MULTIMODAL AND INTERMODAL TRANSPORTATION MODEL OF PETROCHEMICAL COMMODITIES

A DISSERTATION

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Submitted By:

SRISHTI

(2K22/MSCMAT/45)

DIVYA

(2K22/MSCMAT/62)

Under the guidance of:

PROF. L.N. DAS

DEPARTMENT OF APPLIED MATHEMATICS

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road – 110042

JUNE, 2024

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CANDIDATES'S DECLARATION

We, student of M.Sc. Mathematics, hereby declare that the project Dissertation title **"Multimodal and Intermodal transportation of petrochemicals commodities**" which is submitted by me to the Department of Applied Mathematics, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Science, is authentic and not copied from any source without proper citation , under the guidance of Prof. L.N. Das . I hereby ensure that based on this work, no prior degree, certificate, associateship, fellowship, or other title or honor has been given.

Place: Delhi   Srishti

Date: 6th June, 2024

Divya

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

Department of Applied Mathematics

SUPERVISIOR'S CERTIFICATE

To the best of my knowledge, this is to certify that, the project work, named **"Multimodal and Intermodal transportation of petrochemicals commodities"** submitted by **Srishti and Divya,** M.Sc. Mathematics, has never been submitted anywhere else, in whole or in part, for any Degree, Diploma at this University or anywhere.

Place: Delhi

Date: 6th June 2024

Prof. L.N. Das	Prof. Ramesh Srivastava
SUPERVISOR	HEAD OF DEPARTMENT
Department of Applied mathematics	Department of Applied Mathematics
Delhi Technological University	Delhi Technological University

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Srishti

[2K22/MSCMAT/45]

Divya

[2K22/MSCMAT/45]

ABSTRACT

Multimodal container-based petrochemical transportation is not an easy task. The different modes of transportation and transshipment model descriptions are rarely described in the literature on multimodal container-based petrochemical transportation procedures. Moreover, the description of computational models in support of decision- making solutions to the multimodal transportation problem is not found in the literature. We have studied the problem model and have found the Initial basic feasible solution using the Vogel approximation method and we have used the Modified Distribution method. It is now generally acknowledged that Transportation of petrochemical commodities plays a key role in ensuring the smooth flow of goods within the global supply chain. We examine the challenges and opportunities associated with multimodal and intermodal transport systems for petrochemical products with a focus on increasing efficiency, sustainability and safety. It provides an overview of the importance of the petrochemical industry and the unique characteristics that affect transport logistics. Petrochemical products, from raw materials to finished products, require specialized handling and careful consideration of safety regulations. It delves into the concept of multimodal transport and emphasizes the integration of different modes of transport such as road, rail, sea and air to optimize the movement of petrochemical commodities. The benefits and challenges of multimodal transport are discussed, highlighting the potential for reducing transport costs, minimizing environmental impact and increasing supply chain resilience. In conclusion, this thesis advocates a comprehensive approach to the transportation of petrochemical commodities through the integration of multimodal and intermodal strategies. By leveraging technological advances and prioritizing sustainability, stakeholders in the petrochemical supply chain can achieve greater efficiency, resilience and safety in the movement of these critical commodities.

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CHAPTER 1
INTRODUCTION

1.1 Introduction to Multimodal Transportation

Multimodal, or mixed, transport is the movement of goods under a single contract using a minimum of two methods of transportation. The carrier employs a range of transportation methods, such as road, rail, and sea water, and is (legally) accountable for all goods, including the vehicle itself. Under legal parlance, the person who handles carriage is usually referred to as the "true carrier"—a sub carrier.[1] It is not necessary for the carrier to own every kind of transportation; in fact, most of them do not. The carrier managing every cargo is known as the multimodal transportation operator (MTO). The terms "Transportation, combined transportation", "multimodal transportation" and "intermodal transportation" are all used for the transportation of goods from source to destination [2]. These four words have similar meanings; In other words, it means transportation of goods by more than one means of transportation and intermediate transportation. However, the United Nations differs from time to time and defines the transportation conditions in its book Intermodal Transportation (1995). One way to characterize intermodal transportation is as a specific kind of multimodal transportation when the same load unit or road vehicle is transferred using two or more modes of transportation. This suggests that the goods stay in the same shipping containers (or swap bodies) when the mode of transportation is switched; the loading units or road vehicles are the only things that are altered. Intermodal transportation is when goods are sent to a port and then carried by truck or wagon to a railway terminal, depending on how the containers are loaded. Containers are conveyed by rail to the nearest node, where they are picked up and taken further.[3]

1.2 Modes and Means of Transportation

There are numerous forms and methods of transportation. By employing a specific method of transportation, the mode of transportation offers the required infrastructure. It would be impossible to have transportation without this infrastructure. Land transportation encompasses road, rail, and pipeline transportation; water transportation covers inland water transport, deep sea, and coastal shipping; and air transportation includes air traffic.

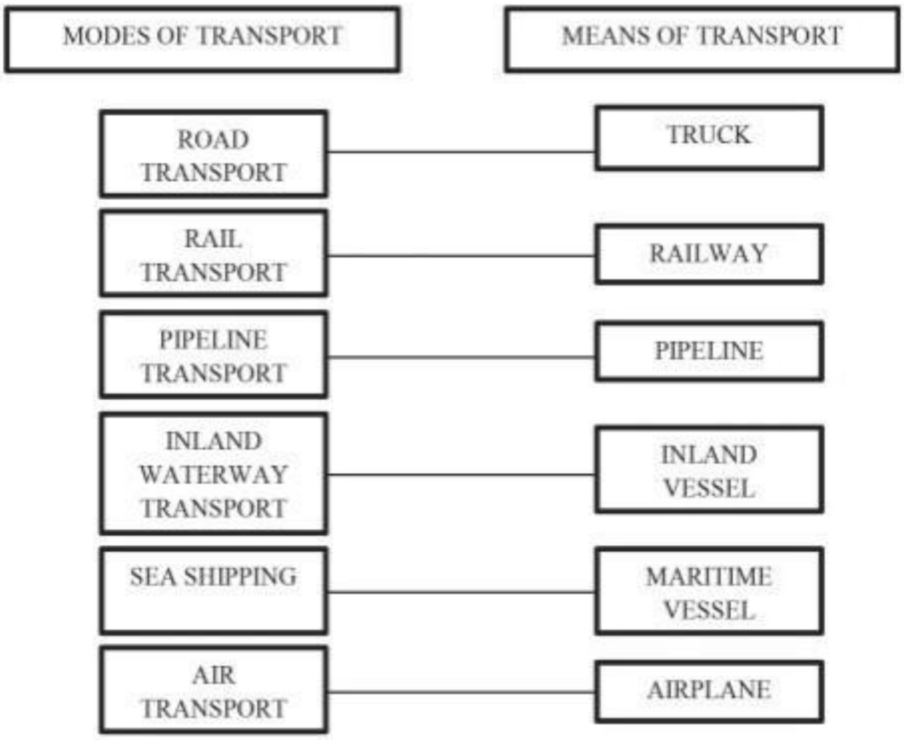

Figure 1: means and mode of transportation (source = author)

Transport means refer to the technical apparatus and devices used for moving people or cargo. Inland vessels, trucks, and airplanes are a few examples of the means of transportation used in freight transportation. Many forms of transportation, also known as transport processes, have been developed because the transfer is generally unmanageable with a single type of transport or means of transport.

