Communication Networks

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Dissertation

Efficient Communication in Agent-based Autonomous Logistic Processes

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PREFACE

It is a pleasure to thank people who supported me in successful completion of this research work. In the following lines only a few among them are acknowledged, though I am aware of the fact that there are many more who supported me in some way or the other throughout this journey. And I am truly grateful to them for the same.

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Lastly, I would also like to thank my parents for indebting in me the value of education based on which I have reached this status in life. I also owe my thanks for the support and love of my in-laws.

ABSTRACT

Transportation of goods plays a vital role for the success of a logistics network. The ability to transport goods quickly and cost effectively is one of the major requirements of the customers. Dynamics involved in the logistics process like change or cancellation of orders or uncertain information about the orders add to the complexity of the logistic network and can even reduce the efficiency of the entire logistics process. This brings about a need of integrating technology and making the system more autonomous to handle these dynamics and to reduce the complexity. Therefore, the distributed logistics routing protocol (DLRP) was developed at the University of Bremen. In this thesis, DLRP is extended with the concept of clustering of transport goods, two novel routing decision schemes and a negotiation process between the cluster of goods and the vehicle.

DLRP provides the individual logistic entities the ability to perform routing tasks autonomously e.g., discovering the best route to the destination at the given time. Even though DLRP seems to solve the routing problem in real-time, the amount of message flooding involved in the route discovery process is enormous. This motivated the author to introduce a cluster-based routing approach using software agents. The DLRP along with the clustering algorithm is termed as the cluster-based DLRP. In the latter, the goods are first clustered into groups based on criteria such as the common destination. The routing is now handled by the cluster head rather than the individual transport goods which results in a reduced communication volume in the route discovery. The latter is proven by evaluating the performance of the cluster-based DLRP approach compared to the legacy DLRP.

After the routing process is completed by the cluster heads, the next step is to improve the transport performance in the logistics network by identifying the best means to transport the clustered goods. For example, to have better utilization of the transport capacity, clusters can be transported together on a stretch of overlapping route. In order to make optimal transport decisions, the vehicle calculates the correlation metric of the routes selected by the various clusters. The correlation metric aids in identifying the clusters which can be transported together and thereby can result in better utilization of the transport resources. In turn, the transportation cost that has to be paid to the vehicle can be shared between the different clusters. The transportation cost for a stretch of route is calculated by the vehicle and offered to the cluster. The latter can decide based upon the transportation cost or the selected route whether to accept the transport offer from the vehicle or not. In this regard, different strategies are developed and investigated. Thereby a performance evaluation of the capacity utilization of the vehicle and the transportation cost incurred by the cluster is presented.

Finally, the thesis introduces the concept of negotiation in the cluster based routing methods. The negotiation process enhances the transport decisions by giving the clusters and the vehicles the flexibility to negotiate the transportation cost. Thus, the focus of this part of the thesis is to analyse the negotiation strategies used by the logistics entities and their role in saving negotiation time while achieving a favorable transportation cost. In this regard, a performance evaluation of the different proposed strategies is presented, which in turn gives the logistics practitioners an overview of the best strategy to be deployed in various scenarios. Clustering of goods aid in the negotiation process as on the one hand, a group of transport goods have a stronger basis for negotiation to achieve a favorable transportation price from the vehicle. On the other hand it makes it easier for the vehicle to select the packages for transport and helps the vehicle to operate close to its capacity. In addition, clustering enables the negotiation process to be less complex and voluminous.

From the analytical considerations and obtained results in the three parts of this thesis, it can be concluded that efficient transport decisions, though very complex in a logistics network, can be simplified to a certain extent utilizing the available information of the goods and vehicles in the network.

KURZFASSUNG

Der Transport von Gütern spielt eine wesentliche Rolle für den Erfolg eines Logistiknetzes. Die Fähigkeit, Güter schnell und kosteneffektiv zu befördern, ist eine der wesentlichen Anforderungen der Kunden. Dynamische Vorgänge innerhalb des Logistikprozesses wie Änderungen oder Stornierungen von Bestellungen oder unklare Informationen über die Bestellungen tragen zur Komplexität des Logistiknetzes bei und können die Effizienz des gesamten Logistikprozesses sogar verringern. Hieraus ergibt sich ein Integrationsbedarf an Technologie, um das System zur Behandlung dieser dynamischen Vorgänge autonomer zu gestalten und die Komplexität zu verringern. In dieser Hinsicht wurde das Distributed Logistics Routing Protocol (DLRP) an der Universität Bremen entwickelt. In dieser Arbeit ist DLRP um das Konzept des Clusterings von Gütern, Korrelation von Routen, transportkostenbasierten Routingentscheidungen und dem Abstimmungsprozess zwischen dem Güter-Cluster und den Fahrzeugen erweitert worden.

DLRP stellt für die einzelnen logistischen Einheiten die Fähigkeit bereit, Routingaufgaben autonom auszuführen, d.h. die beste Route zum Ziel zur gegebenen Zeit zu bestimmen. Obwohl DLRP das Routingproblem in Echtzeit zu lösen scheint, ist das Ausmaß der Überflutung mit Nachrichten, die am Prozess der Routenerkennung beteiligt sind, erheblich. Dies motivierte die Autorin, einen clusterbasierten Routingansatz durch Einsatz der Software-Agenten-Technologie einzuführen. Das DLRP-Protokoll zusammen mit dem Clustering-Algorithmus wird als clusterbasiertes DLRP-Protokoll bezeichnet. In letzterem werden die Güter zunächst basierend auf Kriterien wie einem gemeinsamen Bestimmungsort in Gruppen zusammengefasst. Der Routingprozess wird jetzt vom Clusterkopf anstelle der einzelnen Gütereinheiten gesteuert. Dies resultiert in einem verrigerten Kommunikationsaufkommen im Prozess der Routenerkennung, was anhand der Leistungsbewertung des clusterbasierten DLRP-Ansatzes im Vergleich zum herkömmlichen Ansatz belegt wird.

Nachdem der Routingprozess durch die Clusterköpfe abgeschlossen ist, besteht der nächste Schritt in der Verbesserung der Transportleistung im Logistiknetz durch Identifikation der besten Möglichkeit, die geclusterten Güter zu befördern. Beispielsweise können Cluster, um eine bessere Auslastung der Fahrzeuge zu erreichen, zusammen auf einem Streckenabschnitt einer überlappenden Route transportiert werden. Für optimale Transportentscheidungen berechnet das Fahrzeug das Korrelationsmaß der Routen, die von den verschiedenen Clustern ausgewählt worden sind. Das Korrelationsmaß hilft bei der Erkennung von Clustern, die zusammen befördert werden können und kann daher zu einer besseren Auslastung der Transportresourcen führen. Die Transportkosten, die an das Fahrzeug entrichtet werden müssen, können wiederum zwischen den verschiedenen Clustern aufgeteilt werden. Die Transportkosten für einen Routenabschnitt werden vom Fahrzeug berechnet und dem Cluster angeboten. Letzterer kann anhand der Transportkosten oder der ausgewählten Route entscheiden, ob das Transportangebot des Fahrzeugs angenommen werden soll oder nicht. In dieser Hinsicht werden verschiedene Strategien entwickelt und untersucht.

KURZFASSUNG

Dabei wird eine Bewertung der Kapazitätsauslastung des Fahrzeugs und der durch den Cluster verursachten Transportkosten dargestellt.

Schließlich führt die Arbeit das Konzept der Verhandlung in die clusterbasierten Routingverfahren ein. Der Verhandlungsprozess erweitert die Transportentscheidungen, indem er den Clustern und den Fahrzeugen die Flexibilität gibt, die Transportkosten auszuhandeln. Daher liegt der Schwerpunkt dieses Teils der Arbeit in der Analyse der Verhandlungsstrategien, die von logistischen Einheiten verwendet werden, und ihrer Rolle beim Einsparen von Verhandlungszeit während des Erzielens eines günstigen Transportpreises. In dieser Hinsicht wird eine Leistungsbewertung verschiedener vorgeschlagener Strategien vorgenommen, was wiederum den Praktikern in der Logistik einen Überblick über die beste Strategie verschafft, die in verschiedenen Szenarien angewendet werden soll. Die Zusammenfassung von Gütern in Clustern unterstützt den Verhandlungsprozess, da einerseits eine Gruppe von Transportgütern eine stärkere Verhandlungsgrundlage hat, um gegenüber dem Fahrzeug einen günstigen Beförderungspreis zu erzielen. Andererseits erleichtert Clustering dem Fahrzeug, die Frachtstücke für den Transport auszuwählen und verhilft dem Fahrzeug zu einem Betrieb dicht an seiner Kapazität. Außerdem wird der Verhandlungsprozess durch das Clustering weniger komplex und voluminös.

Aus den analytischen Bewertungen und den erzielten Ergebnissen in den drei Teilen dieser Arbeit kann geschlossen werden, das effiziente Transportentscheidungen, obwohl diese in einem Logistiknetz sehr komplex sind, bis zu einem gewissen Maß durch Nutzung der verfügbaren Informationen im Netz vereinfacht werden können.

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CHAPTER **1**

1. Introduction

The high demand for customized products and their delivery at the right time and with the right quantity and quality has imposed an increasing dynamism in the logistic networks. A logistic network is a network of suppliers, factories, warehouses and distribution centers through which raw materials are acquired, transformed, produced and delivered to the end customer. This dynamic process involves constant flow of physical objects and related information across multiple functional areas both within and between different organizations. The success of a logistic network mainly depends on the efficient transportation of logistic items. The ability to transport goods quickly and cost efficiently is seen as a vital factor for an organization. The traditional transportation systems, though equipped with the best possible transportation handling facilities, still face many complexities and dynamics due to the distributed nature of the system, leading to more congestion in the flow of goods. This additionally increases the requirement for inclusion of new technical innovations or paradigm changes in the logistics network.

The dynamics involved in a logistics network have driven the enterprises and organizations to start restructuring their business processes to introduce autonomy in order to provide rapid response to changing customer demands and operation environment. According to [SWF04], autonomy in the logistics domain implies integrating concepts of management theory, computer science as well as the concepts of technical autonomy from diverse engineering fields. In this regard, the concept of *Autonomous Cooperation (AC)* [SWF04] in logistics network was introduced. *Autonomous Cooperation (AC)* in logistics can be seen as one of the many possible approaches to cope with the rising complexity and dynamics involved within logistic networks [SWF04]. It also brings about a need for an automated system to operate almost without any human intervention. The evolution of the autonomous approach which moves away from the traditional centralized approach demands a strong need for the use of modern technologies in the field of logistics like GPS (Global Positioning System) and RFID (Radio Frequency Identification).

In addition, software agent technology provides the *means* of creating autonomous, intelligent and communicating software entities capable of supporting autonomous decision-making by sharing information on a continuous basis. Software agent technology is a promising field that is widely used in distributed heterogeneous networks. A software agent is a software entity that communicates and acts autonomously, and in some applications migrates from one source host to another destination host to accomplish its assigned tasks, making use of available resources like wired or wireless communication networks. These properties of software agents have led many researchers to study software agents and apply them in various fields of applications, ranging from logistics to network performance management. The software agent paradigm has much to offer in terms of handling the dynamics involved in the logistic networks. As presented in [LT04], several agent-based approaches have been proposed to deal with the dynamic optimization problems in transport logistics. The motivation for the use of software agents in the logistics domain comes from the fact that agent-based systems reflect the distributed nature and are able to deal with the dynamics of planning and execution in a near real-time context [DC05].

Given these motivations, the objective of this thesis is to identify the challenges and potential of integrating software agent technology in the paradigm of autonomous cooperation of logistics processes to ensure robust and efficient planning and operation in the transportation domain. This is realised by introducing the concept of clustering approaches along with the correlation based routing of transport goods to reduce the communication overhead and increase the efficiency of the transport methods, respectively. Additionally, the envisioned concept of cluster based routing is extended with the concept of negotiation between the logistics entities (e.g., between goods and vehicles), introduced to ensure fair and cost efficient transportation of the logistic entities.

1.1 Motivation and Research Goals

An autonomous system brings with it many complexities and dynamics. The analysis and control of logistic chains has been playing an increasingly important role in route planning and information distribution. Products to be delivered are loaded at the distribution centers and the loaded products are transported to the various destinations. Eventually, every vehicle route must start and finish at the assigned terminal and both vehicle capacity and working time constraints are to be satisfied.

A lot of research on autonomous control in logistic networks deals with new techniques and algorithms and eventually the evaluation of the new concepts introduced. As a result, a new concept was introduced at the University of Bremen in the transportation domain named DLRP [WRTG+07, SRF06]. DLRP is designed to solve different routing problems such as the PDP (Pick-up and Delivery Problem) [SS95] for a dynamic scenario; orders may appear at every point in the network and at any time. All the entities in the network have their own objective function, e.g., shortest route for transport goods and best utilization for vehicles. In contrast to traditional algorithms for the *Vehicle Routing Problem* (VRP) [Psar88] problem, which do static optimization, this new approach termed DLRP addresses dynamic transport scenarios. The DLRP protocol is implemented using a software agent based framework. Every object (package or vehicle) is represented by a software agent. The message flow between the entities is accomplished using the FIPA communication protocol within the simulation tool PlaSMA [GO-B07].

One of the crucial properties of transport processes is that they are dynamic as well as complex proportional to the size of the network. The larger the network, the higher is the complexity with additional dynamics involved. The number of agents representing the logistic entities increases with a growing network size, resulting in a potentially enormous amount of communication associated with it. In addition, the distributed nature of the logistics network results in an inefficient utilization of the logistic resources and hence a higher transportation cost. This motivated the author to introduce the novel concept of *Clustering* of logistic objects to reduce the communication overload in the autonomously controlled distributed logistics routing method. Transport decisions are enhanced by utilizing the route information and timing constraints present in the logistics network. Additionally, the automated negotiation among the software agents makes the autonomous cooperation in logistics network flexible in transport decisions.

A few indicative excerpts related to logistics, software agents, autonomous cooperation, DLRP, clustering, transport and negotiation as the main motivation factors of this thesis are presented as follows:

- *Logistics* can be defined as the "integrated planning, control, realization and monitoring of all internal and network-wide material-, part- and product flows including the necessary information flow along the complete value-added chain" [MDC09].
- *Autonomous Cooperation (AC)* can be seen as a main approach to cope with the rising complexity and dynamics involved within the logistic networks [SWF04]. The concept of autonomous control is the research area of the German Collaborative Research Centre (CRC) 637 'Autonomous Cooperating Logistic Processes- A Paradigm Shift and its Limitations' at the University of Bremen from 2004 till present [SWF04].
- Several *software agent* based approaches have been proposed to deal with dynamic optimization problems in transport logistics [LT04]. The motivation for using agent-based systems comes from the fact that these systems reflect the distributed nature and are able to deal with the dynamics of planning and executing in a near real-time context [DC05].
- Message flooding is identified as a potential challenge for the scalability of *DLRP*. The route request flooding is an important issue for the scalability of distributed routing of autonomous logistic entities, and without counter measures, the flooding can be a serious problem for scalability [WRG09].
- Hu et al. [HS02] provided a demonstration of using *clustering* based technologies in research related to both freight transportation and logistics

management. This thesis is aimed at developing advanced time-based demand-responsive logistic distribution technologies involving two-stage distribution strategies including pre-trip customer grouping and en-route fleet management algorithms.

- Optimizing the *transportation cost* which also depends on the best *utilization* of the available resources is the utmost goal of any transport logistics system. Once the preferred routes to the destinations have been identified, a proper and efficient means of transport has to be selected. It is more likely that in most of the cases, the obtained clusters will share a high portion of the route to their respective destinations. And therefore, if there is enough capacity and a benefit in form of cost reduction, then the clusters can be transported by the same vehicle. Thus, the vehicles can offer transport service to the best combination of clusters, thereby, optimizing the transportation cost incurred.
- [PRPJ06] also showed that automated negotiation can bring significant advantages, by allowing negotiating entities parties to discover jointly profitable bundles (allocations) of orders. *Negotiation* is an important part of commerce today, and automated negotiation will be a vital part of electronic commerce in the future [BS97].

1.2 Objectives

Many challenges have come forth with the introduction of the autonomous cooperation paradigm in the field of logistics. This thesis is a step forward to look into the aspect of autonomy in the transport logistics sector. In this direction, the main objectives are:

- The assessment of the usefulness of software agents in bringing about autonomy in logistic processes.
- The introduction of the novel concept of clustering of the autonomous logistics entities and the performance analysis with respect to the communication load.
- The analysis of transport decision based on the correlation of routes as well as the transportation cost.
- The integration and evaluation of the automated negotiation concept in the logistics cluster-based routing approach.

1.3 Thesis Statement

The statement of the thesis can be formulated as follows:

Software agents provide a means for bringing about autonomous cooperation in logistic processes. The introduction of clustering, correlation based routing and negotiation mechanisms results in reduced communication traffic and transportation cost for improved performance of the logistical network in a dynamic environment.

1.4 Thesis Overview

As a first step in this thesis, the theoretical background of software agents as well as logistics network is reviewed. Along with it, the potential usefulness of software agents as well as the concept of autonomous control in logistic processes is also analysed. Software agents are used in several levels of logistics networks ranging from production to e-commerce applications. In most of the levels, software agents are deployed for autonomous control of various processes without human intervention. For example, in transportation logistics, autonomy in transport processes along with a dynamic transport infrastructure makes the logistic processes very complex. The arising complexity and dynamics in logistic networks put forward a great challenge in this domain.

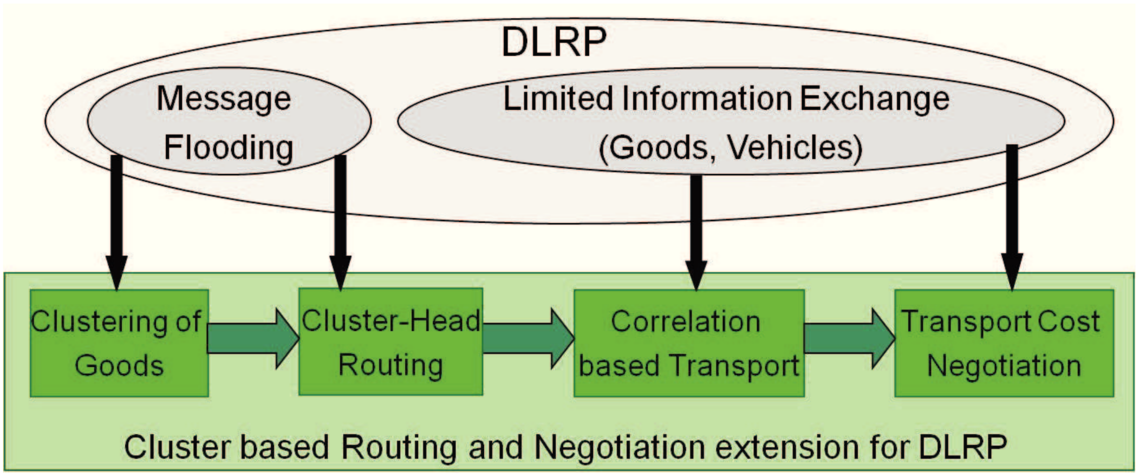

Figure 1.1: Thesis Overview

The complexities and dynamics can also be caused by changes in route planning, incomplete information about the route, etc., resulting for example in an altogether new route. The *Distributed Logistics Routing Protocol* (DLRP) [WRTG+07, SRF06] is one of the algorithms developed for autonomous control of routing in logistic processes. The introduced distributed routing concept is designed to enable software agents representing logistic entities (such as goods and vehicles) to make efficient routing decisions based on the available information in the dynamic logistic environment. However, the communication and decision making process of each logistic network object results in enormous communication overhead (message flooding). Thus, this thesis presents the shortcomings of DLRP and develops concepts to address them. Figure 1.1 presents various solutions proposed in this thesis (represented in blocks) and illustrates various methods to enhance the performance of DLRP.

Initially, the problem of excessive message flooding is handled by introducing the concept of *Clustering of Goods*. In this part of the thesis, various algorithms and theoretical aspects related to clustering and also their application in the logistic processes using the software agent based framework are studied and enhanced. Furthermore, the performance evaluation of the communication volume associated with the cluster-based routing (*Cluster-Head Routing*) method is presented. Various scenarios ranging from small road networks to large road networks are evaluated with respect to the communication performance. The performance evaluation results confirm the performance improvements expected and further justify the value of the proposed algorithms. Since this thesis focuses on autonomous logistic networks with respect to the decision making capability, various scenarios in which the system is fully autonomous (all of the logistic entities are autonomous), semi-autonomous (partially controlled by some central entity e.g., a Distribution Center (DC) giving some autonomy to the transport goods) or fully centralized (totally controlled by a central entity like a Distribution Center) are studied. A brief overview comparing these scenarios with an integrated clustering concept is also presented.

The cluster based routing mechanism is further strengthened by the introduction of strategies that can be used to enhance the transport efficiency of a logistics network by identifying clusters that can be transported together (*Correlation based Transport* in Figure 1.1). In this aspect, the clusters of packages try to deal with two prominent aspects important to them i.e., the transportation cost constraints as well as the best route for transportation. Similarly, the vehicles deal with the issues of selection of clusters based on the cost as well as the capacity utilization. A detailed set of performance measurements to evaluate the different approaches in the context of both the cost and capacity utilization is also presented in this thesis.

Once the transportation cost based on the capacity and correlation of the routes is identified by the clusters and vehicles, they can further negotiate for a better transportation cost deal between each other. Based on this idea the author proposes the concept of automated negotiation (refer *Transport Cost Negotiation* block in Figure 1.1). Automated negotiation is one of the key applications of software agents, particularly in the e-commerce applications domain. In this regard, a survey on the concept of automated negotiation, the strategies and protocols available in literature and their influence on the clusters and vehicles to handle the transportation cost are presented. A theoretical model based on cluster and vehicle negotiation is presented and implemented in the agent-based simulation software. For example, the logistic entities follow a negotiation protocol to negotiate the transportation cost based on a negotiation strategy. Thus, this thesis looks into the various negotiation strategies and protocols that the negotiating entities can use and presents the influence they have on the negotiation time and agreed transportation cost. The final part of this thesis concludes with the simulation results that reflect the implemented negotiation mechanism that the logistics entities follow.

On the whole, the introduction of software agents to handle complex and dynamic logistic processes along with state-of-the-art technologies, distributed communication network concepts and negotiation capabilities allow the logistics network to operate autonomously in handling the transportation decisions efficiently.

1.5 Thesis Roadmap

Chapter 1 gives an overall introduction of the thesis topics and presents the motivation, thesis statement and roadmap.

Chapter 2 presents the state of art associated with this interdisciplinary thesis. This includes definitions of logistics and the paradigm of autonomous cooperation as well as a brief description of software agents and their applicability in logistics.

Chapter 3 complements the previous chapter by focusing on the review of work related to the thesis topic, i.e., the review of research on clustering concepts. The basic clustering algorithms available in literature and their applicability in various fields e.g., communication networks are studied. Based on the conclusion of these studies, the mapping of the applicability of clustering algorithms into the logistics domain is analysed and presented.

Chapter 4 presents the author's theoretical concepts concerning approaches of clustering of logistic entities. Various clustering algorithms for different scenarios ranging from autonomous to centralized are presented. Also a theoretical analysis of the average correlation factor that evaluates the cluster size and that gives the estimation of the number of clusters formed is presented.

Chapter 5 presents the modeling and implementation part done by the author on clustering the autonomous logistics entities using various network scenarios. A brief description of the simulation platform (PlaSMA) and routing protocol (DLRP) developed by the researchers at the University of Bremen is described. The author's enhancements in form of the cluster-based DLRP approach are presented in detail. A performance evaluation of cluster-based routing compared to the distributed routing concept in transport logistics networks is analysed.

Chapter 6 enhances the cluster based routing concept by incorporating the correlation of the route information with respect to different destinations in the decision process. Theoretical analysis on capacity utilization and cost calculation by the vehicles and the clusters are presented and the performance of the network is analysed using various strategies with different scenarios. This enables the vehicles to transport clusters to different destinations with good efficiency, i.e., better capacity utilization and reduced transportation cost.

Chapter 7 and 8 are motivated by the promising approach of automated negotiations and related applications in the logistic processes. Thus, a brief description of negotiation protocols and strategies available in the literature are presented and then a theoretical negotiation model is developed with respect to a logistics scenario. The strategies are implemented and analysed using various scenarios. Finally, the results are presented which help in identifying the best strategy to be deployed in various situations to reach the negotiation agreement.

Finally, Chapter 9 concludes the thesis, summarizing the main results and the contributions. It discusses the extent to which the objectives were addressed and finally, draws the conclusions and points to future research and developments stemming from this thesis.

