Multimodal Transportation for Perishable Products

Maryam SteadieSeifi
21 March 2017

Every day, a significant amount of perishable products are transported around Europe, each with their own characteristics and preservation requirements. Perishable products are products losing their value or quality over time, if not appropriately stored or transported. Given short shelf-life of these products and high degree of supply and demand uncertainty, most industries resort to fast and direct transport (such as air or road) which are usually expensive, and not environmentally desirable. On the other hand, resorting to the cheapest transportation options, results in longer delivery, and therefore, perished products. The focus of this thesis is on developing relevant models and algorithms to find the trade-off between operational consideration and product quality preservation requirements.

A cheap and environmentally friendly long-haul transportation requires consolidation and switching from air and road to other modes of transport. Consolidation and mode switching are the highlighted advantages of multimodal transportation. Multimodal freight transportation is defined as the transportation of goods by a sequence of at least two different modes of transportation. It offers a potential platform for a more efficient, reliable, flexible, and sustainable freight transportation. However, planning operations of a multimodal system added to the extra quality preservation of perishable products is heavily complex. Therefore, *the main research question in this thesis involves an improved understanding whether multimodal transportation platform can be used for perishable products.*

Despite gaining more attention, the literature on “long-haul transportation of perishable products”, especially with including temperature conditions in modeling product quality preservation measure, is very limited. Moreover, the key operational challenge of managing transportation resources, and more specifically, repositioning of the empty loading units called Returnable Transport Items (RTIs), deserves more attention. RTIs can have different sizes ranging from a small box to a large 45-feet container. Their number in the entire chain is limited, and their shortage at locations that they are needed results in quality decay of the products waiting for them, which therefore results in lost sales and less profit. This thesis adds to the current literature by assuming a multimodal infrastructure and including such operational challenges into the planning.

Infrastructure expansion or change is in domain of governmental and national organizations, and ownership of vessels, trains, etc. is not practical for one perishable industry alone, who is merely a user to a multimodal infrastructure. Therefore, in this thesis, strategic planning is out of scope, and in two parts, tactical and operational planning problems are addressed. Moreover, there is a vast literature on first-mile and last-mile distribution of perishable products, therefore, this thesis only focuses on long-haul multimodal transportation planning.

In order to position the current thesis in the literature of “multimodal freight transportation planning”, first in **Chapter 2**, an overview of the recent research on tactical and operational planning problems of multimodal freight transportation is presented. This chapter highlights recent modeling and algorithm design advances, and identifies some gaps that can be subjects of future work. Taking these gaps into account, this thesis contributes to the literature from the perspective of a perishable product industry.

<u>In tactical planning part</u>, in **Chapter 3**, the planning problem of multimodal transportation of perishable products, with its decisions and constraints regarding the flow of products, the repositioning of RTIs, and arrangement of multimodal fleet, is described. This problem is an extension to the classic Fixed-cost Capacitated Multicommodity Network Flow Problem (FCMNFP). It is formulated as a Mixed Integer Program (MIP), where new sets of constraints on quality preservation and RTI repositioning are added. Due to severe complexity of this problem, in this chapter, only one RTI size (e.g. trolleys) is included. The results of this chapter show that the problem is too complex to be solved by a state-of-the-art MIP

solver for the real-world sizes. **Appendix 1** extends this single-RTI planning problem to include three (small, medium, and large) sizes of RTIs with extra attributes: 1) there is a loading heirarchy among these RTIs, and each size should be loaded into (onto) its immediate bigger RTI size, and 2) the empty RTIs can be nested or folded to save space. These properties bring extra complexity to the problem, compared to a state-of-the-art “heterogeneous resource management”. Due to high complexity of the problem in Chapter 3, in **Chapter 4**, an Adaptive Large Neighborhood Search (ALNS) algorithm is proposed to solve the MIP of Chapter 3. Application of ALNS algorithms is new to the FCMNFP literature, and the contribution of this part is in design of new neighborhoods, and in the introduction of extra search strategies to improve performance of the algorithm. The results showed that the algorithm is fast, does not take up much memory, and provides good and robust solutions.

In operational planning part, **Chapter 6** first describes the operational planning problem of long-haul transportation of perishable products, with its decisions and constraints. This problem is a dynamic extension to the planning problem of Chapter 3, where at specific decision occasions (e.g. every 12 hours) and based on collected data on arrived demand and system evolution, a deterministic FCMNFP with updated parameters on new demand, RTI repositioning, and available multimodal transportation options, is reformulated and solved. Chapter 6 then presents a rolling-horizon framework to contain and control this decision process, where a modified version of the ALNS of Chapter 4 is employed to provide new and adjusted plans, in order to efficiently respond to the new demand and system changes. The solutions of Chapter 6 however, rely only on revealed data, and do not include anticipation of future demand. Demand of perishable products fluctuates day to day, and there are daily, weekly, and seasonal trends influencing the volume that each customer wants to transport. As a result, the solutions of Chapter 6 might end up either employing last-minute expensive transportation options when demand is too high, or having underutilized fleet when demand is too low. In **Chapter 7**, demand is assumed to be stochastic, and the operational planning problem of Chapter 6 with stochastic demand is transformed into a dynamic and stochastic planning problem, where at each decision occasion, a Scenario-based Two-stage Stochastic Program (STSP) is reformulated and solved. This STSP is an extension to the planning problem of Chapter 3, where at the first stage, the multimodal fleet is arranged and at the second stage, this arrangement is used to find optimal product flow and RTI repositioning over a generated population of demand scenarios. The rolling-horizon framework of Chapter 6 is further extended to include these scenarios, and the ALNS of Chapter 6 is also modified to include redesigned neighborhoods and parameter tuning. Therefore, at specific decision occasions, and after collecting arrived demand data, a scenario population for demand of the coming time periods is generated, and then by solving the STSP, new plans and adjustments are made. With simulating the results of both deterministic and stochastic planning frameworks, the influence of future demand anticipation is later analyzed. The application of rolling-horizon approaches in planning long-haul transportation operations is very limited, and Chapters 6 and 7 add to the literature by adapting it to the scope of this thesis, incorporating stochastic demand, and presenting vast analysis on its properties.

At the end of this thesis, **Chapter 8** provides a summary of the findings, conclusions, practical insights, as well as the limitations of this thesis and future research suggestions. One of the limitations of this thesis is that the products are assumed homogeneous, while in practice, perishable industries might share and combine their logistics to benefit from economy of scale. In such a setting, each product has its own quality preservation requirement, and its preservation regime might not be compatible with others. Moreover, the objectives of the cooperating industries might not be congruent. Hence, extra constraints and multiple objectives are needed for the combined long-haul transportation planning. This problem becomes more complex, and therefore, it might need different tactical and operational planning algorithms. Another future research suggestion is in the area of multi-size RTI management. This problem is relatively new to the literature of multimodal transportation planning, and the loading and nesting relations among different sizes of RTIs make it extremely challenging to model and to design efficient planning algorithms.