1.2.1 Unimodal Transportation

In transport mode, each carrier provides its own shipping documents (bill of lading /L3, airwaybill, delivery note, etc.).

1.2.2 Combined Transportation

It is the transportation of goods in one and the same container or vehicle by a combination of road, railway and in land water.

1.2.3 Intermodal Transportation

Transportation by different modes of transportation, in which one carrier arranges the entire transportation from a single place or port of origin to one or more connections to the final port or destination. Different documents are used depending on whether responsibility for the entire delivery is shared or not. Intermodal transportation also has different conditions. The ECMT (Conference of European Ministers of Transport) and the European Committee for Standardization (CEN) use the definition of intermodal transport as follows: "The transportation of goods using different modes of transport in the same truck or vehicle, without the need for goods to be transported using at least two different types of door-to-door transport chains". For Mahoney (1986) "intermodal transportation" refers to the movement of goods through two or more modes of transportation, while for Heath (1987) "intermodal transportation" refers to the movement of goods through the Shipper for shippers. At least two different modes of transportation: single price, average payment and guarantee. The term "intermodal transport" is widely used by the EU legislator.

1.3 Transport Process

There are various ways to process transportation (such as directly or by utilizing multiple modes of transportation), thus it's important to be more explicit about these procedures. Initially, there are two categories of transport processes: direct and indirect. Transshipment of the commodities occurs in the event of an indirect transport method, but not in the case of direct transport. When commodities are transported directly, they are moved from the point of departure to the destination. It is also known as door-to-door shipment because of this. In this instance, neither the mode of transportation (such as an inland waterway or railway) nor the means of transportation (such as a truck, ship, or railway) alter. One can always categorize direct shipping as unimodal.

1.4 Phases of Multimodal Transportation

Multimodal transportation is split in phases

1.4.1 Pre-haul

Pre-haul transportation is used to move a consignment from its origination point to an interchange terminal, when it changes modes. Avenue transportation is also used for this purpose.

1.4.2 Lengthy haul

Lengthy haul refers to the leg that travels a greater distance. Rail, sea, inland waterways, or air transportation can all be used for long-haul leg cargo. Additionally, it's usually required and far less expensive than using the avenue for long-distance transit.

1.4.3 Quit haul

Quit haul is the last mile, or the last leg to the transfer location, and it is typically completed by street transportation, just as pre-haul.

1.4.4 Long-haul

Long-haul travel will include the usage of several modes. If we consider the transcontinental route, for instance, from China to the United States, pick-up delivery typically entails driving from the origin to the nearest multimodal interchange station, where bins are loaded onto trains that are headed for a single port After arriving in the United States, the shipment is transported by sea. Depending on the delivery region, it can then be transported by rail to a multimodal terminal, where it is transported by avenue to the destination. In the 2010 White Paper on Transportation, policy makers such as the European Commission emphasized the need to create a transportation community that can support the growth of multimodality to reduce emissions and traffic, improve efficiency, and reallocate freight transportation among modes. Despite modal split, the balance is still largely unfavorable to road transportation. For the previous 30 years, very few or no actions haves had been made in lowering the proportion of products transported by street. in line with EUROSTAT, in 2018, throughout the 28 international locations participants of the Europe, 76.50% of freight become transported with the aid of avenue, 18.00% via rail and the last 5.50% by way of inland waterways.

CHAPTER 2

SYSTEMATIC EXPLANATION OF TRANSPORTATION

2.1 Multimodal Transportation

The movement of commodities via two or more distinct modes of transportation is known as multimodal transport. The following circumstances call for transshipment of the products to alter the mode of transportation.

While there are advantages to using multiple different means of transportation at the same time, the most affordable and environmentally friendly combination can be selected. Transshipment sites, which enable effective cargo handling over short and long distances, and the use of standardized and reusable load units are the two main characteristics of multimodal transports. Combined freight, however, can be arranged in several ways. Trucks typically cover small distances between loading zones and transshipment zones, or between the point of arrival and the recipient. long-distance delivery.[2]

2.1.1 Advantages of Multimodal Transportation

Time wastage and the possibility of cargo being lost, stolen, or damaged at transshipment locations are reduced when coordinated and organized as a single process. The speedier passage of commodities psychologically restricts the market; in keeping with the issue of globalization, the distance between origin or source materials and buyers is becoming increasingly meaningless with the rise of multimodal transport. There is virtually little work involved in providing numerous documents to each person in the transport segment. In all matters pertaining to the transportation of commodities, the sender and recipient just need to be concerned with the medium- term goal (multimodal carrier).

2.2 Intermodal Transportation

When two or more modes of transportation are employed to move the same load unit or road vehicle, intermodal transportation can be categorized as a specific sort of multimodal transport. This means that the items stay in the same shipping containers (such as containers or swap bodies) when the mode of transportation is changed; only loading units or road vehicles are swapped out. Transportation by ship to the port, where the containers are either loaded straight onto wagons or transported by truck to the railway terminal, is an example of intermodal transportation. Rail carries containers to the closest node, from where they are transported to their ultimate destination.

2.2.2 Advantages of Intermodal Transportation

Possibility of hassle-free door-to-door transport. Consolidation in trunk line movement over a longer distance. Consolidation leads to economies of scale and capabilities more economical transport of goods. It has been shown to effectively reduce CO2emissions and improving the environment, which has become important policy problem [3].

2.3 Combined Transportation

Combined transportation is a unique kind of multimodal transportation in which most of the journey is completed by inland vessels or railroads, with as little pre- and/or final freight moving along the tracks as possible. Combination transport is an environmentally friendly alternative to rail or ocean transportation for the primary foot. The only way combined transportation will be able to realize its full potential and guarantee the anticipated modal shift that both the public and European transport policy makers are hoping for is if legislators fix the regulatory barriers that currently prevent fair economic competition, either on the railway or between various modes of transportation. [4]

2.3.1 Advantages of Combined Transportation

The integration of various forms of transportation within a supply chain, known as combined transportation, offers several benefits for optimizing logistics. By utilizing economies of scale and reducing total transportation costs, cost efficiency is attained by choosing the most cost-effective modes of transportation for each leg of the trip. Using quicker modes strategically for some stretches saves time, and improved intermodal transfers cut down on dwell time. The method reduces the danger of disruptions and accommodates different transportation needs, which improves flexibility and reliability. By optimizing energy-efficient modes, environmental sustainability is enhanced, and carbon footprints are reduced. Combined transportation connects disparate geographic areas effectively and expands global reach.