CHAPTER **2**

2. A Review of Research in Logistics and Software Agents

When was the last time you realized as to where the product you purchased in a local store came from and who produced it? The customer usually purchases the product from the nearby local store and is unaware of the complex transport logistic processes involved behind it. In today's world of globalization and open market, products from distant places can easily be obtained in a local store. Depending on the demand of the product, the organization distributes the product to the desired retailer. The challenge is to ensure that all retailers who have demanded a product get it at the right time, the right quality and the right quantity. Thus, logistics is creating a balancing strategy which takes the above mentioned variables like time, quantity and quality into account.

2.1 Definition of Logistics

As explained in [DHR+05] – "the term logistics refers mainly to issues regarding physical flows of products on an operational level. Today, the term includes both strategic and tactical issues beside the operational ones and includes the information flow connected to the physical flow".

According to the Council of Supply Chain Management Professionals [CSCMP], a professional organization for Logistics and SCM professionals, logistics is defined as: "the process of planning, implementing and controlling the efficient, effective flow and storage of goods, services and related information from point of origin to point of consumption for the purpose of conforming to customer requirements".

Logistics can also be defined as, "the integrated planning, control, realization and monitoring of all internal and network-wide material-, part- and product flows including the necessary information flow along the complete value-added chain" [MDC09].

2.1.1 Logistic Processes

According to Shapiro [SH85] [DHR+05], "the concept of logistics can be defined by the seven R's: ensuring the availability of the *right* product, in the *right* quality, in the *right* condition, at the *right* place, at the *right* time, for the *right* customer, at the *right* cost". The logistic processes are sometimes limited to the physical and information flow within an organization. However, the main concern in this thesis is on the inter-organizational physical flows involved in transport logistics.

According to [DHR+05], logistics comprises several components like

- *inbound logistics* which covers the movement of materials into the distribution centers from the suppliers,
- *material management* which deals with the movement of goods and components within a company,
- *load planning* and *route schedule* which are dependent on the customer demands and govern the delivering process of the goods,
- *goods information and control* which keeps track of the products on the route and in the distribution centers.

Thus, the design of logistic systems depends on the demands imposed by the customers, while the service provided to the customers is related to the distribution and delivery of the logistic items.

2.1.2 Transport Logistics

Transport is an activity where an object moves between point X and Y by one or several modes of transport. The various problems related to transport logistics fall in categories such as route planning, fleet management, different sorts of scheduling, etc. For example, a transport chain comprises a transport good being transported between vehicle, distribution center, ship, and again a vehicle. Thus, there are various interfaces between the different modes.

Transport basically refers to the movement of the goods from one location to another, while traffic refers to the flow of different transports within a network of locations. A vehicle is part of a transport network which takes part in the vehicle traffic flow. There are various modes of transportation: road, rail, air, water and pipeline [SL01]. The different modes of transport are distinguished according to the type, size, and service of the raw good or finished product that is being transported. Water transport via vessels offers less costly options when compared to road transport to distant markets. The flexibility and ease that roads offer for transportation of the goods makes it the most often used form of transport. Often, road transport is associated with fast delivery for short distances. On the other hand, rail transport is the safest land transport when compared to other forms of transport. It has a high level of capacity and energy efficiency, but is less flexible and more capital intensive than road transport. Last but not least, the transportation via air transport mode usually is the fastest and most expensive means of transport compared to the mode of transportation via road/water. This is mostly the mode of transport for high-valued goods that need to be transported across large distances.

The freight transportation represents the most important element in logistics cost for most of the logistic organizations [Ballou99]. Also according to [DHR+05] “transportation is a key decision area within logistics due to a higher percentage of logistics cost being associated with this activity than any other logistics activity" [Ballou99].

2.2 Introduction of Autonomous Cooperation

Considering the complete logistics network, the structure of logistic processes becomes increasingly complex. Especially in transport logistics, atomization of transportation processes, multimodal transport chains, international competition, changing ecological and legal constraints along with congested traffic infrastructure lead to highly dynamic and complex logistic processes that are difficult to plan in advance [HLT05]. The complexity and the difficulty arising in planning of the logistic processes brings forward a great challenge for enterprises. As per the understanding of logistic definitions presented in the previous section, the best logistic strategy would provide the product from the supplier to the customer in the given time constraints and in the required conditions of the product. However, it is a costly asset to maintain due to the increasing complexity in combination with the dynamics arising due to factors such as short delivery time, high schedule reliability, low price, high quality, etc. The rapidly changing conditions in the markets result in an extensive impact on the logistic processes. These impact factors are the drivers of change for a new control paradigm within logistic processes. The vision of the Collaborative Research Centre CRC 637 "Autonomous Cooperating Logistic Processes" is to equip logistic processes and logistic objects with the capability to take autonomous decisions based on available information in the system. For example in dynamic transport logistics, this implies vehicles handling decisions, like choosing a different route due to traffic congestion without initiating a new overall planning and optimization process. In order to cope with these requirements, the integration of new technologies and control methods is required.

This resulted in the ongoing paradigm shift from centralized control of 'non-intelligent' items in hierarchical structures towards decentralized control of 'intelligent' items in heterarchical structures in logistic processes [SWF04]. The intelligent items can be products or transportation units such as vehicles, containers, etc. The main characteristics of an intelligent item are its capability to act autonomously in planning processes. As defined in [SWF04, WH07], "autonomy in general means the system or process or item capability to design its input-, throughput- and output-profiles as an anticipative or reactive action to changing constraints of environmental variables" . The development of information and communication technologies and their integration in the logistic processes offer novel concepts and strategies to implement autonomy in logistic processes.

The paradigm shift is based on the following hypothesis as presented in [WH07]: "The implementation of autonomous logistic processes provides a better accomplishment of logistic objectives in comparison to conventionally managed processes despite increasing complexity."

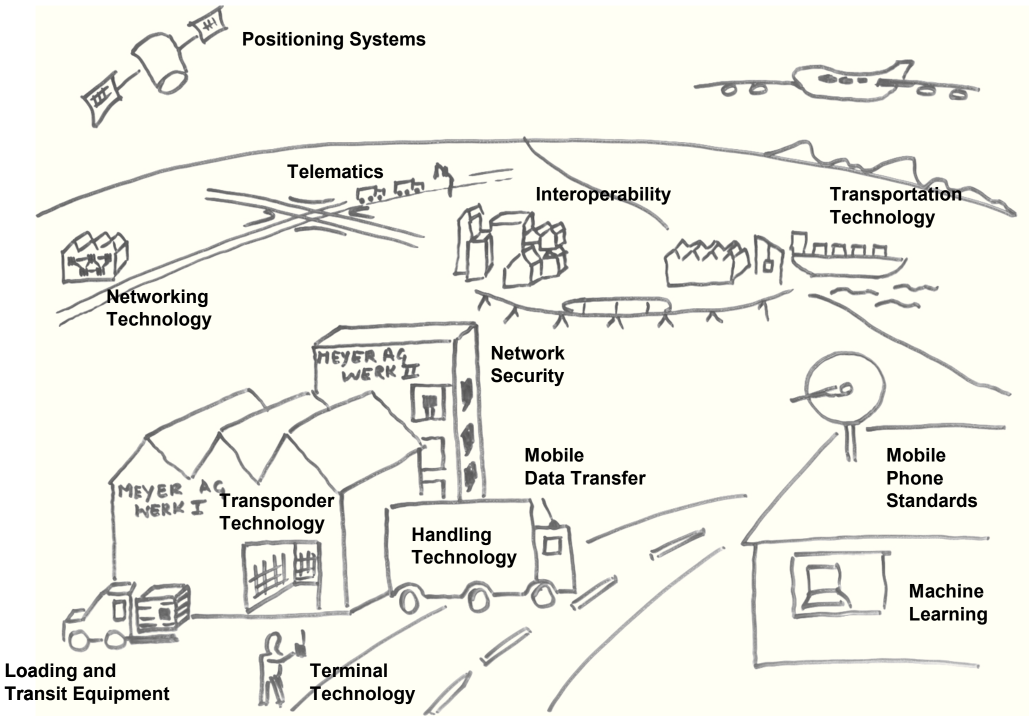

Figure 2.1: Autonomous Cooperation Paradigm [Src: WPT06]

2.2.1 Definition of Autonomous Cooperation

As per [Hüls05], the basic idea of autonomous cooperation and control comess from the idea of self-organization, an interdisciplinary study which has been developing since many years under the labels self-organization, dissipative structures, emergence and complexity theory. Therefore, it was necessary to adapt the idea of self-organization to a thorough understanding for logistic processes. The core of the self-organization concept is the formation and development of order in complex dynamic systems [Pas91].

Therefore the definition has been developed within the interdisciplinary working group (autonomous cooperation and control) of the Cooperative Research Centre (CRC) 637 "Autonomous Cooperating Logistic Processes – A Paradigm Shift and its Limitations" (see Figure 2.1). Autonomous Control and Cooperation as defined in [SWF04] "is a paradigm shift of 'non-intelligent' items in hierarchical structures towards decentralized control of 'intelligent' items in heterarchical structures in logistic processes". This concept assumes that the interacting elements in non-deterministic systems have the capability and possibility of rendering decisions.

According to [Hüls05], the objective of Autonomous Cooperation is the achievement of increased robustness and positive emergence of the total system due to distributed and flexible coping with dynamics and complexity. More elaborately, Autonomous Cooperation describes processes of decentralized decision-making which aims at a flexible self-organizing system structure that is able to cope with dynamics and complexity while maintaining a stable status. More on the concepts and characteristics of Autonomous Cooperation is presented in [WH07].

Thus, the evolution of autonomous cooperation in logistic networks implies the emergence of a paradigm that does not follow the traditional centralized approaches but demands a strong need for integration of various technologies like GPS systems, RFID, Wireless Communication, Software Agent technology, which more or less support the various concepts of the autonomous cooperation. For example, software agent technology provides the *means* of creating autonomous, intelligent and interacting software entities capable of supporting autonomous decision-making by sharing information on a continuous basis.

2.3 Introduction of Software Agents

A multi-agent system comprises multiple software agents to solve specific tasks. In the past the concept of agent-based computing has been hailed as the “next significant breakthrough in software development” [Sargent92], and “the new revolution in software” [GW94]. Software agents are the focus of intense interest on the part of many sub-fields of computer science and artificial intelligence. Wooldridge and Jennings [WJ95] in their paper "Intelligent Agents: Theory and Practice" listed the wide variety of applications where agents are deployed, ranging from comparatively small systems such as email filters to large, open, and complex and mission critical systems such as air traffic control. Although the term “software agent” appears frequently today, there has not yet been introduced a precise unique definition of a software agent.

2.3.1 Definition and Characteristics of Software Agents

One definition of a software agent that many agent researchers find acceptable is: “a software entity which functions continuously and autonomously in a particular environment, often inhabited by other agents and processes” [Shoham97].

Lange et al. [LO98] give a detailed definition of a software agent as follows: “From end-user perspective, a software agent is a program that assists people and acts on their behalf. Agents function by allowing people to delegate work to them. A property shared by all agents is the fact that they live in an environment. They have the ability to interact with their execution environment, and to act asynchronously and autonomously upon it. No one is required either to deliver information to the agent or to consume any of its output. The agent simply acts continuously in pursuit of its own goals”.

From a system perspective, a software agent is a software object that [WJ95]

1) Is situated within an execution environment
2) Possesses the following mandatory properties:
   a) Reactive: senses changes in the environment and acts according to these changes
   b) Autonomous: has control over its own actions
   c) Goal driven: with an objective
   d) Temporally continuous: is continuously executing
3) May possess any of the following properties:
   a) Communicative: able to communicate with other agents
   b) Mobile: can travel from one host to another
   c) Learning: adapts in accordance with previous experience

Based on the property of mobility another category is defined under the paradigm of software agents termed the mobile software agent. This thesis does not concentrate or use the mobile software agent technology but just gives a brief definition of what mobile agents are about.

2.3.2 Associated Issues – Intelligent Agents

The notion of the term "agent" to some means only "autonomous intelligent" agents. Franklin and Graesser [FG96] presented an extensive survey on various agents and taxonomy based on features. In this regard, a mathematical formal definition is presented by them as: "An autonomous agent is a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future."

Foner [Fon97] describes an agent to have "intelligent" and "autonomous" characteristics. Petrie [Pet96] discusses three major issues regarding the definition of agents as "intelligent" and claims that various definition of intelligence exist, but such a label for software agents does not sufficiently distinguish the software agent technology from other technologies which claim also to be intelligent in their performance.

The notion of autonomy seems more specific in distinguishing agents from other software technologies, but sometimes autonomy is used to define an agent as an intelligent entity [Pet96]. Thus, it can be said that the terms "autonomous" or "intelligent" are used to specify that the software is more than a mere server. Often, the term is only a reference to a context of a community and technology. With respect to agents, the label "intelligent" refers to its ability of communicate, as well as exhibition of certain aspects of human characteristics.

Wooldridge and Jennings [WJ95] gave a comprehensive overview of theories of "strong" agent-hood in their paper "Intelligent Agents: Theory and Practice". There are many theories that apply subjective terms to the software agents like “intention” and “belief’. For example, Franklin and Graesser [FG96] also use subjective terms in their formal definition of autonomous agents. However, it can be said that intelligent and autonomous are the terms defining the characteristics of a software agent.

Thereby, it can be concluded that intelligent agent computational environments are suitable for studying classes of coordination issues involving multiple autonomous or semi-autonomous agents where knowledge is distributed and agents communicate through messages [BG88].

2.4 Role of Software Agents in Logistics

As presented in [BST+06] [DHR+05], the research area of agent technology explores techniques, tools, and methods that have been applied or could be applied to the area of logistics. The term logistics is not only related to physical flow of products on operational level but also to the strategic and tactical issues. Additionally, it is also related to the information associated with the physical flow of the transport goods. As defined in [Weiss99 & Wool02] –”agent technology aims to provide new concepts and abstractions to facilitate the design and implementation of systems of this kind”. This section mainly presents an overview and survey of existing research efforts on agent-based approaches to transportation logistics.

Parunak [Par99] defined some characteristics of software agents, which fit the transport logistics applications rather well [DHR+05]:

- “*Modular* implies that each entity has a well defined set of stable state variables that is distinct from those of its environment and that the interface to the environment can be clearly identified.”
- “*Decentralized* implies that the structure of the application may change quickly and frequently.”
- “*Ill-structured* implies that not all information about the application is available when the system is being designed.”
- “*Complex* implies that the system exhibits a large number of different behaviors which may interact in sophisticated ways.”

The above discussed characteristics would suggest that agent technology indeed is a promising approach for the logistics applications. It has much to offer in terms of dynamics involved in the logistic networks.

The motivation comes from the fact that the agent-based systems reflect the distributed nature and are able to deal with the dynamics of planning and execution in a near real-time context [DC05]. Also research on applying multi-agent systems in the logistics domain has put emphasis on auction-based negotiation. The inter-agent communication is utilized for the bidding process, e.g., [ZZR+01], or the internal structure of the agent is defined by the set of equations, e.g., [BWW+99]. Scholz-Reiter et al. [SWF04] apply software agent technology for dynamic production logistics in shop floor logistics. It aims at a flexible and optimal scheduling of production plans in a heterogeneous shop floor scenario. Smirnov et al. [SPC+03] present a prototype of multi-agent community implementation and a constraint-based protocol designed for the negotiations of agents in a collaborative environment. Most of the approaches to agent-based logistics employ simplified models of logistic processes. Langer et al. [LT04] adopted a concept of distributed knowledge management in the agent-paradigm. The knowledge management approach provides a formal description of knowledge management tasks that aid in agent development. It reduces the computational complexity by using a minimum set of reasoning capabilities and processed knowledge.

However, agent technology has its own limitations, which makes it not suitable for applications that are monolithic, centralized, static, well-structured, and simple [Cov99, Jenn00]. Though agent technology seems suitable for application in the logistic domain it requires a certain degree of verification for deployment in a real operating world.

2.5 Autonomous Cooperation with Software Agents

A system or an individual is said to be autonomous if its decisions, relations, and interactions are not dependent on external instances and therefore are operationally closed [Probst87, Hüls05]. The concept of autonomous cooperation belongs to the field of complexity science, wherein it deals with the problems related to complex and dynamic systems in natural science [HW05]. Also, it analyses how the system evolves with adaptivity, robustness to deal with the complexity and dynamics. Autonomy in economic and management (business) science also characterizes the processes of delegation and decentralization [Kappler92], which imposes the degree of autonomous decision making among the organization's employees. The concept of autonomous entities interacting on a local level has been researched in computer science since the early 1980s. Davis and Smith [DS83] invented the contract net approach to negotiate a distributed solution in a system comprising multiple autonomous decision makers with heterogeneous capabilities. The actor theory developed important theoretical models for message-based communication of autonomous entities [Agha86]. These developments resulted in further research on autonomous agents and multi agent systems.

The concept of agent based programming deals with the independent execution state and pro-activity. An agent is able to act in a goal-oriented fashion by interacting and communicating with other agents. As defined by its characteristics an agent has the ability to communicate, exchange messages, adapt to the changes in the environment and to negotiate with other agents. These characteristics of software agents make this technology appropriate in creating an autonomous system. For example, to bring about an autonomous cooperation in logistic networks, agent technology supports autonomous decision-making by communicating and sharing information.

A Review of Research in Logistics and Software Agents

CHAPTER **3**

3. Related Work: A Review of Research on Clustering

Clustering is a principle that has been used in different ways by mankind [Willet88] [Kural99]. Clustering items into groups is also a fundamental issue in information sciences. With advancements in computing technology, it has now also been fully automated in the last few decades [Willet88]. In this thesis, the focus is on clustering of autonomous logistic entities especially the transport goods to reduce the amount of communication traffic. This chapter presents a survey on definitions of clustering as well as clustering approaches/algorithms available in the literature. In addition, the adaptability of clustering algorithms to clustering of autonomous cooperating logistic entities is analysed.

The definitions of clustering available in the literature are presented in section 3.1 and a detailed explanation on concepts of clustering is presented in Section 3.2. Classically, clustering algorithms have been divided into *partitional* and *hierarchical* algorithms. In Section 3.3 hierarchical and partitional algorithms are described with the specific examples of the Single Link hierarchical algorithm and the Hard C-Means partitional (HCM) algorithm. Additionally, the algorithm on cluster establishment (ACE) available in the literature and its enhancements by the author are presented in Appendix A. A brief overview of the application of clustering in various research fields like computer science and engineering along with the main view in the field of logistics is discussed. This chapter is summarized with a discussion of research challenges related to clustering along with software agent technology in autonomous cooperation of logistic processes, thereby providing motivation and perspective for future research.

3.1 Definition of Clustering

A cluster is a group of individual objects that can be made to appear as one single item. In other words, groups of objects are formed in such a way that objects in the same cluster are similar to one another and dissimilar to objects in other clusters [Gordon87]. Thus, a cluster can be simply defined as a closely-packed group with similar characteristics and properties. [JBN+06] proposed that a good clustering method will produce high quality clusters in which the intra-cluster similarity is high and the inter-cluster similarity is low

In other words, clustering can be simply stated as: Given a collection of *G* objects each of which is measured with *x* attributes, a grouping scheme is used for grouping the objects into *c* clusters that are similar according to some criteria based on their attributes. For example, in autonomous cooperating logistics processes, clustering is grouping the logistics entities like transport goods with similar characteristics, e.g., common destination, common route or common type of logistic entities. Thus, the number of clusters are the groups of transport goods of different destinations, routes or types. Therefore, the quality of the clustering method depends on the similarity measure of the entities within a cluster with respect to a certain goal.

3.2 Concepts of Clustering

As per the definitions of clustering presented in the previous section, the goal of clustering is categorizing or grouping similar data items together.

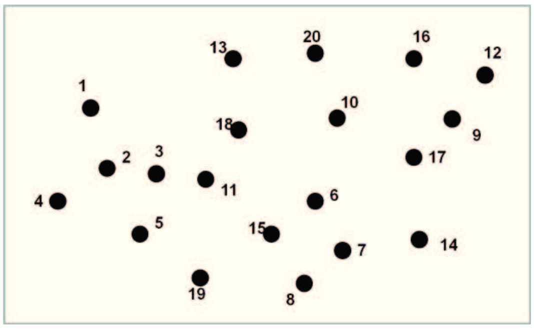

Figure 3.1: System Topology

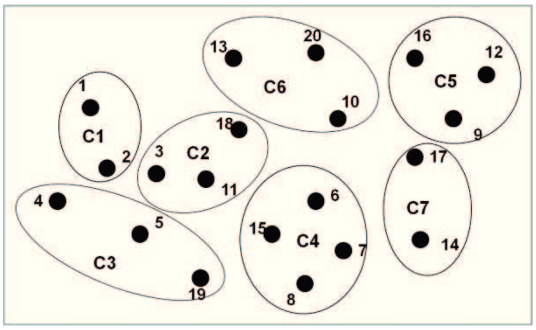

Figure 3.2: Clustered Topology

There is often the usage of the terms cluster *analysis and classification* in the clustering process. [Wata69] and [Willet88] among others, have distinguished between the two. In simple words, the clustering tasks involve grouping objects, based on a defined set of attributes, into clusters according to the common properties the objects share with each other. But, the term cluster classification implies the task of assigning the objects to clusters, and analysis implies the task of assigning a newly arrived object to one of the existing clusters [JS71]. For example, Fig 3.1 presents a network topology with N objects (e.g., transport goods). Eventually, depending on the similarity they can be grouped into different clusters such as *c1, c2,* etc. as shown in Figure 3.2. In this thesis, clusters are formed based on the common destination of the transport goods in the logistics network. Thus, transport goods are assigned to clusters based on their destination (if a cluster already exists for that particular destination) else a new cluster is formed for that particular destination (if the cluster does not exist).

3.3 Types of Clustering

Clustering methods [JD88, Ander73] tend to be divided in the literature into *hierarchical* and *partitional methods*. In *hierarchical* clustering (the older of the two), a tree-structured partitioning of the group of objects is produced. The tree is either constructed top-down or bottom-up. The all-inclusive cluster is at the top of the tree, and at the bottom of the tree are the individual objects. For example, in a transport logistics scenario a cluster of transport goods represents a single destination (cluster with goods which share the property of common destination) and the individual transport goods at the bottom are the objects of this cluster. The different partitions of the tree are formed depending on where the tree is 'cut'. For example, the tree is cut depending on the cluster size. The *partitional* method produces representatives of the clusters. These methods have become prevalent mainly due to their low computational cost. For example, in a transport logistics scenario a partitional method can be applied when some clusters are formed already with respect to certain destinations. But the vehicle cannot transport all of these clusters due to its capacity limitation. Then, a partitional method can be applied that cuts the tree depending on the capacity of the vehicle or the maximum cluster size the vehicle can transport.

3.3.1 Hierarchical Clustering

Hierarchical clustering methods involve either merging smaller clusters into larger ones, or splitting larger clusters into smaller clusters. The hierarchical clustering algorithms transform a proximity data set into a tree-like structure which is called a *dendrogram* [JS71]. As explained in [HLB+09], the dendrogram represents one possible structure to classify resources. It is constructed as a sequence of partitions such that its root is a cluster covering all the objects and the leaves are clusters containing only one object. And also there is a possibility that according to the dissimilarity measure the child clusters partition the objects assigned to their common parent. A dendrogram is not a binary tree but useful up to a few levels, as the clustering process becomes more trivial as the tree depth increases.

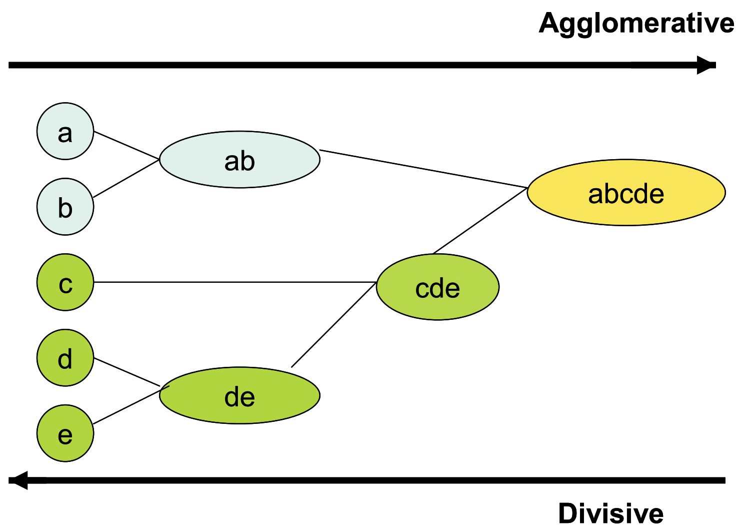

Figure 3.3: Agglomerative and Divisive Clustering

Another common term in hierarchical clustering is the word *agglomerative* clustering (Refer Figure 3.3) which is a bottom-up way of constructing the dendrogram. The hierarchical structure begins with c clusters, one per object, and grows with a sequence of clusters based on a similarity measure until *all D* properties are fulfilled in a single cluster. *Divisive* clustering (Refer Figure 3.3) on the other hand is a top-down way of constructing the dendrogram. The structure begins with one cluster of all *N* objects and successively divides clusters until *C* clusters are achieved. The common examples for hierarchical clustering are the *single link algorithm and complete link algorithm,* which are discussed in detail in [JMF99].

