting delays or breakdowns of any vessel or its equipments and terminals or cargo equipments during loading or discharging of vessels in port. As loading times may change but it will not disadvantage vessels in terms of their priority in queue and there will be flexibility of bringing forward a vessel in turn according to type and grade of cargo availability or requirement of shippers or receivers & in common interest of benefit to all parties by doing so and without resulting any subsequent disputes on commercial matters.

In order to streamline the process and establish priority for vessels it is important to have a clear berthing window of vessel which is notified basis vessels arrival notification & tracking of vessel once Port has allotted arrival time for berthing of vessel then it is recommended to give Notice of readiness of vessel at that time even though it is 10 days prior arrival and not an arrived vessel in port, so that when transiting at slower speeds adjusted for arrival time vessels retain their priority and do not have any disadvantage. However all commercial arrangements for tendering & acceptance of notice of readiness should be dealt with by all concerned parties between Coal & shipping participants, as per Notice of readiness tendering terms of the relevant charter party and shall mutually agree to the notified arrival time given by the Port, But Port should not be involved or held responsible for making these commercial arrangements for whatsoever reasons that may result in any dispute.

To arrive at conclusion of targeted arrival time for each vessel a designated working group will be assigned for the purpose of calculating and implementing vessels 10 days notified arrival time or allotted window, the results calculated for vessels will be incorporated in Port traffic network in conjunction with vessels tracking and records of this shall be maintained, in order to have smooth operation of vessel arrival system in port and effectively observe the priority of vessels in the queue it is of vital importance that Port establishes a set of rules which all vessels and parties concerned must agree and comply with to avoid and tackle any resulting disputes in coordinated manner. This will contribute to safe operation of Port. If vessels do not comply with rules may lose their priority to enter, may be demoted in the arrival queue or their allotted window may be suspended.

4.4 Strategic Factors of Implementation process

So far the implementation process of Vessel Arrival system is considering a voyage of more than 10 days but not necessarily it will be applied to ships only with more than 10 days voyage, in case of short voyage leg of less than 10 days the notifications could start in advance when vessel is performing its previous voyage but then forthcoming voyage for Paradip required to have been fixed which is not the case always as ship operators are always working on different voyage options and the decision is made very carefully with maximum profitability with due regard to considering all risk factors not overlooking suitability of vessel and feasibility of all operations needs to be performed during the voyage. In cases where voyage is fixed at later stage and duration of voyage leg is short, vessel has to transit from a port directly to Paradip within 10 days then the Port has to have flexibility in window to accommodate vessels under these conditions and this of course should not disadvantage other vessel's priority hence accommodating of vessels in this case will be as per sequence in time the first notification is given to the Port by vessel then port will notify vessel of its estimated time of berthing accordingly. However vessel should notify the port at earliest opportunity as practicable and can notify up to the time of their arrival within designated traffic limit area or port limit, basis arrival time vessel will be allotted a position in the queue.

In certain circumstances a vessel which is already fixed for a voyage to Paradip and has been allotted targeted arrival time but due to commercial reason and delay in the queue the vessel operators, shippers or receivers may agree or decide to divert vessel to another nearby port for commercial reasons or to expedite loading or discharging with a vacant berth in that port depending on their terms of contract or charter party, in such cases the slot which was allotted to this particular vessel will assigned to other vessel next in line. However there can be cases of vessel substitution also that the vessel which was fixed or allotted targeted arrival time by port is required by its operators or charterers to be employed for another voyage according to its suitability and for commercial reasons, In these situations if the targeted arrival time of substituted vessel is more than 10 days period of notification by port for allotted time then same targeted arrival time will be applicable to the substituted vessel also, however if the substitution occurs later than time of 10 days notification of arrival time by port then targeted arrival time will be allotted by a new 10 day notified arrival time otherwise it will disadvantage other vessels in queue and may result in disputes. Important point to note here is also that the substitution should be made by similar size of vessel, for same type of Coal cargo, its quantity and its grade so that it does not disrupt the availability of berth and cargo for other vessels as this can affect the whole supply chain. We can summarize the process of Vessel Arrival system flow as per chart given in Appendix 2.

Coordination of Vessel Arrival System process will also require to develop a system using suitable optimization or scheduling software for calculating to arrive at decision of berth allocation to vessels, This can be quite complex with respect to advanced planning and scheduling as it involves integration and optimization of the whole supply chain of coal and requires monitoring, good analysis and decision support system. Hence solution or calculation of allotted time is very critical for entire supply chain with regard to shore transportation and logistics planning which can be very difficult due to delays in clearing stock piles of coal and different grades of different customers and also due to delays in railway and road networks which is further coupled with transportation infrastructure. Hence there is need of coordinating and linking of shore side network also by port in order to have greater flexibility taking in account all constraints for deciding or allotting berthing time without any mix ups. Port has to establish a support system in cooperation with all parties with full transparency of coal supply chain and its distribution process to avoid any surprises. This will give control over supply chain to an extent for performing operational planning and execution. At the same time the important point to note is to plan and maximize utilization also which will involve a good network planning of available port facilities and transport linkages and their smooth flows which of course is very difficult task as this involves lot of bureaucracy, documentation and so on. Not an easy task to have timely arrival of railway rakes or trucks and clear stock piles. However Port can at least plan and provide solutions to transport problems within its perimeter.

As far as vessel scheduling is concerned this will be more or less a real time solution as this is aligned planning together with shippers, receivers, vessel's charterers, owners operations etc. and still quite manageable only thing is to support each other for maximizing overall profit in terms of volumes of cargo flows, market opportunities, vessel capacity utilizations, contracts, lay cans, bunker cost savings etc. Improve coordination among all parties helps in gaining better operational control and flexibility and will help in making good berth allocation decisions for all vessels. This study will use mathematical solutions based on Regression analysis, queuing theory and mixed integer linear program for optimizing.

4.5 Operationalising the concept

For implementation of vessel arrival system all commercial aspects are of vital importance because it will be successful only when there are commercial gains to all concerned parties. As discussed earlier under Vessel arrival system a careful consideration is made to calculate a targeted arrival time for vessel in order to have minimum waiting time and minimized delays for which various factors effecting the arrival of vessel were involved and we saw how to achieve optimal arrival time with regard to all operational aspects .

Now as a one step further emphasis of this study comes to the core element which is of extreme importance and that is commercial gains with regard to prevailing market conditions for using vessel arrival system to optimize arrival time and minimize delays and minimize resulting losses in terms of demurrage and monetary value to the parties concerned.

First of all we need to understand applicable and governing charter parties and its clauses which bound the trade and all recent market trends of Charter hire rates, Coal prices, Freight rates, Bunker prices, Average cargo handling rates (Loading / Unloading rates) of Coal cargoes at Paradip and Average port capacity utilization for Coal cargoes with respect to rate of clearing stock piles with inland transportation (Clearing of railway rakes, wagon and trucks loading / unloading).

4.6 Commercial understanding of charter parties important clauses

It is important to discuss charter parties and governing clauses as there can be contractual or legal problems when applying vessel's optimal arrival system as in order to achieve optimal arrival time vessel may require to reduce to an optimal speed however charter parties require that a ***"vessel must proceed with utmost or due dispatch"*** and also there is agreed charter party speed at an agreed fuel consumption whereas in this case vessel may have to proceed on economical speed and perform slow steaming to match the targeted arrival time which deviates vessel from basis necessity of charter party thus can result in breach of charter party with respect to required utmost dispatch. Similarly there are certain other clauses also need to be interpreted prior engaging in complying with vessel arrival system which is discussed below with emphasis on a standard voyage charter party of coal cargo.

4.6.1 Lay days& cancelling date

A vessel arriving later than or delayed beyond cancelling date will be in breach of charter party and the charterers have option to cancel the charter party so a careful decision is required for optimal speed and any speed reduction or slow steaming under proposed arrival system can result in deviating away from contractual agreement unless slow steaming is agreed in additional clause to benefit the concerned parties.

4.6.2 Demurrage & Dispatch

It is important to note the agreed rate or amount of Demurrage & dispatch money and depends on stipulated lay days in charter party and with vessel's controlled arrival system at optimal speed it can be advantage to one and disadvantage to other party which in normal circumstances would not have been there or would have been other way round hence can be cause of disagreement also so it is important to agree on this.

4.6.3 Notice of readiness tendering terms

Notice of tendering terms are very important if not adequately tendered as per governing charter party may not be accepted and will result in losses as a vessel with targeted arrival system may be arriving at a time when it's not a working day as per tendering terms and notice may be acceptable only during week days and ordinary working hours hence in such cases a careful retendering is done without prejudice to first notice of readiness tendered and parties have to be in agreement and importantly this also involves when and when not lay time to count.

There can be clauses as given in POLCOAL Voyage charter party, "***Misrepresentation clause"*** which is if any delays whatsoever lead to cause of misrepresentation and then shippers may be entitled to certain amount to be paid as compensation by owners unless such adjustment of speed is agreed among all parties.

4.6.4 Delivery / Redelivery clauses and duration of time charter

In a period Time charter or trip time charter this can be important as the agreed Delivery or Redelivery time may be affected due to adjustment of speeds for current or subsequent voyage and result in losses.

There can be *"**clauses related to performance of vessel"*** and if any excess sailing time or bunker is consumed can result in deduction and losses and there may be some additional or rider clauses also as agreed among Parties which can be effected by speed adjustment.

Table 4: Standard Charter party & commonly used Coal Charter party forms

Coal Charter Party	Nippon-Coal (Japan Shipping exchange / BIMCO)
Coal Voyage charter	POLCOAL-VOY (BIMCO)
Americanised Welsh Coal	AMWELSH (ASBA)
General Charter Party	GENCON (BIMCO)
General time Charter	GENTIME (BIMCO)
Bareboat or Demise charter	BARECON (BIMCO)

(Source: BIMCO**)**

4.7 Charter hire rates

Shipping markets are very volatile and follows vicious cycles. We have seen a very grim situation of the shipping market. Here dry bulk market is considered and particularly in coal trade to east coast of India. There are times when there was a surge in the market and now facing significant downturn. There has been sharp decline in Charter hire rates. The Dry bulk market also has been hit hard, specially cape size vessels ther average daily rates stand close to breakeven level. But since India is racing towards fast growth & development there is huge expected demand of Coal and subsequently large amount of coal imports will play a major role in keeping future of Coal freight market firm particularly for handy max and Supramax, which will also help in getting good charter hire rates or at least stable rates for same.

Still at the same time one has to consider volatility in the market mainly because there is a large number of vessel order book and all these deliveries are expected within next 2-3 years which can tumble rates, moreover one has to also watch out for handling capacities in Indian ports which may not cope up with the huge demand which can also affect the charter hire rates.

Average one year time charter rates as per Baltic index are as follows.

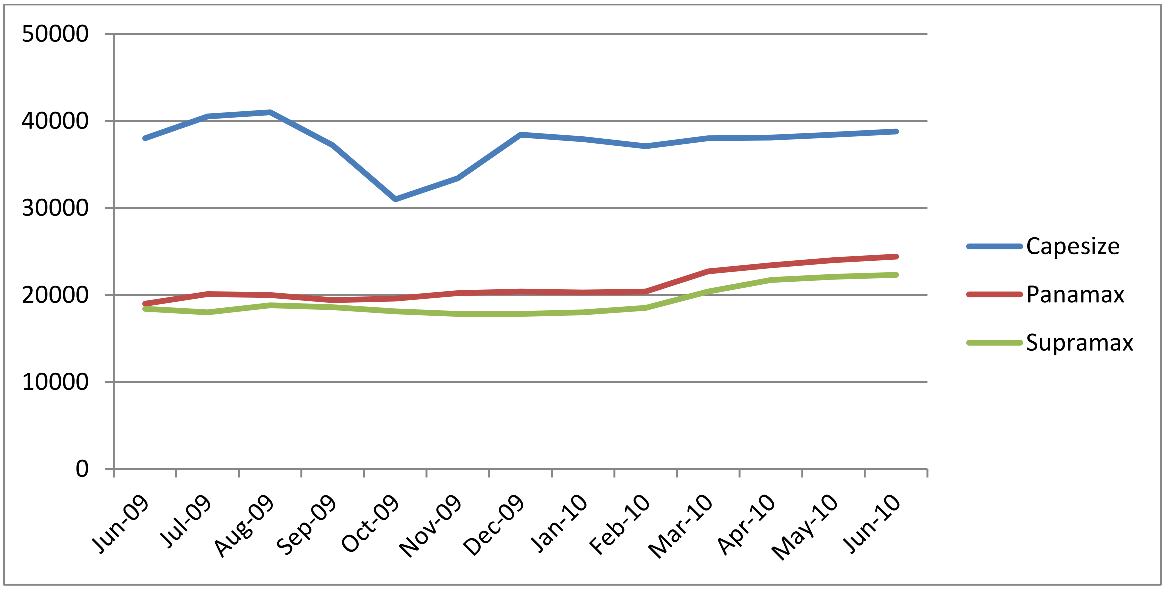


Figure 7: Charter Hire rates

(**Source:** Shipping market report "Baltic Index" by Ship trade services S.A.)

