Chapter 1

Introduction

This Master's thesis deals with the study of the berth allocation problem in a container transshipment port and the development of a multi-way graph partitioning algorithm to solve this problem. This chapter introduces the importance of berth allocation planning in a modern transshipment port and explains the scope of this thesis.

1.1 Background and Motivation

The shipping of goods and commodities via vessels across the oceans is an important mode of transportation in the modern day commercial world. Surface shipping remains a viable alternative to air freight because many types of cargo are either too large or too heavy to be transported by air, or are just not cost-effective to be air-flown. Hence, container transshipment ports around the world today still enjoy a good share of the global transportation business ([LeHu92a], [LeHu92b], [ST96a], [ST96b]).

The business volume for a transshipment port can be well in excess of 10 million containers per year. This is especially so for certain ports which are situated in geographically advantageous locations, such as the port of Singapore which enjoyed a business volume of 12 million containers for the year 1996 ([ST96a]). With an annual business growth of 15% to 20%, the Port of Singapore Authority (PSA) faces stiff competition from other ports in the region which are luring its shippers away aggressively. To maintain its competitive edge, the PSA has to provide the highest level of service quality by berthing some 300 cargo vessels each day and handling up to 80 containers per hour. The average vessel turnaround time is a fast $12\frac{1}{2}$ hours. The PSA is also upgrading the port through automation to maintain and improve upon the current level of service in order to stay ahead of the competition ([ST96b]).

Vessels arriving at a transshipment port are berthed along the berthing area, which is a huge stretch of land at the ocean front. To ensure fast turnaround times, vessels have to be berthed as soon as possible upon arrival and have the necessary containers loaded onto or unloaded from them in the shortest time by the quay cranes. In a transshipment port, the containers unloaded from a vessel are generally transferred by the prime movers to another vessel to be loaded onto it, hence the transshipment process. If the recipient vessel has not arrived yet, these containers will be temporarily stored in a yard area. The containers can be transferred quickest when vessels having to interchange large volumes of containers are either berthed near to each other or berthed near to the yard area for holding the containers ([LeHu92b]). Then the containers will only have to be transported across minimal distances to reach their destinations. The operational efficiency in the berthing of vessels contributes towards a high container handling rate and a low vessel turnaround time, allowing the port to service more vessels per day, thus increasing the volume of business.

The business well-being of a container transshipment port therefore depends on the efficient management of its port resources such as quay cranes, prime movers and berthing area. Among the various port resources, the berthing area ranks as one of the most important, for the reason that while additional quay cranes may be purchased when the business demand rises, it is difficult to increase the berthing area after the port has been established ([LeHu92a]). This limitation is even more so for a land-scarce country like Singapore. In addition, the berthing area could also exhibit certain geographical characteristics such as uneven land boundaries which could pose to be a challenge to berthing vessels. Proper planning is then required to ensure effective utilisation of the berthing area, so that the overall cost of transshipment can be minimised.

1.2 Thesis Overview

This thesis is part of a larger concerted research effort ([ChLe99], [LiLe99], [SiLe99], [XuLe99], [FoLe00]) started by the RAS Group in the Algorithms Lab to solve the problem of allocating suitable berthing locations to vessels so as to minimise the overall transshipment cost. This problem is termed the berth allocation problem (BAP) and it will be defined formally in chapter 2. The BAP is a relatively new problem in the sense that very few research results were published about the problem ([LeHu92a], [LeHu92b], [LoLe96], [HKL97]). The pioneering work on the BAP within the RAS Group was done in an Honours thesis by Loh and Leong ([LoLe96]), whereby the BAP was modelled as a generalised quadratic assignment problem with 2-dimensional packing constraints. The BAP was also identified as being NP-hard. Loh's thesis studied the problem of assigning vessels to sections using genetic algorithms (GA) and GA with tabu search.

In this thesis, we refine the BAP model to be solved in two stages (see Figure 1.1). The first stage, known as the *partitioning stage*, performs an assignment of vessels to sections. The second stage, known as the *packing stage*, allocates the vessels within each section to a wharf mark for berthing.

We focused our attention on the partitioning stage and concentrated on finding a good solution to this subproblem. In particular, we modelled the partitioning stage as a multi-way graph partitioning problem and developed a graph partitioning