3.3.2 Partitional Clustering

Partitional clustering methods attempt to decompose the group of data or objects into a subset of clusters based on certain criteria. Most partitional clustering algorithms assume an *a priori* number of clusters *c*, and partition the data set into *c* clusters. The criterion for division is to minimize the dissimilarity measure within each cluster and to maximize the dissimilarity of different clusters.

The criterion functions are specified using the data set *X*, a distance *d*, the partition matrix U_m, and the set of cluster prototypes CP. The object set *X* and the metric *d* are fixed and act as input. U_m and *CP* are variables whose optimal values are to be investigated. This can be represented mathematically as:

$$\min [Q\,(CP,\, U_m\,;\, X,\, d,\, \ldots)] \qquad 3.1$$

where Q is a generic objective function whose minimum value is investigated. The objective function can use its own set of parameters (which is represented by the dots after *d*). One of the most common examples of the partitioning algorithm is the *Hard C-Means (HCM)* algorithm [Bezd81, Dunn73].

3.4 Clustering Applications

Research on clustering is well-established; it dates back to the 1950s and is widely reported in various current journals. Clustering has been studied in a variety of fields, notably statistics, pattern recognition and data mining etc.

3.4.1 Communication Networks

Clustering is also a research topic in communication networks like sensor networks, ad hoc networks etc. This section introduces common clustering methods used in various communication network domains.

3.4.1.1 Mobile Ad hoc NETworks (MANET)

As defined in [KV00], mobile ad hoc networks consists of wireless hosts which are mobile and are able to communicate with each other in the absence of a fixed infrastructure. Examples include firefighter scenarios, disaster relief and short-term scenarios such as public events. In such networks, the host mobility results in frequent topological changes which in turn requires constant maintenance and updating of the routes [WLB+01]. Thus, to reduce the transmission overhead for updating the routing information after topological changes, the concept of clustering was introduced (cluster formation of communicating nodes). To support large scale ad hoc networks, numerous cluster based routing algorithms like *Location Routing Algorithm with Cluster-based Flooding* (LORA_CBF) [RA06] have been proposed. The idea behind the cluster-based routing is that the network is organized in clusters dynamically in order to maintain a stable effective topology. The clustering in ad hoc networks involves forming the clusters first and then the selection of a cluster head in a distributed fashion [GT95]. The cluster algorithms used for the purpose of clustering plays a key role in the number of clusters formed. But, the clustering process itself incurs cluster maintenance overhead which accounts for the amount of control packets that is exchanged to maintain the cluster members and their information. More details on the clustering in mobile ad hoc networks is presented in [CSR10].

3.4.1.2 Sensor Networks

Another important area in the field of communication networks where clustering is extensively deployed is in the field of sensor networks. Sensor networks have emerged as a fundamentally new tool for monitoring environments such as habitat monitoring, surveillance in military zones, firefighter scenarios, surveillance in transportation etc. [BA02, Lew02]. A sensor network is a distributed network with a base station and several sensor nodes distributed in an environment of interest. The information is communicated to the central site by individual sensor nodes in the network. But, maintaining information in large scalable networks is difficult. In order to handle this, grouping sensor nodes into disjoint and non-overlapping clusters have been a topic of research. Several hierarchical structures have been proposed but do not always satisfy the constraints associated like the reduction of power consumption in the network [CM06]. In this regard, several clustering schemes have been proposed in the literature that take into account the energy consumption issues. One of the famous clustering algorithms, proposed by Heinzelman et al. [HCB00] employed in sensor networks is LEACH. This algorithm randomly selects cluster-heads and provides data aggregation in each hop to reduce energy consumption. [CF03] showed that by using data aggregation with LEACH the lifetime of the network can be increased. In addition [PKG04] showed that the network can exhibit better efficiency by improving the data fusion using the cluster based routing methods. A detailed survey on clustering algorithms for sensor networks is presented in [AY07].

3.4.2 General applications

The concept of clustering has also been used in consolidation networks [HP08]. The term consolidation in terms of business applications is merging many things into one, i.e., merging smaller companies into larger ones. Thus, consolidation avoids competition amongst several small competitors, making the whole process simple and at the same time ensuring a bigger market share.

Clustering also finds its wide applications in various fields like pattern recognition, spatial data analysis, image processing, economic science (especially market research) and web-based applications. In the case of spatial data analysis [SK+98], thematic maps are created in GIS (Geographical Information System) by clustering feature spaces. In case of web-based applications/web services it is used for document classification and to discover groups of similar access patterns.

3.5 Software Agents and Clustering

Clustering of agents in a multi-agent system is a process that allows the individual agents (group of agents) to be autonomous and to handle decisions. Agents that wish to cooperate within a multi-agent environment must have a means to communicate with each other. In other words, clustering can be seen as an autonomous process in multi-agent systems wherein the agents with similar objectives communicate and form groups based on their similar objectives.

Ogston et al. [OOS+03] also suggested that clustering is a basic problem, yet is an essential component for the process of coalition formation. For example, a method for grouping networked agents with similar objectives or data without collecting them in a centralized database was presented, which showed very good scalability and speed in comparison with the k-means clustering algorithm. The basic function of clustering the agents is to transform the agents which are similar (sharing the same attributes) into one group and elect the group-head which will then take the decision on behalf of the other group members. It in turn brings about the advantage of reduction of communication traffic i.e., instead of all the agents acting, the group-head will be the only entity which can handle all the decisions and do the communication. In addition, the group-head can be selected autonomously.

On the whole, it can be concluded that clustering in multi-agent systems involves self-organized cluster formation. This.additionally involves facing primary challenges like *decentralized* clustering and *dynamic* clustering. In case of *decentralized* clustering the objects are widely distributed and volatile, hence, objects which share the common attributes need to be discovered. For example, in case of logistical networks, the goods which share the common attributes should be identified. And in case of dynamic clustering, occurrence of new events require reconfiguration of clusters, i.e., arrival of new transport goods results in constant refinement of formed clusters.

3.6 Summary

In this chapter, an overview of the state of art of clustering and the clustering applications in various fields is presented. For example, in case of communication networks especially ad hoc and sensor networks, clustering techniques are mainly deployed with the objective of maintaining a relatively stable effective topology as well as to achieve better scalability and energy efficiency.

In general, it can be concluded that clustering can be used to induce a categorization. Thus, this chapter presents the basics behind the concept of clustering and gives a direction towards its applicability in autonomous logistics scenarios. The integration of clustering techniques can be used to improve the performance of the logistics network in terms of communication as well as the transportation cost which will be analysed in subsequent chapters.

CHAPTER **4**

4. Approaches for Clustering in Logistical Networks

Clustering in an autonomous transport logistics network involves grouping of logistics entities like transport goods. This comes from the fact that a large number of autonomous entities (transport goods/vehicles) communicating with each other to reach a transport decision may result in a large communication volume. Thus, one key aspect of clustering is to reduce the communication overhead. For example this implies that instead of individual entities communicating with each other, one among this group of entities, e.g. a cluster-head communicates and takes the final transport decisions. Thus, this chapter mainly discusses the approaches of clustering as well as the issues associated with it in a logistics network. In section 4.1 the refinement of the clustering approach at various levels of a whole logistics network is discussed. Based on the refinement of clustering, the classification of clustering namely *Centralized, Autonomous or Semi-autonomous* is presented in section 4.2. An overview and comparison of the different approaches of clustering and their role in improving the logistics performance are presented in detail. Additionally, as clusters are mainly formed based on the common information, a measure of this common information termed the correlation factor is defined and derived in section 4.3, which in turn gives the measure for the number of clusters formed in the network.

4.1 Clustering of Logistics Entities

As explained in the previous chapters, a logistics network is a large information domain with several hierarchies. Hierarchies in a logistics network can be defined with respect to different levels like distribution centers (DCs) within a city, DCs concentrated within a particular geographical area, etc. Similarly, clustering can be refined to various levels of hierarchies depending on the common information available at those levels. Thus, this section describes the concept of clustering applied to form clusters of DCs, their geographical locations, vehicles, etc.

Regional Clustering: This clustering refers to the clustering of regions based on the geographical locations of the DCs. In this case as shown in the Figure 4.1, the cities within a region (North-West, North-East, South, etc.) can be clustered with respect to their distance. For example, in a logistics scenario, if there are packages to be delivered to some DCs located at *Munich* (South Region) from some DCs in the cities like *Bremen, Hamburg* or *Hanover* (North Region), then it is better that the DCs at these three cities form a cluster over the larger geographic region to pool the resources and the requirements. Eventually, a cluster-head can be selected among these cities based on the appropriate location as an information pool for decision making. E.g. in this case, *Hanover* can be selected as the cluster-head (information pool) which has all the knowledge of various cities and their distribution centers. Hence, the vehicles can collect all the information of various cities that have packages to be delivered to the common destination from this cluster-head.

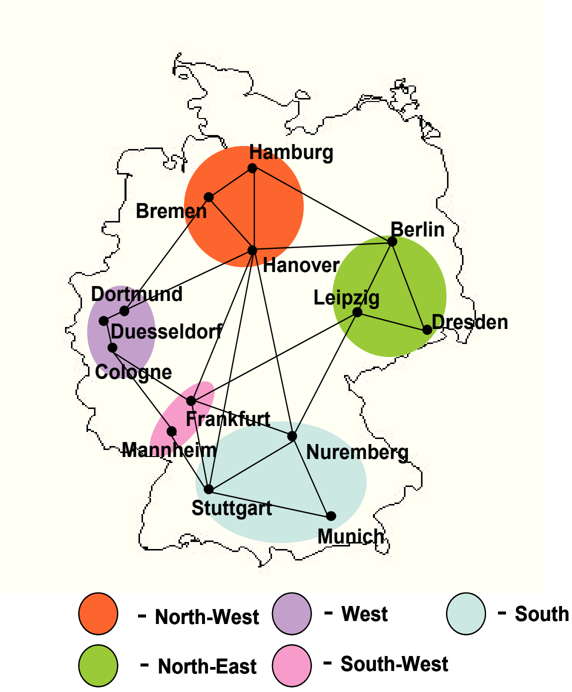

Figure 4.1: Regional Clustering

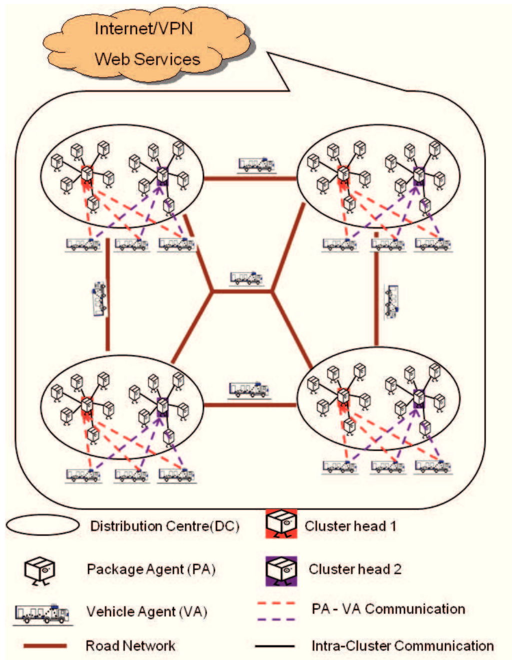

Figure 4.2: Package Clusters within a Distribution Center Cluster [SWSG07]

Distribution Center (also referred to as Associated Vertex) Clustering: It is possible that there are many DCs within a city, concentrated in different parts of the city. Therefore in such a case (refer Figure 4.2), the various DCs within a single city can be clustered based on their location within the city, refining the clustering to a level down from the regional clustering. This clustering method also increases the efficiency of the vehicles to transport packages that are concentrated within a certain area of the city. The DCs can be clustered depending on the easy accessibility to one another (distance between them). Therefore, the vehicle can make appropriate decisions of picking from the nearest DCs first and then traveling to other nearby DCs depending on the cluster's (cluster-head) information. Thus, the concept of sub-grouping can bring about efficient information flow between the DCs (as the DCs only need to communicate with the DCs within the sub-group).

Clustering of Vehicles: In this approach, the vehicles can be clustered based on their destination or type of packages (glass, clothes, etc.) they transport. A cluster-head of the clusters of vehicles can be selected so that it possesses the knowledge of all the vehicles. Eventually, it can gather information as to which vehicle is free or which vehicles would be available, depending on which it can schedule and allocate different types of packages.

Clustering of Packages: Each package can be defined with certain attributes: Origin, Destination, Location, Type, Priority, Due Date, Price, etc. The packages can be clustered within a distribution center with respect to their attributes. Once various clusters are formed, a cluster-head is selected for each cluster. The idea of the cluster-head selection is that instead of all package agents communicating with the drivers/vehicles, the cluster-head will communicate/negotiate with the vehicle (head) agent or with the distribution center. The attributes that were used to cluster the packages can also be helpful to select the proper mode of transport.

This thesis mainly concentrates on the implementation of clustering of packages in the distribution centers based on their destinations. The clustering concepts related to regions, DCs and vehicles was not considered and is left for future research.

4.2 Classification of Clustering Approaches

As this thesis concentrates on analyzing methods to bring about more autonomous cooperation in the logistics network, a brief survey on the classification of clustering namely Centralized, Hybrid (Semi-autonomous) and Autonomous are described in this section. The classification is based on the degree of autonomy shared by the logistics entities at the level of vehicles and packages. Here it is assumed that each package/vehicle is associated with a computing entity embedded with a software agent (program code) which in turn is controlled remotely by a high capacity processing unit (host computer) at the distribution center or else the software agent can travel around the network remotely (between different packages) and gather the information of the goods and bring it back to the main processing unit [HMA06].

The scope of clustering of logistics entities can be extended to various attributes such as common destination, type of goods, delivery time (urgency) etc. But, this thesis work as a first step tries to concentrate on the concept of clustering based only on the attribute of common destination the logistics entities share and analyses its implication on the performance of the logistics network. Nevertheless, it can be further extended as future work with various other fore-mentioned attributes to further enhance the logistics processes.

In the *Centralized* approach, the DC plays the role of the decision making entity for cluster formation of the packages with respect to their destination or type of packages etc. as well as for the selection of the vehicle for the delivery of packages.

In the *Hybrid* approach, the knowledge/information regarding the status of the newly arrived packages and the clusters already formed (autonomously) is known by the DC whereas the decision making capability of including a particular package (depending on the destination) in a particular cluster is with the respective cluster-head. Additionally, the cluster-head will take decisions on behalf of the cluster members in selecting the appropriate vehicle for transportation.

In the Autonomous approach, the decision making as well as the information sharing capacity is under the control of the packages, which makes this approach fully decentralized. The DC plays no role in any knowledge sharing or decision making process and the cluster-head acts as the information pool for all the packages.

4.2.1 Centralized Approach for Clustering

In Figure 4.3, the *Centralized Approach* is presented. In this approach, the DC referred to as Associated Vertex will take the decision on behalf of all other package agents (PAs).

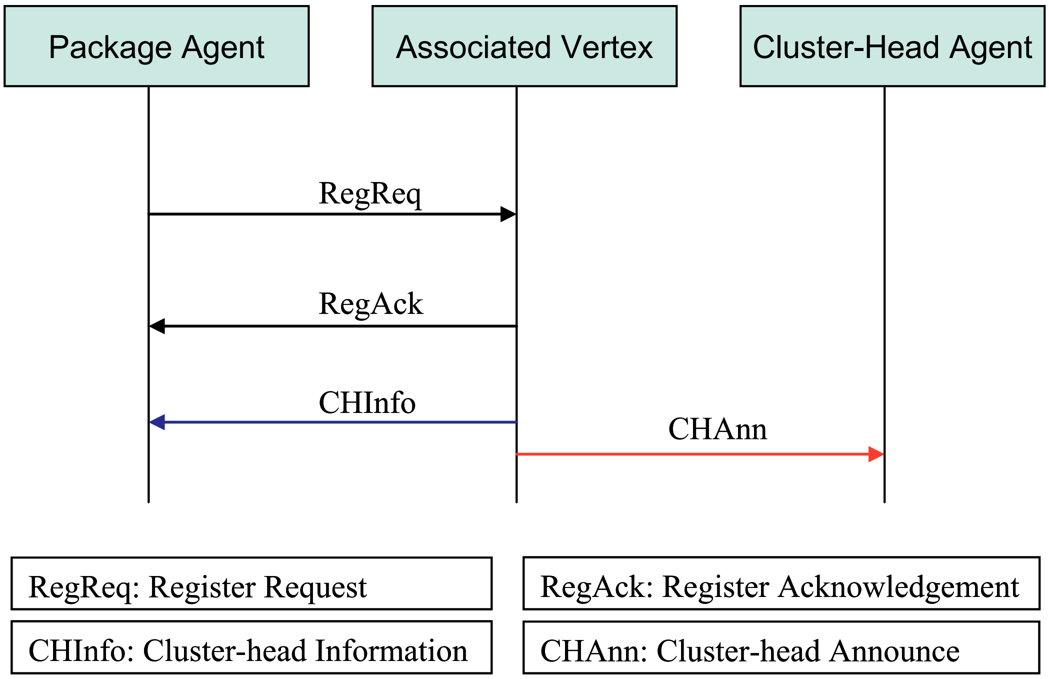

Figure 4.3: Centralized Approach for Clustering of Logistical Entities

Hence, once a package (represented as Package Agent, PA) is generated, it sends the register request (RegReq) to the associated vertex. After registration, the associated vertex sends the registration acknowledgement (RegAck) back to the PA. Once the package information such as the destination is known by the Associated Vertex, it counter checks the available clusters for that particular destination. If there is a cluster-head present for that particular destination, then it sends the cluster-head information (CHInfo) to the PA, else the PA is announced as the cluster-head (CHAnn) as it is the first member with respect to that particular destination. In this approach, all cluster formation decisions are made by the Associated Vertex, with a low degree of autonomy associated with the packages. Although the Associated Vertex itself is autonomous as it is represented as an agent, the approach is centralized with respect to one central entity (Associated Vertex) taking the decision rather than the individual entities (PAs, cluster-head etc).

4.2.2 Semi-Autonomous Approach for Clustering

In Figure 4.4, the Semi-autonomous approach (Hybrid approach) is presented. In contrast to the centralized approach, in the Semi-autonomous approach, the information handling is mostly done by the Associated Vertex while the decision making capability is handled by the PAs and the Cluster-head Agents.

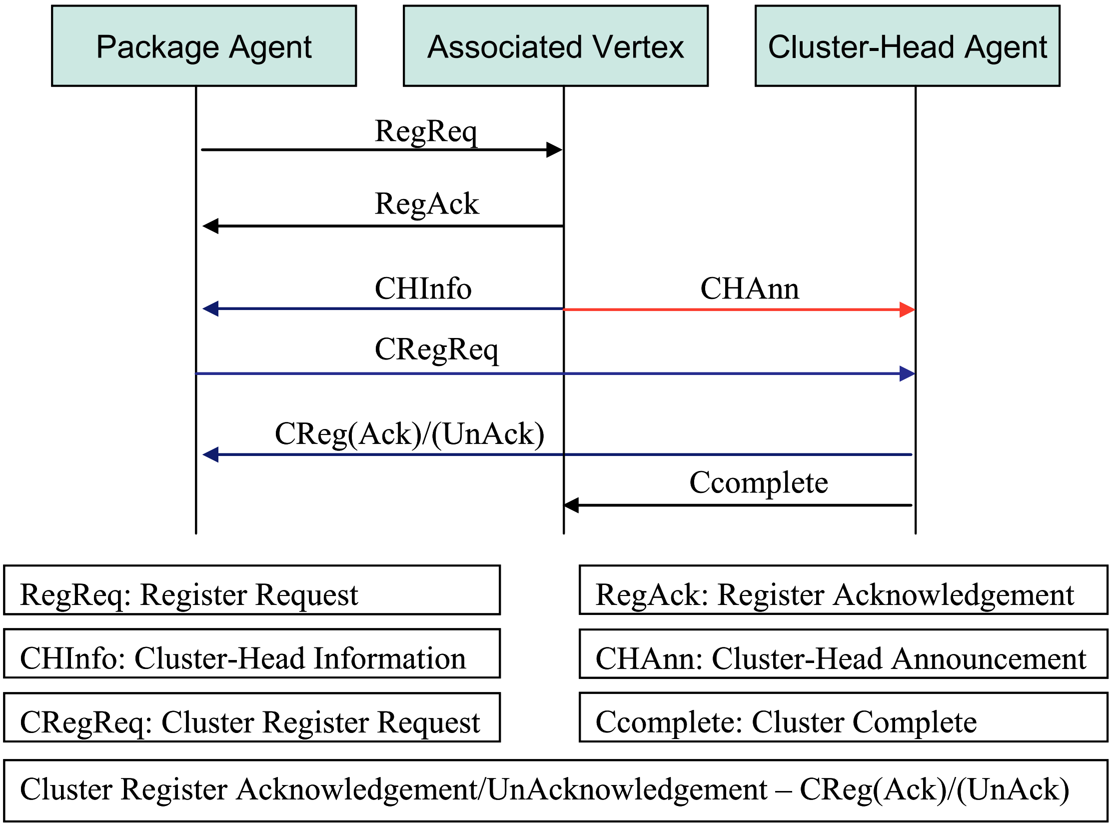

Figure 4.4: Hybrid Approach for Clustering of Logistical Entities

The package registers and gets an acknowledgement (RegReq, RegAck) from the associated vertex. The associated vertex then possesses all the information with respect to the package. If the registered package is the first one with respect to that destination, then the associated vertex announces that package as the cluster-head for that destination with the cluster-head announce message (CHAnn). In case that the destination matches with the destination of an already existing cluster, it sends cluster-head information to the package so that the package can join the cluster destined to the same destination. Eventually, on receiving this message, the package sends the cluster registration request message (CRegReq) to the cluster-head. In this semi-autonomous case, contrary to the centralized approach, the cluster register message is sent to the cluster-head without the need to inform the associated vertex.

The cluster-head sends the response to the package registration via a cluster registration acknowledgement message (CRegAck). The respective cluster-head can also reject the package registration message in case the cluster size limit is reached. Eventually, it sends the cluster complete message (Ccomplete) with pre-defined cluster size to the associated vertex. The package (whose registration was rejected) needs to form another cluster for that particular destination by announcing itself as the cluster-head.

4.2.3 Autonomous Approach for Clustering

In Figure 4.5 the autonomous approach is presented. In this case all the decision making and message exchange is handled only between the packages and the cluster-heads, in other words the complete process of cluster forming and decision-making is handled only by the packages with no role of the associated vertex. Hence, this approach is termed as fully autonomous approach.

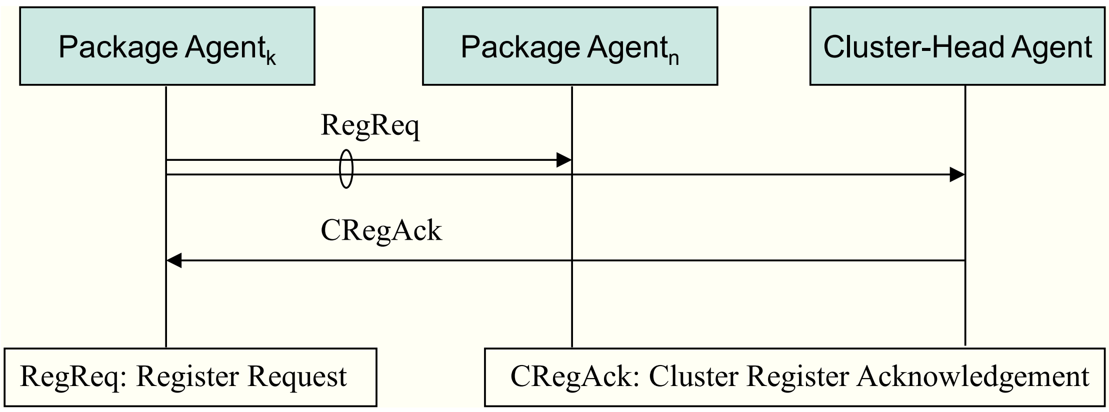

Figure 4.5: Autonomous Approach for Clustering of Logistical Entities

The package at first sends a broadcast message of register request to all the packages. In case, if a cluster-head already exists for that particular destination (same as that of the sender), then the cluster-head adds the requesting package to the cluster and sends the Cluster Register Acknowledgement message (CRegAck) to the requesting package. In case that there is no cluster-head available with respect to its destination, then the package itself announces itself as the new cluster-head with respect to that destination after a time out.

