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Literature review

There are few studies on offshore logistics systems (see Chapter 3) reported in the academic literature, as previously observed by other authors (Kaiser, 2010; Kaiser and Snyder, 2010; Aas *et al.*, 2009). According to Kaiser (2010), "the study of the logistics of the upstream offshore oil and gas industry has been diverse, but not theoretically unified or well developed". These studies deal with topics like operational research applied to offshore logistics systems, information management, outsourcing and others. In fact, although many people have gained an understanding of this issue empirically, the accumulation of academic knowledge is still in its early stages.

Aas *et al.* (2008) have discussed the outsourcing of logistics activities. Regarding the routing of supply vessels, Aas *et al.* argue that personnel who work in Supply Terminal Management have low formal logistics competence, mainly when compared to other activities in the oil and gas industry and to other professionals working in logistics companies. The authors also note the low priority of the logistics discipline, as it is not the core activity of the company, and that professionals trained in logistics could add value to the company in complex issues like routing of supply vessels. Aas and Wallace (2010) worked on logistics planning and presented a case from Statoil's supply base in Kristiansund. Supply vessels have also been studied by Aas *et al.* (2009), and the authors discussed their features, such as carrying capacity and sailing capacity as well as the determination of the fleet configuration.

Batista (2005) created a model to simulate the operations at the Port of Imbetiba. Their paper describes the model but does not discuss better ways to operate the port. One problem of this model is that it does not consider the cycle of the vessels as a closed loop.

Kaiser (2010) built a model to quantify service vessel trips in order to forecast the activity in the Gulf of Mexico. The logistics was modeled as a linear time-invariant deterministic system. The aim of the author was to understand the economic and ecological impacts of vessel usage. The author also indicated that his results could be used as a basis for infrastructure investment decisions. With the same objective, Kaiser and Snyder (2010) carried out a study on the number of trips required to offshore units in the Gulf of Mexico, analyzing data provided by the companies. The authors claim to have performed the first empirical analysis of the offshore service industry and, in fact, this article by Kaiser and Snyder is the only one known to address this particular issue. No other publication discusses the service frequency of the offshore units or presents real data analysis. The lack of knowledge and parameters available makes it difficult to compare operations around the world and to study this issue efficiency in terms of the cost and service level.

The transport of cargo to the offshore units represents a physical distribution problem which encompasses pickup and delivery, a heterogeneous fleet, multiple goods, stochasticity, the priority of some cargo, multiple trips, weather issues, and restrictions like the vessel deck area limits and the number of berths at the port. The problem usually involves only one depot (the port). A good solution has to guarantee a high service level with a minimal cost. All of these characteristics make the routing of supply vessels a challenging task. The approaches to the routing of supply vessels to the offshore units can be divided into two categories: those which propose a solution to the periodic vehicle routing problem (Fagerholt and Lindstad, 2000; Halvorsen-Weare and Fagerholt, 2011; Shyshou *et al.*), in order create periodic schedules; and those which propose a solution to the vehicle routing problem (Aas *et al.*, 2007; Lopes, 2011; Almeida, 2009), in order to design algorithms to route the vessels considering the cargo available for transportation, that is, operational algorithms for the day-to-day running.

In relation to non-periodic models, Aas *et al.* (2007) addressed the vehicle routing problem with pickups and deliveries (VRPPD) adopting a single vessel and considering customer capacity restrictions. The model is deterministic and allows two visits to some customers, delivering first and picking up later. The objective function is the minimal cost, which is achieved with CPLEX 9.0. According to the authors, this is a basic model and it needs some improvement in order to represent the real-life problem. Almeida (2009) used a genetic algorithm in the optimization to maximize the service level and to minimize the cost. Almeida's algorithm has two runs: in the first no cargo can be delayed, but in the second this restriction is loosened and some cargo can be delayed according to the service level required by each offshore unit. The model includes characteristics like the direction of the maritime current, weather conditions and restrictions such as time windows and port availability. Lopes (2011) addressed the same problem adapting the library created by Groer *et al.* (2010) and the algorithm of Li (2005) to solve the heterogeneous fleet vehicle routing problem (HVRP).

Regarding periodic models, Fagerholt and Lindstad (2000) created a model to study the financial cost of having some offshore units closed for service at night and to propose an optimal routing policy. The objective function in this model is the cost. Furthermore, the same authors evaluated the influence of the frequency of visits to the offshore units and added slack to increase the robustness of the schedule. Halvorsen-Weare and Fagerholt (2011) studied different approaches to create robust schedules, mixing optimization and simulation. Shyshou *et al.* worked on a heuristic approached to the periodic vessel routing and fleet composition problem, in order to solve large-scale instances of the problem. Panamarenka (2011) presented a neighborhood search heuristic model with speed optimization in order to evaluate costs and environmental aspects, since nowadays lowering fuel emissions is an important issue.