Latest average charter hires for ECI and from Australia and south Kalimantan as per data provided by Coal spot (Vistaar shipping Singapore) is as follows

Cape/US$ 24,283 per day, Panamax/US$ 24,472 per day, Supramax/US$ 22,192 per day

The future for three years (2010-2012) as per data from Coal spot(Vistaar shipping Singapore) was expected at around Cape/US$ 28,000 per day, Panamax/US$ 20,000 per day, Supramax/US$ 17,500 per day, Handy size/US$ 14,000 per day.

Table 5: Baltic Dry Index Change

	This week	Last week	Change	Change %
Baltic Dry Index	2501	2694	-193	-7.16
Baltic Cape Index	1717	3134	-417	-13.31
Baltic Panamax Index	3045	2980	+ 65	2.81
Baltic Supra Index	2122	2232	-110	-4.93
Baltic Handy size Index	1182	1247	- 65	-5.21

*As of 25 June 2010 (**Source:** BDI)*

4.8 Coal Price

There is likely an increasing trend in Coal prices due to growing demand from Indian power plants and also due to some supply constraints in Indonesia.

Table 6: Australian Coal Index (Price)

Month	Current	Previous	Change	Change %
May 2010	107.28	107.30	0.02	0.02 %
April 2010	107.30	101.12	6.18	6.11 %
March 2010	101.12	100.92	0.20	0.20 %
February 2010	100.92	103.93	3.01	2.90 %
January 2010	103.93	89.04	14.89	16.72 %
December 2009	89.04	76.15	12.89	16.93 %
November 2009	76.15	84.43	8.28	9.81 %
October 2009	84.43	72.47	11.96	16.50 %
September 2009	72.47	77.68	5.21	6.71 %
August 2009	77.68	79.07	1.39	1.76 %
July 2009	79.07	76.48	2.59	3.39 %
June 2009	76.48	69.11	7.37	10.66 %

(Source: Coal spot-Vistaar shipping Singapore and IMF-commodity prices**)**

Table 7: Indonesian Coal Price Reference (HBA) (US$/MT)

Coal Brand (Basic Coal Brand)	GCV (GAR)	TM (GAR)	Total Sulphur	Ash	May 2010	June 2010	Change Price (US$/ MT)	Change %
Gunung Bayan I	7,000	10.0	1.0	15.0	99.13	104.71	5.58	5.63
Prima Coal	6,700	12.0	0.6	5.0	96.93	102.16	5.23	5.40
Pinang 6150	6,200	14.5	0.6	5.5	87.36	92.06	4.70	5.38
Indominco IM East	5,700	17.5	1.6	4.8	75.01	79.18	4.17	5.56
Melawan Coal	5,400	22.5	0.4	5.0	70.45	74.16	3.71	5.27
EnviroCoal	5,000	26.0	0.1	1.2	64.81	68.09	3.28	5.06
Jorong J-1	4,400	32.0	0.3	4.2	52.27	54.92	2.65	5.07
Eco Coal	4,200	35.0	0.2	3.9	48.41	50.82	2.41	4.98

(Source: Coal spot – Vistaar shipping Singapore & The Directorate General of Mineral, Coal and Geothermal, Ministry of Energy and Mineral Resources, Indonesia**)**

4.9 Coal Freight rates

Coal Ships calling at Paradip are mainly Panamax and Supramax so freight rates for Cape size for this trading zone are not available.

Table 8: Panamax Average Freight rates

Load Port	**Discharge Port**	**Freight (US$/MT)**
Indonesia	East Coast India	13.00
Queensland	East Coast India	21.00
Richards Bay	East Coast India	19.00

(Source: Coal spot – Vistaar shipping Singapore**)**

Table 9: Supramax Average freight rates

Load Port	Discharge Port	Freight (US$/MT)
Indonesia	East Coast India	17.50
Queensland	East Coast India	27.50
Richards Bay	East Coast India	25.00

(Source: Coal spot – Vistaar shipping Singapore**)**

4.10 Bunker Prices

Coal ships on trading route between Australia / Indonesia to East coast of India mostly replenish bunkers at Singapore en route. Coal vessels coming from South Africa or South America will normally take bunkers in South Africa. In this paper to avoid complexity we are considering Asia Pacific routes. In past few months Bunker market has been stable. Focus in this paper is Singapore being a major shipping hub and bunker spot for south east Asia. Bunker prices account for a large sum of vessel operating costs and with economic downturn it is the most important cost factor hence give a viable reason for slow steaming of vessels. Additionally Bunker industry is also facing lot of changes in regulations coming into force to control emissions & make standards. All these factors can change bunker prices with bunker quality in future.

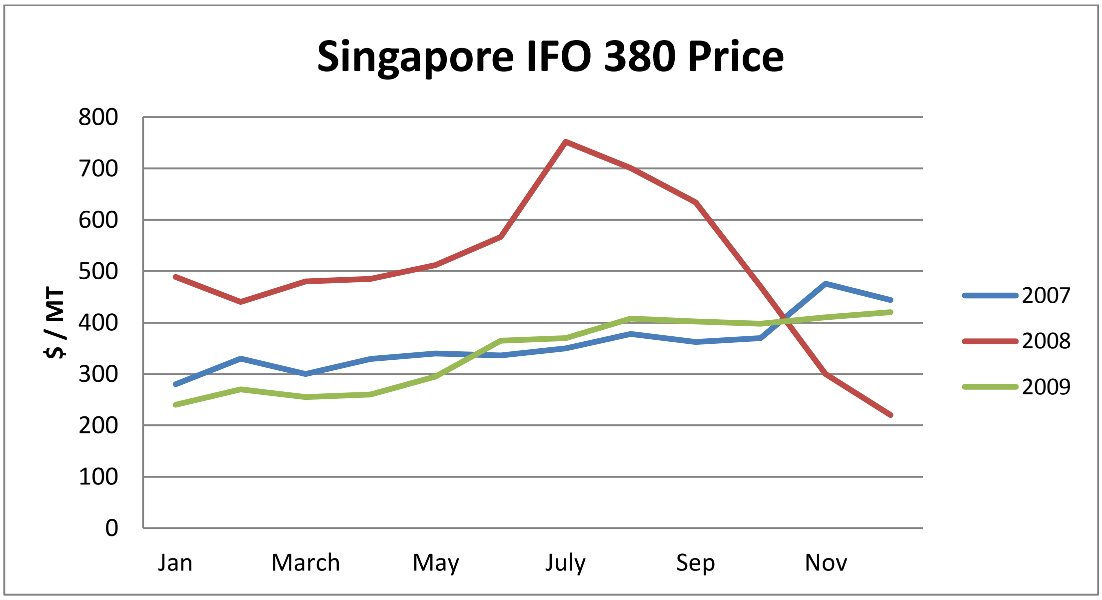


Figure 8: Singapore IFO 380 Price

(**Source:** Bunker world price review)

Table 10: Average Bunker Price at Singapore

Date	Average Price $/MT
28.06.2010	439.0
27.05.2010	422.0
28.04.2010	498.0
29.03.2010	458.0
28.02.2010	461.0
28.01.2010	479.0
27.12.2010	468.0
30.11.2009	466.0
29.10.2009	420.0
29.09.2009	424.0
31.08.2009	410.0
29.07.2009	401.0

(Source: Bunker World, Bunker Index & MSAR-BIMCO**)**

4.11 Cargo handling at Paradip

(2010) - Average Total cargo handling rate per day for all commodities = 1, 58,919 Metric Tons
(2009) - Average Total cargo handling rate per day for all commodities = 1, 68,416 Metric Tons **(Source: Paradip Port trust)**

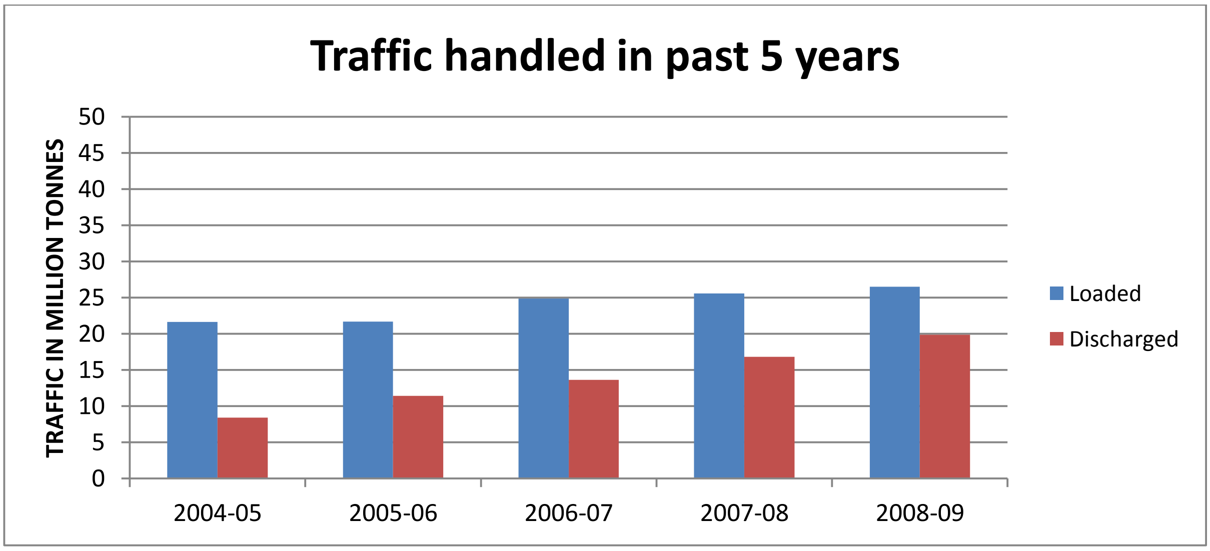


Figure 9: Paradip – Traffic Handled in Past 5 years

(Source: Paradip port trust annual review**)**

As we can see from above graph there is steady average growth of about 3 million tonnes for cargoes discharged and about 1 million ton for cargoes loaded.

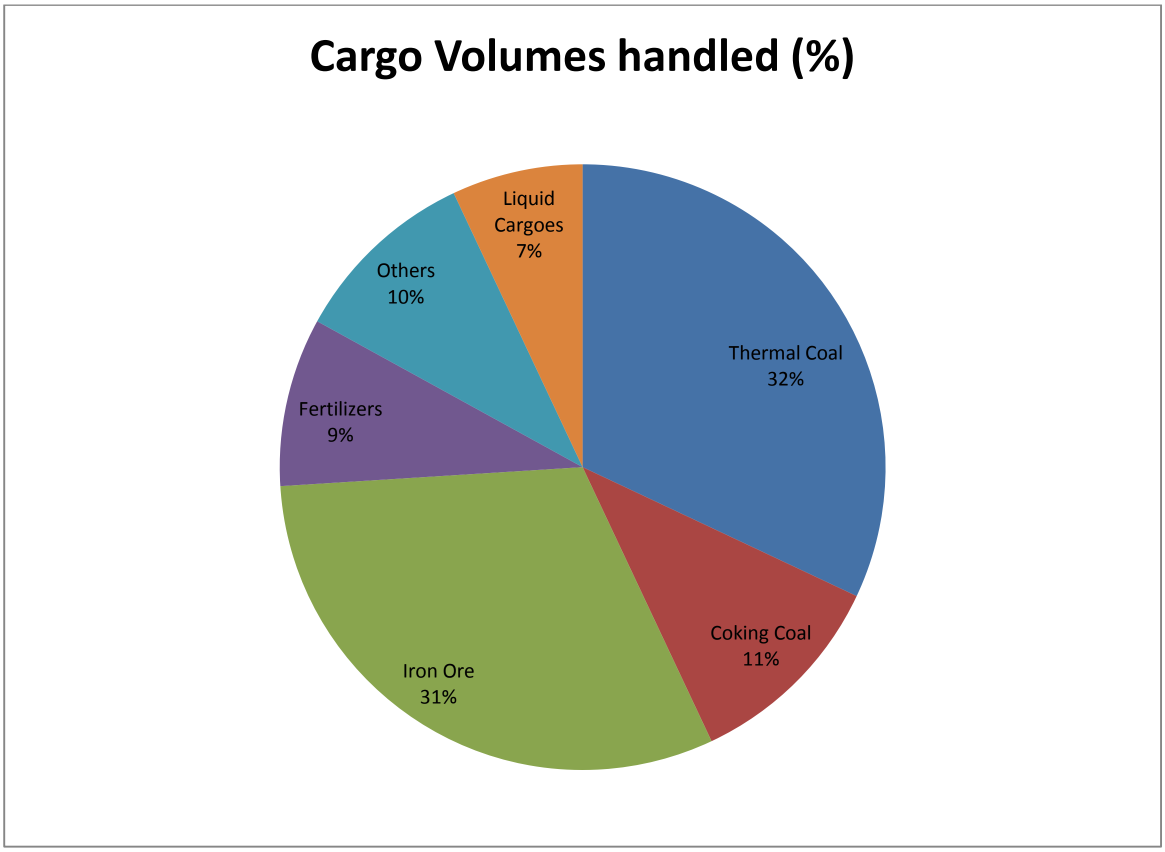


Figure 10: Commodity wise traffic handled at Paradip during 2008-09 (Total traffic – 46.41 Million Tonnes)