A clustering algorithm studied for an autonomous logistic scenario is the algorithm proposed by Chan & Perrig [CP04] termed as Algorithm for Cluster Establishment (ACE). In the proposed algorithm each agent communicates with a set of neighboring agents in order to achieve the desired global objective of cluster formation and cluster-head selection. The outcome of this algorithm is based on the communication range of the broadcasts made by the individual package agents to determine possible neighbors. The agent with the most neighboring agents is chosen as the cluster-head. This algorithm was identified not to be directly suitable for a logistical scenario, but nevertheless it can be usefull in limited broadcast range scenarios. The ACE algorithm and its extensions are presented in Appendix A.

4.3 Derivation of Optimum Number of Clusters

One of the key advantages of clustering using an agent-based framework in an autonomous logistics network is to reduce the communication overhead associated with the individual autonomous entities. The similarity measures on information of the agents play a vital role in determining the number of clusters as well as the cluster size. For example, if there are large numbers of packages to be delivered to certain common destinations, then the autonomous packages can send this information to the vehicle (see Figure 4.6). However, since the packages are to be carried by the vehicle to the same destination, it makes more sense if only one message (information) is passed on to the vehicle rather than flooding the common information (i.e., message of the common destination) to the vehicle. In other words, the packages can form a cluster and elect a cluster-head which will then send this single information (message about destination) to the vehicle on behalf of all other packages who are members of the cluster (see Figure 4.7).

Information sharing is one of the key requirements for efficient operation in a logistics network. But, sometimes redundant information (e.g., the same information shared with the vehicle about the same destination by several goods) can bring about the need of more communication and eventually more bandwidth requirements. Thus, the measure of correlation of information is directly and indirectly proportional to the size of the clusters and the number of clusters formed, respectively. Thus, this section presents the theoretical derivation of a correlation factor based on the correlated information of each entity and its effect on the size of clusters as well as on the number of clusters formed.

4.3.1 Theoretical Evaluation of the Average Correlation Factor

The number of clusters formed and the size of the clusters play an important role in reducing the communication overhead and consequently the latency/delay associated with it. The methods addressed for calculating the cluster size and number of clusters to be formed are expressed in mathematical form and mapped on to a logistics scenario. A major part of the mathematical formulation presented in this section is adapted from the work presented in [CM06] for sensor networks.

Entropy in “information theory” is defined as the measure of uncertainty of a random variable. Shannon described entropy as a measure of expected value of information contained in a message in the units referred to as bits [Shan48]. In other words, entropy can be attributed to be the amount of information of a random variable. The entropy formulations in this thesis are aimed to find the similarity in information (such as common destination) of the logistical entities such as packages.

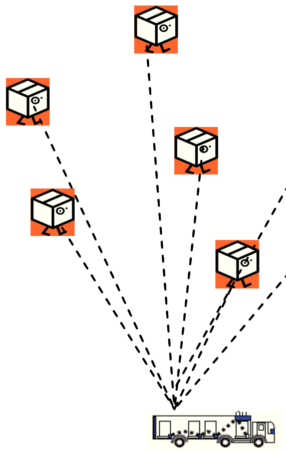

Figure 4.6: Package Agents Communication with Vehicle Agents

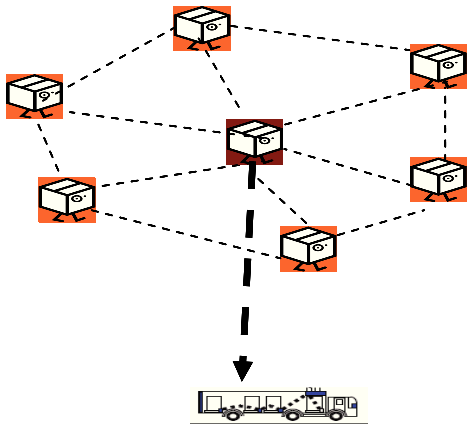

Figure 4.7: Cluster-head Communication with Vehicle Agents

Assume a logistics network that contains N package agents $(a_1, a_2, ..., a_N)$. Thus, the entropy H of the whole logistics network represented by a discrete random variable a with possible values $(a_1, a_2, ..., a_N)$ is given by $H(a_1, a_2, ..., a_N)$ and can be expressed by:

$$H(a) = H(a_1, a_2, ..., a_N) = H(a_1) + H(a_2 \mid a_1) + ... + H(a_N \mid a_1, a_2, ..., a_{N-1}) \quad 4.1$$

where $H(a_2 \mid a_1)$ is the entropy of information of package agent a_2 given information of package agent a_1 and $H(a_2 \mid a_1) \le H(a_2)$. Similarly, $H(a_N \mid a_1, a_2, ..., a_{N-1})$ is the entropy of package agent a_N given the information of all other package agents; $a_1, a_2, ..., a_{N-1}$

and also $H(a_N \mid a_1, a_2, ..., a_{N-1}) \le H(a_N)$. If all the package agents have completely uncorrelated information, then the entropy of the whole logistics network would be:

$$H(a_1, a_2, ..., a_N) = H(a_1) + H(a_2) + ... + H(a_N) \qquad 4.2$$

The above equations describe the general formulation of information theory aspects mapped to a logistic network. But, coming to an individual agent, the entropy of messages of a single agent a_i is $H(a_i)$. The entropy of the unique information provided by the package agent a_i is defined by the variable $H(a_i^{\,u})$ and is given as:

$$H(a_i^u) = H(a) - H(a \cap \overline{a_i}) \qquad 4.3$$

where $H(a)$ is the entropy of the whole network where a is the set of its elements; $H(a \cap \overline{a_i})$ is the entropy of the whole network excluding that of package agent a_i represented as $\overline{a_i}$. The information the i^{th} agent shares with all other agents in the network is given by the correlation factor, cf_i, which is defined as the ratio of correlated information of package a_i to the complete information $H(a_i)$:

$$cf_i = 1 - \frac{H(a_i^u)}{H(a_i)} \quad ; 0 \le cf_i \le 1, \ \ H(a_i^u) < H(a_i) \qquad 4.4$$

The correlation factor, $cf_i = 0$ implies that the package agent *i's* information is totally uncorrelated in comparison to the information of the rest of the package agents. On the other hand, $cf_i = 1$ implies that the package agent *i*'s information is completely correlated to the information of rest of the package agents and hence package agent *i* does not have any unique information with respect to other package agents.

4.3.2 Derivation of Optimum Cluster Size based on Information Exchange

Consider a logistics network with N number of package agents. The minimum number of clusters formed with N package agents is defined by,

$$K = \frac{N}{Cl_{size}} \qquad 4.5$$

where Cl_{size} is the cluster size, i.e., the number of package agents in the clusters and it is assumed to be of same value for all the clusters.

The total communication volume (i.e., the information exchanged between the agents) within the whole logistics network is given by:

$$C_{whole} = \sum_{j=1}^{K} (C^{j}_{\text{intra}} + C^{j}_{\text{extra}}) = K(C_{\text{intra}} + C_{\text{extra}}) \qquad 4.6$$

where C^{j}_{intra} is the intra-communication cost within the jth cluster and C^{j}_{extra} is the external communication cost of the cluster-head of the jth cluster with the vehicles while, C_{intra} is the average communication cost within the clusters and C_{extra} is the average communication cost between the cluster-heads and the vehicles. The expressions for each are given as:

$$C_{\text{intra}} \propto Cl_{size}H + \{(Cl_{size}/2 - 1)H(1-cf)\}(Cl_{size} - 1) \qquad 4.7$$

$$C_{\text{extra}} \propto H + \{(Cl_{size} - 1)H(1-cf)\} \qquad 4.8$$

where H is the average entropy over all the package agents and cf is the average correlation factor between the package agents. In an autonomous clustering approach, clusters are formed by intra-communication between the entities. Thus Eq. 4.7 represents the communication volume generated within the cluster due to the information exchange amongst the cluster members. Initially when a package (agent) is generated, it broadcasts its information and looks for packages with correlated information to form clusters autonomously. The cluster keeps on growing one by one with each new cluster member until the clustering process is complete to result in a cluster of size Cl_{size}. Since every member of a cluster broadcasts its information therefore for a cluster the total information in these broadcast messages is given by the term $(Cl_{size}H)$.

To accept a new cluster member either the unique information of all the cluster members can be sent as a response or just the contribution (unique information) of the new cluster member $H(1-cf)$. Eq. 4.7 represents the upper bound for the total communication volume as it assumes the exchange of all cluster members' unique information with the new cluster member. This allows for more flexibility within the cluster to handle special cases such as if the existing cluster head stops operating and a new cluster head has to be selected. Since, the cluster formation is an active process with its size growing with the addition of each new member to Cl_{size}, therefore the average amount of information sent as a response by the cluster-head per cluster member is given by $(Cl_{size}/2-1)H(1-cf)$. Thus the total amount of information sent by a cluster-head to its cluster members to complete the clustering process will be $(Cl_{size}-1)\{(Cl_{size}/2-1)H(1-cf)\}$, refer Eq. 4.7. Whereas Eq. 4.8 represents the information with respect to each cluster-head that needs to be exchanged outside the cluster e.g. with the vehicle. Here also the expression in the curly brackets is the unique information obtained from the cluster members.

The overall average communication volume for K clusters is given by

$$\begin{aligned} C_{whole} &= KC_{\text{intra}} + KC_{\text{extra}} \\ &\propto KCl_{size}H + K(Cl_{size}-1)(Cl_{size}/2-1)H(1-cf) + KH + K(Cl_{size}-1)H(1-cf) \end{aligned} \tag{4.9}$$

$$\Rightarrow C_{whole} \propto KCl_{size}H + K(Cl_{size}/2)H(1-cf)(Cl_{size}-1) + KH \tag{4.10}$$

$$C_{whole} \propto NH + \frac{1}{2}NH(1-cf)(Cl_{size}-1) + \frac{N}{Cl_{size}}H = NH\left[1 + \frac{1}{2}(1-cf)(Cl_{size}-1) + \frac{1}{Cl_{size}}\right] \tag{4.11}$$

The optimum value of the cluster size $Cl_{size\,opt}$ can be determined by setting the derivative of the above expression equal to zero:

$$\frac{\partial C_{whole}}{\partial Cl_{size}} = 0 \Rightarrow \frac{1}{2}(1-cf) - Cl_{size\,opt}^{-2} = 0 \tag{4.12}$$

$$\Rightarrow Cl_{size\,opt} = \frac{\sqrt{2}}{\sqrt{1-cf}} \tag{4.13}$$

The optimum number of clusters can be expressed as

$$K_{opt} = \frac{N}{Cl_{size\,opt}} = \frac{N\sqrt{1-cf}}{\sqrt{2}} \tag{4.14}$$

Thus, the optimum number of clusters K_{opt} depends on the number of package agents in the entire logistics network and the average correlation factor cf.

The set of equations obtained in this section are only valid for an autonomous clustering approach and acts as a guideline for the cluster formation. For the calculation of the optimal cluster size based on correlation factor, the intra-cluster communication to form a cluster and communication cost of cluster head's interaction with an external logistical entity like a vehicle is considered. Further messages between the cluster-head and other logistical entities are not considered.

Similar considerations are also considered for a semi-autonomous scenario, where there is a central entity (e.g., an associated vertex) that controls the cluster formation. In other words, for a semi-autonomous approach as suggested in this work, the associated vertex only plays a role in the cluster formation and provides the cluster information to the cluster-head. Therefore, every package registers with the associated vertex. The term NH in Eq. 4.15, represents the registration of the packages with the associated vertex while $(Cl_{size}-1)H(1-cf)$ represents cluster information provided by the associated vertex to the cluster-head on an average. Once the cluster is initialized, the cluster is autonomous in its actions and decisions.

For the semi-autonomous approach, the cluster communication cost outside the cluster is still given by Eq. 4.8. Thus the overall communication cost for K clusters can be deduced to Eq. 4.15,

$$C_{whole} \propto NH + K(Cl_{size}-1)H(1-cf) + K(H + (Cl_{size}-1)H(1-cf)) \quad 4.15$$

$$\Rightarrow C_{whole} \propto NH + 2K(Cl_{size}-1)\,H(1-cf) + KH \quad 4.16$$

$$\Rightarrow C_{whole} \propto NH\left[1 + 2(1-\frac{1}{Cl_{size}})\,(1-cf) + \frac{1}{Cl_{size}}\right] \quad 4.17$$

$$\Rightarrow C_{whole} \propto NH\left[1 + 2(1-cf) + \frac{2cf-1}{Cl_{size}}\right] \quad 4.18$$

Thereby, the incurred communication volume is dependent on the correlation factor and cluster size. In other words, for a semi-autonomous approach the following holds, the larger the correlation factor, the larger is the cluster size and hence the smaller the incurred overall communication volume. The communication volume if no clustering is performed (i.e., $Cl_{size} = 1$) will be $2NH$ (refer Eq. 4.15). For $cf = 1$ the overall communication volume will be smallest with a single cluster $(K = 1; Cl_{size} = N)$ and is given by $(N+1)H$. For $cf = 0.5$, the overall communication volume already equals the communication volume without clustering i.e., $2NH$. For low correlation, the amount of information that needs to be shared outside the cluster is more and hence there is smaller gain due to clustering which is further nullified by clustering cost. For example, the overall communication volume for $Cl_{size} = 2$ with $cf = 0.25$ and $cf = 0$ will be $2.25NH$ and $2.5NH$, respectively. Therefore, for the above model of semi-autonomous clustering approach, clustering of packages should not be performed if $cf \leq 0.5$.

4.3.3 Results

This section presents the results obtained for the autonomous and semi-autonomous scenario discussed in section 4.3.2.

4.3.3.1 Autonomous Clustering Scenario

Figure 4.8 depicts the effect of the number of agents in the network *N* on the number of clusters formed *K* and the average correlation factor *cf* respectively. Figure 4.9 depicts the effect of the correlation factor *cf* on the number of agents *N* and the number of clusters formed *K* respectively (refer Eq. 4.14).

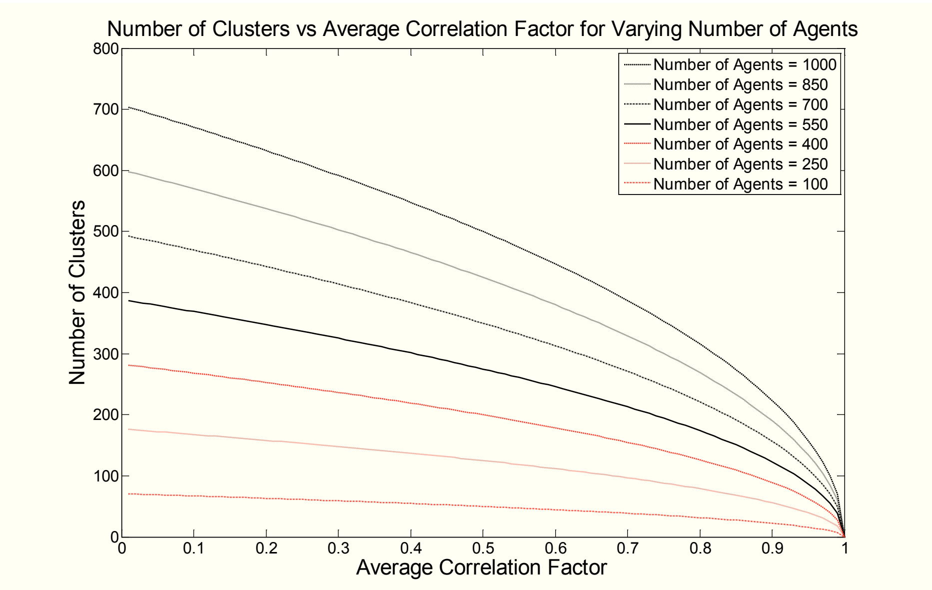

Figure 4.8: Number of Clusters *K* *vs* Average Correlation Factor *cf* for Varying Number of Agents in the Network (Eq. 4.14)

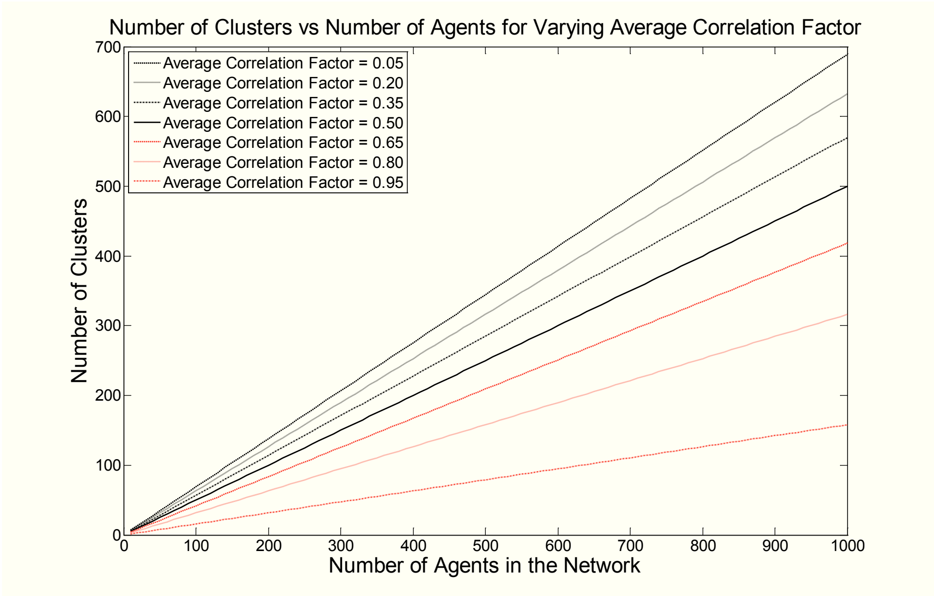

Figure 4.9: Number of Clusters *K vs* Total Number of Agents *N* in the Network for Varying Average Correlation Factor (Eq. 4.14)

With the results observed in Figure 4.8, it can be concluded that as the value of the correlation factor increases the number of clusters formed decreases, eventually also depending on the lower value of the number of agents in the network. The correlation factor *cf*= 1 if the agents data is correlated and *cf*=0 if the data is uncorrelated. Thus, it implies that, the more correlated the information of the agents is, the less is the number of clusters, but eventually the cluster size of clusters formed becomes larger. Figure 4.9 depicts that as the number of agents in the network increases, the number of clusters increases linearly. The increase in the number of clusters is higher when the information shared by the agents is less correlated, i.e., for a lower value of the correlation factor.

Figure 4.10, 4.11 and 4.12 depict the incurred overall communication volume for an autonomous scenario with respect to the average correlation factor, optimal cluster size and number of agents in the network, respectively. As expected the communication volume reduces with an increase in the average correlation factor (refer Figure 4.10) or increase in the corresponding optimal cluster size (refer Eq. 4.13 and Figure 4.11). Figure 4.12 illustrates that with an increase of the number of agents in the network, as expected the communication volume increases but the increase is smaller for scenarios with larger average correlation factor.

Derivation of Optimum Number of Clusters

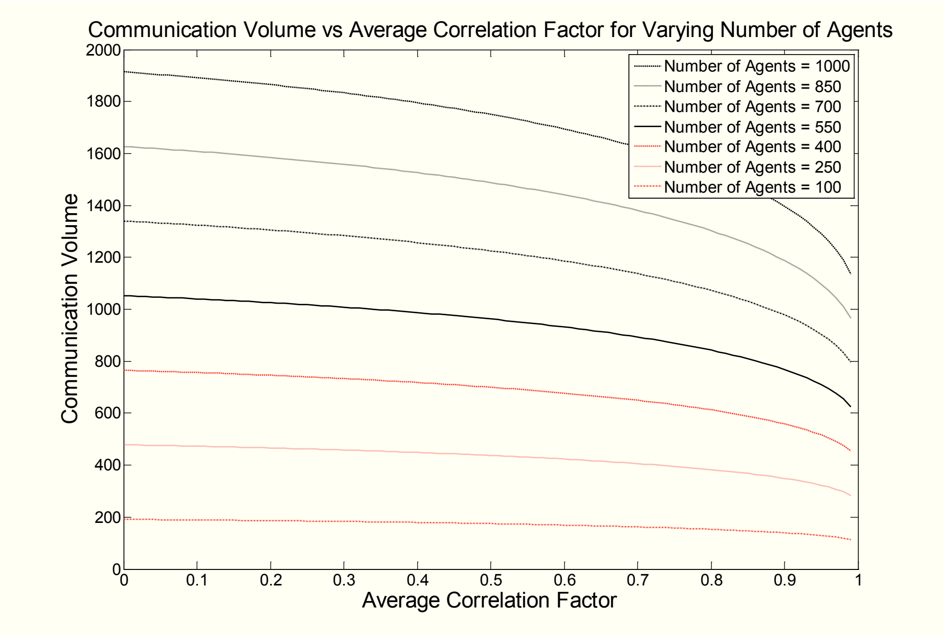

Figure 4.10: Communication Volume *vs* Average Correlation Factor for a Varying Number of Agents in the Network (Eq. 4.11, 4.13)

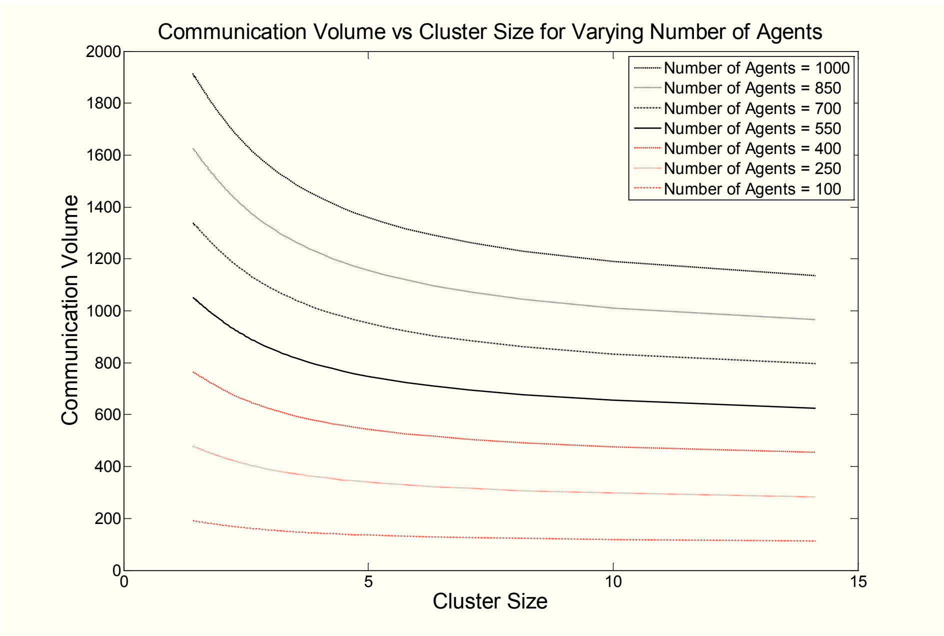

Figure 4.11: Communication Volume *vs* Optimal Cluster SIze for a Varying Number of Agents in the Network (Eq. 4.11, 4.13)

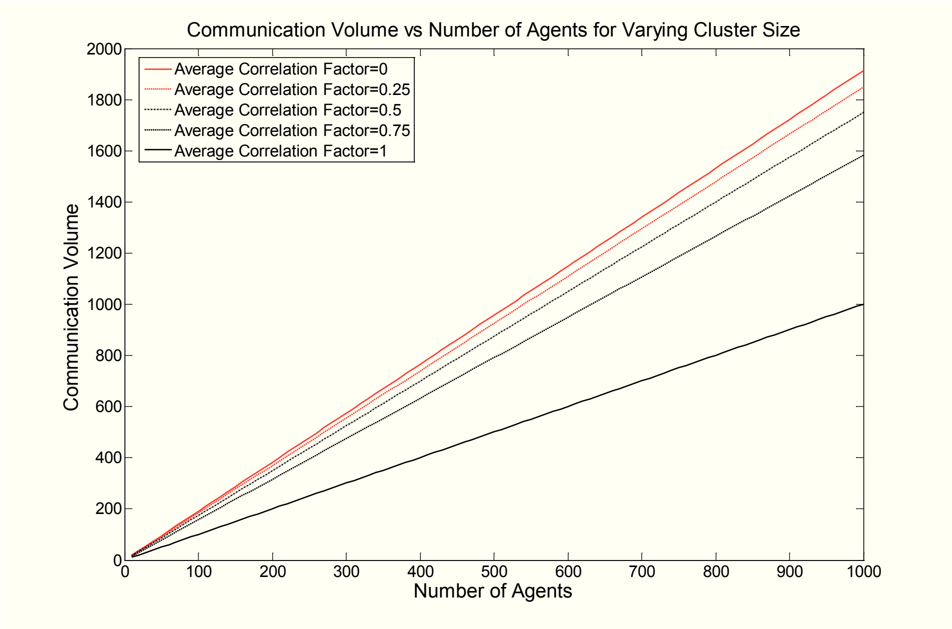

Figure 4.12: Communication Volume *vs* Number of Agents in the Network for a Varying Average Correlation Factor (Eq. 4.11, 4.13)

4.3.3.2 Semi-Autonomous Clustering Scenario

For the results described in this section, a fixed number of 100 package agents (*N*) are considered with an average Entropy (*H*) of 1 (refer Eq. 4.18). Figure 4.13 depicts the effect of the average correlation factor *cf* on the overall communication volume with varying cluster size Cl_{size}.

