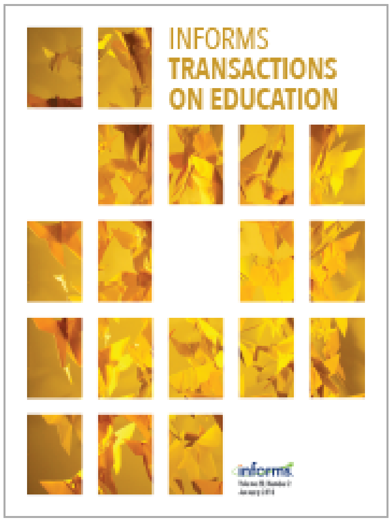

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Case Article

Coastal Shipping for Automobile Distribution

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Abstract. With growing concerns related to the environment, sustainable transportation has gained importance. For geographies with an ample coastline, coastal shipping offers a sustainable transportation option to move massive freight quantities. This paper presents a case that allows students to appreciate the role of coastal shipping in multimodal logistics planning. Furthermore, it gives students an opportunity to mathematically model transportation planning at a strategic and tactical level for automotive distribution. The students learn how to assess the financial viability of a mode shift from roadways to coastal shipping. The instructors can use this case for theoretical discussion on multimodal logistics and the application of mixed-integer linear programming (MILP) and heuristics as solution methods. Furthermore, the case presents an opportunity to demonstrate the improvement in solution quality with an MILP solver compared with heuristics.

Supplemental Material: Supplemental material is available at https://doi.org/10.1287/ited.2021.0253ca. The Teaching Note and restricted supplemental material are available at https://www.informs.org/Publications/Subscribe/Access-Restricted-Materials.

Keywords: coastal shipping • multimodal transport • shipment routing

1. Introduction

Our motivation in writing this case is to develop academic material that can be used for strategic and tactical planning in multimodal logistics. Instructors teaching courses related to supply chain and logistics management rely on real-life case studies to discuss practical challenges. This case shares a contemporary business problem of developing coastal shipping in a country for the distribution of finished automobiles. It allows an instructor to discuss qualitative challenges in enabling large-scale logistics operations as well as quantitative modeling of the problem. The main aim of this case (and the supplemental files) is to teach the use of management science modeling to develop and analyze the transportation system design for enabling multimodal distribution of a cargo type (automobiles) using coastal shipping. Furthermore, this case helps us to understand and explore the business and regulatory challenges that impact these operations. The case allows students to approach a logistics problem of national importance from a holistic point of view. The exercise allows students to structure and work with a real-life data set and derive actionable insights from the analysis. Quantitative analysis is supplemented by a thorough examination of the business and regulatory environment's challenges that concern the transportation sector in general and coastal shipping in particular.

The pedagogy literature on logistics planning provides ample material on well-understood operations research (OR) models such as the vehicle routing problem, travelling salesman problem, and distribution planning, among others. However, there is a shortage of literature on multimodal transportation planning problems in a geographical context. We discuss some of the cases dealing with distribution planning and related issues in the supply chain and highlight the contribution made by our case.

An interesting application of linear programming (LP) and mixed-integer linear programming (MILP) for brewery location, capacity expansion, and distribution of beer is provided by Köksalan and Salman (2003). The authors discuss their experiences in using this case in undergraduate and MBA-level management science and operations research courses and found it a useful exercise to model, solve, and interpret the outputs of LP and MILP. Sundaravalli and

Ravichandran (2017) discuss a case of rice distribution with the existing storage and transportation assets in the Indian state of Andhra Pradesh. Other pedagogical literature using OR techniques in distribution logistics includes Drake et al. (2011) and Manno et al. (2019). Drake et al. (2011) discuss a case of product distribution for an office supply firm and integrate ethical dilemmas in a logistics network design with a parcel carrier at known parcel rates. Manno et al. (2019) present an OR modeling case integrating production and distribution optimization in a beach equipment company.

To the best of our knowledge, this is the first case in pedagogy literature that presents transportation assets and route planning along with product distribution at a national level. Dong and Boute (2019) present a classroom simulation game on the modal shift from road to rail, focusing on logistics decarbonization. The aim of this case is in line with this game, where we discuss the modal shift to coastal shipping for improving the cost and environmental performance of the logistics system.