(Source: Paradip Port trust Annual review report**)**

Table 11: Daily average Berth Productivity for Coal cargoes

Coal Type	**2008-09**	**2007-08**
Thermal Coal (Mechanical)	32,459 Tonnes	33,826 Tonnes
Thermal Coal (Conventional)	6,084 Tonnes	9,173 Tonnes
Coking coal	9,501 Tonnes	9,274 Tonnes

(Source: Paradip Port trust**)**

Berth Productivity is overall Loading / Unloading rates achieved which means it is obtained taking into account inland transportation constraints & clearing of stock piles in the port.

4.12 Cargo handling at major Indian ports

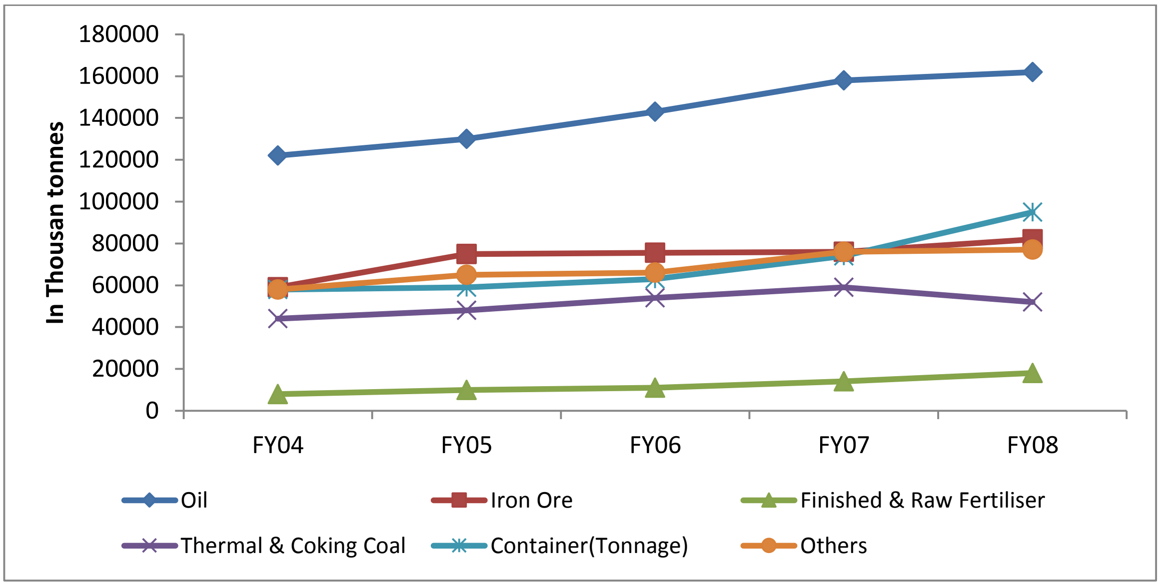


Figure 11: Principal Commodity wise Cargo traffic handled (Indian Major Ports)

(Source: Indian Ports Association**)**

Table 12: Average annual growth rates of major Indian ports on east coast:

Major Ports	Cargo traffic handled in FY08 (MtPA)	Annual growth in traffic handled (%)	Projected traffic FY12 (Mt)
East Coast			
Visakhapatnam Port	64.597	14.56	82.2
Chennai Port	57.154	7.00	57.5
Haldia Dock Complex	43.541	2.56	44.5
Paradip Port	42.438	10.18	76.4
Tuticorin Port	21.48	19.33	31.7
Kolkata Dock System	13.741	9.09	13.43
Ennore Port	11.563	7.92	47.0

(Source: Department of shipping and Indian port Association**)**

Paradip has posted average growth rate for coal about 11 % in last decade with impressive growth observed in last year 2008-09 which was 22.84%. We can see from the table that projected growth for year 2012 is 76.4 Mt almost becoming double from 2008.

Table 13: Commodity wise projected traffic for 2012

Commodity	Existing capacity FY06	Projected traffic FY12 (Major ports)	Planned capacity addition FY12	Total capacity planned FY12
POL (Oil)	162	215	132	294
Iron ore	56	99	66	122
Coal	46	109	69	115
Container(M.TEUs)	62 (5.2)	144 (12)	161 (13.4)	224 (18.6)
Other cargoes	130	141	118	247
Total	456	708	546	1002

(Source: Planning Commission, Report of the task force on financing plan for ports)

4.13 Average Demurrage costs

Demurrage is defined in the Voyage Charter Party Lay time Interpretation Rules (1993) as, *"an agreed amount payable to the owners in respect of delay to the vessel beyond the lay time, for which the owners are not responsible. Demurrage shall not be subject to lay time exceptions."*

Demurrage will only be payable if provided for in a clause in the charter party, e.g. a Demurrage Clause or Demurrage /Despatch Money Clause. The demurrage rate, which is normally quoted in US Dollars, will normally be a daily rate that will at least cover the owners' costs of keeping the ship in the port. Demurrage in most cahrter parties agreements is normally paid per running day, i.e. without exclusion of any Sundays, holidays, or bad weather, strikes, etc., occurring during the detention period-hence the well-known expression "once on demurrage, always on demurrage" Malcolm Maclachlan, *The Ship master's Business companion* (2004). In general Demurrage costs have direct relation with freight rates the trends show that it is usually about 15% of fright rates and / or agreed pro rata per working day among concerned parties such as Charterer, Ship owner, Terminals, Shippers, receivers or road & railways haulage companies. We can see even though demurrage is payable by charterer to the vessel but in turn it may be recoverable by other party responsible for delay similarly it goes for demurrage paid to road transportation or for currency etc.

An example demurrage calculation

- A vessel arrives and Lay time starts to count on 02/06/10
- Vessel Loading Commences on 03/07/10
- Vessel Loading completed on 05/07/10
- No of lay days or lay time = 10 days +
- Additional free days = 0 days
- Total lay time or free Days = 10 Days
- 1st 10 Demurrage Days = $8000 per day
- After 10 Days = $15000 per day
- Start date = 02/06/10
- Stop date = 12/06/10
- Days on hand = 34
- Less free days = 10
- Demurrage days = 24
- 1st 10 Demurrage Days @ $8000 = $ 80000 +
- Next 14 Demurrage Days @ $15000 = $ 2,10,000
- 24 Total Demurrage Days

- **Total Demurrage Charges** = $ 2,90,000

So we can see Demurrage amounts can be quite significant similarly when there are delays there can be demurrage charges for land transportation or networks in coal supply chain also at their stipulated rates.

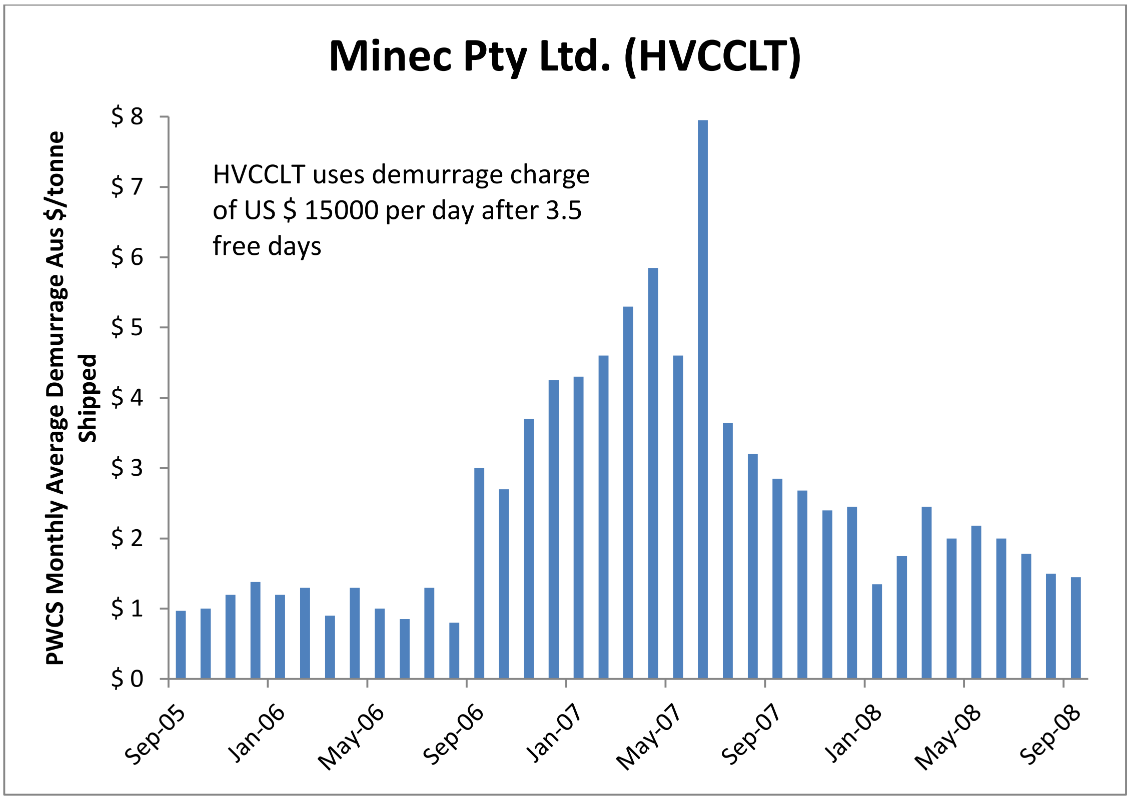


Figure 12: Demurrage costs in a coal supply chain

(Source: World coal outlook seminar 2008, Australian coal consulting alliance**)**

If we compare the above demurrage rate chart with average fright rate chart it will be about 15% of freight rates for that period.

4.14 Regression Analysis approach

Now in model formulation as a first step with available data and inputs a model of multiple regression analysis will be used for determining relationship between speed of vessel and various cost factors involved in main commercial aspects of vessel operations and we will test how well the model fits the actual data and once relationship among variables and the model is analyzed to be a good fit.

Basically now in regression analysis primarily it is intended to find correlation between variables & forecast the values which will help to prove at a later stage the impact of speed reduction on minimizing delays in port and thus reducing overall costs.

This leads to question how much speed we can reduce in other words what should be optimal speed to achieve minimum voyage costs which is reached by reducing or minimizing delays.

So decision of speed depends on various factors of voyage costs which will effect this decision only if cost is saved. This is what will be analyzed after results of regression analysis are obtained

Therefore or regression analysis model now we consider function of speed as dependent variable and all resulting voyage costs as independent variables.