The result depicted in Figure 4.13 highlights the observation, that for an average correlation factor smaller than 0.5, clustering can increase the communication volume. What also can be seen in Figure 4.13, is that for an average correlation factor larger than 0.5, the cluster size should be as large as possible. For the case presented, it means the cluster size of 100 will result in the smallest communication volume.

Figure 4.14 depicts the effect of the cluster size Cl_{size} on the overall communication volume with a varying average correlation factor *cf*. Here also, it can be seen that clustering only helps if the average correlation factor is larger than 0.5. It can also be seen that a higher average correlation factor also results in small communication volume even with a relatively smaller cluster size.

Derivation of Optimum Number of Clusters

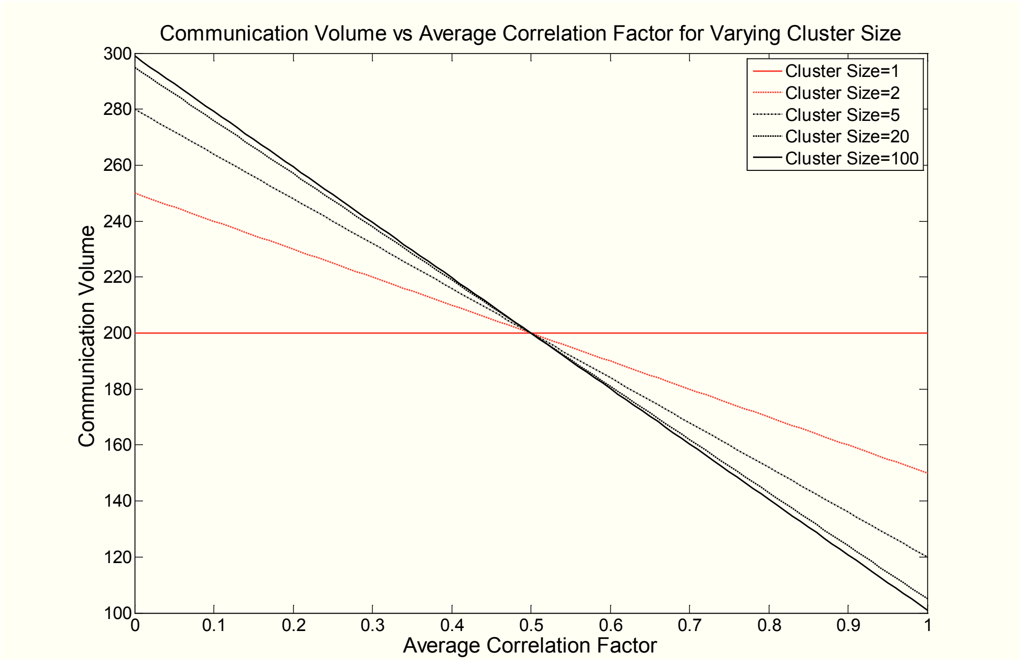

Figure 4.13: Communication Volume *vs* Average Correlation Factor for a Varying Cluster Size (Eq. 4.18; $N = 100, H = 1$)

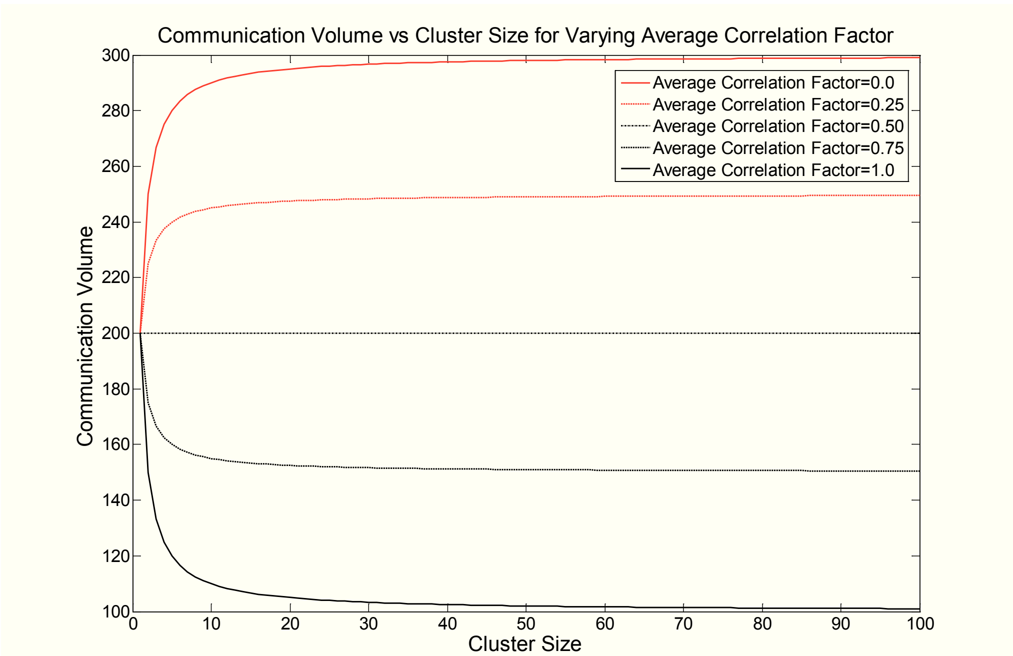

Figure 4.14: Communication Volume *vs* Cluster Size for a Varying Average Correlation Factor (Eq. 4.18; $N = 100, H = 1$)

Thus Figures 4.13 and 4.14, show that overall communication volume is reduced tremendously if the packages that have correlated information are grouped together into large clusters. This aspect will be further highlighted in the clustering based routing mechanisms introduced in chapter 5.

4.4 Implications on the Logistics Network

The primary objective of clustering the logistics entities is to minimize the total communication cost associated within the logistics network. In this chapter, the method of clustering applied at various levels of a logistics network and their advantages were discussed. This implies that scope of clustering extends to any level in a network.

However, this thesis concentrates on the clustering of transport goods. Taking this into account various algorithms for clustering of logistics entities in various scenarios like centralized, autonomous and semi-autonomous were discussed. Each of the scenarios discussed have their own set of advantages and disadvantages. In the centralized case, the communication is mainly handled by the distribution center, whereas, in the autonomous case, each entity does its own set of communications. Even though the centralized approach is advantageous in terms of one entity handling all the data, failure of this entity can result in enormous data loss. In the autonomous case, clustering may lead to more time consumption and complexity. Once the cluster-head is selected, it can handle all the decisions.

The semi-autonomous approach combines the advantages of both the autonomous and centralized approaches i.e., in providing a hybrid solution. Thus, this thesis analyses the semi-autonomous approach. For the semi-autonomous solution, the associated vertex (also referred to as DC) stores all the information regarding the packages and also performs all the tasks like registering packages and vehicles and enables information flow about available clusters etc. between the logistical entities. While, the transport decisions are handled by the cluster-head. The only drawback of the semi-autonomous approach can be the reliance on the central associated vertex for all the information while waiting for the transportation.

Lastly, the theoretical analysis was presented on the calculation of the optimum cluster size for an autonomous clustering approach based on the information exchange amongst entities to form clusters. A similar analysis is also presented for a semi-autnomous approach. For both approaches, the overall cluster communication volume depends on the correlated information of the packages. The correlation of information also forms the basis of the route correlation factor based routing decisions made by the vehicles for transport decisions. More on this is presented in chapter 6.

CHAPTER **5**

5. Modeling and Simulation of Transport Logistics Scenarios

A logistics transportation domain poses many challenges. These challenges can be due to the constraints caused by the limited resources in the network or due to the changes in the information settings of the orders like shorter delivery times, etc. This brings about a strong need of enhancing the transportation performance by optimizing the transportation time as well as reducing the transportation costs. This also demands a need of a simulation platform that facilitates the design and implementation of such transportation scenarios in the real world. In this regard, [HCC03] presented various standard scenarios of logistics processes that are modeled based on the static graph theoretic representations. But this approach lacks the inclusion of knowledge and communication involved in real-world logistics processes [LGH06]. On the other hand, a software agent based simulation model is said to provide new concepts and abstractions to address these issues [Weiss99, Wool02]. Thus, a software agent based simulation environment for transport logistics is used in this thesis to analyse and handle the various issues that are involved in the real-world transportation scenarios.

This chapter presents the implementation of a clustering algorithm (semi autonomous approach) in the transport logistics scenario using a multi-agent based simulation tool. Furthermore, the performance evaluation of the implemented clustering algorithm w.r.t. the communication volume is also presented in this chapter. In section 5.1, the basic notion of multi-agent based simulation and its role in logistics applications is presented. Section 5.2 gives a brief description of the agent based simulation platform, which is used for simulating the logistics scenarios. The used simulation platform is termed "Platform for Simulation with Multiple Agents" and abbreviated as PlaSMA [GO-B07]. Since the clustering algorithm in PlaSMA is built over the underlying routing protocol termed DLRP, a brief description of the same is presented in section 5.3. In section 5.4 and 5.5, the clustering algorithm as well as the analytical evaluation of the cluster based routing approach are presented. Finally, the performance evaluation and the conclusion derived is presented in section 5.6 and 5.7, respectively.

5.1 Multi-agent based Simulation in Logistics

Multi agent based simulation has gained importance both in science and industry and in particular it is used and adapted in the logistics networks to handle various logistic problems [Paw06]. For example, in autonomous logistics processes, the decentralized decision making demands for autonomous entities. Thus, using the multi agent based simulation systems (MABs), the entities of the logistics network are modeled as agents [Dav00]. In other words, the environment and the objects acting within a MAB are modeled using a number of software agents which are handled as logical simulation processes [LLMO04, GO-B07]. The agents representing the objects interact with one another by sending messages.

A logistics scenario in an agent-based simulation platform consists of agents representing real-world active entities (such as vehicles, packages and distribution centers) and edges representing the roads connecting to the various distribution centers. Therefore, the planning and running of autonomous logistics networks is a complex task as the system dynamically evolves from the interaction of individual components within the network.

Another important component in the agent-based framework as described in [LGH06] is the terminological domain knowledge. It is organized as an associated ontology for transportation logistics which includes, e.g., a representation of the transportation network as an annotated graph together with a two-dimensional map-like representation (similar to geographic information systems). An agent-based framework also enables spatial reasoning by specifying basic types of agents and their properties, e.g., for an agent type vehicle, maximum speed, preferred routes in the network, load capacity, etc. can be some of the properties attached to it. It also contains the properties of currently inactive objects such as highways, traffic hubs, depots etc.

5.2 Platform for Simulation with Multiple-Agents (PlaSMA)

Based on the requirements of simulating and analyzing an autonomous logistics networks, a multi-agent based simulation platform named, Platform for Simulation with Multiple Agents (PlaSMA) [GO-B07] was developed by the researchers at the University of Bremen, Germany, as part of the Collaborative Research Centre (CRC) 637 "Autonomous Cooperating Logistic Processes – A Paradigm Shift and Its Limitations". The CRC is an interdisciplinary project within which the PlaSMA system provides a distributed multi-agent platform simulation environment intended for the simulation, evaluation and demonstration of autonomous logistics applications. It is based on the FIPA-compliant Java-Agent Development Framework JADE [BPR01].

The PlaSMA platform provides means for the simulation of large-scale scenarios (e.g. transport, production or storage) where autonomously acting simulation entities such as means of transport and cargo are represented as software agents. For example, in a transportation logistics scenario the items like containers, packages, vehicles or distribution centers etc. are represented as software agents. The individual entities or in other words the software agents, can communicate with one another to perform the autonomous tasks by exchanging messages in the FIPA agent communication language ACL [FIP98]. For example, package agents perform the route discovery process to find a route to the destination and can also perform negotiations with the vehicle agent regarding the route traversed. Similarly, the autonomous vehicle agent can take decisions in terms of route, load and which packages it wants to transport.

On the whole, the simulation platform PlaSMA is designed to support and simulate arbitrary logistics scenarios in the transportation domain. In addition to the simulation backend and graphical visualization of the client, it also provides a generic platform for evaluating the various scenarios with logistic entities as autonomous actors. Thus, logging, evaluation, visualization, and interaction are some of the key features embedded within PlaSMA. More about the simulation tool PlaSMA and its components is discussed in detail in [GO-B07].

5.3 Distributed Logistics Routing Protocol (DLRP)

Distributed routing has been successful in communication networks for several decades. In CRC 637, a new concept for dynamic logistics transport networks was developed named Distributed Logistics Routing Protocol (DLRP). It was designed to match the goods and vehicle actions and simultaneously make route decisions within the dynamic transport network. In DLRP, the routing methods used in communication networks are identified and mapped for use in transport networks. However, for a transfer of routing methods from communication networks to logistics networks, it is necessary to identify the similarities and differences between them. A short hypothesis derived from [WRTG+07] on this aspect of comparison is presented in the following which is used as a motivation factor for this thesis.

The utmost similarity is that payloads have to be transported from a source to a destination. There are different possible routes available for the transportation. The best route has to be chosen based on one or more selection criteria. The criteria of selection can be specific w.r.t. the network type. Additionally, the possibility of resource reservations is an important aspect in both networks as it is related to the Quality of Service (QoS) which is on its own a unique research topic. For example, in case of logistics, the QoS is fulfilling the transportation conditions, while in case of communication networks, it is guaranteeing the requirements of bandwidth, loss probability limits etc. Also, size and dynamics of both network types are comparable. In case of communication networks, the dynamicity of large scale networks is handled by using decentralized control methods whereas in logistics networks there is the vision of using the autonomous control approaches.

Various significant differences also exist between both networks. One of the main differences is that entities in logistics networks are physically existent and limited in number. Hence, a lost piece of good in transportation cannot be duplicated easily and retransmission is an expensive or in some cases even impossible choice. The choice of route conflicts with the interests of both the vehicles and the transport goods which is one of the criteria considered and analysed in this thesis. For example, the transport goods need to decide based on the criteria of just-in-time transport and hence, would choose for a fastest route, whereas the vehicle's goal would be maximum utilization of its capacity on that particular route. Another important difference is the scale of time. In communication networks the time required for the route selection is not negligible in comparison to transmission time and is in range of milliseconds or seconds. But, in case of logistics network, the goods are transported in longer duration of time (hours, days).

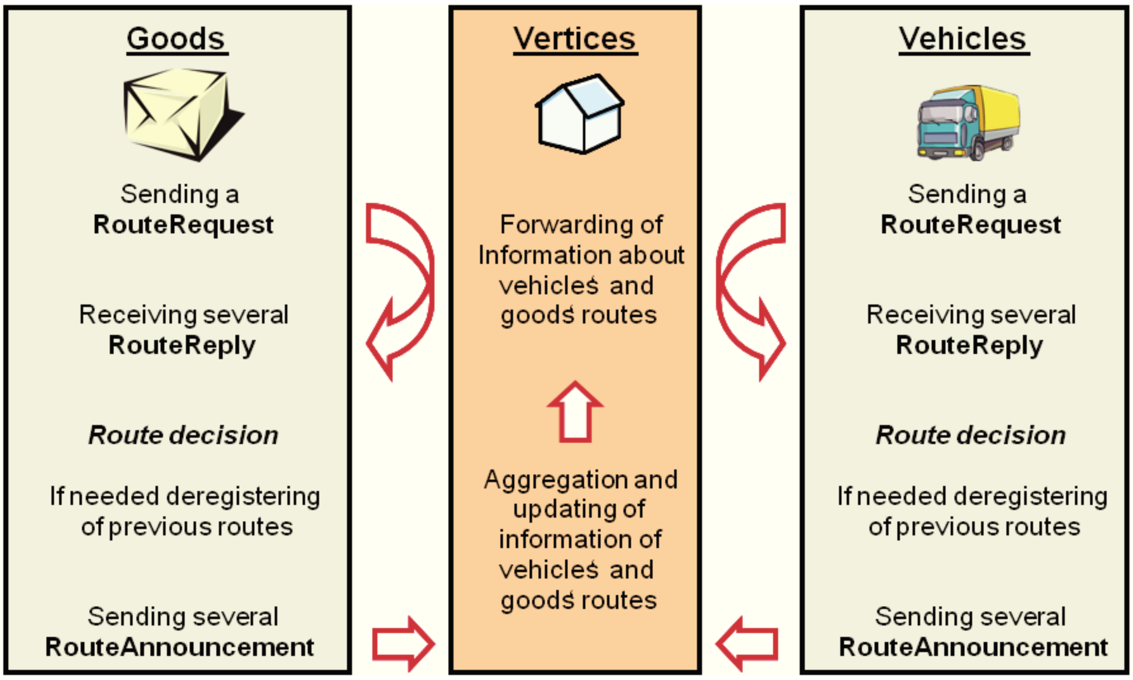

Figure 5.1: Distributed Logistics Routing Protocol [SRF06, WRTG+07]

The real life scenarios of logistic processes require a kind of continuous control of objects. For example, in a logistics transport network, objects like packages and vehicles are dynamic and hence, appear and disappear continuously i.e., new packages are generated periodically after a certain time interval and vehicles appear and dissapear from a certain vertex during the transportation mode. Thereby considering these issues, a distributed routing concept for logistics, DLRP [SRF06, WRTG+07], was developed inspired by the Adhoc routing protocols. DLRP was designed with the view to find routes through permanently changing and unknown network scenarios. In addition, it is able to deal with very large network scenarios without the centralized perspective. In DLRP (refer Figure 5.1), the package (represented as an agent) destined to some destination can accomplish its route discovery process with the Route Request/Reply mechanism. It sends the Route Request to all the neighbor vertices, which in turn forward it to the other neighboring vertices until the final destination is found. The appropriate destined vertex replies to the received Route Request with the Route Reply message. Simultaneously, the vehicle also initiates the route discovery process in a similar way as that of the package. After receiving some route replies (with various different routes), the vehicle decides and selects a route which best suits its needs, for example, the route with maximum expected utilization. This route is then announced to the other vertices with the Route Announcement messages. This indicates a cooperative structure in the network. The whole DLRP concept as described in [SRF06] offers outstanding advantages for real life applications such as: self-adaptation, estimation of future network conditions and for arbitrary kind or quantity of information. The approach taken for the DLRP to the transportation problem is basically different to the approach taken in the traditional *Vehicle Routing Problem* (VRP). The developed protocol is not an optimization algorithm for a static scenario, but an autonomous control algorithm designed for a continuously changing process [Rek08].

5.3.1 DLRP in PlaSMA

In the software agent based framework, every logistic entity like container, package or good, vehicle, distribution center (vertex), etc. is represented by a software agent. Every logistic entity communicates individually with other logistic entities in order to perform the tasks autonomously. For example, packages can find routes to the destination individually and can do the negotiations with the vehicle regarding the route traversed. As seen in Figure 5.2, in the DLRP approach, initially the vehicles and the goods register with the vertex. And the information with respect to the schedule of transportation, the number of vehicles, the available load, etc. is also exchanged with the vertex. Once the vehicles and the goods are registered with the vertex, the vertex updates its information and exchanges it with the goods and vehicles.Thus, once the information is exchanged, the vehicles and goods start the routing process, which is based on the concept of ad hoc routing protocols. Ad hoc routing protocols are designed for infrastructure less dynamic communication networks.

The concept of autonomy in a logistics network enhances the logistic processes to handle the dynamics involved in an efficient way. As a result each and every logistical entity communicates and negotiates with the available information in the network to perform better decisions. But in some cases, such as logistic networks with a large number of entities, this can result in an enormous amount of communication traffic. For example in the routing process, each of the package agents or vehicle agents floods the route search information throughout the network leading to a large communication volume. The communication traffic can be reduced by keeping the exchange of messages concentrated within the local proximity of the logistic entities. This can be done by means of clustering similar logistic items together. Section 5.3.2 provides a detailed overview of the clustering approach applied on a logistic scenario and the advantages associated with clustering.

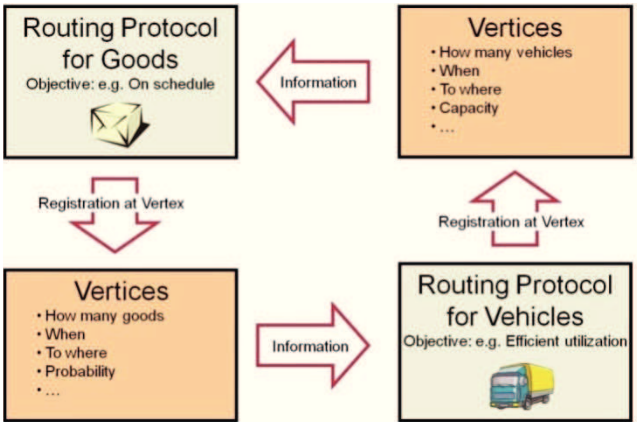

Figure 5.2: Distributed Logistics Routing Protocol Approach [WRTG+07, SWG-a08, SWG-b08]

5.3.2 Clustering Approach with DLRP in PlaSMA

This section addresses the semi-autonomous clustering approach proposed for the logistics network. Clustering is a well known concept that has been studied in a variety of fields (refer Chapter 3). For example in a logistics network, certain logistic entities may have common aims, e.g., several goods that are at the same location and have the same destination. In such a case, it can be reasonable to form groups or clusters of those entities and determine a cluster-head with certain additional capabilities compared to the other cluster members like higher lifetime, later delivery date etc. The cluster-head acts as the information pool for its cluster members and can initiate as well as handle the communications within the cluster members and take decisions on behalf of them depending on the responsibility or capability transferred to it. But in this thesis the cluster-head is chosen based on the First Come First Serve (FCFS) basis and other criteria are considered for future work.

Figure 5.3: depicts the model of the cluster based DLRP concept implemented in the agent-based framework PlaSMA. The idea behind this approach is, instead of individual goods starting the routing process, a cluster of goods is formed with respect to a common destination. The goods after generation or newly arriving register with the vertex and then the vertex forms the various clusters based on the common destinations of the goods. When the clusters are formed, a cluster-head is selected (in this case the first member that registers with the vertex becomes the cluster-head). Once the cluster-head has fulfilled the cluster size limit, or the time-out for cluster formation is reached, it will then start the routing process similar to an individual good as in case of DLRP. Thus, on behalf of all other members, the cluster-head initiates routing. Thereby, the

amount of communication traffic associated with all the individual entities searching for individual routes to the destination is reduced to the case wherein only the cluster-head has to search for the route. A performance evaluation w.r.t. the reduced communication volume of the cluster-based routing method in comparison to the package-based routing method is analysed and presented in the next section 5.4 and is also discussed in [SG08].

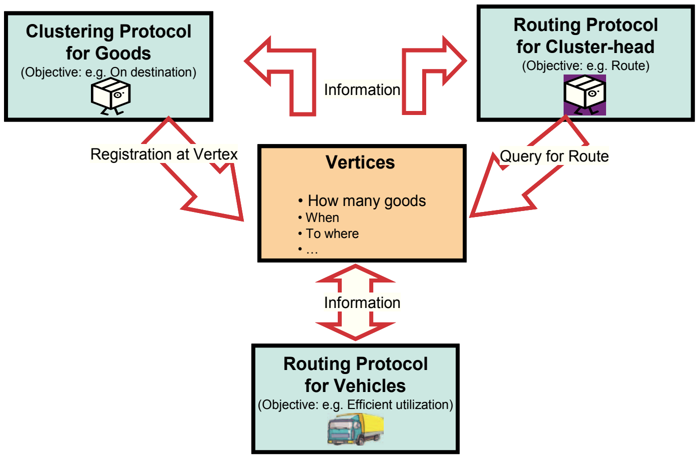

Figure 5.3: Cluster-based Distributed Logistics Routing Approach [SWG-a08, SWG-b08]

5.4 Analytical Evaluation

This section presents the analytical evaluation of the cluster-based routing methods. The amount of communication for the routing process as well as the clustering process are discussed and evaluated.

5.4.1 Clustering Messages

The clustering process for a semi-autonomous scenario (refer section 4.2.2) starts by exchanging the registration request (RegReq) and Acknowledgement (RegAck) messages between the package and the associated vertex. These messages inform the associated vertex with the initial parameters it needs to start the clustering process e.g., the destination of the package, etc. Once the package registers with the vertex, the associated vertex looks if there is already a cluster formed with the presently registered package destination and sends the Cluster-Head Information (CHInfo) message of that cluster to the package. Then, the package registers with that cluster-head with the Cluster Register Request (CRegReq) message, and the cluster-head acknowledges with the Cluster Register Acknowledge (CRegAck) message. In case there is no cluster available for that destination the package itself becomes the cluster-head and the associated vertex sends a new Cluster-Head Announcement message (CHAnn).

The messages exchanged during the clustering process are illustrated in Figure 5.4. The black lines represent the initial registration and acknowledgement messages. The red lines indicate that the cluster-head is not selected yet (and the respective package is elected as the cluster-head) and the blue lines are the messages after the cluster-head is available for a particular destination.