2.4 Transshipment

Transshipment is a vertical kind of transportation that can be separated into operations where intermodal loading units are raised and processes where units are not raised. Transshipment, in which loading units or trailers are rolled horizontally across ramps, is the process of moving them from one mode of transportation to another using a crane or forklift at the terminal. The primary benefit here is that loading units may be switched around without the need for cranes or reach warehousemen. This hybrid vessel has ramps for vehicle decks and other cargo platforms that are only reachable by crane or during tidal changes. Standardized cost units are used in intermodal shipping to cut down on time and expenses during the transshipment process [5]. Easy handling, improved planning, and more efficient use of space (stack ability containers) are made possible by the standardization of loading unit sizes and required equipment (spreader). Intermodal loading units and intermodal transport units (ITU) are moved by means of specialized machinery between roadways, railroads, and waterways. European integrated transport (road/rail) is dominated by interchangeable superstructures and containers. In certain markets, such as Ro Ro Process, semi-trailers are significant. Metal containers are common containers that come in a range of sizes and designs. Because of their various benefits, including reduced packaging costs, less damage risk, and excellent stack ability and resilience, they make best use of available space. There are various sizes and shapes of containers for certain uses. Intermodal containers' standard measurements and allowable total weights are largely determined by two ISO standards: ISO 668:2013 and ISO 1496- 1:2013. The most common container sizes available are 20 feet, 40 feet and 45 feet in length.[5] Truck trailers with interchangeable bodies are completely compatible with euro pallets and do not require a chassis. Exchangeable superstructures have essentially uniform sizes. The exchangeable superstructure's primary benefit is its four foldable legs, which enable quick loading and unloading and allow the structure to stand freely. Hauliers benefit monetarily from the fact that a single vehicle can utilize many convertible bodyworks. Other replaceable superstructures may be hauled by the truck while loading occurs at the ramp. For the truck to pick up the loaded body and begin a new journey, it must first park an empty swap body at the ramp. This reduces vehicle waiting times and downtime. One drawback of the exchangeable superstructure is that stacking it can be challenging. A bridge overhead crane is used to transfer the exchangeable superstructure from the road vehicle to the track car. The crane's four arms fit into slots that are permanently attached to the bottom exchangeable superstructure.

CHAPTER 3

PETROCHEMICAL VARITITES

3.1 Petrochemicals

Petrochemicals (sometimes abbreviated as petrochemicals) are obtained chemical products from oil by refining. Some chemical compounds made from petroleum are also obtained from other fossil fuels such as coal or natural gas, or renewable resources such as corn, palm fruit or sugarcane.[6]

3.2 Sources and by product of Petrochemical

Olefins (such as ethylene and propylene) and aromatic chemicals (such as benzene, toluene, and xylene isomers) are the specialized types of petrochemical intermodal transportation. Olefins and aromatics are produced in liquid form by oil refineries. petroleum fractions' catalytic cracking. Chemicals Olefin natural products are produced by steam decomposition in plants. Gases in liquid form, such propane and ethane. They have a pleasant scent. generated via naphtha's catalytic reformation [7]. A broad variety of ingredients contain olefins and aromatics. Different materials, such detergents and solvents, etc. glue the building blocks of polymers, plastic, resin, fiber, elastomers, lubricants, gels, etc. are olefins. In 2019, 190 million tons of ethylene and 120 million tons of propylene were produced worldwide [8]. Aromatics are produced in over 70 million pools. Though the Middle East and Asia are seeing a sharp rise in new production capacity, the United States and Western Europe still have the largest petrochemical industries. Significant petrochemical trade occurs across regions.

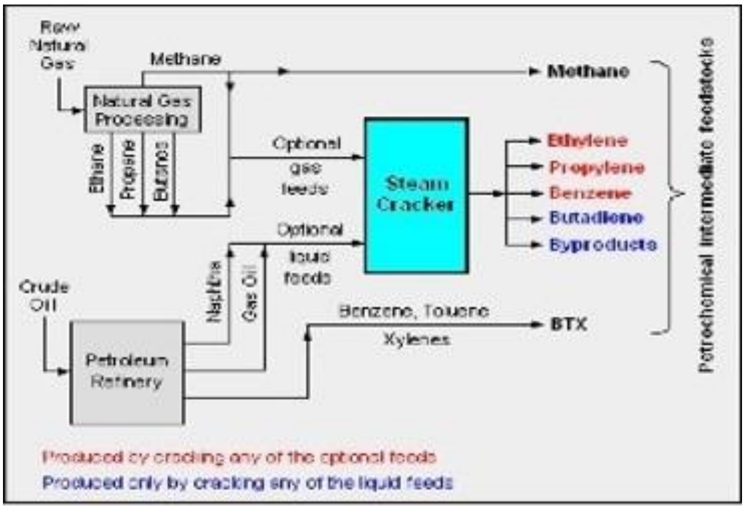

Figure 2: A diagram of steam cracker (source =10)

The adjacent diagram shows schematically major source of hydrocarbons and processes used in producing petrochemicals products.

3.2.1 Petrochemical feedback sources

These are large-scale petrochemicals, just like commodity chemicals. Unlike commodity chemical facilities, petrochemical production units frequently generate a variety of related goods. In contrast, the production of fine and specialty chemicals uses distinct batch procedures to produce their products. Most of the petrochemical production takes place in a small number of locations across the globe, such as the industrial cities of Jubail and Yanbu in Saudi Arabia, Texas and Louisiana in the USA, Teesside in northeastern England in the United States, Tarragona in Catalonia, Rotterdam in the Netherlands, Jamnagar, Dahej in Gujarat, India, and Singapore. It is common for groups of related materials to be manufactured next to production plants to promote industrial symbiosis, material and utility efficiency, and other economies of scale. Not all petrochemical or commodity chemical compounds produced by the chemical industry are produced in one location. Integrated manufacturing is the term used in chemical engineering to describe this. While specialty and fine chemical firms can occasionally be located on petrochemical production sites, they are more often found in multi sector business parks because they don't require the same amount of substantial infrastructure (such as pipelines, storage, ports, and power, among other things)

Huge petrochemical production sites consist of groups of units that share infrastructure and public services, including highways, rail terminals, storage tanks, powerplants, and port facilities. For instance, in the UK, production is concentrated in four main areas: Teesside, which is a part of the Northeast of the English Process Industry Cluster (NEPIC), near the River Mersey in north-west England, on the Humber on Yorkshire's east coast, and at Grangemouth, which is close to the Firth of Forth in Scotland. About 50% of the commodity chemicals used in the UK's petrochemical and petrochemical sector are generated by NEPIC industrial cluster enterprises located in Teesside, demonstrating the process of clustering and integration.