Notations:

Dependent variable denoted as, S

Independent variables denoted as, $x_1, x_2, x_3, \ldots, x_k$ (k is number of independent variables)

Dependent variable

Average Speed, S

Independent variable

Average Charter hire rate Cape size, x_1

Average Charter hire rate Panamax, x_2

Average Charter hire rate Supramax, x_3

Average Australian coal price, x_4

Average Indonesian Coal price, x_5

Average Panamax freight rate for transporting coal from Australia east coast to India east coast, x_6

Average Panamax freight rate for transporting coal from Kalimantan Indonesia to India east coast, x_7

Average Supramax freight rate for transporting coal from Australia east coast to India east coast, x_8

Average Supramax freight rate for transporting coal from Kalimantan Indonesia to India east coast, x_9

Bunker price at Singapore, x_{10}

Average Thermal coal mechanised handling rate per day at Paradip, x_{11}

Average Thermal coal conventional manual handling rate per day at Paradip, x_{12}

Average Coking coal handling rate per day at Paradip, x_{13}

Average Demurrage cost, x_{14}

As we know for k numbers of independent variable related to a dependent variable the model equation is represented as follows

$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots\ldots\ldots\ldots + \beta_k x_k + \varepsilon$

Where $\beta_0, \beta_1, \beta_2 \ldots\ldots\ldots \beta_k$ are coefficient
and ε is error variable

Basis this we can write equation as follows

$S = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_2 x_3 + \beta_2 x_4 + \beta_2 x_5 + \beta_2 x_6 + \beta_2 x_7 + \beta_2 x_8 + \beta_2 x_9 + \beta_2 x_{10} + \beta_2 x_{11} + \beta_2 x_{12} + \beta_2 x_{13} + \beta_2 x_{14} + \varepsilon$

The data inputs used are generated & accumulated from average actual data obtained from various sources and practical knowledge from ship brokers and sailing experiences, vessel operations experiences of various individuals and obtained from referring to various charter parties and voyage instructions of vessels with regard to speed & consumption in terms of charter hire rates and also referred to contracts of sale between cargo seller and buyer with respect to coal prices, fright rates & cargo handling rates at Paradip. The accumulated data has been modified & tabulated in Appendix 3 for a specific period for all variables.

Table 14: Regression Analysis Results

Regression Statistics	
Multiple R	1
R Square	1
Adjusted R Square	0.666666667
Standard Error	5.25122E-16
Observations	25

F Stat.
2.1E+31

(Source: Excel Work sheet**)**

Assessment of regression Model: Assessment of model indicates that since R square value being 1 and adjusted R square value is 0.67 i.e. 67 % of total variation is explained and hence a good model and also the F statistics value is infinitely large & the standard error for most cases is either zero or very small hence considered as good model thus satisfies that the model fits the data as well as possible and required conditions are satisfied and model predicts the residual and probability outputs for Average speed and plots obtained give clear linear relationships between Average speed and all variables.

4.15 Modelling Approach for waiting line and Optimization

So far formulation of procedures for implementing Vessel arrival System is discussed and a relationship between various cost factors and speed is established, now it will be seen how the calculation of vessel's optimal speed is made to achieve optimal arrival time & matched targeted berth allocation time is made for better overall productivity and minimizing delays and waiting time of vessels. We proceed further for estimating overall impact of Vessel arrival system with objective of reducing waiting time of coal vessels in port and subsequently reducing overall voyage costs, demurrage costs etc. which is achieved by reducing to an optimal speed.

The assignment or allotment of berthing time is basically the better berth scheduling to increase productivity; vessel arrival times for bulk carriers are variable which is optimized to match with berth schedule such that idle time of berth as well as ship in port is minimized at the same time objective is also to reduce vessels service time or turnaround time at berth. As all vessels calling will have an assigned arrival time for berthing hence to account for that objective also includes minimization of vessels delayed departure so that berth is available for the next vessel in line upon her arrival Golias *et al*, 2009).

Vessel arrival times are optimized for the objectives of policy proposed in the study and is considered as a variable which provides with an optimized vessel speed. Using real data included in above study show that the proposed policy optimizes vessel's fuel consumption & waiting time at the port by reducing vessel operating speeds to optimal levels and simultaneously it reduces the amount of emissions also from vessels while idle in port, Golias *et al*, (2009). This study refers to a literature of Theofanis et al (2009) for a detailed review and critical analysis of the berth scheduling.

The most desirable situation for vessel operators as well as Ports, Terminals and all concerned parties in transport supply chain, is to have all berths occupied and yet no vessels have any waiting time in port which though is very impracticable to say hence effort have been made in this study to minimize waiting time and increase productivity which results into cost savings. With vessel arrival system program we have a concept which needs to be quantified for which we have already established a relationship between variables and speed of vessel and the waiting time of vessels which is also a function of speed has impact on these variables. In waiting line model the emphasis is given to arrival and service function. Ships arrivals are random and served in a queue according to their arrival. Service time is referred to the duration when ship is at berth for cargo operations. Using queuing theory waiting line model which will give a distribution of ships arrivals for a given time and average waiting time before berthing will be obtained and the model will evaluate average time that a ship is in port and average number of ships waiting for a berth. With the results obtained an objective of minimisation of average number of waiting ships and waiting time before berthing is applied as mixed integer linear programme approach & basis results so obtained optimal speed for a vessel is determined.

Chapter 5 Analysis & Results

5.1 Applying Queuing model for ships arrival time and service times

In queuing theory waiting line model the first step will involve modelling of ship arrival function. The ships arrival in a port is random and even if scheduled it can be with delays El-Naggar (2010). The arrival pattern of ships follows an exponential distribution, Kozan (1997). In order to get average number of ship for a given time period the arrival pattern should be known which can evaluated by waiting line Poisson model, Tadashi (2003). This Poisson model gives a probability distribution of the arrival of ships in port for a given time period and is expressed as follows, (Introduction to Management science-11th Edition) Anderson *et al* (2008).

$$P_n = \frac{(\lambda)^n}{n!} . e^{-\lambda}$$

Where P_n = *Probability of arrivals of n number of ships*

λ = Average arrival rate of ships for a given time period (this will be obtained from Port data for a certain period, e.g. one day or one week or one month)

λ_n *or* $(\lambda)^n$ *= Average arrival rate of n ships*

e = 2.71828 (base of Nat. Log)

n! = Factorial of number of ships (= n(n-1)(n-2)………(2)(1).)

Expected frequency or on an average n number of ships in port for a given time, F_n which can be calculated with average arrival rate obtained above in Poisson model for a time period T of one year as follows: $F_n = P_n . T$

Queuing discipline used in the model will be on "first come first serve" basis.

Further the validity of this predicted frequency of number of ships in port can be verified using Chi-squared goodness of fit test.

Next step is to evaluate mean service time. Service time of ship is total time vessel is at berth for loading or discharging operations & this time while vessel is at berth follows different stages including berthing operations, inward clearances & documentation, initial draft surveys, cargo handling, final draft surveys, Outward clearances & documentations. Hence in view of this multiple exponential service time distribution and the probability density function which is cumulative is represented by Erlang distribution function Kuo et al (2006). This duration of ships cargo handling operations whilst at berth are often described by Erlang function for service times, Son & Kim (2004).

The probability distribution of total service time is obtained from following equation, which is clearly stated by El Naggar (2010) as follows:

$$P_0 = e^{kb \sum_{n=0}^{n=k-1} (kb).\frac{n}{n!}}$$

Where

b = Average service time of vessel at berth in days

k = Erlang number (k = 1,2,3,….., ∞)

n = Total numbers or counter

k (Erlang number) is the number of Erlang phases of vessel service time distribution at berth. All the operating phases follow one another and ship remains at berth till all the phases are completed. With increase in value of k the total service time will be more uniform and when k becomes infinite then all service times considered same and it changes from completely random exponential at k =1 to regular constant service time at k = ∞ .

We can see below each function has a negative exponential.

for *k = 1,* $P_0 = e^{-b}$

for *k = 2,* $P_0 = e^{-2b.(1+2b)}$

for *k = 3,* $P_0 = e^{-3b.(1+3b+9b^2/2)}$

similarly probability distribution of service time for any required Erlang number can be computed and most suitable Erlang number for distribution of berth time is chosen and validity of same can be tested using Chi-squared goodness of fit test.

However with regard to multi berths, with exponential arrivals and multiple exponential service the solutions are not feasible due to complexities (Zoran and Branislav 2005) and these models can be applied only if there is exponential distribution of both arrivals and service time or secondly with exponential arrivals and a constant service time.

According to recent research by Wen-Chih *et al* (2007) for exponential arrivals and a constant service time an approximate method of queuing model has been proposed which is as follows:

The average waiting time before berthing is $w_k = w_1 \frac{1}{2(k=1)}$

w_1 is correction of average constant service time for an Erlang function with constant k number.

$$w_1 = \frac{\lambda^s}{(s-1)!\mu^{(s-1)} .(s.\mu-\lambda^2)\left[\sum_{n=1}^{s-1} \frac{1}{n!}.\left(\frac{\lambda}{\mu}\right)^n\right]+ \lambda^2 .(s.\mu- \lambda)}$$

The notations used here are as follows:
λ = Average arrival rate i.e. ships / day (Poisson distribution)

μ = Average service rate i.e. ships served / day (Erlang distribution) = 1 / average berth service time = *1 /b*

s = number of berths in port

n = total number of ships in port for a certain time period

The ratio of average arrival rate and average service time rate which is called as traffic intensity for this purpose and represented as σ,

$$\sigma = \frac{\lambda}{\mu}$$

once w_k is computed from above equation and expressions the total average time of a vessel in a port can be calculated as follows:

$$t_s = b + w_k$$

to obtain average length of queue or average number of ships waiting in port following expression is used

$$\eta_w = \lambda.\ w_k$$

similarly average number of ships present in port with a certain number of berths for a certain time can be calculated as follows:

$$\eta_s = \eta_w + \eta_b$$

where η_b *= average number of ships served at berth*

= s x berth utilization factor = $s\ .\ (\frac{\lambda}{\mu}.\ S) = \sigma$

Hence traffic intensity σ also equals to average number of ships served at berth η_b

5.2 Application of Queuing models for ships arrival time and service times at Paradip

For the purpose of calculation of queuing models traffic data of Paradip port is obtained for month of May 2010 to July 2010. (Source: Paradip port trust, Indian ports association and Tickerplant India news prepared by Nilofer Shah).

In this study the queuing model is established for whole port system instead of taking just a sub system of a terminal or a particular berth as this will be more realistic which is also explained by Kuo *et al* (2006). Since the distribution is exponential presents a Poisson random arrival distribution, the previous studies analyzes that the value of Erlang coefficient number reduces from a system of just a single berth (k = 5) to whole port system (k = 1) which is supported by chi-squared goodness of fit test, Kuo *et al* (2006).

Basis analysis of data collected the following observation noted and compiled as follows:

Total number of berths in Paradip for all type of ships including 8 General cargo berths, 2 dedicated coal berths, 1 dedicated iron ore berth, 1 dedicated Tanker berth, 2 Captive fertilizer berths = 13 berths. Basis this capacity at Paradip for bulk carriers to berth there are two options, first being one of the general cargo berths and other is one of the mechanised dedicated berths depending on loading or discharging operations.

Total Average number of vessels in port = 33

Average number of waiting vessels = 21

Table 15: Annual Number of vessels

Port	Period	Dry Bulk	Liquid Bulk	Break Bulk	Container	Total	Others #	Grand Total
Paradip	2009-10	1154	326	40	11	1531		1531
	2008-09	1230	239	58	9	1536		1536

(Source: Indian ports association**)**

Table 16: Ships arrival distribution in an observed period

Arrival Rate (Ships/Day)	0	1	2	3	4	5	6	7	8
Actual number of days	0	3	4	7	8	9	21	26	14

From the above data we can see actual average arrival rate / day = 5.75 ships / day

Cumulative for total cargo handled at Paradip 2009-2010: 17807802 MT.
Cumulative average of cargo handled at Paradip for 2009-2010: 149645 MT. / day
Average cargo handling per ship / per day: 12470 MT / day

(**Source:** Paradip Port trust)

Table 17: Ships service time distribution in an observed period

Service Rate (Ships/Day)	0	1	2	3	4	5	6	7	8
Actual number of days	6	12	17	18	14	11	8	3	3

Actual service or cargo handling rate per ship = 3.3 days

Applying all relevant input parameter in queuing model following results is obtained:

1. 1). Poisson exponential multi server queue with unlimited system capacity first come first serve queuing discipline (M/M/c: Poisson arrivals to multiple exponential servers).