We discuss some of the relevant academic literature closer to this work. This case is motivated by the problem studied by Chandra et al. (2020). Their work considers multiple ports and sea routes. However, in this case, we have presented a simplified version of the problem suitable for class discussion. There is rich literature in short sea network design. For example, Liu and Qin (1994) consider the problem of determining ship types for transportation from the Yangtze River to other countries. Karlaftis et al. (2009) consider a case with a hub-and-spoke system for container transportation among 25 islands in the Aegean Sea. Polat et al. (2014) study the feeder network design problem in the Black Sea. For the multimodal network, Reis (2014) argue that findings on mode choice in long-distance services are not necessarily transferable to the short-distance transport. Hence, the challenges and opportunities with coastal shipping are very different compared with long-distance services. Suárez-Alemán (2016) reviews the current multimodal transport policy in Europe with a focus on short sea shipping. Elaborating on the challenge inherent in developing coastal shipping, Venkatesh et al. (2017) identify and analyze the most critical barriers in the Indian context.

The case presents the potential application of heuristic or mathematical programing for shipment planning in modal shift. A unique aspect of the case is that the use of heuristic or mathematical programming is not very apparent from the case. Furthermore, the mathematical modeling for this problem is innovative and nontrivial. This case leads students to appreciate the power of management science techniques in strategic planning in a not-so-obvious setting.

The remainder of the paper is organized as follows. In the next section, we present a brief synopsis of the case. Section 3 gives the pedagogical goals of the case. A brief description of the analysis and solution is presented in Section 4. Section 5 outlines the suggested classroom use. Finally, we present classroom experiences in using this case.

2. Case Description

Coastal and Automotive Logistics Corporation (CALC), a third-party logistics provider based in Chennai, India, has automobile manufacturers as its clients. The clients have manufacturing plants in one of the three major automobile manufacturing clusters: Delhi NCR (National Capital Region), Sanand in the state of Gujarat, and Chennai in the state of Tamil Nadu. As part of their transportation plan for automobiles, they need to evaluate the feasibility of multimodal transportation. One question of special interest is whether coastal shipping (between Chennai and Pipavav) can significantly reduce transportation costs. Furthermore, they need to have a transportation strategy that reduces their risk (low volumes) as well as their clients' risk (delay in delivery or lost sales).

CALC has two alternative transportation plans to evaluate: (1) Should all the automobiles be sent to the destination directly by road? (2) Should coastal shipping be used between the ports of Chennai and Pipavav? This case introduces students to the analysis of multimodal transportation involving coastal shipping. Students will be exposed to short-term and long-term planning issues at play for such multimodal transportation design. Furthermore, this case provides students an opportunity to model the problem as an MILP problem and subsequently check whether coastal shipping can lead to significant cost benefits. Other than the quantitative analysis, many qualitative issues also determine the feasibility of coastal shipping.

This case can be taught as an in-class discussion or as a project work. The ideal audience is MBA students in an elective course on operations or senior students in an undergraduate program in operations management or operations research.

2.1. Pedagogical Goals

The main pedagogical goal of this case is to understand the use of operational research models in the design of sustainable large-scale transportation systems. The case provides a data-intensive scenario where one needs to analyze a multimodal transportation system's viability. The use of a mathematical model is not very apparent in the first reading, which makes it even more interesting as a case in this domain. Students can use a heuristic solution approach and mathematical modeling in the context of a large-scale transportation scenario. The purpose is not only to plan the operations but also mainly to derive strategic insights. Most cases on operations research modeling present simple examples with limited dimensions. As a drawback, students may assume that the operations research techniques are fool-proof and can solve a problem completely, which may not be accurate in real-life settings. It may be advisable to make the participants conversant with standard operations research models beforehand. Well-known textbooks on these topics include those by Hillier and Lieberman (2001) and Taha (2010)and have an extensive collection of examples to learn these techniques. Other cases present real-life problems, although the operations research models are pretty standard, which may convey that these methods are limited to a few standard model types. In this context, this case not only presents an entirely new logistics network design and routing model, but it does so in a real-life setting. Students also realize at the end that mathematical modeling is just a tool in the decision-making process. The latter depends on a lot of factors coming from the business and regulatory environment (Gallo 2004, Drake et al. 2011).

The second goal of this case is to teach mathematical programming and, with its nontrivial formulation, encourages participants to formulate such problems innovatively. Developing simple mathematical models for real-life problems is an art. Furthermore, students may find it challenging to understand the concept of mathematical formulation in a realistic setting (Rubin and Wagner 1990, Drake et al. 2010). This case allows students to first understand the applicability of mathematical modeling in this problem, then build a mathematical formulation with the available data and inherent assumptions, and finally develop a solution model on a mixed-integer programming solver to derive optimal answers to a given data and then conduct parametric analysis to derive useful insights.