3.3 Petrochemicals material transportation through multimodal containers

- Vessel Containers - Transporting goods by truck, train, or ship requires the use of standardized steel boxes called vessel containers, sometimes referred to as shipping containers or cargo containers. Due to their ability to move goods globally in an efficient and standardized manner, these containers completely changed the shipping and logistics sectors. To carry a variety of cargo, many kinds of containers are available. Tank containers for liquids, refrigerated containers for temperature-sensitive commodities, dry cargo containers for general goods, and customized containers for bulky or oddly shaped cargo are examples of this.
- Train Portable containers- Transshipment involves transferring goods from one mode of transportation, such as vessels, to another, like trains. When transshipping through vessel containers to train portable containers, the process typically involves several key steps:
- Arrival at the airport: The vessel carrying the containerized cargo arrives at the port. The containers are unloaded from the ship using specialized cranes.
- Container Stacking: Containers are stacked in designated storage areas at the port, often in stacks several containers high. The arrangement allows for efficient use of space and ease of access for subsequent transportation modes.
- Customs Clearance: Customs clearance procedures may be conducted at the port. This involves verifying the documentation, inspecting the cargo, and ensuring compliance with import/export regulation.
- Transfer to Railway Terminal: Containers destined for train transportation are loaded into

specialized transport vehicles, such as container chassis or gantry cranes, for transfer to the nearby railway terminal. This transfer can be done using trucks or other equipment. Loading onto Rail Cars: At the railway terminal, the containers are loaded onto rail cars. This process may involve using container handling equipment and cranes designed at rail transport.

CHAPTER 4

LITERATURE REVIEW

There is a vast and continuously expanding body of research on multimodal transportation. This paper's goal is to provide an overview of the research on optimization models for multimodal transportation. Specifically, our goal to investigate the unique issues and difficulties that represent each whole of multimodal transit. We are mindful of categorizing the material according to the long-haul leg's modality. This predilection is primarily driven by two factors. Initially, a problem description for optimization that involves a positive combination of modalities typically yields distinct features that may be like the modalities in question. Research categorized according to the modality employed in the long-haul leg should make it easier for interested scholars to find related publications. Second, as the information in table 1 shows, some decision problems are specific to modalities, while others are shared by extraordinary combinations of modalities. Here's how the table is set up. Operational, tactical, and strategic decision-making difficulties are distinguished. Because they deal with routine or daily procedures, operational problems are frequently simple to identify. Strategic issues are typically identified when choosing investments, usually in the infrastructure. By selecting services and related transportation options, figuring out their capacities, and scheduling their routes and frequencies, tactical challenges address how to make the most rewarding use of the infrastructure that is already in place. Certain issues may be tactical or strategic in nature, depending primarily on the time horizon and size considered. Not every observation can truly be classified as tactical or strategic, and drawing the line between them isn't always clear-cut [10]. Therefore, we decided to categorize the papers based on how each one contributed to tactical/strategic and operational issues. The selections covered in the papers evaluated in this literature review help determine which are the most significant in each class. In Table 1, the number of papers handling each selection according to modality is given.

Tabel:1

Tactical and strategies	LOCATION	3	7	0	1
	NETWORK DESIGN	2	9	12	17
	SCHEDULING	0	0	3	4
	TRANSPORTATION	0	2	0	0
	FLEET RENEWAL	0	0	1	0
	ALLOCATION	0	0	0	1
Operational	TRANSPORTATION	2	4	3	6
	VESSEL SCHEDULE	0	0	6	0
	ROUTING (multiple)	5	3	1	3
	ROUTING (single)	11	0	0	0

Table1. Classification of papers based on decision and modality.

In Table1 decisions are classified as follows:

- Vicinity: Papers reading troubles with the primary and sole consciousness on optimizing the vicinity of centers are protected on this class. troubles where the location is part of a popular network definition are labeled as network layout problems.
- Network layout: This class includes papers that maximize network definitions. Here, we'll focus on community and service community design choices.
- Scheduling: Papers on this elegance look at issues on carrier timetable, transshipment timetable, backyard operations timetable, shipment and delivery agenda.
- Transportation: This splendor is covered in a paper; however, the primary focus is on outlining the first-rate collection of services utilized to move goods from one place to another. These concerns are occasionally referred to as "course choice" or "path planning" challenges (e.g., Xiong & Wang, 2014). This type of selection was found in both tactical and strategic problems.

- Fleet Renewal: This class includes papers in which the renewal of a fleet is the primary focus.
- Resource Allocation: These concerns center on the decision of how resources should be distributed to exceptional sites or activities.
- Vessel: One of the most significant problems with maritime transportation is timetable recovery. Documents pertaining to the recovery of the ship's itinerary following disruptive events are included in this chapter.
- Routing: The primary choice is to determine the route taken by a single vehicle or a collection of vehicles [9]. Any research that aims to maximize the trajectory of one or more cars is discussed on this amazing We consider the primary decisions modeled in the reviewed publications for every modality used in the long-haul leg, together with the operational, tactical, and strategic nature of the issues raised. We also consider possible research directions. For each modality, we also provide the mathematical components of the operational and/or tactical/strategic problem that is frequently studied in the literature, giving interested readers a place to start for more research. We didn't follow the authors' original notation for the formulations since we wanted to highlight the shared features of the problems. Instead, we created a common notation.

CHAPTER 5:

IN MATHEMATICAL PROGRAMMING

METHOD

For quantity transported from refinery to storage is designed with the help of an example-fig [3]. Containerization has played a crucial role in the globalization of trade by enabling faster and more cost-effective movement of goods between and mega- container ships that can transport thousands of containers at once have also been developed because of it.