The low use of techniques like optimization, simulation and routing algorithms in the offshore logistics system was reported by Aas *et al.* (2007) and Aas *et al.* (2009). In fact, such techniques are just beginning to be used at Petrobras, but this approach is still in its very early stages. Valente *et al.* (2008) presented some challenging factors which must be addressed in order to achieve the efficiency and rationalization of fleet management, considering the Brazilian scenario. All of these factors are considered by the offshore logistics department of Petrobras:

- the complexity of the problem leads to empirical procedures that may be far from optimal
- the advances in information technology are relatively recent and these have been slowly adopted by the companies
- personnel do not trust advanced techniques or believe that they may help them
- personnel resist changing the way they have been working to date
- lthere is a lack of tools and software in relation to some activities

Aas *et al.* (2007; 2009) have discussed many questions regarding the scheduling and routing of trips to offshore units. The demand and weather uncertainties are challenging factors of the offshore logistics system. In general, the companies plan fixed routes, but these routes might be changed if some unexpected event occurs. The fleet can not be dimensioned for the average demand, but instead an excess capacity is needed, making it easier to deal with peaks and bad weather periods. The number and size of vessels is another complex issue to be dealt with in the offshore logistics system. The transport of large amounts of cargo in a single voyage will decrease the unit cost, although it is not always possible to achieve high deck occupation because of the required frequency of service, lead time and demand uncertainties. Furthermore, it is usually necessary to include many offshore units in a single route to increase the use of large vessels, increasing the probability of route deviations and affecting a greater number of offshore units than if the route was covered by a small vessel involving less offshore units. A small vessel is more flexible and it is more probable that the vessel is at the port when some priority cargo has to be shipped. On the other hand, larger vessels are better in terms of decreasing the number of trips, to deal with large demand peaks, to cover periods of bad weather and to service an offshore unit in a single visit.

Papers on related topics can aid the development of research on offshore logistics systems. Christiansen *et al.* (2004) revised the literature on ship routing and scheduling. Most of the relevant studies deal with problems somewhat different from those that are faced by offshore logistics. Ships operating along international routes do not return to their origin after a trip. Also they have longer voyages and the port-compatibility is dependent on load weight. In contrast, an offshore logistics system is a particular case of seaborne transportation. The vessels usually return to their origin, their voyages are shorter and they do not usually travel fully loaded, which means that port-compatibility will not change from trip to trip. On the other hand the similarities include high uncertainty, dependence on weather conditions, changes in the destination of the vessels during a trip, operations around the clock (although this does not apply to some offshore units and ports), and characteristics like the importance of flexibility and robustness of the schedules.

Christiansen *et al.* (2004) discussed some aspects of the scheduling problem that can also be found in Campos Basin. The schedules are often constructed manually according to the planner's knowledge and experience. Planners who have a good reputation and position in the shipping companies are often skeptical of decision support systems based on optimization. Christiansen *et al.* noted that, as the fleet becomes larger the manual work becomes harder. Nowadays, companies are hiring planners with more emphasis on their academic background, even if they have less practical experience, which may pave the way for the use of computational techniques. In addition, the same authors found that only a small fraction of the studies described in the literature are used in practice.

Considering that the transport of cargo to offshore units is a physical distribution problem, the literature on this issue is a valuable aid. According to Valente *et al.* (2008), this kind of problem has two levels of resolution:

the **planning and system design level** and the **operational level**. At the planning level, the company can work with simple calculations and rough estimates in order to analyze the alternatives. However, since all parameters may have large variations from the mean, the randomness effects should be considered.

In this study, the Clarke and Write algorithm was applied to build the clusters of offhore units (see Section 5.2(a)). This algorithm is a classical heuristic for the Vehicle Routing Problem (VRP) and this is based on the notion of savings. This is widely known and remains used in practice (Laporte and Semet, 2002; Cordeau *et al.*, 2002). There are two versions: parallel and sequential. The Clarke and Write algorithm is easy to understand and easy to code (Cordeau *et al.*, 2002). It "tends to produce good routes at the beginning, but less interesting routes towards the end, including some circumferential routes" (Laporte and Semet, 2002). In fact, the algorithm "is based on a greedy principle and contains no mechanism to undo early unsatisfactory route merges" (Cordeau *et al.*, 2002). This was classified by Courdeu *et al.* (2002) as being of low accuracy, very high speed, very high simplicity and low flexibility. Enhancements for the Clarke and Write algorithm have been proposed by several researchers (Pichpibul and Kawtummachai, 2012), but in this study the original version was used.