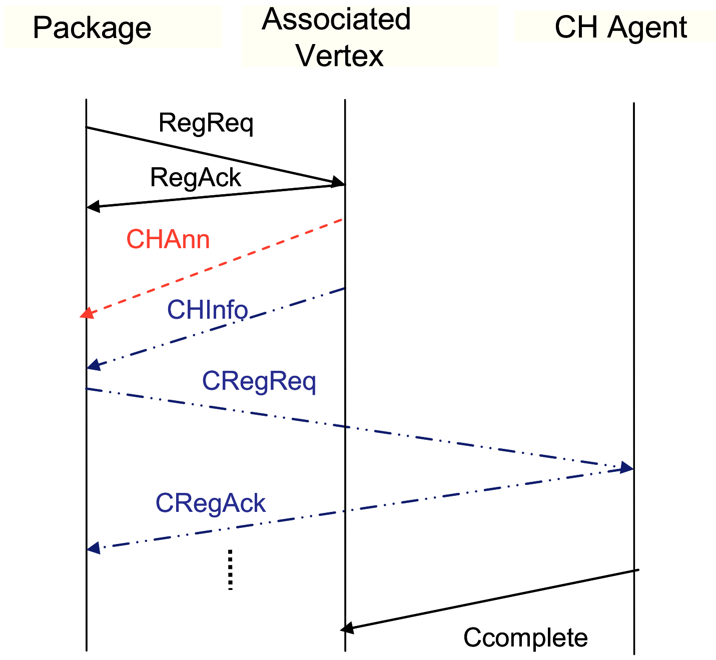

Figure 5.4: Message Flow for the Semi-Autonomous Clustering Process

The total number of RegReq and the RegAck equals the number of packages (N_{packs}). The total number of CHAnn equals the number of clusters ($N_{clusters}$). If there is no cluster size limit then the number of clusters ($N_{clusters}$) is equal to number of destinations (N_{dests}). The total number of CHInfo messages is N_{packs} - $N_{clusters}$. Once the clusters are formed, the total number of CRegReq and the CRegAck also equals N_{packs} - $N_{clusters}$, respectively. Thus, the total message count for clustering is given by:

$$N_{Clustering} = 5 * N_{packs} - 2 * N_{clusters} \qquad 5.1$$

In the scenarios of this thesis, packages are generated uniformly for the different destinations and therefore the total number of packages generated per destination is more or less the same for the different destinations. Since the cluster size is assumed to be fixed for an associated vertex, cluster sizes of the complete clusters for different destinations will be the same. Therefore, the total number of clusters that are formed depends on the total number of packages generated; the number of destinations as well as the cluster size limit (refer Eq. 5.2). In order to take into account the incomplete clusters formed for the different destinations after the time-out (a time deadline with respect to the cluster-head after which no new packages will be accepted into the respective cluster), the ceil function is used to give the number of clusters formed per destination.

$$N_{clusters} / N_{dests} = \left\lceil \frac{N_{packs} / N_{dests}}{Cl_{size}} \right\rceil \qquad 5.2$$

The cluster size determines the number of clusters that will be formed for a destination. The communication volume associated for cluster formation before the routing process is directly proportional to the number of entities in the cluster (Cl_{size}). The lesser the number of entities, the lesser the messages exchanged for cluster formation with respect to a common destination. A small cluster size also implies that the number of clusters formed will be higher given a fixed number of packages (N_{packs}). Thus, the overall communication volume generated due to the clustering process will be small if large number of clusters are formed (refer Eq. 5.1).

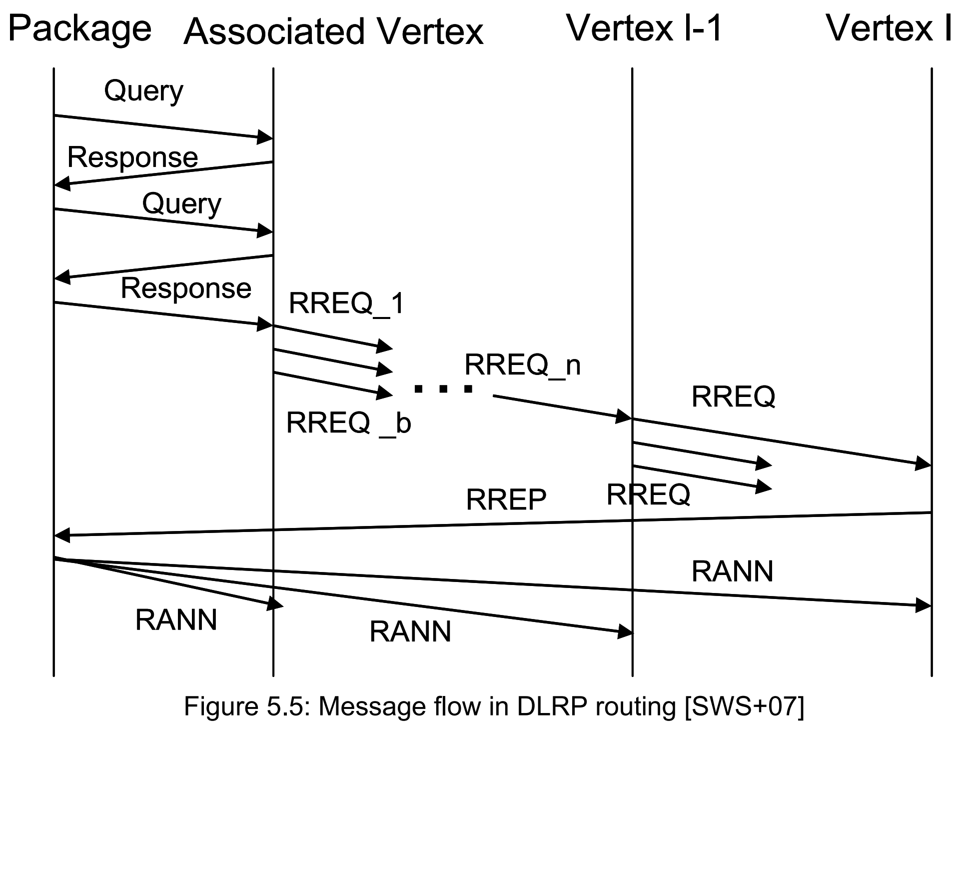

Figure 5.5: Message flow in DLRP routing [SWS+07]

5.4.2 Routing Messages

During the routing process in DLRP, the entity (package or vehicle) that performs the routing generates a significant amount of data traffic [SWS+07]. In the simulation scenarios, the package generation rate is fixed much higher than the available number of vehicles. Thus, in this thesis only packages are clustered together and not the vehicles.

The routing process and the messages exchanged during the routing process by the packages and vertices are illustrated in Figure 5.5. The routing starts with two queries to the associated vertex and the corresponding responses (i.e. 4 messages). These queries inform the package about initial parameters that it needs for the routing. Then, the package sends a route request (RREQ, exactly one) to its associated vertex, which in turn adds some data to the request (available transport capacity, estimated handling times etc., depending on which parameters are used for route decisions) and forwards it to all neighbor vertices. Thus, it is multiplied by the vertex's *branching factor*, which states how many neighbors are available as recipients of the forwarded route request. This is continued until the request reaches the destination or its hop limit (which is a limit set to avoid an endless propagation of the route request message). Therefore, the calculation of the routing overhead gives an optimized estimation of the worst-case scenario limited to certain hops. A route reply (RREP) is sent back for each request that reaches the destination.

Assuming an average branching factor b, a maximum route length of l hops and the average number of neighboring vertices nv_j that are reached by the route request at a distance of j hops, then the average number of route requests sent in the network for a route discovery is given by

$$R_l = 1 + \sum_{j=1}^{l} nv_j \quad \text{where} \quad b = nv_1 \qquad 5.3$$

The first RREQ packet is from the cluster-head to the associated vertex where the cluster of packages is stored. The associated vertex will broadcast the RREQ to all its neighbors and hence will send out the RREQ utilizing all its branches i.e., *b* branches on an average. Any neighboring associated vertex which is not the destination, will further broadcast the RREQ on all its branches except the branch on which it received the RREQ.

For a package, the route discovery is performed for a specific destination and therefore routing loops are not formed. While for a vehicle the objective is to maximize its utilization and it does not have any specific destination, therefore during the route discovery process an already visited neighbor can be re-visited. Thus specifically for vehicles, routing loops are acceptable. To avoid that vehicles operate only in a small logisitical area, route requests are not allowed to be forwarded on an edge already present in the route.

The number of route replies depends on how many of the paths that the requests travelled lead to the destination. Assuming m paths led to the destination, then this is also the number of replies that will be generated by the destination vertex.

After having received the route replies, the package selects the favorable routes and announces only these selected routes to the affected vertices. This mechanism leads to $l+1$ route announcements (RANN) per selected route for a maximum route length l. Since not all of the replied routes may be selected by the package, the package announces n alternative routes ($n \leq m$), and the total number of route announcements are $n(l+1)$. In case of more than one announced route, there are also route disannouncements (not depicted in Figure 5.5). Once a route is selected for transportation, the other alternative routes are disannounced. Therefore, the total number of disannouncement messages sum up to $(n-1)(l+1)$.

Thus, the upper limit of the total message count from one routing process is given by

$$N_{routing} = 5 + \sum_{j=1}^{l} nv_j + m + (2n-1)(l+1) \qquad 5.4$$

In the case where each package routes individually, each package generates this amount of messages. In contrast, if the routing is only done by one cluster-head instead, only the cluster-head generates these messages.

5.4.3 An Estimation of Number of Route Requests

The estimation of the number of route requests generated in the network depends on the number of neighboring vertices (see Eq.5.43). This section therefore gives the analytical description for the calculation of the average number of neighboring vertices.

The notation and the formulation used in this section is adapted from the work presented in [NSW01]. The authors in this paper use generating functions to describe graphs with arbitrary probability distribution of number of branches connected to any particular vertex. Therefore, the presented approach in this section is based on the generating function $G_0(x)$ for the probability distribution p_k of vertex with an exact degree of k branches, given by

$$G_0(x) = \sum_{k=0}^{\infty} p_k x^k \quad 5.5$$

The average number of 1-hop neighboring vertices, nv_1 of a vertex over the probability distribution of branching factor is given by

$$nv_1 = G_0'(1) = \sum_k k p_k \quad 5.6$$

The average number of immediate neighboring vertices also is the average branching factor of the network, $b = nv_1$.

Since, the route requests propagate over multiple edges with route lengths greater than 1, the distribution of the branching factor of the vertices that the route request propagates through is important. The distribution depends on the individual branching factor of the vertices and hence is proportional to kp_k. Therefore, the normalized distribution is given by

$$\frac{\sum_k kp_k x^k}{\sum_k kp_k} = x\frac{G_0'(x)}{G_0'(1)} \quad 5.7$$

The vertices at which the packages arrive at a distance of 1 hop from the initiator vertex have one incoming edge and the remaining edges can be used as the outgoing branches. Thus, the distribution of the outgoing edges of the neighboring vertices can be generated similar to Eq. 5.7 with $(k-1)$ branches i.e., one power of x less and is denoted by $G_1(x)$.

$$G_1(x) = \frac{G_0'(x)}{G_0'(1)} = \frac{G_0'(x)}{nv_1} \quad 5.8$$

Based on Eq. 5.5 the generating function for the probability distribution of the number of 2-hop neighbors of the initiator vertex is

$$G_0(G_1(x)) = \sum_{k=0}^{\infty} p_k \left[G_1(x)\right]^k \quad 5.9$$

and the average number of 2-hop neighbors is given by

$$nv_2 = \left[\frac{d}{dx} G_0(G_1(x)) \right]_{x=1} = G_0^{'}(G_1(1))G_1^{'}(1) = G_0^{'}(1)G_1^{'}(1) = G_0^{'}(1)\frac{G_0^{''}(1)}{G_0^{'}(1)} = G_0^{''}(1) \qquad 5.10$$

Similarly, the generating function for 3-hop neighbors is given by

$$G_0(G_1(G_1(x))) = \sum_{k=0}^{\infty} p_k \left[G_1(G_1(x))\right]^k \qquad 5.11$$

By extension, the generating function for neighbors at a distance of l hops will be given by $G_0(G_1(...(G_1(x))...)$ with $(l-1)$ iterations of the generating function G_1. Thus, the general generating function for a probability distribution of the branching factor for the vertices can be written as,

$$G^{(l)}(x) = \begin{cases} G_0(x) & \text{for } l = 1 \\ G^{(l-1)}(G_1(x)) & \text{for } l \geq 2 \end{cases} \qquad 5.12$$

and the average number of l hop neighbors is given by

$$nv_l = \left[\frac{d}{dx} G^{(l)}(x) \right]_{x=1} = G_0^{'}(1)G_1^{'}(1)^{l-1} \qquad 5.13$$

From equation 5.10 and 5.13, we get

$$nv_l = G_0^{'}(1)\left[\frac{nv_2}{G_0^{'}(1)} \right]^{l-1} = nv_1\left[\frac{nv_2}{nv_1} \right]^{l-1} \qquad 5.14$$

This holds only if there is no restriction that paths have to be loop-free in the network Thus, a transport logistics network can be characterized by the generating function of the probability distribution of the branching factor i.e., the probabilities p_k that a randomly chosen vertex in the network has a branching factor *k*.

With the obtained average branching factor and the average number of neighboring vertices with respect to the route length, from Eq. 5.3 the average number of route requests generated for one route discovery with the known route length can be calculated as

$$R_l = 1 + \sum_{j=1}^{l} nv_j = 1 + \sum_{j=1}^{l} nv_1 \left(\frac{nv_2}{nv_1} \right)^{j-1} \quad 5.15$$

5.4.3.1 Poisson Distributed Branching Factor

Assume a transport logistics network to be represented as a graph where each pair of vertices *(i, j)* has a connectivity edge with independent probability *p*. Thus, a random vertex is directly connected to the other *(N-1)* vertices with an independent probability of *p,* where *N* is the total number of vertices in the network.

Therefore, the probability p_k that the vertex *i* has a degree exactly of *k* is given by the binomial distribution

$$p_k = \binom{N-1}{k} p^k (1-p)^{N-1-k} = \binom{N-1}{k} \left[\frac{p}{1-p} \right]^k [1-p]^{N-1} \quad 5.16$$

The average branching factor of a vertex in the network is $b = (N-1)p$

$$\Rightarrow p_k = \binom{N-1}{k} \left[\frac{b}{N-1-b} \right]^k \left[1 - \frac{b}{N-1} \right]^{N-1} \cong \frac{b^k}{k!} e^{-b} \quad 5.17$$

where, $\cong$ refers to equality for large *N*.

The generating function is then given as,

$$G_0(x) = \sum_{k=0}^{N} \binom{N}{k} p^k (1-p)^{N-k} x^k \quad 5.18$$

$$\Rightarrow G_0(x) = (1 - p + px)^N = e^{b(x-1)} \quad 5.19$$

where the last equality applies in the limit $N \to \infty$. The average branching factor of a vertex is given by $G'_0(1) = b$. Notice also that in this special case,

$$G_1(x) = G_0(x), \quad 5.20$$

Therefore, the distribution of the outgoing edges at a vertex is the same regardless of whether the vertex was chosen randomly or by following the randomly chosen edge. This property is specific w.r.t. a Poisson-distributed random graph.

5.4.3.2 Exponentially Distributed Branching Factor

The expression for an exponential distribution of the vertex branching factor is given by

$$p_k = (1-e^{-1/\kappa})e^{-k/\kappa}, \tag{5.21}$$

where κ is a constant.

The generating function for the exponential distribution will be

$$G_0(x) = (1-e^{-1/\kappa})\sum_{k=0}^{\infty} e^{-k/\kappa}x^k = \frac{1-e^{-1/\kappa}}{1-xe^{-1/\kappa'}} \tag{5.22}$$

and

$$G_1(x) = \left[\frac{1-e^{-1/\kappa}}{1-xe^{-1/\kappa'}}\right]^2 \tag{5.23}$$

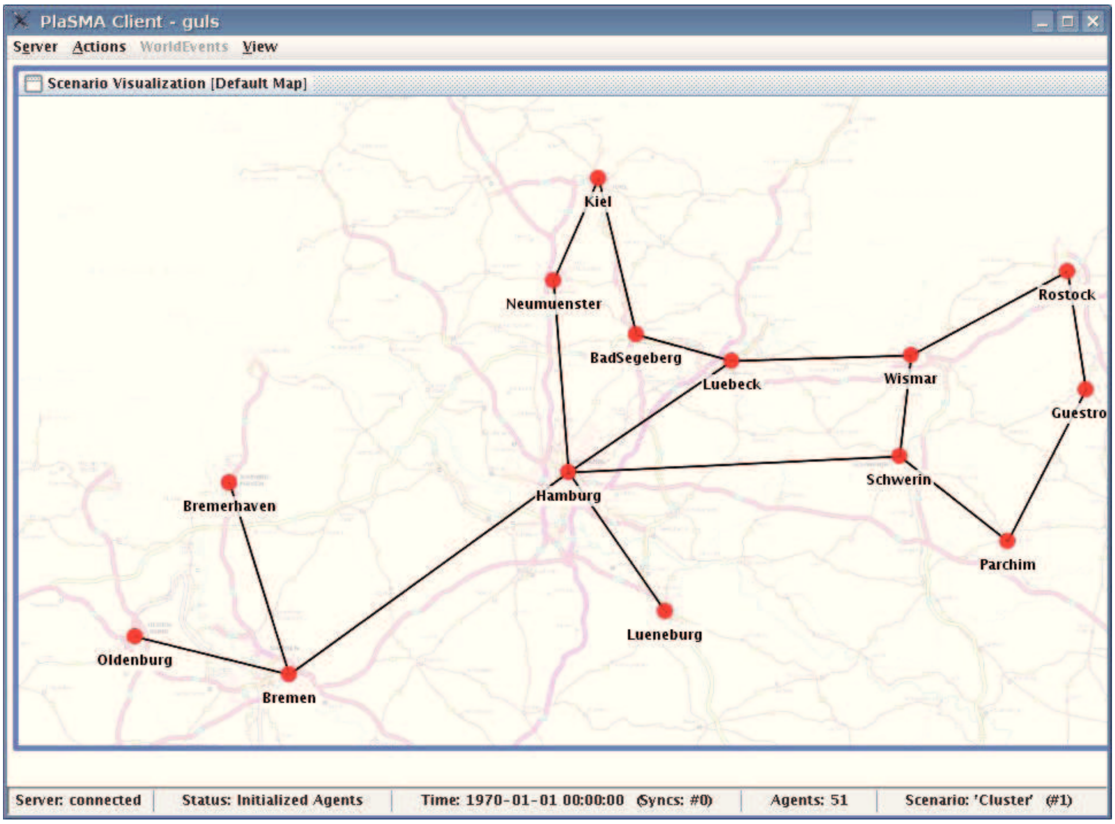

Figure 5.6: North Germany Scenario – 1

5.4.3.3 North Germany Scenario – 1

In the case of graphs with an arbitrarily specified branching factor distribution, the branching factors can be determined directly. For a logistical network with the exact numbers of vertices n_k having a degree *k*, the exact and properly normalized generating function for the probability distribution is given in the polynomial form.

$$G_0(x) = \frac{\sum_k n_k x^k}{\sum_k n_k} \qquad 5.24$$

The scenario depicted in Fig. 5.6, is one such example where the degree distribution can be explicitly measured due to the fixed road transport connections. It can be seen that the vertices: Oldenburg, Lueneburg and Bremerhaven have a degree of 1; Kiel, NeuMuenster, BadSegeberg, Guestrow, Rostock and Parchim have a degree of 2; Wismar, Schwerin, Luebeck and Bremen have a degree of 3 and Hamburg has a degree of 5. Therefore, the generating function will be given as

$$G_0(x) = \left[\frac{3x + 6x^2 + 4x^3 + x^5}{3 + 6 + 4 + 1}\right] = \frac{3x + 6x^2 + 4x^3 + x^5}{14}$$

$$\Rightarrow b = nv_1 = G'_0(1) = \frac{3*1 + 2*6*1 + 3*4*1 + 5*1}{14} = \frac{32}{14} = 2.285,$$

$$G_1(x) = \frac{G'_0(x)}{G'_0(1)} = \left[\frac{3 + 12x + 12x^2 + 5x^4}{14}\right]\left[\frac{14}{32}\right] = \frac{3 + 12x + 12x^2 + 5x^4}{32},$$

$$\Rightarrow G'_1(1) = \frac{12 + 2*12*1 + 4*5*1}{32} = \frac{56}{32}$$

This implies that on an average a vertex will have b immediate neighbors and the 2 hop neighbors will be given by

$$nv_2 = G'_0(1)G'_1(1) = \left(\frac{32}{14}\right)\left(\frac{56}{32}\right) = 4$$

From Eq. 5.13, the average 3 hop neighbors can be calculated as

Analytical Evaluation

$$nv_3 = \left[\frac{nv_2}{nv_1}\right]^2 nv_1 = \left(4\frac{14}{32}\right)^2 \left(\frac{32}{14}\right) = 7$$

Thus, the average number of RREQ generated for a route discovery with the known route length of 3 hops from Eq. 5.14 will be

$$R_l = 1 + \sum_{j=1}^{3} nv_1 \left(\frac{nv_2}{nv_1}\right)^{j-1} = 1 + 2.285 + 4 + 7 = 14.285$$

To validate this number a closer look is taken at all the vertices to calculate the number of RREQs that would have been generated from them for the route length of 3. The calculation begins with the vertices that have only 1 outgoing branch. Bremerhaven and Oldenburg will have 8 RREQs. Lueneburg on the other hand will have 13 RREQs. It has a higher number of RREQs generated as Hamburg is its neighboring vertex. Guestrow is the vertex farthest from Hamburg and hence will have lesser influence of the high branching factor of Hamburg. The RREQs generated from it for a route length of 3 will be 9. The other vertices which have a branching factor of 2 like Kiel, NeuMuenster, BadSegeberg, Rostock and Parchim will have 11, 15, 13, 11 and 13 RREQs generated, respectively. The other vertices with 3 branches like Bremen, Wismar, Schwerin and Luebeck will have 13, 20, 20 and 20 RREQs generated respectively. And finally, Hamburg will generate 20 RREQs if it was the source for a route discovery with a route length of 3. From the obtained numbers, the average number of route requests generated will be equal to 13.857. Thus the approximated average number of route requests from the analytical model gives an error of about 3%. Therefore, it can be concluded that the analytical model fits pretty closely to the real topology even though it does not have the exact topology connectivity information.

In a logistics network it is not necessary that all the vertices initiate the same number of route discoveries i.e., the distribution of the packet generation rate need not follow a uniform distribution. Eq. 5.15 gives a good estimation of the number of route requests generated in the network where it is assumed that all the vertices are sources with uniform distribution. Where as for a non-uniform distribution of transport goods in a transport logistic network the number of route requests initiated from individual vertices has to be considered.

5.4.3.4 Arbitrary Scenario – 2

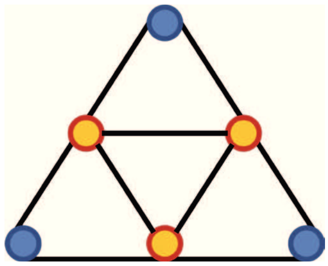

Figure 5.7: Arbitrary Scenario – 2

Figure 5.7 depicts another example of an arbitrary scenario with 6 nodes out of which 3 (blue) nodes have 2 branches and the rest of the 3 (orange) nodes have 4 branches. Thus the average branching factor of this scenario is 3. This can also be confirmed by using Eq. 5.24, where the generating function for the example scenario 2 will be

$$G_0(x) = \frac{\sum_k n_k x^k}{\sum_k n_k} = \frac{3x^2 + 3x^4}{3+3} = \frac{3x^2 + 3x^4}{6}$$

From Eq. 5.6, we have

$$b = nv_1 = G_0^{'}(1) = \left|\frac{2*3x^1 + 4*3x^3}{6}\right|_{x=1} = \frac{6+12}{6} = 3$$

And from Eq. 5.10 we have the average number of 2-hop neighbors for this example scenario

$$nv_2 = G_0^{"}(1) = \left|\frac{1*2*3 + 3*4*3x^2}{6}\right|_{x=1} = \frac{6+36}{6} = 7$$

The average 2-hop neighbors can also be easily confirmed by closely looking at the example scenario depicted in Figure 5.7. Due to the symmetric structure of the example scenario, all the blue nodes have each in total six 2-hop neighbor nodes (including nodes that are also 1-hop neighbors) while all the orange nodes have each in total eight 2-hop neighbor nodes. Thus in this example scenario, there will be a total of forty two (3*6+3*8) 2-hop neighbor nodes resulting in an average of seven (42/6) 2-hop neighbors.