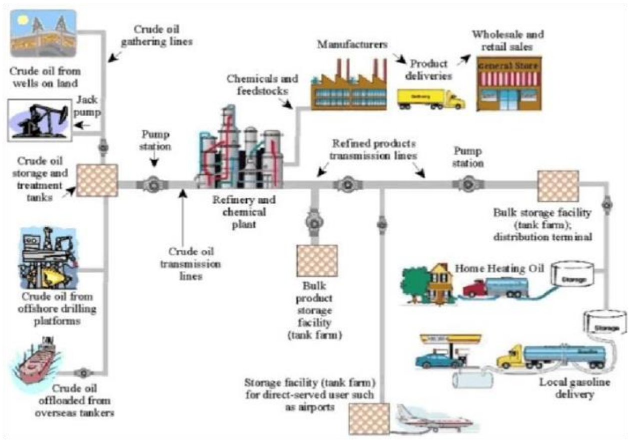

Figure 3: Petrochemical pipeline system

An overview of an oil pipeline system from the wellhead to downstream consumers

5.1 The Vogel Approximation Method (VAM) –

It is a method for solving transportation problems that is used in linear programming and transportation to discover a first feasible solution. By accounting for the variations in transport expenses between sources and destinations, it reduces expenditures. The process is computing the highest and second-highest penalties for each row and column in a cost matrix, determining Units are distributed to the cell with the lowest transportation cost in the corresponding row or column.

For more complex optimization algorithms to effectively solve transportation problems, VAM offers a foundation . We consider the following problem model from [5] which mentions the transportation costs, the supply quantity from the locations to destination location and the demand quantity specifications also. We have modelled it like a transshipment problem model that means the transportation, or the petrochemicals are transshipped from refinery i to refinery j where i, j {1,2,3}, from refinery to port i and from port i to refinery j or port j as mentioned in the table

Problem Model:

Vogel's Approximation approach should be used to obtain the first basic workable answer. The Modified approach and Steppingstone Method should be used to find the best solution.

	Ref 1	Ref 2	Ref 3	Port1	Port2	Port3	Supply
Ref 1	0	1	2	3	4	5	120
Ref 2	1	2	3	4	5	6	130
Ref 3	2	3	4	5	6	7	150
Port 1	3	4	5	6	7	8	100
Port 2	4	5	6	7	8	9	100
Port 3	5	6	7	8	9	10	100
Demand	100	100	100	130	140	130	

Solution:

The given problem is balanced.

So, applying Vogel approximation method by taking the difference of first minimum element and second minimum element in the respective row and column and find row penalty and column penalty.

Table 2

	Ref 1	Ref 2	Ref 3	Port1	Port2	Port3	Supply	Row Penalty
Ref 1	0	1	2	3	4	5	120	1
Ref 2	1	2	3	4	5	6	130	1
Ref 3	2	3	4	5	6	7	150	1
Port 1	3	4	5	6	7	8	100	1
Port 2	4	5	6	7	8	9	100	1

Port 3	5	6	7	8	9	10	100	1
Demand	100	100	100	130	140	130		
Column Penalty	1	1	1	1	1	1		

The largest penalty from the row and column penalties is selected, and the lowest supply and demand are now allocated to the corresponding cell. If more than one row or column has the same penalty, we choose any one of them.

Choose the worst penalty that can be administered. The maximum penalty in Row Ref1 is 1.

The lowest supply should be assigned to the row Ref1 with the lowest cost, and the lowest demand should be assigned to the column.

In this case, supply is more than demand.so take out the Ref1 column.

Table 3

	~~Ref 1~~	Ref 2	Ref 3	Port 1	Port 2	Port 3	Supply	Row Penalty
Ref 1	~~0(100)~~	1	2	3	4	5	20	1
Ref 2	~~1~~	2	3	4	5	6	130	1
Ref 3	~~2~~	3	4	5	6	7	150	1
Port 1	~~3~~	4	5	6	7	8	100	1
Port 2	~~4~~	5	6	7	8	9	100	1
Port 3	~~5~~	6	7	8	9	10	100	1
Demand	0	100	100	130	140	130		
Column Penalty	-	1	1	1	1	1		

Once more, select the highest penalty from the row and column penalties, then designate the cell with the lowest supply and demand.

Row Ref1, or 1, is the maximum punishment.

Next, determine which row Ref1 has the lowest cost and assign the lowest supply and demand to that row and column, respectively.

The supply in this case is less than the demand.so remove the row Ref1.

Table 4

	~~Ref 1~~	Ref 2	Ref 3	Port 1	Port 2	Port 3	Supply	Row Penalty
~~Ref 1~~	~~0(100)~~	~~1(20)~~	~~2~~	~~3~~	~~4~~	~~5~~	0	-
Ref 2	~~1~~	2	3	4	5	6	130	1
Ref 3	~~2~~	3	4	5	6	7	150	1
Port 1	~~3~~	4	5	6	7	8	100	1
Port 2	~~4~~	5	6	7	8	9	100	1
Port 3	~~5~~	6	7	8	9	10	100	1
Demand	0	80	100	130	140	130		
Column Penalty	-	1	1	1	1	1		

Repeat the process until we get all the demand and supply should be zero.

Table 5

	~~Ref 1~~	~~Ref 2~~	Ref 3	Port 1	Port 2	Port 3	Supply	Row Penalty
~~Ref 1~~	~~0(100)~~	~~1(20)~~	~~2~~	~~3~~	~~4~~	~~5~~	0	-
Ref 2	~~1~~	~~2(80)~~	3	4	5	6	50	1
Ref 3	~~2~~	~~3~~	4	5	6	7	150	1
Port 1	~~3~~	~~4~~	5	6	7	8	100	1
Port 2	~~4~~	~~5~~	6	7	8	9	100	1
Port 3	~~5~~	~~6~~	7	8	9	10	100	1
Demand	0	0	100	130	140	130		
Column Penalty	-	-	1	1	1	1		

Table 6:

	~~Ref 1~~	~~Ref 2~~	Ref 3	Port 1	Port 2	Port 3	Supply	Row Penalty
~~Ref 1~~	~~0(100)~~	~~1(20)~~	~~2~~	~~3~~	~~4~~	~~5~~	0	-
~~Ref 2~~	~~1~~	~~2(80)~~	~~3(50)~~	~~4~~	~~5~~	~~6~~	0	-
Ref 3	~~2~~	~~3~~	4	5	6	7	150	1
Port 1	~~3~~	~~4~~	5	6	7	8	100	1
Port 2	~~4~~	~~5~~	6	7	8	9	100	1
Port 3	~~5~~	~~6~~	7	8	9	10	100	1
Demand	0	0	50	130	140	130		
Column Penalty	-	-	1	1	1	1		