The third goal of this case is to develop an intuition on the supply chain and regulatory issues that impact the development of sustainable transportation systems such as coastal shipping. Despite positive results from the mathematical modeling exercise, students need to realize that some other important considerations are revenues and costs that impact the operations. Various issues related to competition with other modes, traffic bottlenecks at important changeover points, and existing supply chain configurations act as barriers to the development of a new logistics option (Beth et al. 2003). A systematic presentation of barriers and challenges from the case facts will synthesize students thinking about real-life challenges that have no easy quantitative solutions.

3. Analysis and Solution

In the teaching note, we present the complete solution, which incorporates qualitative and quantitative aspects of this case. Because this is a data-rich case, instructors can bring their perspectives and issues involved in developing sustainable coastal shipping operations.

The solution provided uses an MILP formulation of the shipment routing problem. Hence, this is suitable for students who have exposure to mathematical or integer programming. Although students can attempt to solve the problem without using the MILP, it would be interesting to compare the total cost of their solution vis-à-vis an MILP solution.

This case is suitable for a course where transportation or integer programming formulation is the major focus of the class. This is also suitable for industry participants working in the logistics sector. If the participants are not familiar with MILP, a heuristic solution method (such as the one provided in the teaching note) can be discussed. Ideally, students would perform their analysis of the case in a group or as a case project. Because the case can be discussed with various levels of difficulty to different participants, the discussion questions and teaching note provide an outline for in-class discussion.

4. Suggested Classroom Use

The case is suitable for logistics and OR courses at a graduate and senior undergraduate level in both business and engineering schools. We have used this case in the following courses in business schools: a third-year undergraduate course on mathematical modeling and a second-year MBA course on warehousing and logistics management. The undergraduate students in the former course had already completed a course on linear programming. This course on mathematical modeling dealt with formulating and solving business problems using mathematical programming techniques. The logistics management course with the second-year MBA students had a module on transportation planning where this case was introduced. We have also used this case in a doctoral-level course on mathematical programming. The instruction method needs to be adjusted based on the course level. So, at an undergraduate level, we focus more on developing a mathematical formulation for the problem and developing solutions. By contrast, in the MBA course on logistics management, the focus is more on the business problem, and students are motivated to come up with a commonsense heuristic approach to solve this problem before presenting the optimization technique. The doctoral course encourages the students to apply optimization techniques in maritime logistics and develop novel solution methods for contextual issues.

Going by our experience with the case, we recommend that the full solution method be discussed only if the class is aware of the mathematical programming techniques and prepared for the analysis. Because the mathematical formulation is slightly evolved, the class needs to be given sufficient time for the analysis. Some of the analyses (e.g., those for which of the shipments coastal shipping should not be used) can be discussed qualitatively, and some rules can be provided. For more advanced analysis such as ship size, quantity, number of voyages, etc., participants can be encouraged to develop rules or perform scenario analysis. Even without the implementation of mathematical programming techniques, this case offers ample opportunity to address various aspects of the problem using simple quantitative analysis. In fact, from our experience, participants must be allowed to think through the solution to the problems without the use of mathematical programming. As mentioned earlier, the use of mathematical programming is not obvious from merely reading the case. The eventual demonstration of the MILP technique showcases the power of the mathematical modeling technique to address large-scale logistics problems in real life.

In its complete form, the MILP model is too large to be solved using the Excel Solver basic tool, so we suggest the implementation using the OpenSolver (Saltzman et al. 2004) tool in Excel. OpenSolver is a freely available Excel add-in, which is compatible with the basic Solver and can solve large problems such as these. Instructors may also promote the application of advanced mathematical modeling software such as AMPL or GAMS, for example, if it is feasible given the scope of the course. In most business school graduate and undergraduate courses, the use of Excel is common, so we demonstrate the case solution using the OpenSolver tool.

For a logistics course, we recommend that the case be given in advance in a classroom discussion session. The students may be given a group assignment to understand and analyze the current business scenario and develop solution approaches to the issues raised in the case. Ideally, a week should be given for analysis, as some participants may not be familiar with the shipping industry. Guideline questions may be provided in advance to contemplate. Students can submit their case reports before the wrap-up classroom session, and one or two groups may be allowed to voluntarily present their analysis. The case discussion session of a typical 75-minute class can be broadly divided into the following timelines:

- *The first 20 minutes*: Case facts are discussed along with the business and regulatory scenario in the given geographical context. The benefits of coastal shipping as a cheaper and environmentally friendly mode of transportation are outlined. The opportunities and challenges present in this sector are discussed. Eventually, the issue at hand that is the requirement of a logistics distribution plan is laid down for further discussion.
- *The next 20 minutes*: Discussion on heuristic approaches to solve the case problem is carried out. Some groups, invited to show their approach, share the basic idea behind their analysis. The instructor eventually points out the shortcomings in student approaches and presents the heuristic approach in detail using a spreadsheet (supplement provided with the teaching note).
- *The following 20 minutes*: The instructor introduces the idea of using mathematical programming to address the problem and guides the students in developing the model in three broad steps: (1) identifying the decision variables that address the important questions, (2) writing the objective function and the constraints using the decision variables, and (3) establishing the guidelines for setting up the model on Excel using OpenSolver. The Excel setup is simple, although a bit time consuming, so a prebuild model needs to be demonstrated after giving proper guidelines on setting up. An Excel solution can be shown and parametric analysis carried out to show the viability of the coastal shipping operations and changes in the proposed configuration when changing various cost parameters.
- *The last 15 minutes*: Finally, business and regulatory challenges related to this sector can be analyzed, supported by reports on this area. Students may be told to come up with policy and business guidelines to make these operations successful.

For an optimization-based course, the discussions on business and regulatory issues may be reduced, and more focus may be given on heuristic approaches and mathematical programming methods. Students may be allowed to develop the mathematical model in the class working in groups. Various extensions to the model may be discussed that can address more complex issues.

5. Classroom Experiences

The case was discussed in courses across a diverse set of audiences. The focus of the case was varied depending on the audience's background. We present our experiences with two courses—one a logistics management course at graduate MBA level and the other a mathematical modeling course with executive participants. The classroom participants' profile is illustrated in Table 1.

We present our experiences with each set of participants and discuss the teaching objectives, class strategies, participant feedback, and challenges addressed.

Table 1. Classroom Participant's Profile

Participant type	Participant profile	Course title	Class size
G	Graduate MBA second-year students with a background in basic OR techniques, an understanding of logistics and supply chain management as a business area, and years of work experience varying from 0 to 3 years across different industries.	Warehousing and Logistics Management	41
E	Executive MBA students with little or no background in OR techniques, a good understanding of logistics and supply chain management, and years of work experience varying from 12 to 17 years.	Mathematical Modeling	12

5.1. Participant Set G

5.1.1. Teaching Objectives. The teaching objective for the graduate students for a logistics management course focused on the supply chain and logistics scenario faced by the firm and the planning problem to address the operational challenges. The teaching objectives can be outlined as follows:

- To understand the multimodal logistics industry, with its various transportation options and linkages
- To understand the applicability of coastal shipping as an intermodal transportation option in a logistics network
- To understand the complexities involved in operating sustainable transportation options such as coastal shipping
- To select the appropriate mode in a multimodal transportation scenario
- To mathematically model a shipment routing problem in a multimodal network
- To understand the interdependencies between shipment routing and ship size and the number selection decision
- To understand the supply chain–related managerial challenges involved in the coastal shipping of automobile cargo
- To understand the regulatory and economic challenges in running coastal shipping

5.1.2. Class Strategy. The case is distributed a week before the classroom session, and participants are also instructed to read reports on multimodal logistics, focusing on coastal shipping for the given geographical context. Guideline questions on the current logistics operations, applicability of coastal shipping, cost estimation of various transportation options, system configuration required to run coastal shipping operations, and associated business and regulatory issues are shared in advance to work on in groups. There should be no mention of mathematical programming at this stage, as the students should be able to develop a spreadsheet analysis–based solution to this problem. The class session can be divided into the timelines as suggested in Section 5, and the suggested guidelines may be followed for class discussion.

5.1.3. Challenges. The challenges faced by the MBA participants are as follows:

1. To understand the business scenario and the need for a sustainable logistics solution, and how coastal shipping is going to help
2. To identify the design elements of a coastal shipping–based intermodal logistics network
3. To develop a heuristic approach to determine an optimal coastal shipping network design
4. To formulate a mathematical model to solve the problem optimally
5. To solve the mathematical model on a spreadsheet
6. To identify supply chain and regulatory issues that may put further constraints on the development of coastal shipping

Students can usually overcome challenges 1 and 6 without much input from the instructors. Challenge 2 needs discussion on multimodal and intermodal logistics networks in related scenarios through examples from other industries such as container shipping and petroleum cargo shipping.