5.4.4 Estimation of Branching Factor

To calculate the number of 2-hop neighbors, one may try to use the average branching factor, b of the scenario. Following the notion that a source node will have on an average b neighbors, these b neighbors will lead to further b*(b-1) 2-hop neighbors. From the example described in section 5.4.3.4, this hypothesis is proved to be incorrect. For the example scenario 2, the average branching factor is 3 while the average number of 2-hop neighbors is 7 and not 6 (3*2). Therefore in this thesis, the calculation of the total number of route requests for a given maximum route length, *l* is based on the average branching factor, b_l (average branching factor for a route length of *l)*.

In this section an extended formulation of Eq. 5.3 i.e., the number of route requests with varying branching factors for different route lengths is presented [STG10]. Assume a scenario with route length *l*, the number of route requests *RREQ* is given by,

$$R_l = 1 + tnv_l = 1 + (b_l + b_l * tnv_{l-1}) \quad \text{for } l \geq 1 \qquad 5.25$$

where, tnv_l represents the total number of connected neighbors of the vertex upto a distance of l hops.

$$tnv_{l-1} = b_{l-1} + b_{l-1} * tnv_{l-2} \qquad 5.26$$

tnv_l can also be described as the sum of the average neighbor vertices upto the route length of *l*,

$$tnv_l = \sum_l nv_l \qquad 5.27$$

and

$$tnv_0 = 0 \qquad 5.28$$

For example, for the case $l = 1$,

$$R_1 = 1 + b_1 + b_1 * tnv_0 = 1 + b_1 = 1 + nv_1 \qquad 5.29$$

For example, for the case $l = 2$,

$$R_2 = 1 + b_2 + b_2 * tnv_1 = 1 + b_2 + b_2 nv_1 = 1 + b_2 + b_2 b_1 \quad \text{as} \quad tnv_1 = nv_1 = b_1 \qquad 5.30$$

From Eq. 5.15,

$$R_2 = 1 + nv_1 + nv_2 \qquad 5.31$$

From Eq. 5.30 and 5.31,,

$$b_2 = \frac{nv_1 + nv_2}{1 + nv_1} \quad 5.32$$

For a route length *l*,

$$R_l = 1 + b_l + b_l b_{l-1} + b_l b_{l-1} b_{l-2} + b_l b_{l-1} b_{l-2} ... b_3 b_2 b_1 \quad 5.33$$

$$\Rightarrow b_l = \frac{\sum_{j=1}^{l} nv_j}{1 + \sum_{j=1}^{l-1} nv_j} = \frac{tnv_l}{1 + tnv_{l-1}} \quad 5.34$$

If $b_l = b_{l-1} = b_{l-2} = ... = b_3 = b_2 = b_1 = b$

then $$R_l = \sum_{i=0}^{l} b^i = \sum_{i=0}^{l} nv_1^i \quad \text{where } nv_2 = nv_1^2 = b^2 \quad 5.35$$

The formulation in Eq. 5.25 are validated with a simulation scenario depicted in Figure 5.6. The simulation scenario under consideration is assumed to have 3 different sources: *Hamburg*, *Bremen* and *Guestrow*. Each of these sources has packages (transport goods) destined to a number of different destinations. To make the readers clear with the calculation of branching factor and RREQs w.r.t. the three different sources, three different scenarios are defined. For example, source *Hamburg* has clusters destined to destinations *Guestrow* and *Rostock* (refer Figure 5.8), source *Bremen* has clusters destined to 5 destinations; *Bremerhaven, Hamburg, Lueneburg, Kiel and BadSegeberg* (refer Figure 5.9) and source *Guestrow* has a cluster destined to *Luebeck* (refer Figure 5.10).

Analytical Evaluation

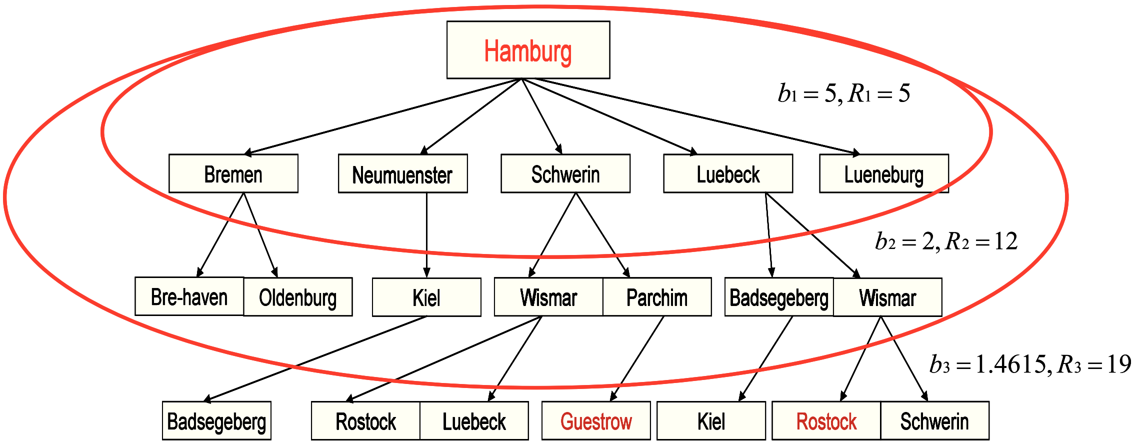

Figure 5.8: Source: *Hamburg* and Destination: *Guestrow* and *Rostock*

Consider the case from the source *Hamburg* (Figure 5.8), the number of route requests generated in this case will be, $R_1 = b_1 + b_1 * tnv_0 = 5$ where $tnv_0 = 0, b_1 = 5$. Coming to the second level of the scenario (from vertices: *Bremen, Neumuenster, Schwerin,* etc.) the number of route requests generated in this case is given by $R_2 = b_2 + b_2 * tnv_1 = 12$ where, $tnv_1 = 5$ and b_2 = 2. Similarly, for third level of scenario (from vertices: *Bremerhaven, Oldenburg, Kiel, Wismar, etc*) the number of route requests $R_3 = b_3 + b_3 * tnv_2 = 19$ where, $tnv_2 = 12$ (number of neighbours: 5 from the source node and 7 from the intermediate nodes) the average branching factor b_3 =1.4615.

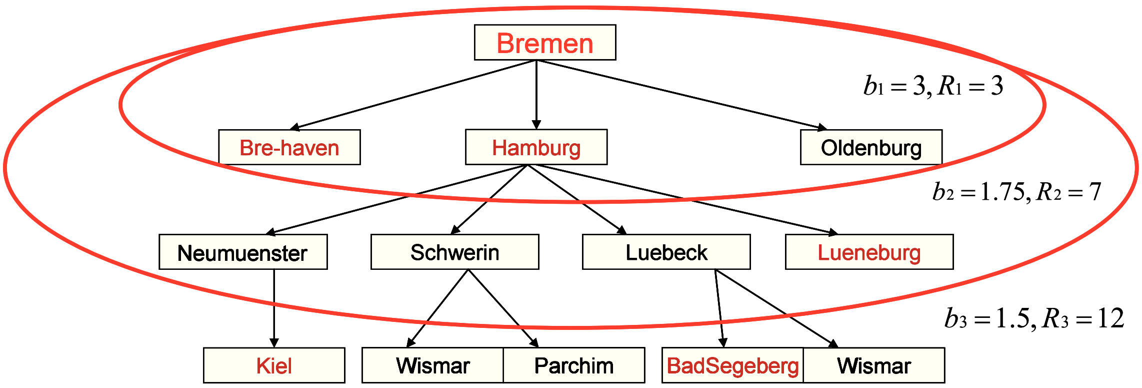

Figure 5.9: Source: Bremen; Destination: Bre-haven, Hamburg, Lueneburg, Kiel and BadSegeberg

For the case with source *Bremen* (Figure 5.9) and destinations being *Bremerhaven, Hamburg, Lueneburg, Kiel and BadSegeberg* respectively, the number of route requests from the source itself is $R_1 = b_1 = 3$. For the second level (RREQ propagating from vertices: *Bremerhaven, Hamburg and Oldenburg*), the average branching factor, $b_2 = 1.75$ which results in $R_2 = 7$ route requests. Similarly for a route discovery for a route length of 3, the average branching factor seen by the source Bremen is $b_3 = 1.5$ resulting in 12 route requests.

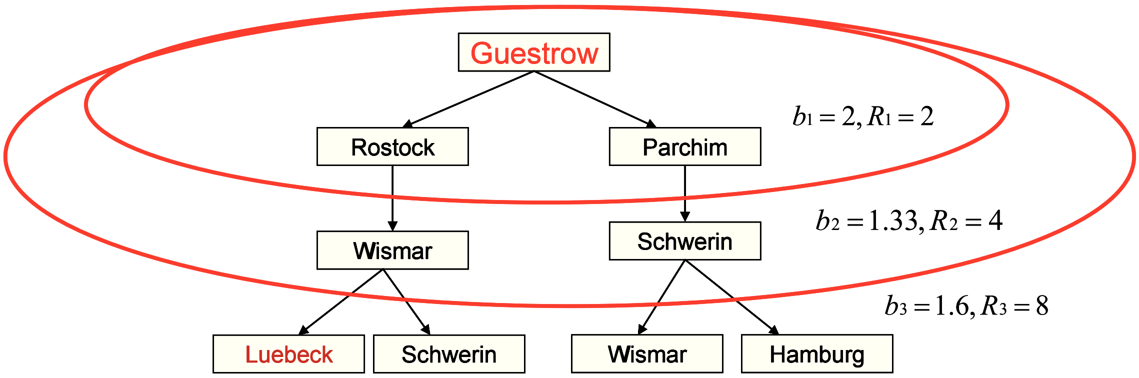

Figure 5.10: Source: Guestrow; Destination: Luebeck

Similarly, consider the case with source *Guestrow* (Figure 5.10) and destination as *Luebeck*. Here also the destination is at a distance of 3 hops and therefore the branching factor seen by Guestrow is given by b_3=1.6 (b_1=2 and b_2=1.33). The resulting number of route requests from the source is R_3 = 8.

5.4.4.1 Weighted Branching Factor

As shown in the examples in the previous section, a source may have packages generated for various destinations. Since the routing process does not take into account the previous history of the routes to the destination, the route discovery is performed with a fixed Time-To-Live (TTL) to discover destinations at a distance of TTL-1 which gives the maximum possible route length l from the source. Therefore, for the route discovery process initiated at a source, the analytical model does not take into account the respective destination for which the route discovery is initiated. The author is aware of the small error that this assumption brings in the model for the cases when the destination is located at a distance less than the maximum route length or if the routing loops are present. Therefore, these numbers give an upper limit for the number of route discovery messages that will be generated.

Since, every source of the route discovery sees a different topology and hence a branching factor for a specific route length, it is important that the analytical model takes into account the number of route discoveries that are done at the various vertices in the network. In this regard, the probability that a packet is generated at a vertex q is given by weights w^q, which leads to the weighted average branching factor for a route length l, given by

$$\mathrm{b}_l^{\mathrm{w}} = \frac{\sum_k w^q b_l^q}{\sum_k w^q} \qquad 5.36$$

For example, in case of the simulation scenario presented in the Figure 5.6, the total average branching factor is given as,

$$\mathrm{b}_3^{\mathrm{w}} = \frac{w^{ham}\mathrm{b}_3^{\mathrm{ham}} + w^{bre}\mathrm{b}_3^{\mathrm{bre}} + w^{gue}\mathrm{b}_3^{\mathrm{gue}}}{w^{ham} + w^{bre} + w^{gue}} = \frac{2*1.4615 + 5*1.5 + 1*1.6}{2+5+1} = 1.5028$$

where, *w* represents the weight associated with each vertex (for the simulations, uniform distribution of package generation was used and therefore the weights for the three source vertices is the number of destinations with respect to each source i.e. Hamburg - $w^{ham}=2$, Bremen - $w^{bre}=5$, and Guestrow - $w^{gue}=1$) and *b* is the average branching factor for each source as calculated in the previous section.

The weighted average of the neighbours' tnv_l^w is given by

$$\mathrm{tnv}_2^{\mathrm{w}} = \frac{w^{ham}\mathrm{tnv}_2^{\mathrm{ham}} + w^{bre}\mathrm{tnv}_2^{\mathrm{bre}} + w^{gue}\mathrm{tnv}_2^{\mathrm{gue}}}{w^{ham} + w^{bre} + w^{gue}} = \frac{2*12 + 5*7 + 1*4}{2+5+1} = 7.875$$

Therefore, the average number of route requests *RREQ* for a route discovery is given by (Eq. 5.25)

$$\mathrm{R}_3^{\mathrm{w}} = 1 + \mathrm{b}_3^{\mathrm{w}} + \mathrm{b}_3^{\mathrm{w}}\mathrm{tnv}_2^{\mathrm{w}} = 14.33$$

It can be seen that the obtained average number of route requests by this method is comparable to the result obtained for the same variable in section 5.4.3.3.

5.4.5 Scenario Description

To evaluate the clustering algorithm's performance and compare the analytical results for the expected communication traffic to simulation results, some sample scenarios with different characteristics were chosen [SWG-a08].

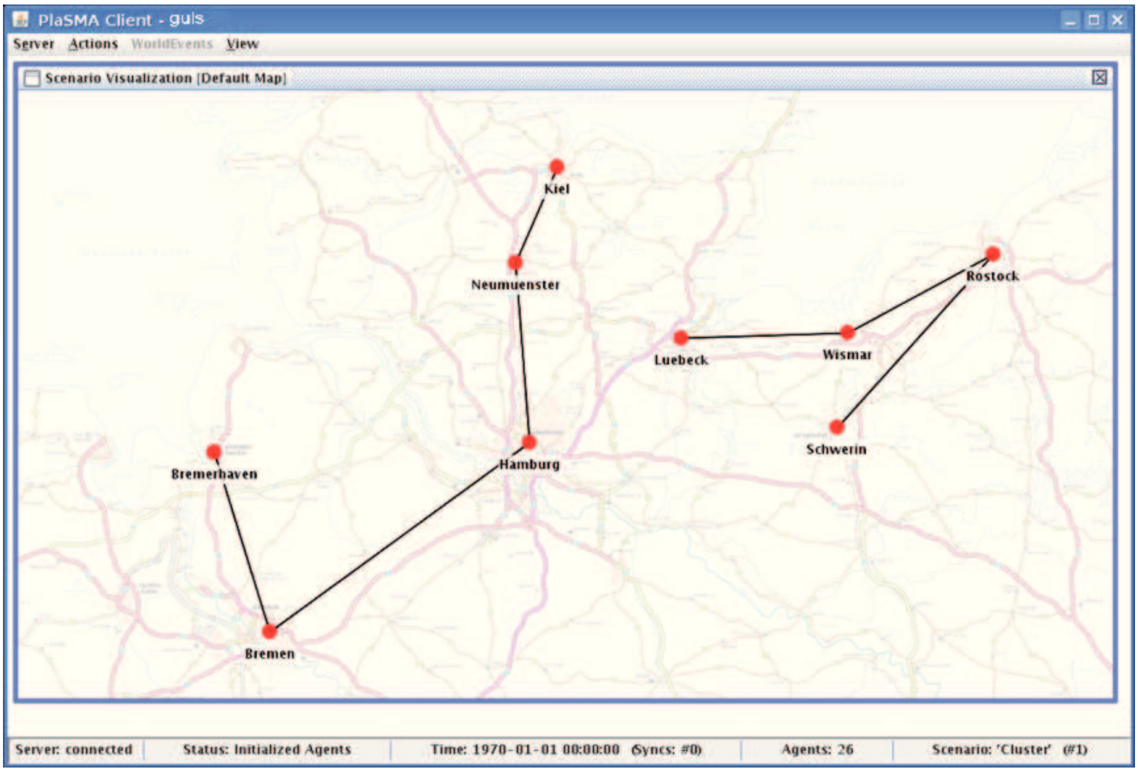

Figure 5.11: Topology 1 – Scenario with Branching Factor = 1

In all of the scenarios, packages are generated until a maximum package number, the generation limit, is reached. Then the generating agent stops. The total generation rate in each source of each scenario is 20 packages per hour of model time, i.e. if there is only one source, 20 packages per hour are created in the scenario, in case of s sources, the total generation rate in the scenario is s *20 packages per hour. The simulation scenarios, despite being displayed on a real map and labeled with real city names, are assumed scenarios that were created to have specific topology parameters, especially related to the branching factor and the route hop count.

As described in the previous section, the clustering is done by the vertex (the distribution center) according to the semi-autonomous clustering principle, which adds packages with the same destination to an existing cluster until either the cluster size limit or time-out (~ 1 day) are reached. The cluster is then closed and the cluster-head initiates the routing process.

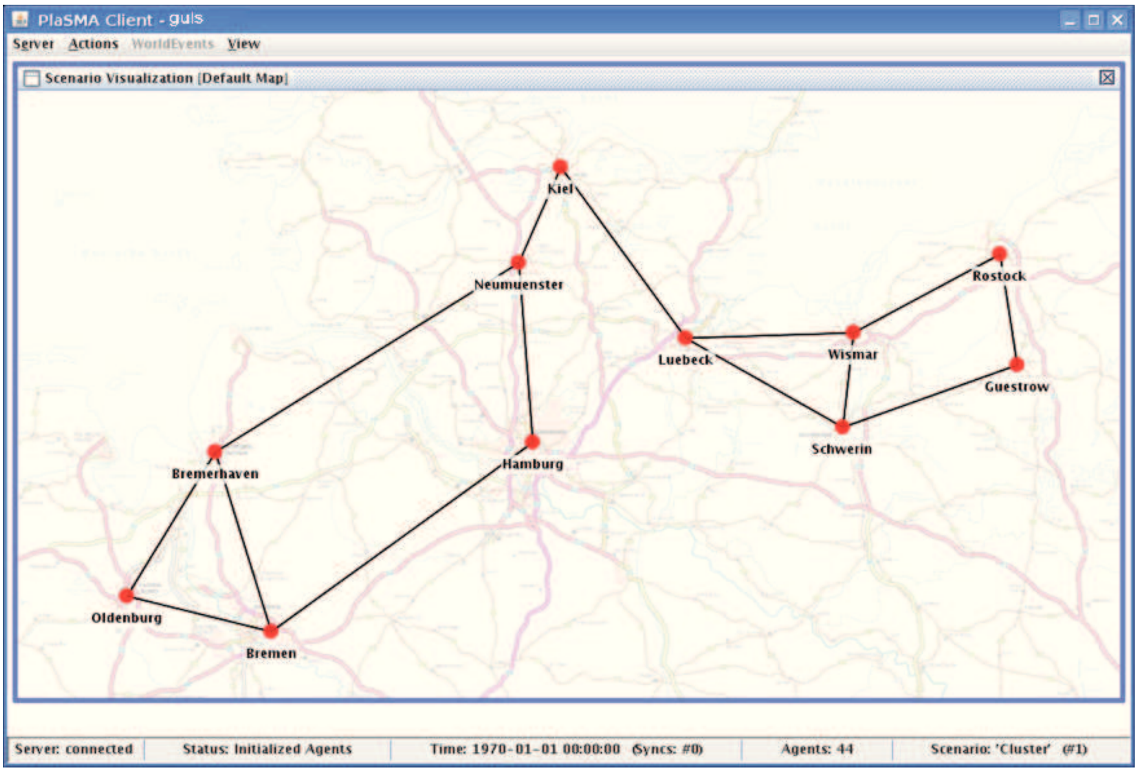

Figure 5.12: Topology 2 – Scenario with Branching Factor = 2

Figure 5.11 depicts a simulation scenario with a topology that consists of two disconnected parts. Since, Kiel is one of the sources and to maintain a branching factor of 1, in the particular scenario the link between Kiel and Luebeck is disconnected. The sources are located at the vertices labeled "Bremerhaven", "Kiel", "Luebeck" and "Schwerin". Thereby each route starting at one of the sources, experiences a branching factor of 1. The destinations are chosen such that the hop count from source to the destination is 2 e.g., the destination of the packages generated at Kiel and Bremerhaven is Hamburg. The topology in Figure 5.12 represents a topology with an increased branching factor of 2. For example, the sources "Hamburg" and "Kiel", each route experiences a branching factor of 2. Locations that are at least at a 2-hop distance from a source are destinations for packages created at that particular source itself.

5.4.6 Results

The number of routing packets increases with increase in network parameters such as branching factor, route length, number of alternate routes to the destination, etc. A larger average branching factor *(b)* or route length *(l)* means more flooding of the route request packets in the network, whereas a larger number of alternate routes leads to more route reply, announcement and disannouncement messages.

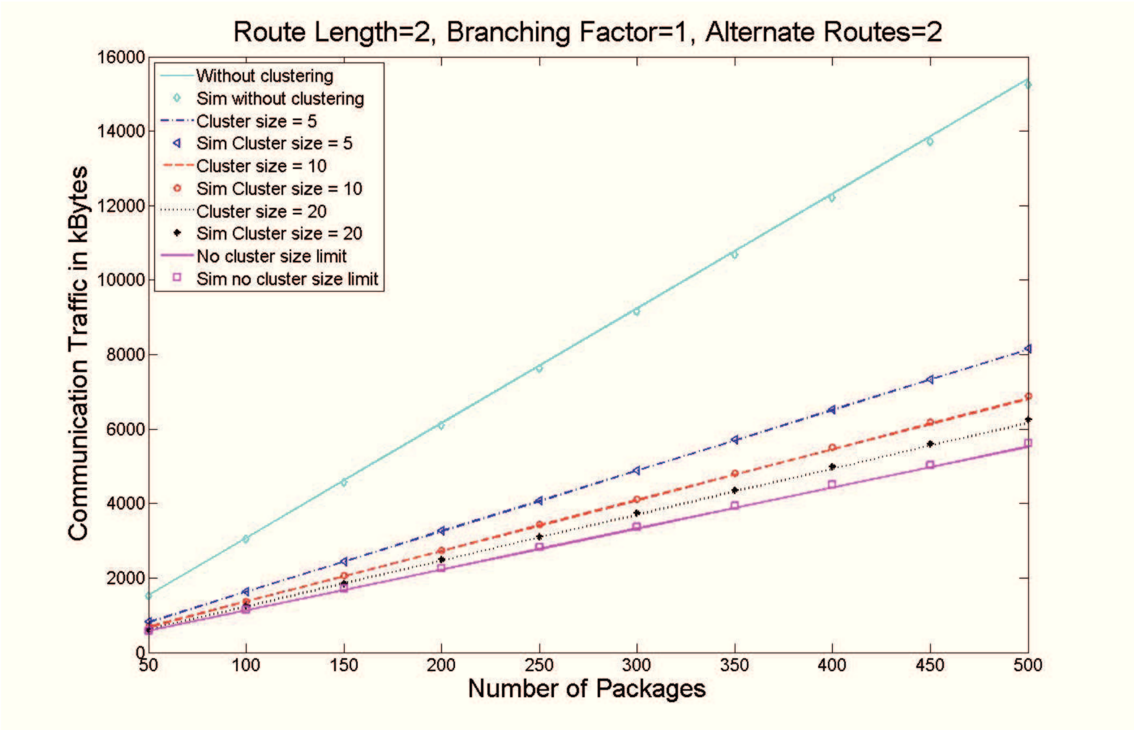

Figure 5.13: Communication Traffic *vs* Number of Packages (Topology 1)

The diagrams in Figure 5.13 and 5.14 depict the simulative and analytical results (weighted average branching factor estimation) for the simulated topologies depicted in Figure 5.11 and 5.12, respectively. The diagrams represent the total amount of communication traffic associated with the routing and clustering processes for varying number of packages. The curves represent the communication traffic for different cases such as *Without clustering* (communication traffic associated with only routing), *Varying cluster size* and one with *No Cluster size limit*. The latter implies that the cluster size can be infinite and cluster formation is only limited by a timeout. In the simulation implementation, the limit is set to be equal to the number of packages being generated at the vertex. Figure 5.15 depicts the simulative and analytical results for the scenario presented in Figure 5.6, representing the total amount of communication traffic associated with routing and clustering processes for varying number of packages.