Table 7

	~~Ref 1~~	~~Ref 2~~	~~Ref 3~~	Port 1	Port 2	Port 3	Supply	Row Penalty
~~Ref 1~~	~~0(100)~~	~~1(20)~~	~~2~~	~~3~~	~~4~~	~~5~~	0	-
~~Ref 2~~	~~1~~	~~2(80)~~	~~3(50)~~	~~4~~	~~5~~	~~6~~	0	-
Ref 3	~~2~~	~~3~~	~~4(50)~~	5	6	7	100	1
Port 1	~~3~~	~~4~~	~~5~~	6	7	8	100	1
Port 2	~~4~~	~~5~~	~~6~~	7	8	9	100	1
Port 3	~~5~~	~~6~~	~~7~~	8	9	10	100	1
Demand	0	0	0	130	140	130		
Column Penalty	-	-	-	1	1	1		

Table 8

	~~Ref 1~~	~~Ref 2~~	~~Ref 3~~	Port 1	Port 2	Port 3	Supply	Row Penalty
~~Ref 1~~	~~0(100)~~	~~1(20)~~	~~2~~	~~3~~	~~4~~	~~5~~	0	-
~~Ref 2~~	~~1~~	~~2(80)~~	~~3(50)~~	~~4~~	~~5~~	~~6~~	0	-
~~Ref 3~~	~~2~~	~~3~~	~~4(50)~~	~~5(100)~~	~~6~~	~~7~~	0	-
Port 1	~~3~~	~~4~~	~~5~~	6	7	8	100	1
Port 2	~~4~~	~~5~~	~~6~~	7	8	9	100	1

Port 3	~~5~~	~~6~~	~~7~~	8	9	10	100	1
Demand	0	0	0	30	140	130		
Column Penalty	-	-	-	1	1	1		

Table 9

	~~Ref 1~~	~~Ref 2~~	~~Ref 3~~	~~Port 1~~	Port 2	Port 3	Supply	Row Penalty
~~Ref 1~~	~~0(100)~~	~~1(20)~~	~~2~~	~~3~~	~~4~~	~~5~~	0	-
~~Ref 2~~	~~1~~	~~2(80)~~	~~3(50)~~	~~4~~	~~5~~	~~6~~	0	-
~~Ref 3~~	~~2~~	~~3~~	~~4(50)~~	~~5(100)~~	~~6~~	~~7~~	0	-
Port 1	~~3~~	~~4~~	~~5~~	~~6(30)~~	7	8	70	1
Port 2	~~4~~	~~5~~	~~6~~	~~7~~	8	9	100	1
Port 3	~~5~~	~~6~~	~~7~~	~~8~~	9	10	100	1
Demand	0	0	0	0	140	130		
Column Penalty	-	-	-	-	1	1		

Table 10

	~~Ref 1~~	~~Ref 2~~	~~Ref 3~~	~~Port 1~~	Port 2	Port 3	Supply	Row Penalty
~~Ref 1~~	~~0(100)~~	~~1(20)~~	~~2~~	~~3~~	~~4~~	~~5~~	0	-
~~Ref 2~~	~~1~~	~~2(80)~~	~~3(50)~~	~~4~~	~~5~~	~~6~~	0	-
~~Ref 3~~	~~2~~	~~3~~	~~4(50)~~	~~5(100)~~	~~6~~	~~7~~	0	-
~~Port 1~~	~~3~~	~~4~~	~~5~~	~~6(30)~~	~~7(70)~~	~~8~~	0	-
Port 2	~~4~~	~~5~~	~~6~~	~~7~~	8	9	100	1
Port 3	~~5~~	~~6~~	~~7~~	~~8~~	9	10	100	1
Demand	0	0	0	0	70	130		
Column Penalty	-	-	-	-	1	1		

Table :11

	Ref 1	Ref 2	Ref 3	Port 1	Port 2	Port 3	Supply	Row Penalty
Ref 1	0(100)	1(20)	2	3	4	5	0	-
Ref 2	1	2(80)	3(50)	4	5	6	0	-
Ref 3	2	3	4(50)	5(100)	6	7	0	-
Port 1	3	4	5	6(30)	7(70)	8	0	-
Port 2	4	5	6	7	8(70)	9	30	9
Port 3	5	6	7	8	9	10	100	10
Demand	0	0	0	0	0	130		
Column Penalty	-	-	-	-	-	1		

Table 12

	Ref 1	Ref 2	Ref 3	Port 1	Port 2	Port 3	Supply	Row Penalty
Ref 1	0(100)	1(20)	2	3	4	5	0	-
Ref 2	1	2(80)	3(50)	4	5	6	0	-
Ref 3	2	3	4(50)	5(100)	6	7	0	-
Port 1	3	4	5	6(30)	7(70)	8	0	-
Port 2	4	5	6	7	8(70)	9	30	9
Port 3	5	6	7	8	9	10(100)	0	-
Demand	0	0	0	0	0	30		
Column Penalty	-	-	-	-	-	9		

Tabel 13

	Ref 1	Ref 2	Ref 3	Port 1	Port 2	Port 3	Supply	Row Penalty
Ref 1	0(100)	1(20)	2	3	4	5	0	-
Ref 2	1	2(80)	3(50)	4	5	6	0	-
Ref 3	2	3	4(50)	5(100)	6	7	0	-
Port 1	3	4	5	6(30)	7(70)	8	0	-
Port 2	4	5	6	7	8(70)	9(30)	0	-
Port 3	5	6	7	8	9	10(100)	0	-

Demand	0	0	0	0	0	0		
Column Penalty	-	-	-	-	-	-		

Here, no balance remains.

Initial feasible solution is:

Table 14

	Ref 1	Ref 2	Ref 3	Port 1	Port 2	Port 3	Supply
Ref 1	0(100)	1(20)	2	3	4	5	120
Ref 2	1	2(80)	3(50)	4	5	6	130
Ref 3	2	3	4(50)	5(100)	6	7	150
Port 1	3	4	5	6(30)	7(70)	8	100
Port 2	4	5	6	7	8(70)	9(30)	100
Port 3	5	6	7	8	9	10(100)	100
Demand	100	100	100	130	140	130	

The minimum total transportation cost:

0*100 + 1*20 + 2*80 + 3*50 + 4*50 + 5*100 + 6*30 + 7*70 + 8*70 + 9*30 + 10*100 = 3530 As a result, m+n-1 = 6+6-1 = 11 is the number of assigned cells in this case.

Moreover, the solution is non-degenerative.

Currently, the modified method of the optimum test

Optimality test iteration one for every cell (i, j) that is occupied, get ui and vj, where cij=ui+vj.