5.1.4. Participant’s Feedback. The MBA participants appreciated the case in various aspects.

- First, the case gives a nice introduction to the multimodal and intermodal logistics practices. As one participant pointed out, “Before the case, I never realized that coastal ships can be used for the outbound logistics of cars. The seamless integration of different modes of transportation to achieve end-to-end logistics is interesting.”
- Second, the case allows one to deal with a large data set in a very logical manner. As one participant pointed out, “Working with the data helps in learning the art of spreadsheet modeling, as a poor organization may make it difficult to analyze.”
- Third, the application of mixed integer programming to analyze the case is not so obvious. Very few

participants could guess using this method for the problem, although once introduced, it was easy to develop conceptually.

5.2. Participant Set E

5.2.1. Teaching Objectives. The teaching objective for the executive students for the mathematical modeling course focused on (1) understanding the planning problem and data, (2) finding a heuristic solution method to the problem, and (3) using a mathematical modeling approach to address the problem. The teaching objectives can be outlined as follows:

- To understand the planning problem in detail in terms of its constituents, such as the appropriate ship sizes required, suitable routes, shipment sizes, etc.
- To develop a heuristic method to solve the problem and derive answers to the planning problem
- To mathematically model a shipment routing problem in a multimodal network
- To understand the interdependencies between shipment routing, ship size, and the number of ships selected

5.2.2. Class Strategy. The case is distributed two days before the classroom session. Participants are instructed to understand the planning problem and try to develop a solution method for the same. Guideline questions on the current logistics operations, cost estimation of various transportation options, and system configuration required to run coastal shipping operations are shared in advance to work on in groups. There should be no mention of mathematical programming at this stage, as the students should be able to develop a spreadsheet-based solution to this problem. The class session starts with describing the problem, identifying available data, and laying down the problem details. Then students can present the heuristic solution technique. The mathematical model is subsequently built gradually with participant inputs. Finally, a parametric analysis is carried out to show the impact of various parameters on the system.

5.2.3. Challenges. The challenges faced by the executive participants are as follows:

1. To identify the design elements of a coastal shipping–based intermodal logistics network
2. To develop a heuristic approach to determine an optimal coastal shipping network design
3. To formulate a mathematical model to solve the problem optimally
4. To solve the mathematical model on a spreadsheet
5. To conduct parametric analysis to understand the impact of various parameters such as port charges

Students can usually overcome challenges 1 and 2 without much input from the instructors. Challenge 3 needs to be addressed stepwise. It is important that this class has already completed some simple mathematical models beforehand and has basic knowledge of working with a mathematical modeling approach in mixed-integer linear programming. The step-by-step approach involves identifying decision variables, writing the objective function, and finally specifying constraints on the decision variables. Challenge 4 requires complex spreadsheet engineering that needs to be explained in detail, but students should develop their own models. Finally, once the instructor demonstrates the parametric analysis, students should be able to analyze the impact of various costs extensively.

5.2.4. Participant's Feedback. The executive participants particularly enjoyed the following aspects of the case:

1. *Case realism*: They concurred with the challenges faced by the coastal shipping industry in India despite the recent focus by the government. Issues such as the minimum assured order for coastal shipping to succeed and how trust needs to be built were also discussed. Because the case is based on real data and a real-life scenario, participants could appreciate that this is, indeed, an important problem to solve. As one participant pointed out, "These are the types of problems we deal with in supply chain strategy consulting quite frequently."
2. *The development of a mathematical model*: For many industry participants, this was a good opportunity to see how mathematical modeling can be used to solve such a complicated-looking, real-life problem. Furthermore, because the MILP formulation is not that straightforward, many participants enjoyed the challenge.
3. *The ability to solve the case using reasoning and scenario analysis*: This case also gives the participants an opportunity to decide in multiple stages—for example, first deciding what size and how many ships will be used (different scenario) and then finding the best shipment routing plan for that. This scenario analysis can also give a good solution. Furthermore, the participants agreed that such scenario analysis will get very complicated if there are more ports and ship types. Hence, they appreciated the MILP technique.

6. Conclusions

The case is well suited as a pedagogical tool for conducting sessions on a variety of topics on logistics management and optimization. It can be used to conduct (a) lecture-based sessions on environmentally friendly multimodal logistics management, (b) student assignments on strategic and tactical transportation planning in the context of multimodal logistics, and (c) optimization modeling of a complex logistics planning problem for a class of graduate and doctoral students in operations management.

The case presents a rich context at a national level to understand and appreciate the complexities involved in planning and sustaining environmentally friendly multimodal logistics operations. The problem context is generic to many countries and firms managing large-scale logistics operations using coastal waterways throughout the world. The inherent complexity of these problems offers excellent opportunities for optimization modeling as a tool to address the issues. Depending on the profile of the students and the scope of a session, an instructor may focus on the most suitable aspects of the case.

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