Table 18: Poisson arrival distribution model results

Input Parameters:	Arrival rate (l)	5.75
	Mean service time (1/m)	0.3
	Number of servers in the system (c)	2
Plot Parameters:	Maximum size for probability chart	10
	Total time horizon for probability plotting	20
Results:	Mean inter arrival time (1/l)	0.173913
	Service rate (m)	3.333333
	Average # arrivals in mean service time (r)	1.725
	Server utilization (r)	86.25%
	Fraction of time all servers are idle (p0)	0.073826
	Mean number of customers in the system (L)	6.735815
	Mean number of customers in the queue (Lq)	5.010815
	Mean wait time (W)	1.171446
	Mean wait time in the queue (Wq)	0.871446

(Source: From QTSPlus4 Calc release ver. 0.7**)**

	Customer Distribution	**Size**
N	**Prob(n)**	**CDF(n)**
0	0.073826	0.073826
1	0.087349	0.161174
2	0.098385	0.259560
3	0.109474	0.369033
4	0.121710	0.490743
5	0.140474	0.631217
6	0.160784	0.792001
7	0.152426	0.944428
8	0.055572	1

Figure 13: Probability Distribution Number of Customers

(Source: From QTSPlus 4 release ver. 0.7**)**

2). Poisson input to server queue with Erlang service times , unlimited system capacity first come first serve queue discipline. (M/E/ (k)/c: Multi server Poisson-Erlang (k) queue. This gives same result as given in above model.

Table 19: Erlang distribution model results

Input Parameters:

Arrival rate (l)	5.75
Mean service time (1/m)	0.3
Erlang shape parameter (k)	1
Number of parallel servers (c)	2

Results:

Mean interarrival time (1/l)	0.1739
Service rate (m)	3.3333
Expected number of busy servers (r)	1.725
Server utilization (r)	86.25%
Approximate mean system size (L)	6.7358
Approximate mean queue size (Lq)	5.0108
Approximate mean system wait (W)	1.1714
Approximate mean line delay (Wq)	0.8714

(Source: From QTSPlus 4 release ver. 0.7**)**

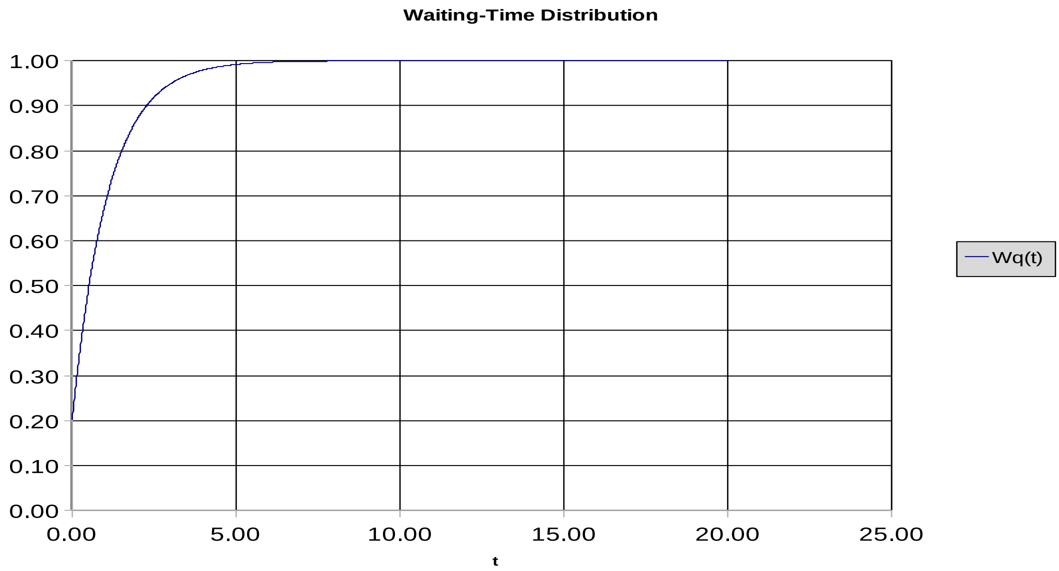


Figure 14: Waiting Time Distribution

(Source: From QTSPlus 4 release ver. 0.7**)**

Testing validity of models using chi-squared goodness of fit test

1). For ships arrival rate:
Expected frequency or on an average n number of ships in port for a given time, F_n will be calculated with average arrival rate obtained above in Poisson model for a time period T (3 months May to July = 92 days in this case) as follows:
$F_n = P_n \cdot T$ *Using probabilities obtained in results we can evaluate expected frequencies*

Table 20: Arrival rate and expected number of days

Arrival Rate (Ships/Day)	0	1	2	3	4	5	6	7	8
Expected number of days	7	8	9	10	11	13	15	14	5

(**Source:** From results)

Basis actual and expected values obtained Chi-squared test performed gives following values.

x^2 = 44.74 , p value = 4.12656E-07.

As p value is very small hence there is sufficient evidence to infer that test is valid.

2). For Erlang Distribution:

Expected Values obtained from the probabilities of waiting time distribution in the plot.

Table 21: Service rate and expected number of days

Service Rate (Ships/Day)	0	1	2	3	4	5	6	7	8
Expected number of days	1	8	15	18	16	14	11	4	5

(**Source:** Evaluated from results)

Basis actual and expected values obtained Chi-squared test performed gives an x^2 = 30.03 with a p value = 0.0002090. As p value is very small hence there is sufficient evidence to infer that test is valid.

Queuing results: The relevant data from results to be used for next model of optimization (Linear programming) is compiled below

Total average waiting time = 1.17 days

Average waiting time per ship in queue W_k = 0.87 day

Average number of waiting ships in queue n_w = 5.01

Average number of arrivals in mean service time = 1.725

Average arrival rate = 5.75 ships / day

Average per ship service rate = 3.33 days

5.3 Optimization of Vessel arrival time & evaluation of Optimal speed

In a port there are various local factors resulting into delays in a port which differ from port to port and conditions during a period hence cannot be based on overall market condition as we can use in case of vessels it will be different for each port and in a specific time period hence In this case the data is obtained for port of Paradip is just a historical data for a certain period basis that averages for handling time or turnaround time are used for a period with usual total number of hours or days when ship was idle or there were delays in port. So these are uncontrollable inputs normally resulting from any decrease in port or berth productivity, berth availability, lack of capacity or storage, any inefficiency in coal supply chain for the port such as late arrival of railway rakes and trucks or there is simultaneous arrival of rakes more than required capacity, any time delays during loading or unloading due to quality or property of coal cargoes, varying loading or unloading times, labour output and changes in consumption pattern or differing requirement and blending requirements for different grades. All these delays may be compounded with or can be as a result of network problems, logistics problems, weather conditions, bureaucracy, strikes etc. hence we can see port delays there are vast number of factors and becomes impracticable to formulate in a function which is still feasible in case of vessels to an extent hence for port we will only assume some of parameters observed.

Based on these aspects and data inputs a model can be formulated which will be applied for a particular vessel or number of vessels separately which is employed in carrying Coal to Paradip.

For formulation of problem a mixed integer Linear programming model will be used as one or some of the variables can be an integer or binary variable, the average waiting time and average number of ships waiting for berth obtained from queuing model is also applied.

To formulate problem now first of all it is required to know the objective function, As Port will be notified by vessel of estimated time of arrival at normal sea speed and port also obtains with all other relevant data vessels most economical speed. So using this variation or range of arrival time of each vessel port will plan schedules for all vessels. This range of arrival times is used in the model to optimize vessel arrival time with objective of minimized waiting time of vessels and minimized delays basis which vessel is allocated a berth schedule and vessel proceeds at an optimal speed corresponding to this schedule. To reach objective function with all inputs of vessels and berths, vessel handling times as per their capacities or DWT and all factors effecting shore side handlings is formulated to give minimum waiting time of the vessel and minimum departure delay of vessel served to have minimum idle times.

At Paradip there are two dedicated Coal berths for mechanised loading and unloading operations and there are eight numbers general cargo multipurpose berths which also can be used for coal loading unloading purpose if available.

We assume now notations used in the problem as follows, Golias *et al* (2009)

i = Number of vessels (1,……I), $i \in V$

j = Number of berths (1,……J), $j \in B$

k = Number of vessels served (1,……I-J+1) (each berth can serve one vessel berthed) $k \in K$

Notations parameters:

$A^e i$ = Earliest arrival time of vessel i

$A^l i$ = Latest arrival time of vessel i

T_j = Time when berth becomes idle for the first vessel in vessel arrival system

VWP_i = Average number of vessels waiting in port queue system

VAWi = Average arrival waiting time for vessels to be berthed in the port (time interval between when ship arrives at the port and when it is finally berthed as this is important for accessibility of berth) Here average waiting time of ships in queue from previous waiting line model is applied.

VDWi = Average departure waiting time for vessels to be un berthed in the port(time interval between when the ship starts un berthing process and when the ship departs & clear of the port's channel as this is important for accessibility of berth).

VL_j = Average ship loading (of Coal cargo) service rate for ship at berth j (Quantity of Coal

Cargo loaded on ships per hour of loading time).

VU_j = Average ship unloading (of Coal cargo) service rate for ship at berth j (Quantity of Coal unloaded from ships per hour of unloading time).

VDC_i = Time beyond lay time causing average Demurrage costs for Vessels

$ITPC_j$ = Idle times for Port operations costs & Vessel operation costs in port when idle (Running costs: Cargo handling / Storage / Port facilities / Railway workings / Infrastructure / Capital costs / Administration & Manning expenses)

VTL_j = Average shore transport (Rail rakes and / or Trucks) loading service rate at berth j (tons of cargo loaded on per hour of loading time).

VTU_j = Average shore transport (Rail rakes and / or Trucks) unloading service rate at berth j (tons of cargo unloaded on per hour of unloading time).

CA = Port channel accessibility (Limitations of channels for accessibility at certain times during day)

BA = Berth accessibility (Limitations of berth for accessibility with respect to size, depths and widths and accessibility at certain times during day)

SDT_i = Scheduled Departure time of vessel i

WD = Weather delays affecting the port (Accessibility of port when port is not open for navigation due to adverse weather conditions, restricted visibility and any inclement weather conditions effecting cargo operations at berth such as high winds or heavy rain)

Decision variables

x_{ijk} = If vessel i is served at berth j as kth vessel = 1 other wise 0

y_{ijk} = Idle time of berth j between start of cargo operation of vessel I as kth vessel and departure of previous vessel

WT_{ijk} = Waiting time of vessel I at berth j as the kth vessel

DD_{ijk} = Departure delay of vessel i at berth j as kth vessel

OC_{ijk} = Idle time factor causing additional operational costs incurred by port & vessel operations cost in port

Objective Function:

$$min \sum_{i \in V} \sum_{j \in B} \sum_{k \in K} (WTijk + DDijk)$$

Subject to:

Constraints:

1)

$$\sum_{j \in B} \sum_{k \in K} x_{ijk} = 1 \qquad \forall\, i$$

This constraint implies each vessel is served at a berth one time.

2)

$$\sum_{i \in V} x_{ijk} \leq 1 \qquad \forall\, j\ k$$

This constraint implies that one vessel is served at each berth at any given time.

3)

$$y_{ijk} \geq (A_i - T_j) - \sum_{m \neq i \in V} \sum_{o < k \in K} \{ (VL_j . x_{jmo} + y_{jmo} + WD + BA + CA)(VU_j . x_{jmo} + y_{jmo} + WD + BA + CA)(VTL_j . x_{jmo} + y_{jmo} + WD + BA + CA)(VTU_j . x_{jmo} + y_{jmo} + WD + BA + CA) \}$$

Where *VL_j, VU_j, VTL_j, VTU_j*, together is total handling time (*TT_{ij}*) & *WD, BA, CA* all together is regarded as uncertainties causing delays.

This constraint ensures Vessels berthing on arrival

4)

$$DD_{ijk} \geq WT_{ijk} + (TT_{ij} + A_i - SDT_i)$$

This estimates delay in departure of a vessel.

5)

$$WT_{ijk} \geq \sum_{m \neq i \in V} \sum_{o < k \in K} \{ (VL_j . x_{jmo} + y_{jmo} + WD + BA + CA)(VU_j . x_{jmo} + y_{jmo} + WD + BA + CA)(VTL_j . x_{jmo} + y_{jmo} + WD + BA + CA)(VTU_j . x_{jmo} + y_{jmo} + WD + BA + CA) \} + (T_j - A_i) + VAW_i + VDW_i$$

This constraint estimates total waiting time of each vessel while assigned berth handling other vessel including uncertainties.