$c11=u1+v1 \Rightarrow v1=c11-u1 \Rightarrow v1=0-0 \Rightarrow v1=0$

$c12=u1+v2 \Rightarrow v2=c12-u1 \Rightarrow v2=1-0 \Rightarrow v2=1$

$c22=u2+v2 \Rightarrow u2=c22-v2 \Rightarrow u2=2-1 \Rightarrow u2=1$

$c23=u2+v3 \Rightarrow v3=c23-u2 \Rightarrow v3=3-1 \Rightarrow v3=2$

$c33=u3+v3 \Rightarrow u3=c33-v3 \Rightarrow u3=4-2 \Rightarrow u3=2$

$c34=u3+v4 \Rightarrow v4=c34-u3 \Rightarrow v4=5-2 \Rightarrow v4=3$

$c44=u4+v4 \Rightarrow u4=c44-v4 \Rightarrow u4=6-3 \Rightarrow u4=3$

$c45=u4+v5 \Rightarrow v5=c45-u4 \Rightarrow v5=7-3 \Rightarrow v5=4$

$c55=u5+v5 \Rightarrow u5=c55-v5 \Rightarrow u5=8-4 \Rightarrow u5=4$

$c56=u5+v6 \Rightarrow v6=c56-u5 \Rightarrow v6=9-4 \Rightarrow v6=5$

When we replace, u1=0, we obtain

$c66=u6+v6 \Rightarrow u6=c66-v6 \Rightarrow u6=10-5 \Rightarrow u6=5$

Table 15

	Ref 1	Ref 2	Ref 3	Port 1	Port 2	Port 3	Supply	u_i
Ref 1	0(100)	1(20)	2	3	4	5	120	u1=0
Ref 2	1	2(80)	3(50)	4	5	6	130	u2=1
Ref 3	2	3	4(50)	5(100)	6	7	150	u3=2
Port 1	3	4	5	6(30)	7(70)	8	100	u4=3
Port 2	4	5	6	7	8(70)	9(30)	100	u5=4
Port 3	5	6	7	8	9	10(100)	100	u6=5
Demand	100	100	100	130	140	130		
v_j	v1=0	v2=1	v3=2	v4=3	v5=4	v6=5		

Find dij for all unoccupied cells (i, j), where dij = cij-(ui+vj)

$d13 = c13-(u1+v3) = 2-(0+2) =0$

$d14 = c14-(u1+v4) = 3-(0+3) =0$

$d15 = c15-(u1+v5) = 4-(0+4) =0$

$d16 = c16-(u1+v6) = 5-(0+5) =0$

$d21 = c21-(u2+v1) = 1-(1+0) =0$

$d24 = c24-(u2+v4) = 4-(1+3) =0$

$d25 = c25-(u2+v5) = 5-(1+4) =0$

$d26 = c26-(u2+v6) = 6-(1+5) =0$

$d31 = c31-(u3+v1) = 2-(2+0) =0$

$d32 = c32-(u3+v2) = 3-(2+1) =0$

$d35 = c35-(u3+v5) = 6-(2+4) =0$

$d36 = c36-(u3+v6) = 7-(2+5) =0$

$d41 = c41-(u4+v1) = 3-(3+0) =0$

$d42 = c42-(u4+v2) = 4-(3+1) =0$

$d43 = c43-(u4+v3) = 5-(3+2) =0$

$d46 = c46-(u4+v6) = 8-(3+5) =0$

$d51 = c51-(u5+v1) = 4-(4+0) =0$

$d52 = c52-(u5+v2) = 5-(4+1) =0$

$d53 = c53-(u5+v3) = 6-(4+2) =0$

$d54 = c54-(u5+v4) = 7-(4+3) =0$

$d61 = c61-(u6+v1) = 5-(5+0) =0$

$d62 = c62-(u6+v2) = 6-(5+1) =0$

$d63 = c63-(u6+v3) = 7-(5+2) =0$

$d64 = c64-(u6+v4) = 8-(5+3) =0$

$d65 = c65-(u6+v5) = 9-(5+4) =0$

Table 16

	Ref 1	Ref 2	Ref 3	Port 1	Port 2	Port 3	Supply	u_i
Ref 1	0(100)	1(20)	2[0]	3[0]	4[0]	5[0]	120	u1=0
Ref 2	1[0]	2(80)	3(50)	4[0]	5[0]	6[0]	130	u2=1
Ref 3	2[0]	3[0]	4(50)	5(100)	6[0]	7[0]	150	u3=2
Port 1	3[0]	4[0]	5[0]	6(30)	7(70)	8[0]	100	u4=3
Port 2	4[0]	5[0]	6[0]	7[0]	8(70)	9(30)	100	u5=4
Port 3	5[0]	6[0]	7[0]	8[0]	9[0]	10(100)	100	u6=5
Demand	100	100	100	130	140	130		
v_j	v1=0	v2=1	v3=2	v4=3	v5=4	v6=5		

Since all dij>=0.

So, the final optimal solution arrived.

Table 17

	Ref 1	Ref 2	Ref 3	Port 1	Port 2	Port 3	Supply
Ref 1	0(100)	1(20)	2	3	4	5	120
Ref 2	1	2(80)	3(50)	4	5	6	130
Ref 3	2	3	4(50)	5(100)	6	7	150
Port 1	3	4	5	6(30)	7(70)	8	100
Port 2	4	5	6	7	8(70)	9(30)	100
Port 3	5	6	7	8	9	10(100)	100
Demand	100	100	100	130	140	130	

The total minimum transportation cost is:

0*100 + 1*20 + 2*80 + 3*50 + 4*50 + 5*100 + 6*30 + 7*70 + 8*70 + 9*30 + 10*100 = 3530

5.2 Result

Different storage containers at port and transporter route locations are presumed to be the locations of dynamic storage. The areas designated for static storage are those used for refining crude. We attempted to create a decision-making process in this model, where the Modified Distribution approach is used to discover the optimal answers and the Vogel approximation method [4] is used to obtain the first basic solutions. The steppingstone approach estimation confirms the obtained optimal solution as well.

In Table: 2,3,4,5,6,7,8,9,10,11,12,13 we calculated row penalty and column penalty. Best on the row and column penalty we assign the supply and demand and in tabular 14 we have shown the initial basic feasible solution. In the tabular 16, we determine the Optimality by modified method.

CHAPTER 6

APPLICATIONS OF MULTIMODAL TRANSPORTATION

1. Supply Chain Optimization:

- Integration of Various Modes: Combining different modes of transportation (e.g., trucks, trains, ships) ensures the most efficient and cost-effective routes. For example, crude oil can be transported by pipeline to a port, then shipped via tanker, and finally delivered by truck to a refinery.
- Minimizing Bottlenecks: Using multimodal transport helps to alleviate bottlenecks by distributing the load across various transport modes, thereby avoiding delays associated with reliance on a single mode.

2. Cost Efficiency:

- Reduced Transportation Costs: By selecting the most cost-effective modes for different segments of the journey, companies can significantly reduce transportation costs. Rail transport, for instance, is more cost-effective for long-distance inland movement compared to road transport.
- Economies of Scale: Utilizing large cargo ships and trains for bulk transport reduces per-unit transportation costs compared to smaller, less efficient modes.