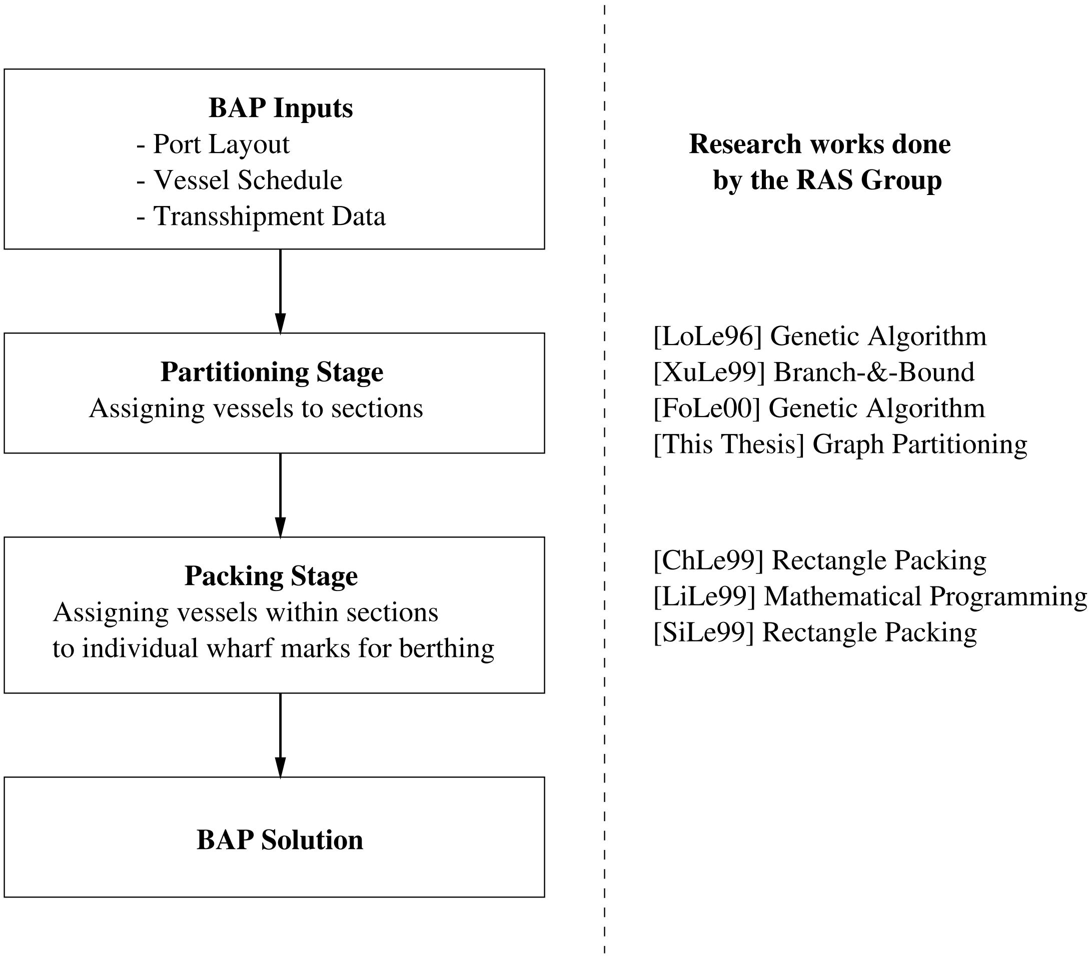

Figure 1.1: BAP as a Two-Stage Problem

algorithm to solve it. To do so, we had to study existing graph partitioning techniques. We confined our research focus to circuit partitioning algorithms which, in the area of VLSI CAD, have been proven to be very effective, both in terms of the running time and the solution quality. Our literature survey took us to many research works on VLSI circuit partitioning ([KeLi70], [ScKe72], [FiMa82], [Sanc89], [WeCh89], [WeCh90], [HHK95], [KK95], [DuDe96], [KK98]). This survey not only provided us with various ideas on solving the BAP partitioning problem but it also helped us to identify the important differences between our problem and the circuit partitioning problem. As the BAP partitioning problem is a generalisation of the circuit partitioning problem, the existing algorithms for the latter cannot be applied directly to solve the former. We went on to develop our own BAP graph partitioning algorithm from the insights and knowledge obtained from our literature survey.

To test the effectiveness of our solution, we designed a Berth Allocation Planning System (BAPS) to implement a complete BAP solution of both partitioning and packing. This BAPS was done in collaboration with fellow Master student Foo ([FoLe00]) and it attacked the BAP by linking together several other BAP modules, some done as part of this thesis and some done by other theses within the same research group ([RAS99], [ChLe99], [FoLe00]). Currently the BAPS comprises our graph partitioning algorithm and the genetic algorithm from [FoLe00] for partitioning, together with the rectangle packing algorithm from [ChLe99] for packing.

The BAPS framework is object-oriented in nature and allows the various BAP modules to be plug-and-play depending on a customisable set of user preferences, thus providing different combinations of algorithms for solving the BAP.

Finally, we conducted extensive experimentations to verify the correctness of our algorithms and to evaluate their effectiveness. Prior to conducting our experiments, we had to divert our efforts to data collection and data generation. This was because the actual BAP data is highly classified information in the commercial world and we were unable to obtain the actual data for testing. What we did was to collect real world information from port periodicals and other reliable sources of information ([RAS96]). Then we reverse-engineered and generated our own test data based on this information. In the process, we also designed and implemented a complete data generation system.

We ran our BAP partitioning algorithm through a wide range of generated data sets, which depict different port, vessel and transshipment scenarios. The results we obtained provided strong evidence that our partitioning algorithm is effective for solving the BAP partitioning problem. During the course of our experiments, we noticed a subset of our test data consistently caused our BAP partitioning algorithm to produce infeasible solutions, whereby some of the vessels could not be assigned to any section at all. Further study of these data sets revealed that the infeasibility was caused by a density-related problem which we later identified to be an instance of the multiple knapsack problem. This took us into the study of knapsack related problems ([MaTo90]) in order to devise a heuristic solution to overcome the infeasibility. We will present the details in the chapters that follow.

1.3 Thesis Organisation

The rest of this thesis is organised as follows: Chapter 2 gives a detailed description and a formal problem definition of the BAP. It also covers the literature survey we have done on BAP and graph partitioning. Chapter 3 proposes a generalised graph partitioning model for the BAP partitioning stage. We then present a fast partitioning algorithm to solve it and describe in detail the mathematical formulae and data structures used by our algorithm. We also present a solution framework whereby our algorithm is extended with pre- and post-processor heuristics. Chapter 4 covers the system architecture and implementation issues behind the BAP planning system. Chapter 5 discusses our experiments and results. Here, we describe the generation of our test data and present our analysis of our algorithm after comparing it with other BAP algorithms. Chapter 6 concludes this thesis by summarising our research contributions and findings, and provide some ideas for future enhancements.