6)

$$WT_{ijk} \geq VWP_i \{ (T_j - A_i) + (VAW_i + VDW_i) \}$$

This estimates total waiting time of a vessel for want of delays in berthing and un berthing of all other vessels in port

7)

$$OC_{ijk} \geq ITPC_j . (A_i - T_j) - \sum_{m \neq i \in V} \sum_{o < k \in K} ITPC_j . \{ (VAW_i + VDW_i) . x_{jmo} + y_{jmo} + VDC_i \}$$

This estimates total idle time causing additional operational cost of port and vessel when idle

8)

$$A_i^e \geq A_i \qquad \forall\, i$$

9)

$$A_i \geq A_i^l \qquad \forall\, i$$

10)

$$A_i \geq 0 \qquad \forall\, i$$

11)

$$x_{ijk}, \in (0, 1) \qquad \forall\, i, j, k$$

12)

$$y_{ijk} \geq 0 \qquad \forall\, i, j, k$$

13)

$$WT_{ijk} \geq 0 \qquad \forall\, i, j, k$$

14)

$$DD_{ijk} \geq 0 \qquad \forall\, i, j, k$$

15)

$$OC_{ijk} \geq 0 \qquad \forall\, i, j, k$$

Constraints 8 to15 represent the ranges and all variables as positive numbers constraint 11 represents an integer.

Above model is experimented using historical data of certain ships calling to Port of Paradip in a certain period of time Using Microsoft Excel 12.0 version solver and solver engine Gurobi LP/MIP solver. For evaluation 5 vessels carrying different coal quantity resulting in different handling times are chosen. Number of berths to be allocated is also limited to two dedicated berths for coal vessels only. This data set constitutes of Coal vessels average waiting times, average delayed departures and average handling or service times which is extracted from Vessel movement data obtained from Paradip Port trust for a certain period between May 2010 to July 2010, in order to avoid complex numerical experiment of the model.

Following summary of results is obtained from the solver solution.

Microsoft Excel 12.0 Answer Report
Worksheet: [MILP model.xlsx]Model
Report Created: 8/21/2010 2:17:24 PM
Result: Solver found a solution. All constraints and optimality conditions are satisfied.
Engine: Gurobi LP/MIP Solver
Objective Cell (Min)

Cell	Name	Original Value	Final Value
Total_WT	Total_WT	4419	4172

Microsoft Excel 12.0 Structure Report
Worksheet: [MILP model.xlsx]Model
Report Created: 8/21/2010 2:38:44 PM
Model Type: LP Convex Assumption: NLP
Statistics

	Variables	Functions	Dependents
All	25	80	350
Smooth	25	80	350
Linear	25	80	350

As solver found a solution and satisfying constraints and optimality conditions, The solution obtained is cumulative solution for total waiting times optimized for traffic within certain period. For larger sample problems GA based heuristics method is recommended as referred by Golias et al (2009) as this becomes very complex additionally an improved solution is obtained using GA based heuristic approach.

The resultant total optimized waiting time is used to evaluate an optimum arrival time of vessel, basis this optimum arrival time vessel is assigned an arrival time & ordered to proceed at an optimal speed to arrive at this targeted time, However as optimal speed has to be a speed which is practicable and vessel can operate in normal circumstances, normally it would be the top economic speed (Maximum sea speed) of the vessel, economical speed (Normal economical speed as per vessel's engine parameters) or most economical speed(Minimum feasible speed which can be performed by vessel within safe parameters of vessels engine), as per results optimal speed is observed to be closest reduced economical speed which can give minimum of delays or demurrage for vessel and reduced consumption of Bunkers and results in significant cost saving.

A careful consideration has also been made to assign an optimal speed for vessel to arrive at the targeted optimal arrival time with respect to prevailing bunker prices which any way in case of maximum sea speed will be more than economical speed and most economical speed as consumption can increase exponentially. Similarly

Charter party hire rates are also fixed on vessels sea speed performance same way it is applicable to other variables.

Standard and most commonly observed speeds for each vessel category of Cape size, Panamax and Supramax are as follows:

Cape Size

Speed
Max sea speed (14.2 Knots)
Economical speed(13.2 knots)
Most economical speed(12.0 Knots)

Panamax

Speed
Max sea speed (14.5 Knots)
Economical speed(13.7 knots)
Most economical speed(12.8 Knots)

Supramax

Speed
Max sea speed (15.0 Knots)
Economical speed(14.0 knots)
Most economical speed(13.2 Knots)

5.4 Application of optimal speed & evaluation of Vessel operation costs

Now these optimal speed will be applied to actual case scenarios for different vessels which called Paradip with Coal cargoes to discharge during months of June 2009 to September, 2009 when congestion was quite high with average waiting delays of about 12 days resulting in huge amounts of demurrage costs and also to some vessels which called during March 2010 to June 2010 when average waiting delays were about 2-3 days only. Evaluation results are given in Appendix 4 in tabular form.

In all 4 cases as given in Appendix 4 the discharge operations were done by using Mechanised unloading whereas if this berth is occupied and vessel is allotted general cargo berth which will involve conventional un loading using shore or ships gear it would take handling time of 3-4 days.

The results indicate cost savings for vessels in terms of Demurrage costs and bunker costs which are quite significant, However if there is only 2-3 days delay and not much congestion in port the demurrage cost for vessel may not be there as total time in port may not exceed the agreed lay time of vessel but still there is saving of fuel costs. In this case also vessel can slow down and minimize waiting time at port and reduce bunker cost as shown above. We can check and clarify this cost saving further with an actual voyage estimation of a voyage to Paradip performed by a vessel

Voyage Estimate Cost (Trip time charterer)

Vessel: Panamax bulk carrier, X
Cargo: Coal
Sea Speed: 14 Knots
Daily Consumption At Sea: 39 MT IFO, 0.1 Mt MDO
In Port: 3 MT IFO, 0.1 MT MDO
Lay Time: Load/Disch: 12 WWSHEX
Cargo: 71000 MT
Stipulated Discharging Rate In C/P: 18000 MT/PWWD
Itinerary: Abbot Point (Load Port) / Paradip (Discharge Port)
Total Distance: 5189 Nm

<u>Normal Speed:</u>
Steaming: 15.5 Days
Cargo Gross Fright Revenue: 71000 Mt @ 100 $ Mt = $ 7,100,000
<u>Variable Costs:</u>
Fuel At Sea: 15.5 Days Sea Steaming: 15.5 X 39 MT/Day X $ 439/MT
= $ 265375
Berthing Delay: 3 Days
Fuel In Port: (Waiting + Discharging): 7 Days X 3 MT/Day X $ 439/MT
= $ 9219
Port Charges: = $ 300,000
Demurrage: @ $ 8000 / PDPR
Suppose Now Waiting Has Resulted In Delay To Vessel Beyond Lay time By 3 Days
Therefore Demurrage Payable = $ 24000
Total Variable Costs: = $ 598594

Net Revenue: **= $ 6,501,406**
<u>Slow Steaming (Economical Speed – 12.8kts):</u>
Steaming: 17 Days
Cargo Gross Fright Revenue: 71000 MT @ 100 $ MT = $ 7,100,000

<u>Variable Costs:</u>
Fuel at Sea: 17 Days Sea Steaming: 17 X 31 MT/Day X $ 439/MT = $ 231,353
Berthing Delay: 1.5 Day, Now As Steaming Time Has Increased So Vessel Will Berth Upon Arrival.
Fuel in Port: (Waiting + Discharging): 4 Days X 3 MT/Day X $ 439/MT
= $ 5268
Port Charges: = $ 300,000
Demurrage: There Is No Delay beyond Lay time
Total Variable Costs: = $ 536,621

Net Revenue: = **$ 6,563,379**

Total Saving: $ 61,973 (For Loaded Passage)

Considering these aspects we can see that if vessel's berthing schedule is ascertained then a properly planned scheduled arrival time of vessel can save lot of costs hence an optimal schedule is very valuable.

From a vessel operator point of view the major concern is to achieve minimal costs which will be helped by vessel arrival system primarily an optimal scheduling of vessels to match berthing time as far as practicable.

Scheduling decisions incur the following types of costs, Gerald G. Brown *et.al*, (1987) which are carefully considered for making a decision.

1. Daily cost: Which represents the opportunity cost of ship as any delays may result in losing a very promising forthcoming employment or charterer of vessel also.

2. Bunker fuel consumption: Bunker consumption is directly proportional to speed and increases exponentially from economical speed to Max sea speeds so it has strong correlation with speed as it is proved earlier.

3. Fuel for vessel's auxiliary engines and systems consumed also needs to be taken into account while in port and not steaming.

4. Port and Canal dues are ship-specific costs incurred in port or when transiting a Canal depends on their tonnage.

5. Costs incurred in Spot charter of vessel for hiring to carry cargos.

6. Cost of an idle ship is a combination of daily costs, fuel for auxiliary engines & Port dues.

Chapter 6 Conclusions

6.1 Final interpretation of results

As this arrival time is optimized to have minimized delay or waiting time in port prior berthing and it further ensures minimized delayed departure of vessel also as port has allocated a berthing time to the next vessel also so every vessel needs to be completed in a time window to accommodate subsequent vessels at the targeted berthing time. So in a way it will provide the vessel a reliability of departure time which will have positive effect for planning and fixing vessels next employment also as this is the biggest uncertainty in bulk trade as depending on vessels reliable availability the lay time delivery / redelivery can be agreed with at ease by operators and it gives more possibility of fixing a more profitable voyage also it will help to increase berth and port productivity.

Once a system is established which is flexible and transparent then advanced planning and scheduling of all operations and resources is of vital importance and will help in achieving high level of optimization of transportation and logistics and whole supply chain will become very efficient, The concept of vessel arrival system is very much part of this whole process which is being implemented as the first rung as this is the only feasible option at this stage which can be controlled in present conditions other optimization and transportation processes and solutions for whole supply chain efficiency can only be undertaken when a streamlined system exists.

While the vessel arrival system is being implemented Paradip port trust simultaneously has to plan optimization scheduling for its Coal handling facility mechanised and conventional both, basis that they can give more realistic targeted berthing time windows for vessels, which involves planning of berth capacity, Coal stock pile / storage yard capacity and its utilization as this is already almost over 70%. Port has to plan optimization and scheduling of its resources & workforce i.e. ports railway link which will involve properly organising shunting of wagons, flexibility to handle last minute changes, any locomotives breakdowns, maintenance so all these should be taken into account, utilization of equipments and cranes within port which is under their control, internal transport its travelling distances is also important and proper planning for entry and exit of trucks to avoid bottlenecks. Workforce scheduling will help in good labour through put. Once all this is synchronised with targeted vessel arrival or berthing times it will influence the service time of vessel there will be reliable berthing windows and minimized delays during cargo operations and increase port productivity also for handling coal. It will be an advantage for vessels also as more reliable departure times also known to them.

Planning for the allocation of berth for vessels port has to consider customer contracts and volumes, market opportunities, vessel capacities, lay cans etc this will have advantages for the port for increasing productivity and capacity and tonnage optimization and in a way will increase customer service also.

6.2 Impact of Optimization of vessel arrival time and system

If we summarize benefits with fully operationalized Vessel arrival system correctly in coordination with all parties, from vessel operator / owners / Charterers point of view, the benefit will be in terms of reduced vessel time in port & costs for vessel and fast discharge of vessel with reliable departure schedule also as port has to meet the assigned berthing windows for all vessels.

From Shippers / receivers point of view there will be reduced demurrage costs, they have advantage to negotiate a better fright rates with improved turnaround time. As there are minimized delays in port coal cargo condition and quality is also retained to an extent. There will be reduced insurance costs also on cargoes for fluctuations in commodity prices. In the end overall reductions in cost reflects reduced cost to consumers and end users also.

There will be benefits to the port in terms of their improved productivity which will improve their status and in turn improve their market share and can recover the lost share which was diverted to other ports in the region and of course is a major competitive factor to penetrate in hinterland, this will also give better utilization of berth and stock yard.

The fact which plays role in determining the optimization and implementation of vessel arrival obviously is with the motive of the maximization of daily income for ship commercial operators, port, shippers/ receivers etc. As shown in the cost structures evaluated above in the model. The optimal speeds are decided according to the fixed daily costs and variable cost structures at which the daily income can be maximized from the freight collected. As we have seen in the model Cost of bunker and demurrage costs incurred in the supply chain are the principal determinant for ships speed. When Fuel prices are high then speed reduction is definitely an incentive to operate at economical speeds and avoid unnecessary consumption and reduce emissions also. In these circumstances as greater efficiency is achieved then ship can be traded at a given economical speed and proportionately lesser fuel consumptions and therefore with improved description of vessel can attract better charter rates also.