3. Enhanced Safety and Compliance:

- Regulatory Compliance: Different regions and countries have varying regulations for transporting hazardous materials. Multimodal transport allows petrochemical companies to navigate these regulations more efficiently by choosing compliant transport modes for specific regions.
- Safety Enhancements: The use of specialized transport modes like tankers designed for hazardous materials reduces the risk of accidents and spills.

4. Flexibility and Reliability:

- Route Flexibility: Multimodal transport provides flexibility in route planning, allowing companies to adjust routes in response to disruptions such as natural disasters, strikes, or political instability.
- Improved Reliability: Combining different modes of transport can increase overall reliability and reduce dependence on a single mode, ensuring more consistent delivery schedules.

5. Environmental Impact:

- Lower Emissions: Shifting portions of transportation from road to rail or sea can reduce greenhouse gas emissions and other pollutants, as rail and sea transport generally have lower emissions per ton-mile compared to road transport.
- Sustainability Initiatives: Petrochemical companies can enhance their sustainability profiles by adopting multimodal transportation strategies that emphasize greener transport options.

6. Inventory Management:

- Just-in-Time Delivery: Multimodal transport enables precise scheduling and coordination, supporting just-in-time (JIT) inventory systems which reduce the need for large on-site inventories.
- Storage and Transshipment Hubs: Utilizing multimodal hubs for transshipment allows for temporary storage and better inventory management, ensuring that products are readily available for onward transport when needed.

7. Global Reach:

- International Trade Facilitation: Multimodal transport systems facilitate international trade by linking different countries and continents through integrated transport networks. This is crucial for the global reach of the petrochemical industry.
- Customs and Documentation Efficiency: Streamlined customs processes and documentation handling in multimodal transport systems reduce delays at borders and ports.

8. Technological Integration:

- Tracking and Monitoring: Advanced tracking and monitoring technologies integrated into multimodal transport systems provide real-time visibility of shipments, enhancing security and operational efficiency.
- Digital Platforms: Use of digital platforms and transportation management systems (TMS) helps in coordinating different transport modes, optimizing routes, and improving communication across the supply chain.

CHAPTER 7

FUTURE RELEVANCE OF MULTIMODAL TRANSPORTATION

1 Increasing Demand for Petrochemicals:

- Global Growth: As the global population and industrialization continue to rise, the demand for petrochemical products is expected to increase, necessitating more efficient and scalable transportation solutions.
- Emerging Markets: Growth in emerging markets will drive the need for robust multimodal transportation networks to connect production sites with consumption hubs worldwide.

2. Technological Advancements:

- Digitalization and Automation: Innovations in digital platforms, Internet of Things (IoT), and artificial intelligence (AI) will enhance the coordination and efficiency of multimodal transport. Automated systems will streamline logistics, optimize routes, and reduce human error.
- Block chain: Block chain technology can improve transparency and security in the supply chain by providing immutable records of shipment data across various transport modes.

3. Sustainability and Environmental Regulations:

- Mission Reduction: With increasing pressure to reduce carbon footprints, multimodal transportation will play a crucial role in adopting greener transport modes. Rail and sea transport, which are more energy-efficient than road transport, will be increasingly integrated into supply chains.
- Regulatory Compliance: Stricter environmental regulations will necessitate the use of multimodal transport to meet compliance requirements while minimizing environmental impact.

4. Resilience and Risk Management:

- Disruption Mitigation: Multimodal transportation provides flexibility to reroute shipments in response to disruptions such as natural disasters, geopolitical tensions, and supply chain bottlenecks.
- Diversification: Utilizing multiple transport modes diversifies risks, ensuring that a disruption in one mode does not halt the entire supply chain.

5. Cost Efficiency and Economic Pressure:

- Cost Optimization: Rising transportation costs and economic pressures will drive the petrochemical industry to seek cost-effective logistics solutions. Multimodal transport
- Allows companies to balance cost and efficiency by leveraging the strengths of different transport modes.
- Infrastructure Investments: Increased investments in transport infrastructure, such as ports, rail networks, and intermodal terminals, will enhance the viability and attractiveness of multimodal transport.

6. Global Trade Dynamics:

- Trade Agreements: New and evolving trade agreements will facilitate smoother cross-border transportation, making multimodal transport more critical for international supply chains.
- Supply Chain Integration: Greater integration of global supply chains will require seamless connectivity between different transport modes to ensure timely delivery of raw materials and finished products.

7. Urbanization and Regional Development:

- Urban Logistics: The growth of megacities and urban areas will require efficient multimodal transport solutions to manage the increased flow of goods, reduce congestion, and minimize environmental impact.
- Regional Hubs: Development of regional logistics hubs and free trade zones will enhance the role

of multimodal transport in connecting different regions and facilitating trade.

8. Innovation in Transport Modes:

- Electric and Autonomous Vehicles: Adoption of electric and autonomous vehicles for road transport will complement multimodal networks by providing last-mile connectivity with reduced environmental impact.
- Hyperloop and Advanced Rail Systems: Emerging technologies like Hyperloop and advanced high-speed rail systems could revolutionize long-distance transport, integrating seamlessly with existing multimodal networks.

CHAPTER 8

CONCLUSION

In summary, a critical first step in boosting the effectiveness, sustainability, and security of the global supply chain is the implementation of multimodal and intermodal transport solutions for petrochemical commodities. Because petrochemical goods are unique, transport logistics must be carefully considered and integrated, and there are several benefits to investigating alternative modes of transportation. The advantages of multimodal transportation, which encompasses air, sea, rail, and road transportation, include the possibility of lower expenses, more flexibility, and enhanced resistance to disturbances. In addition to maximizing transit time, the smooth integration of various modes lessens the difficulties that come with moving petrochemicals, like security concerns and regulatory compliance. These benefits are further enhanced by inter modal transport, which permits the seamless transfer of petrochemical goods between various means of transportation without the requirement for repackaging. This effective strategy lessens handling, lowers the possibility of product contamination, and improves supply chain effectiveness overall. The petrochemical industry's efforts to lessen its carbon footprint are congruent with the use of multi modal and inter modal transportation, given the increasing focus on environmental sustainability. A more sustainable supply chain, resolution of environmental concerns, and compliance with changing regulations are all facilitated by incorporating cleaner energy sources and putting ecologically friendly procedures into place. In addition to addressing the difficulties posed by petrochemical logistics, a radically diverse approach to multi modal and intermodal transportation also makes it possible for the sector to flourish in the long run. an ever-changing global environment.

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