However at the same time there are complexities related to speeds, consumption, lay time and demurrage clauses and it also requires vessel to proceed at utmost dispatch as mentioned earlier also under charter party section, Ship is fixed basis a description provided by owners which clearly indicates vessel’s speed and consumption at laden in ballast as well as sometimes intermediate conditions also which includes economical speeds. In Time Charter, charter rates are based on this description and under time charter fuel is always paid by charterer so if the vessel will underperform in terms of lesser speed as agreed on charter party or if over consumes a specific consumption as agreed on charter party hence these aspects must be clearly agreed between vessel’s charterer or commercial operator and owners as it may lead to legal complications later on. Similarly a careful understanding and agreement is required for Notice of readiness tendering times and to be an arrived ship, lay time and demurrage otherwise they can also lead to arbitrations among shippers/ receivers, vessel operator and owners, Demurrage is often paid by shippers or receivers in Free in / out (as per Inco terms or sales contracts) fixtures and depends on where it is incurred. Such matters sometimes depend on certain circumstances on which commercial operator and owners have no control that is why it is necessary that all parties are in agreement.

An important point to note here is that all ships at slower speeds are more fuel efficient but that does not necessarily means that going slower will be cost efficient for overall supply chain hence in regression analysis model the correlation of bunker prices as well as fright rates is also shown and for optimizing speed the function obtained incorporates freight rates and bunker price also as the ratio of fright rates and bunker price is an important influencing factor for speeds.

As we have seen in the actual cases calling to Paradip the speed is adjusted by about 2 knots operating at most economical speed to meet the targeted arrival time so system is basically optimized on a certain engine load of course depending on the prevailing weather conditions and over a period of time with this system established and as we know from past trend that bunker prices will increase substantially then it would make even more economic sense to operate vessels on slow speeds and it will meet all the objectives then without any legal complications. For time being Vessel engines on economical speeds will be operated taking all safety parameters of main engine in account and in due course when this becomes a norm due to commercial & environmental aspects then engine designs also will be suitable or retrofitted to get efficient exhaust energy, steam productions and work efficiently for dry steam requirements etc. and then can even operate at more low speeds.

6.3 Commercial and standard safe working issues for vessel arrival system

As we talk of changing system with optimal arrival system we must bear in mind that the vessels are following utmost dispatch and charter parties speeds and consumptions are complied and vessels are bound under law system so even if by reducing speed and minimizing waiting times at port there are commercial gains but still concerned parties are sometimes reluctant to get involved with any arbitrations or whatsoever. Hence this also requires a behavioural change and all have to get convinced of the known inefficiencies of the existing system as it is totally wasteful for a vessel to come to port with max sea speed with known delays and then wait at anchor for long time it makes the whole chain unproductive, which can be improved by implementing vessel arrival system and in turn can improve that supply chain of coal, the waiting is minimized, more reliable departure times are may be attained, and further more emissions from vessels can be reduced at sea as well as when idle for less time in port. It also improves navigational safety in port with regard to traffic density in port area and traffic is coordinated as arrival times of vessel are known. So a mutual agreement for economical speeds on specific fuel consumptions is important in order to have smooth process and achieve agreed or targeted arrival time for vessel.

In concept of implementation of Vessel arrival system the required conditions are already discussed earlier but certain aspects which are not discussed so far are related to daily running of vessel and standard safe working practices because it is of utmost importance that any concept applied for commercial gains should not affect safe operation of a vessel. Safety and security of vessel is Paramount and takes precedence over all matters and Master's authority should remain same with regard to these aspects.

For better understanding it may be prudent to make the system as transparent as possible with all concerned parties so that they are all convinced with the steps taken and agree to it, normally prior adopting Vessel arrival system vessel's charterer who through its agents and the cargo receiver in discharge port know about delays due to congestion or berth allocation problems, they can get into agreement and suggest shippers, owners and other concerned parties to agree for a controlled vessel arrival or targeted arrival in conjunction with advice from port authority for berth availability. If ship owner or vessel operator have no special arrangement for taking advantage of extra time in port with regard to next voyage or employment then the system can be started in agreement by all concerned parties and possibly a binding agreement for that voyage in accordance with an agreed Charter party clause then instructions will be passed to Master of vessel to reduce / adjust speed for the targeted arrival / berthing time for vessel at most economical speed with due regard to navigational safety and prevailing weather conditions, it will reduce waiting time of vessel and reduce demurrages and save bunkers. Demurrage and fuel costs saved can also be shared among all concerned parties equally as agreed.

As an immediate solution Vessel arrival system is most practical process with objective of minimizing waiting times, reducing demurrage and fuel costs and most of all improving overall efficiency within transport chain hence it will be a sustainable solution also with respect to commercial as well as environmental aspects

The operational costs and minimal delays are not only important to vessel but also to Port, terminals, Shippers, Steel plants and Power plants etc as it will help in reducing their demurrage costs which are quite extensive at their end as transport chain of coal is not optimized and has lot of unreliability and with present economic scenario there is increasing pressure of reducing operational cost and the first thing which comes to mind is demurrage costs particularly for this sector. In India the demurrage expenses incurred by steel plants or Power plants are in the coal receipt process, The plants use mainly railway wagons of railways to transport coal from the ports to the plants, these loaded railway rakes need to be unloaded and released in a stipulated time otherwise plants have to pay a demurrage cost to the railways Amit Bhatnagar *et.al*, This is also coupled with transport problems of wagons of railways. The various underlying causes for delays in hinterland transport chain are identified as follows.

Demurrage causes for Thermal plants / steel plants as Identified by CEC
1: Receipt in quick succession
2: Outlet problem
3: Oversized coal
4: Due to outage of one tippler / Due to outage of stream of a tipple
5: Derailment
6: Too much wet and sticky coal
7: Low Ambient temperature
8: Failure of electrical power system / major electrical tripping
9: Granulator problem; includes mechanical and electrical problems.
10: Empties could not be turned-out / No room on I/C lines / AYM did not allow

even though line was clear.
11: Rain continue at the time of unloading which made coal more wet and sticky
12: Successive detention
13: Locomotive / Dozer trouble
(Source: Mathematical modelling for demurrage reduction in coal transportation for an Indian Thermal Power plant- *Amit Bhatnagar et. al*)

The problem of railway rakes gets worse by the fact that any wagon which fails to be unloaded in allotted time cannot be interchanged by empty wagons in other rakes it has to go back with the same rake and now if for some reason one wagon is not unloaded in time the whole of rake is stranded there causing demurrage costs and as this rake cannot be released hence subsequent delay is caused for its arrival to port also due to which stock piles of cargo in port cannot be cleared in time hence delaying unloading process of vessels and congestion problems, high waiting times.

6.4 Recommendations for further research

An interesting point to mention here is that, as vessel arrival system is intended to be applied for minimizing waiting times of vessel similarly a controlled arrival system can be used for arrival of railway rakes and trucks to Thermal power plants and Steel plants and with this optimal arrival demurrages costs can be reduced at their end also however this process will involve improved service time i.e. time of unloading rakes with minimal loss of time due to all external factors which cause demurrage but in the case of Thermal power plants and Steel plants it is difficult to control and operationalize, as in India railways are government entity and for that matter controlling arrival process of railway rakes will require necessary approvals and lot of bureaucracy is involved to organize and coordinate the supply chain. If the arrival process can be controlled there will be definitely saving of demurrage costs and most important is that it will improve the supply chain of coal. Moreover to improve service times for fast unloading of rakes and releasing them in time can be improved by better engineering design and process which would require huge investments so in this case it is important to the trade off between the investment and demurrage costs. Also there is shortage of expertise and adequate man power within power industry all these factors make the supply chain of coal inefficient. The process of arrival system and improvement in service time can only be achieved by better coordination and with joint effort of Power companies, Steel companies, Indian railways and Government. But unfortunately focusing too much for better improved coordination takes years of discussions and by then many circumstances would have changed and such processes and supply chain networks always require constant analyzing of all processes hence the immediate solution which is still feasible is at interchange of Port and Vessel by implementing Vessel arrival system to minimize delays & waiting times at least in a part of supply chain which will make it more profitable than it is now.

The way India is growing now there is huge demand of power but unfortunately there are innumerable challenges to cope up with that demand as there is gap between what is required and what power sector is able to deliver and this is attributed by mainly inefficient coal supply chain as coal being the main source of power production in India and is expected to remain so in future also. This additional power requirement will require continuously incremental amount of coal supply by increasing coal imports and transportation at Ports in India and also internal transportation by Indian railways within the country. The existing Power plants have to always struggle for such capacity shortages and huge demurrage costs. Hence for new projects it is vital that if they can manage their own supply chain with better logistical solutions and necessary approvals beforehand so as to minimize such delays in supply chain. This of course would require lot of investment by private sector and Government also has to step forward to be more flexible with clearances and fast in decision making process and have concession agreements like Built-Operate-Transfer (BOT) arrangements. In order to meet the demand it will be prudent for Power plants and Steel plants to have their own Loading / Unloading Jetty for Coal vessels and direct link with the plants using conveyor belt system or rail link with dedicated freight line for that purpose and own railway infrastructure then it would be very easy to implement controlled arrival system not only for vessels but for railway rakes and improve the whole supply chain and its profitability. Ports can also in their expansion projects invite tenders or influence or attract Power companies and Steel companies to have their captive jetty's in their port this would help to increase Ports through put also, although some of the ports already have captive jetty's but Paradip does not have any captive jetty for any big customer and moreover Paradip has limited number of business partners for which Paradip port trust must emphasize to reduce dependency on just few major players as this is important for competitive strength.

If all these improvements can be made easily and in short span of time then maybe there will be no need to implement vessel arrival system but problem is such developments can take ages and there is need for a solution which is practicable and can be implemented within short time, that is why the vessel arrival system is the easiest solution available which can be implemented to minimize waiting times on sea leg which will help to improve a proportion of transport chain and reduce demurrage costs for this segment at least.

Although improvement of coal supply chain after the port segment may appear to be quite difficult task due to its complexity but it is not impossible and can be done, for that apart from investments in infrastructure & technology an advanced planning and scheduling will be required with a clear understanding between government its intergovernmental departments and all public and private sector involved in this supply chain.

The concept of advanced planning and scheduling will only be successful when the whole system is streamlined and there are no hindrances of delays in getting necessary approvals and clearances of plans & projects for infrastructure and technology needs and there is well established coordination within all segments.

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Appendices

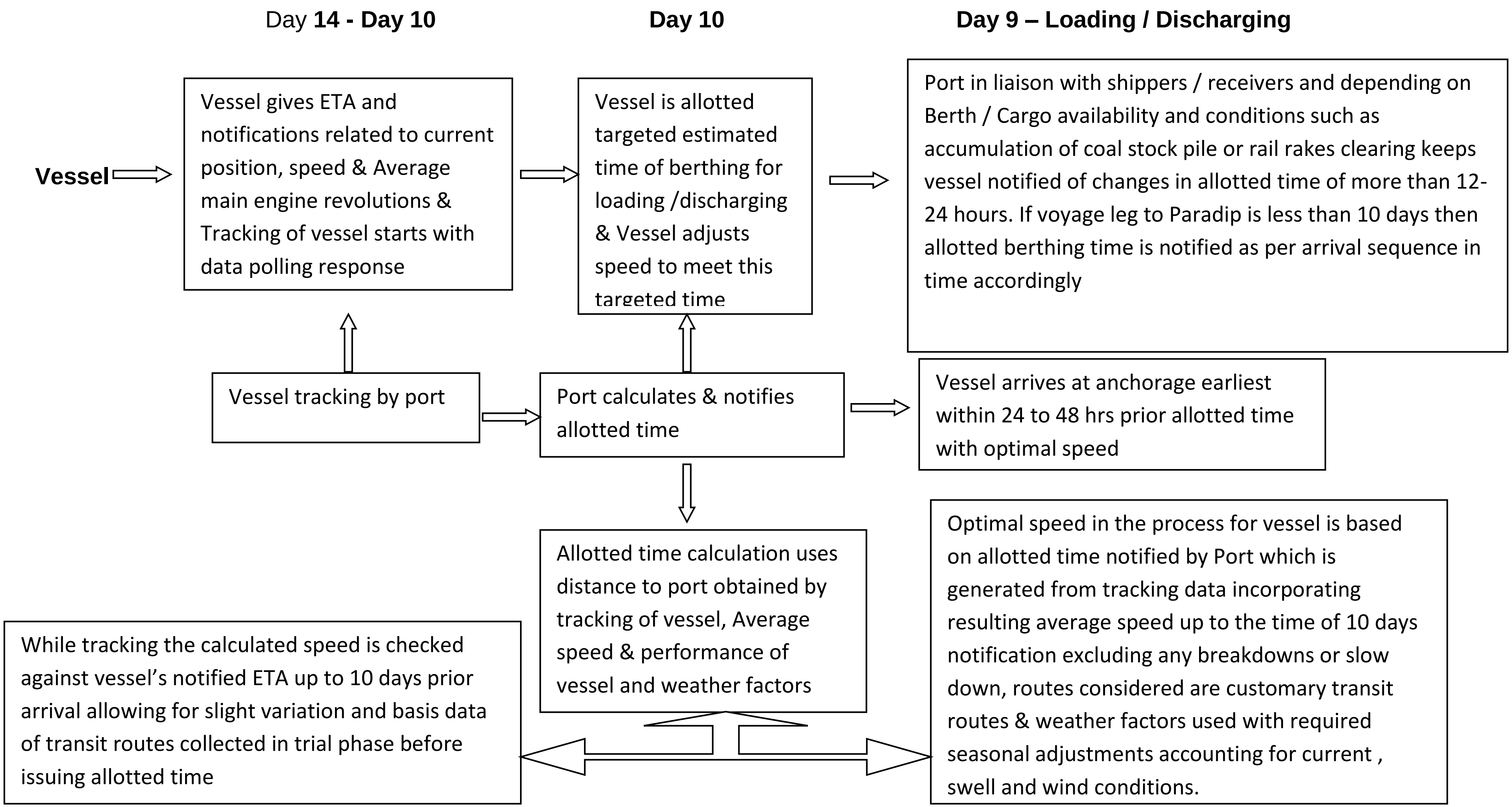
Appendix 1: Traffic Handled at Major Indian Ports

(DURING APRIL TO MARCH'2010* VIS-A-VIS APRIL TO MARCH'2009) (IN '000' TONNES)

PORT	TARGET/ TRAFFIC	P.O.L.	IRON ORE	FERTILIZER FIN.	FERTILIZER RAW	COAL THERMAL	COAL COKING	CONTAINER TONNAGE	CONTAINER TEUs	OTHER CARGO	TOTAL	% VAR. AGAINST 2008-09
KOLKATA	TRFAPRIL-MAR.'2010	724	809	2	45	-	16	6645	377	4804	13045	
	TRF APRIL-MAR.'2009	3436	288	-	9	-	-	5476	302	3219	12428	4.96
Haldia Dock Complex	TRF APRIL-MAR.'2010	9338	7684	176	118	1489	6036	2010	124	6399	33250	
	TRF APRIL-MAR.'2009	16949	8747	317	230	1915	5923	2373	127	5337	41791	-20.44
TOTAL: KOLKATA	TRF APRIL-MAR.'2010	10062	8493	178	163	1489	6052	8655	501	11203	46295	
	TRF APRIL-MAR.'2009	20385	9035	317	239	1915	5923	7849	429	8556	54219	-14.61
PARADIP	*TRF APRIL-MAR.'2010*	*11647*	*16158*	*81*	*3486*	*14818*	*5003*	*44*	*4*	*5774*	*57011*	-
	TRF APRIL-MAR.'2009	*4816*	*14272*	*173*	*3396*	*14698*	*5435*	*31*	*2*	*3591*	*46412*	*22.84*
VISAKHAPATNAM	TRF APRIL-MAR.'2010	18290	18108	2909	775	3712	7406	1679	98	12622	65501	
	TRF APRIL-MAR.'2009	19758	17521	3408	726	3440	7581	1362	88	10112	63908	2.49
ENNORE	TRF APRIL-MAR.'2010	395	936	-	-	9279	-	-	-	93	10703	
	TRF APRIL-MAR.'2009	366	1111	-	-	9708	-	-	-	315	11500	-6.93
CHENNAI	TRF APRIL-MAR.'2010	13425	7882	357	234	1835	1527	23476	1225	12321	61057	
	TRF APRIL-MAR.'2009	13132	8358	516	267	2446	1656	20580	1144	10536	57491	6.20

TUTICORIN	**TRF APRIL-MAR.'2010**	**514**	**41**	**1223**	**868**	**5813**	**-**	**6599**	**440**	**8729**	**23787**	
	TRF APRIL-MAR.'2009	**503**	**-**	**1147**	**677**	**5713**	**-**	**5482**	**439**	**8489**	**22011**	**8.07**
COCHIN	**TRF APRIL-MAR.'2010**	**11957**	**-**	**143**	**211**	**148**	**-**	**3928**	**290**	**1042**	**17429**	
	TRF APRIL-MAR.'2009	**10491**	**27**	**193**	**265**	**259**	**-**	**3256**	**261**	**737**	**15228**	**14.45**
NEW MANGALORE	**TRF APRIL-MAR.'2010**	**21339**	**7062**	**820**	**13**	**-**	**2791**	**475**	**31**	**3028**	**35528**	
	TRF APRIL-MAR.'2009	**21328**	**9774**	**905**	**13**	**-**	**1929**	**404**	**29**	**2338**	**36691**	**-3.17**
MORMUGAO	**TRF APRIL-MAR.'2010**	**964**	**40574**	**125**	**-**	**957**	**3784**	**192**	**17**	**2251**	**48847**	
	TRF APRIL-MAR.'2009	**898**	**33809**	**182**	**-**	**449**	**4107**	**147**	**14**	**2089**	**41681**	**17.19**
MUMBAI	**TRF APRIL-MAR.'2010**	**34596**	**-**	**201**	**241**	**3745**	**-**	**606**	**58**	**15154**	**54543**	
	TRF APRIL-MAR.'2009	**34371**	**-**	**117**	**193**	**3266**	**-**	**1291**	**92**	**12638**	**51876**	**5.14**
J.N.P.T.	**TRF APRIL-MAR.'2010**	**5082**	**-**	**-**	**-**	**-**	**-**	**53078**	**4061**	**2586**	**60746**	
	TRF APRIL-MAR.'2009	**4552**	**-**	**-**	**-**	**-**	**-**	**50602**	**3953**	**2137**	**57291**	**6.03**
KANDLA	**TRF APRIL-MAR.'2010**	**47211**	**660**	**4912**	**788**	**2296**	**929**	**2421**	**146**	**20304**	**79521**	
	TRF APRIL-MAR.'2009	**45538**	**129**	**5195**	**298**	**1407**	**467**	**2136**	**137**	**17055**	**72225**	**10.10**
ALL PORTS	**TRF APRIL-MAR.'2010**	**175482**	**99914**	**10949**	**6779**	**44092**	**27492**	**101153**	**6871**	**95107**	**560968**	
	TRF APRIL-MAR.'2009	**176138**	**94036**	**12153**	**6074**	**43301**	**27098**	**93140**	**6588**	**78593**	**530533**	**5.74**
% Variation from previous year		**-0.37**	**6.25**	**-9.91**	**11.61**	**1.83**	**1.45**	**8.60**	**4.30**	**21.01**	**5.74**	

Appendix 2: Vessel Arrival System Process Flow Chart



Appendix 3: Variable Data Table

Depen--dent Var.	Independent Variables													
Avg Spd (Kts)	**Cape size Charter Hire**	**Pana---max Charter hire**	**Supra-max charter hire**	**Avg. Aus. Coal Price**	**Avg. Indo. Coal price**	**Pana-max avg frt rate (ECA)**	**Panamax avg freight rate Indo.**	**Supra-max avg frt rate (ECA)**	**Supramax avg freight rate Indo.**	**Ag.Bunker price @ Singapore**	**Avg. T. coal handling rate (Mech)**	**Avg. T.coal handling rate Conventional**	**Avg C. coal hndlng rate**	**Avg Demurrage rate**
15.0	30283	30472	28192	107.28	92.26	27.00	19.00	33.50	23.50	439	32459	6084	9501	6.00
14.8	29783	29972	27692	107.30	92.01	26.50	18.50	33.00	23.00	422	33826	9173	9274	5.75
14.6	29283	29472	27192	101.12	89.70	26.00	18.00	32.50	22.50	498	30656	7689	9056	5.50
14.4	28783	28972	26692	100.92	84.33	25.50	17.50	32.00	22.00	458	29879	6456	8838	5.25
14.2	28283	28472	26192	103.93	84.52	25.00	17.00	31.50	21.50	461	29102	6203	8620	5.00
14.0	27783	27972	25692	89.04	75.60	24.50	16.50	31.00	21.00	479	28325	5950	8402	4.75
13.8	27283	27472	25192	76.15	73.66	24.00	16.00	30.50	20.50	468	27548	5697	8184	4.50
13.6	26783	26972	24692	84.43	71.44	23.50	15.50	30.00	20.00	466	26771	5444	7966	4.25
13.4	26283	26472	24192	72.47	69.45	23.00	15.00	29.50	19.50	420	25994	5191	7748	4.00
13.2	25783	25972	23692	77.68	67.46	22.50	14.50	29.00	19.00	424	25217	4938	7530	3.75
13.0	25283	25472	23192	79.07	65.47	22.00	14.00	28.50	18.50	410	24440	4685	7312	3.50
12.8	24783	24972	22692	76.48	63.48	21.50	13.50	28.00	18.00	401	23663	4432	7094	3.25
12.6	24283	24472	22192	73.89	61.49	21.00	13.00	27.50	17.50	388	22886	4179	6876	3.00
12.4	23783	23972	21692	71.30	59.50	20.50	12.50	27.00	17.00	321	22109	3926	6658	2.75
12.2	23283	23472	21192	68.71	57.51	20.00	12.00	26.50	16.50	299	21332	3673	6440	2.50
12.0	22783	22972	20692	66.12	55.52	19.50	11.50	26.00	16.00	280	20555	3420	6222	2.25
11.8	22283	22472	20192	63.53	53.53	19.00	11.00	25.50	15.50	260	19778	3167	6004	2.00
11.6	21783	21972	19692	60.94	51.54	18.50	10.50	25.00	15.00	255	19001	2914	5786	1.75
11.4	21283	21472	19192	58.35	49.55	18.00	10.00	24.50	14.50	240	18224	2661	5568	1.50
11.2	20783	20972	18692	55.76	47.56	17.50	9.50	24.00	14.00	244	17447	2408	5350	1.25
11.0	20283	20472	18192	53.17	45.57	17.00	9.00	23.50	13.50	275	16670	2155	5132	1.00
10.8	19783	19972	17692	50.58	43.58	16.50	8.50	23.00	13.00	433	15893	1902	4914	0.75
10.6	19283	19472	17192	47.99	41.59	16.00	8.00	22.50	12.50	640	15116	1649	4696	0.50
10.4	18783	18972	16692	45.40	39.60	15.50	7.50	22.00	12.00	610	14339	1396	4478	0.25
10.2	18283	18472	16192	42.81	37.61	15.00	7.00	21.50	11.50	708	13562	1143	4260	0.00

Appendix 4: Evaluation of vessel Operation cost saving

	Vessel size	Max Sea speed	Cargo Qty	Port of origin	Distance & Normal steaming est. days	Average Handling time @ Paradip	Total delay / Idle time	Adjusted optimal speed	Demurrage per WWD	Reduced Demurrage & cost	Reduced Bunker Cons. & cost
Case 1: *Vessel A*	Panamax 73400 DWT	14.5 Knots	71250 Metric tonnes	Abbot point , Australia	5189 NM & Voyage 15 days	40 hours	12 Days or 288 hours	13 knots	8000 USD /WWD	2 days waiting reduced = 16000 USD	75 MT @ 439 USD / MT = 32925 USD
Case 2: *Vessel B*	Panamax 72372 DWT	14.5 Knots	69000 Metric tonnes	Gladstone, Australia	5410 NM & Voyage 15.5 days	39 hours	3 Days or 72 hours	13 knots	10000 USD /WWD	2 days waiting reduced	80 MT @ 439 USD / MT = 35120 USD
Case 3: *Vessel C*	Suprama x 54394 DWT	15.0 Knots	50250 Metric tonnes	Newcastle, Australia	5887 NM & Voyage 16.5 days	29 hours	8 Days or 192 hours	13.2 knots	7000 USD /WWD	2 days waiting reduced = 14000 USD	71 MT @ 439 USD / MT = 31169 USD
Case 4 *Vessel D*	Suprama x 52898 DWT	15.0 Knots	47500 Metric tonnes	Samarind, Indonesia	2942 NM & Voyage 8.2 days	27 hours	2.5 Days or 60 hours	13.2 knots	7000 USD /WWD	2 days waiting reduced	70 MT @ 439 USD / MT = 30730 USD