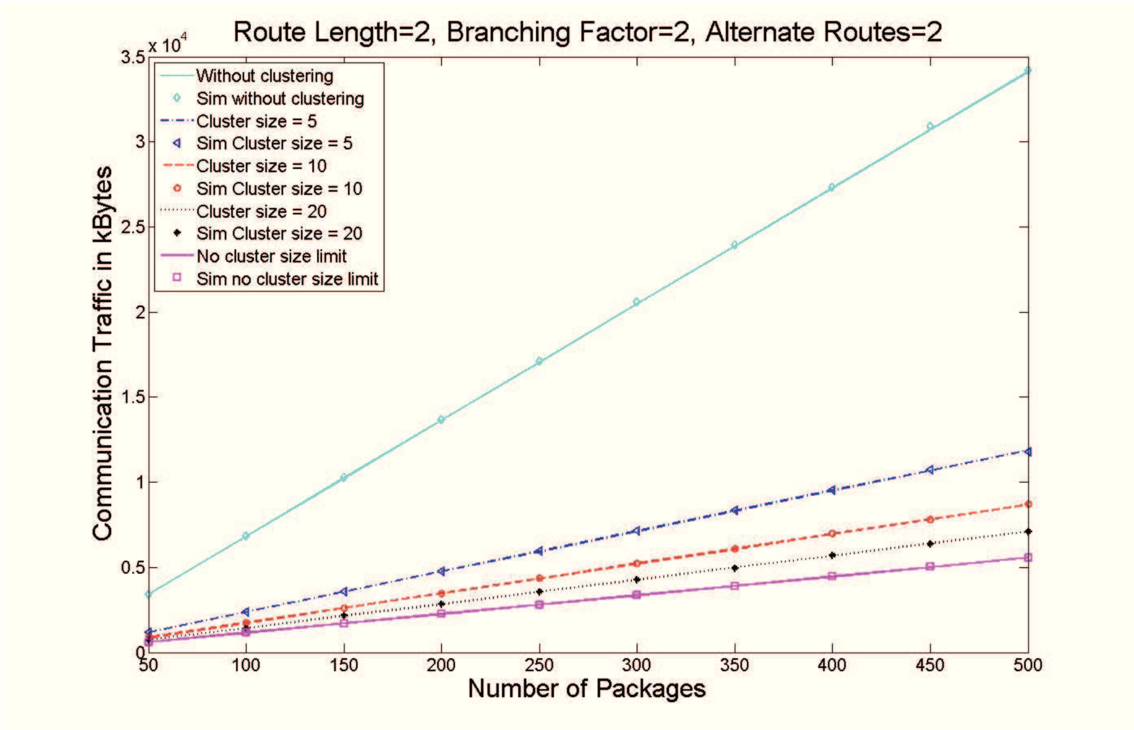

Figure 5.14: Communication Traffic *vs* Number of Packages (Topology 2)

As seen in the Figures 5.13, 5.14 and 5.15, as the number of packages increases the communication traffic increases linearly in all cases. But the communication traffic is maximum in case of no clusters being formed (*Without clustering*). Additionally, as the cluster size increases, the communication traffic decreases, the lowest curve is the case of *No Cluster size limit*. This implies that, the higher the number of members in a formed cluster is, the less becomes the communication traffic as the cluster-head is the one that handles the communication on behalf of all other members. In addition, clustering aids in reducing the influence of large values of network parameters such as branching factor, route length, etc. By clustering, only the cluster-head initiates the routing and thereby the communication traffic decreases considerably with increase in the network complexity. Thus, cluster-based routing shows better performance than routing without clustering processes. Figures 5.13, 5.14 and 5.15 also show that, the analytical results also match the simulation results.

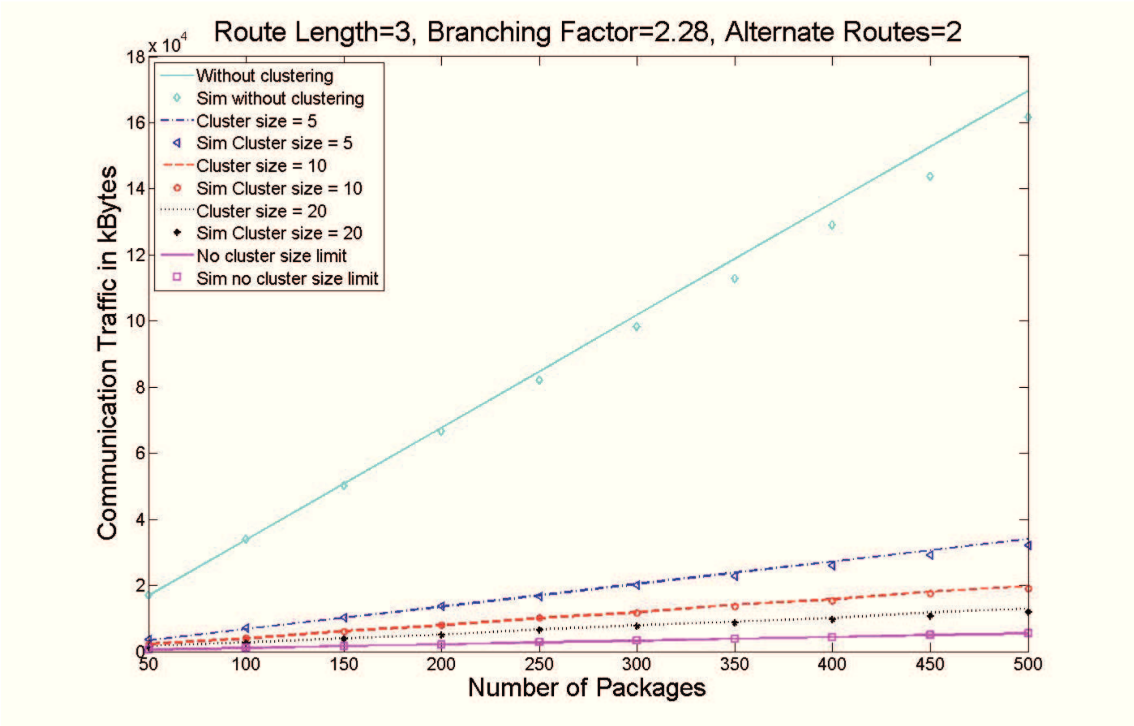

Figure 5.15: Communication Traffic *vs* Number of Packages (North Germany Scenario)

5.5 Conclusion

This chapter presents the cluster based routing model and its performance evaluation w.r.t. reduction in communication volume using the simulation tool PlaSMA. An analytical model is also presented and the results obtained are evaluated with the simulation results using different scenarios. The analytical and the simulation results match with respect to each other. Additionally, a formulation to calculate an average branching factor is also introduced in this thesis and the performance evaluation on the same is presented. For example, if the topology of the network is unknown then the formulation presented gives the possibility of calculating an average branching factor analytically, even for multiple source-destination pairs. The communication overhead due to the number of route requests generated in the network can also be approximately calculated.

Thus, it can be concluded from the obtained results that the cluster-based routing approach results in less communication traffic in comparison to the non-cluster based routing approach. It can also be seen that the cluster size plays an important role in determining the overall communication traffic. With a larger cluster size, the number of clusters in the network are reduced which in turn reduces the number of route discoveries initiated by the cluster-heads of each individual cluster.

Conclusion

Even though clustering helps in reduced communication volume, but the absolute value of communication (in terms of kBytes) is directly proportional to the size of ACL messages used for communication as defined in the FIPA software agent platform architecture specifications [FIP98]. The communication volume may be further reduced with appropriate optimization of the exchanged message block especially for bandwidth limited domains like SS.7 e.g., by means of compressing the size of ACL messages [BJC99].

CHAPTER **6**

6. Logistic Transport Decision Criteria – Correlation Based Transport

Clustering in autonomous logistics processes implies grouping of those autonomous entities that share common properties. In chapter 5, the performance of the implemented clustering and routing protocol was evaluated in terms of communication volume. The criterion used for clustering was the common destination of the package agents and in terms of the correlation concept (introduced in chapter 4), this implies that the members of a cluster have a 100% correlation with respect to their destination. For transport logistics, the correlation based concept of clustering can be further extended to include the correlation of the routes of the package clusters to their respective destinations. In this chapter, the correlation based transportation method is presented. It deals with the strategies that can be used to enhance the transport efficiency of a logistic network by transporting the clusters together.

In the context of this chapter, transport is initiated with a routing process performed initially by the clusters and the vehicles. After the route discovery process, vehicles offer transport to different clusters based on specific criteria e.g., load, profit, route, etc. The clusters can have different transport criteria as compared to the vehicles and choose amongst the various transport offers made by the vehicles. For example, the transport decision of the clusters can be based on transport cost, time of delivery, route, etc. On the other hand, the vehicles' transport decision is based on the capacity utilization as well as the maximum profit they achieve with a particular route for transportation. Thus, this chapter presents the strategies that take into account the transport decision based on capacity utilization as well the transportation cost. The capacity utilization and the transportation cost in turn depend on the route correlation factor, which will be discussed in detail in this chapter.

6.1 Decision based on Route Correlation Factor (*rcf*)

A lot of research is associated with efficient transportation by the vehicles in a logistics network [GSL06, RSL05 and Sand02]. Several trends among them have a significant impact on the transportation processes. As per case study presented in [PVL06] [Deal03], in the Netherlands the capacity utilization (CU) of the vehicle is only 40 % - 60 % of the full capacity. Increasing or optimizing this criterion is one of the ongoing goals to be achieved by most of the researchers and the industry.

In this section the model implemented to achieve high capacity utilization based on correlation of routes to the destination of clusters is presented. Vehicles do not have a destination assigned to them; thereby they get the information of the formed package clusters at the neighboring vertices, up to a certain number e.g., 3 hops. Based on the gathered information, vehicles offer transport to the favorable clusters. Favorable clusters are identified with a correlation factor calculated with respect to the common route the different clusters of packages and the vehicle have selected for transport.

Assume a logistics transportation scenario where K clusters are stored at a distribution center (o) that need to be transported to their respective destination. The logistic network can be depicted as a graph of vertices (distribution centers) connected by edges representing the distance. Referring Figure 6.1, the total distance that the vehicles will have to travel to transport these clusters to their destinations individually (tot_dist_{ind}) is given by

$$tot\_dist_{ind} = \sum_{i=1}^{K} d_{\mathrm{oi}} \qquad 6.1$$

where d_{oi} is the distance that a vehicle will have to travel to deliver the cluster i to its destination.

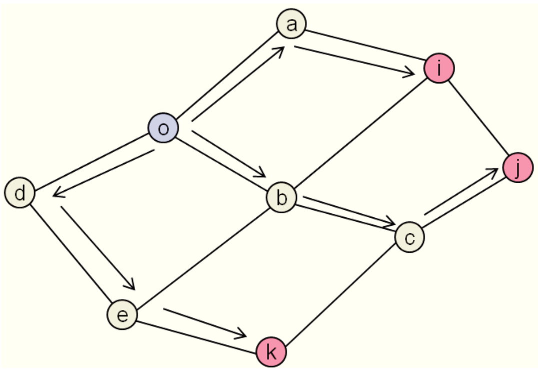

Figure 6.1: Transport of Individual Clusters

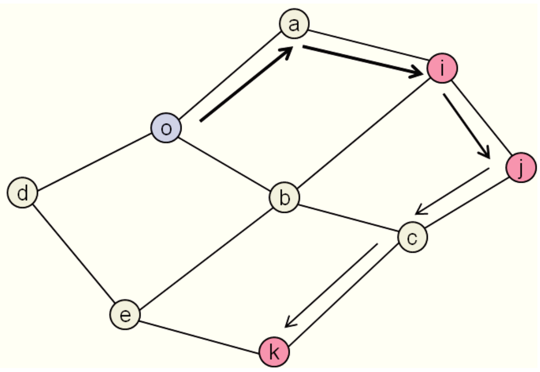

Figure 6.2: Transport Shared by Clusters

The transportation cost can be saved by reducing the distance traveled by the vehicles to transport the clusters to their respective destinations. The reduction in distance traveled can be obtained if more than one cluster is transported by the vehicle, provided the capacity of the vehicle is not exceeded. For example as shown in Figure 6.2, if clusters i, j and k are delivered to their respective destinations together (in the sequence depicted in Figure 6.2) with one single vehicle, then the total distance traveled (tot_dist_{tog}) by the vehicle will be given by

$$tot\_dist_{tog} = d_{\mathrm{oi}} + d_{\mathrm{ij}} + d_{\mathrm{jk}} \qquad 6.2$$

Decision based on Route Correlation Factor (rcf)

If $(tot\_dist_{tog} < tot\_dist)$ or $(d_{ij} + d_{jk} < d_{oj} + d_{ok})$ then, the transportation cost would be reduced due to the reduction in the traversed distance by the vehicle.

The set of clusters that can be transported together can be identified by the portion of the routes that they share, i.e., the common path that the clusters will traverse together. Assume for illustration of the common path that, the route for the destination of cluster k is via the destinations of the other two clusters i and j. In this case, the above relation will be simplifed as follows,

$$d_{ij} + d_{jk} < (d_{oi} + d_{ij}) + (d_{oi} + d_{ij} + d_{jk}) \qquad 6.3$$

This in turn leads to the reduction of the traveled distance as follows,

$$(d_{oi}) + (d_{oi} + d_{ij}) = (d_{oi}) + (d_{oj})$$

i.e., the path from the distribution center to destination of cluster i and j , which is nothing but the common path that the clusters i , j and k traversed together (first all three and then clusters j and k after delivering cluster i) .

To identify the favorable combination of clusters for a vehicle to transport together, the correlation of their respective routes can be used. The correlation between different routes is described by a *route correlation factor (rcf)*. Thus, *rcf* is defined as the ratio of the sum (over all the hops that the vehicle travels with more than one cluster) of the product of hop distance Hop_{dist} with the number of clusters $Load_{clusters}$ (more than one) to the total individual distance of all the clusters (i.e., to be transported by the vehicle) to their destinations, as described by Eq. 6.4.

$$rcf = \frac{\sum_{hops_{clusters} > 1} (Load_{clusters} Hop_{dist})}{tot\_dist_{ind}} \qquad 6.4$$

In other words, *rcf* is defined as the ratio of the sum of the product of the common path and the number of clusters (at least 2 or more clusters are transported together) to the total path of the clusters from the source to their respective destinations.

Considering the example of 3 clusters (Figure 6.2) whose destinations lie on the same route, *rcf* would be defined as

$$rcf = \frac{3d_{oi} + 2d_{ij}}{tot\_dist} = \frac{3d_{oi} + 2d_{ij}}{d_{oi} + d_{oj} + d_{ok}} = \frac{3d_{oi} + 2d_{ij}}{3d_{oi} + 2d_{ij} + d_{jk}} \qquad 6.5$$

Thus, the *rcf* lies in the range [0, 1], where 0 represents for clusters that share no common path of the route and 1 for clusters that share the same destination and eventually the same route. The *rcf* is higher for clusters that have a higher distance from the distribution center but a smaller distance between each other.

For example, consider a scenario presented in Figure 6.3. In this scenario, the distance between two nodes is described by weights on the edge connecting the two respective nodes.

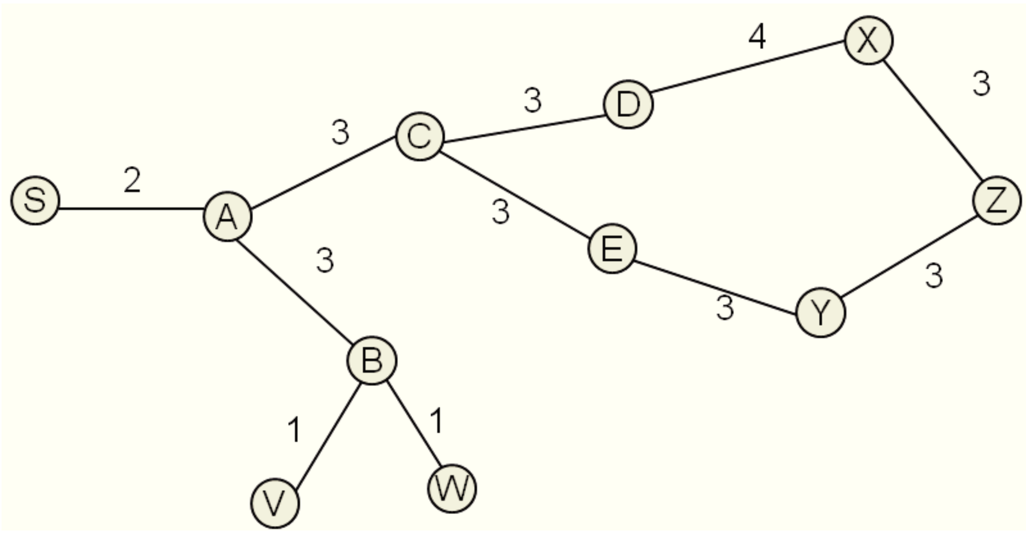

Figure 6.3: Example Scenario

In this example, S is the source and if there are two clusters to be delivered to destination X and Z, then given that the vehicle has enough capacity it is better if the vehicle transports both the clusters together on the common route until destination X (common route for both X and Z). For this example, *rcf* is,

$$rcf_{XZ} = 2SX/(SX + SZ) = 0.89$$

where 2*SX in the numerator denotes the common path the vehicle travels multiplied by the number of clusters that the vehicle carries. The denominator denotes the total distance the vehicle has to travel in case the clusters are transported separately.

Another example that illustrates the *rcf* is the case where the vehicle has to transport clusters to destinations C and W. It is clear from Figure 6.3 that it might not be very beneficial to transport the two clusters together as they have a very short common route, between S and A. The *rcf* in this case is given as,

$$rcf_{CW} = 2SA/(SC + SW) = 0.36$$

Another possible case can be that the vehicle transports three clusters to X, Y and Z (the clusters' size is small enough for the vehicle to load all three of them). If the vehicle is not traveling in a sequential order w.r.t. the destinations then, the *rcf* is,

$$rcf_{XYZ} = (3SC + 2CY)/(SX + SY + SZ) = 0.79$$

where all 3 clusters travel together from S until C. At C, the cluster destined to X is left at the associated vertex and the clusters destined to Y and Z are transported together until destination Y. From Y, the cluster destined to Z is transported to its destination.

In case the vehicle is traveling to cluster destinations in a sequential manner i.e., in the order Y, Z and X, the *rcf* is,

$$rcf'_{xyz} = (3SY + 2YZ)/(SX + SY + SZ) = 0.93$$

The *rcf* not only takes into account the clusters that are to be delivered to various destinations but also the clusters that can be picked on the way. For example in scenario depicted in Figure 6.3, if there are two clusters to be delivered to C and X from S while there is another cluster waiting at C to be delivered to Z. In this case the *rcf* will be

$$rcf_{CXZ} = (2SC + 2CX)/(SC + SX + CZ) = 0.89$$

Hence, based on this calculated correlation factor and the cluster sizes, the vehicle can decide about the favorable route and clusters to be transported. Once the favorable clusters are identified the vehicles can offer transport to the selected clusters. In case, the vehicle identifies that it is not able to achieve the maximum capacity utilization, then the vehicle can attempt to transport clusters which traverse the shortest route. Thus, this chapter presents the influence of route correlation factor in improving the capacity utilization of the vehicle by analyzing various strategies under different scenarios.

6.2 Decision based on Total Transportation Cost (*TTC*)

Unlike discussed in the previous section (decision based on the capacity utilization), here the cluster decision criterion is based on transportation cost per package expressed in monetary units (mu). Assume the transportation cost of the vehicle to be T_c and profit P per kilometer. In addition, the vehicle wants to have a profit P_{Tr} per trip in case it has to do a number of small trips. The *Total Cost (TC)* calculated by the vehicle with respect to the distance to be travelled plus the *Profit* P_{Tr} for a single trip is distributed over the carried load resulting in the *Total Transportation Cost* (*TTC*) for an individual package. For example, a vehicle transporting a single cluster i to its destination, the *TTC* for a package of cluster i is given by,

$$TTC_i = \frac{((T_C + P)d_{oi}) + P_{Tr}}{ClusterSize_i} \tag{6.6}$$

As usual in the scenario considered for the simulation in this particular case, the vehicle gets the information of the clusters formed at the vertices, the cluster size, destinations and the next hop the clusters are travelling to. Based on this information, the vehicle calculates the cost and the profit it wants to achieve for the transportation of each cluster and then offers the cost per package to the cluster. In the transportation cost, the loading and unloading costs have not been considered.

From Eq. 6.6, it can be seen that the vehicle will prefer to take clusters for a destination with a larger distance to travel, as it will maximize the profit. The carried load will bear no relevance to the decision of the vehicle but will reduce the cost for the cluster if the vehicle is loaded to full capacity. For the rest of this chapter, a total of 4 vehicle types for the investigated scenarios with varying capacity will be considered:

- Vehicle Large (T_L) with capacity = 50 packages
- Vehicle Medium -1 (T_M-1) with capacity = 30 packages
- Vehicle Medium -2 (T_M-2) with capacity = 30 packages
- Vehicle Small (T_S) with capacity = 20 packages

Arbitrary values have been assumed for the different transportation cost parameters for different vehicle types, as depicted in Table 6.1. The behaviour can be different in reality for different vehicles according to the requirements of the transport company.

Table 6.1 : Transportation entities, parameters and values

Vehicle Type (Load Capacity)	Transportation Cost per km, T_c (mu)	Profit per km, P (mu)	Profit per Trip, P_{Tr} (mu)
Large: T_L (50)	8	2	100
Medium: T_M-1 (30)	6	1	100
Medium: T_M-2 (30)	6	1	100
Small: T_S (20)	4	1	100

6.3 Strategies Designed and Investigated

A logistics network is a dynamic network with large space (large number of entities performing relative to each others requirements). As mentioned in [RMS09], the real life scenarios in logistics transport processes need a continuous control of the logistic entities, where in they appear and disappear continuously, hence, dynamic in nature. Additionally, the size of the network also plays a crucial role. Obtaining a global optimum is not possible as all the relevant information cannot be received at one point in time. The dynamics also further increase the computational complexity which is already NP-hard in static logistic optimization scenarios [RSZ10]. Thus, the author tries to handle these dynamics and complexities to a certain extent by refining the problem into three different strategies. These strategies are based on the motivation of improving the capacity utilization of the vehicles. These strategies defined below are implemented to exploit the correlation between the routes of the various clusters.

a) Strategy based on Common Route

In this strategy, the vehicle calculates the *route correlation factor (rcf)* between a pair or set of destinations that lie on the same route. Considering the example depicted in Figure 6.3, with this strategy a vehicle will either deliver the clusters for destinations C, D and X or C, E and Y (based on the *rcf*) on the way to deliver a cluster destined to Z.

b) Strategy based on Large Common Route

In the previous strategy, the *rcf* was calculated for destinations that were part of the same route. In this strategy, the correlation factor is calculated for combinations of destinations that may not fall on the same route but share a large common route. Referring to the example depicted in Figure 6.3, with the large common route strategy a vehicle can transport clusters destined to V and W together until B.

c) Strategy based on Common Next Hop

In this strategy, the transport route of clusters is broken into multiple hops with the vehicles preferring to transport clusters with a common next hop.

6.4 Implemented Algorithms

This section explains the algorithms implemented using the above mentioned strategies and the transport decision parameters. In the first algorithm implemented, the author only considers and analyses the effect of *rcf.* And further the impact of *TTC* along with *rcf* is analysed. The effect of these parameters on the transportation performance are futher analysed in the results section using various scenarios.

6.4.1 Algorithm for Different Strategies using *rcf*

The algorithm implemented using different strategies but considering only *rcf* is described as follows:

Step 1: Get cluster information from the associated vertex: Cluster destination, size and next hop of its selected route.

Step 2: Identify clusters and their combinations with respect to vehicle's capacity.

Step 3: Perform routing for the destinations of preferred clusters.

Step 4: Obtain *route correlation factor* for the different combinations of clusters (based on the used strategy):

> a: Common Route Strategy – Select clusters whose routes overlap such that the destination of the cluster with the shorter route lies on the route of the cluster with the longer route i.e., the two routes completely overlap.
>
> b: Large Common Route Strategy – Select clusters whose routes either overlap completely or have a large portion of the route overlapping.
>
> c: Common Next Hop Strategy – Select clusters that have the same next hop towards their destinations.

Step 5: Select the cluster or their combination based on the highest *route correlation factor*.

Step 6: Offer transport to the selected clusters.

Step 7: If any of the clusters has already accepted transport from another vehicle then the vehicles offer will be rejected. In that case, the vehicle will have to offer transport to the next best clusters w.r.t. the *rcf* until the vehicles transport offer is accepted.

Step 8: End

6.4.2 Algorithm for Different Strategies using the *rcf* and *TTC*

The algorithm used by the vehicle for different strategies using *rcf* and *TTC* is described as follows:

Step 1: Get cluster information from the associated vertex: Cluster destination, size and next hop of its selected route.

Step 2: Identify clusters and their combinations with respect to vehicle's capacity.

Step 3: Perform routing for the destinations of preferred clusters.

Step 4: Obtain different combinations of clusters based on the obtained routes and the strategy used:

a: Common Route Strategy – Select clusters whose routes overlap such that the destination of the cluster with the shorter route lies on the route of the cluster with the longer route i.e., the two routes completely overlap.

b: Large Common Route Strategy – Select clusters whose routes either overlap completely or have a large overlapping of the route.

c: Common Next Hop Strategy – Select clusters that have the same next hop towards their destinations.

Step 5: Determine the best cluster or set of clusters based on the *route correlation factor* (based on Eq. 6.4)

Step 6: Determine the transportation cost per package for the selected set of cluster/s based on the Eq. 6.10. The profit P_{Tr} per trip is shared equally over all the packages while the transportation cost is shared relative to the distance travelled with a specific load.

a: Common Route Strategy – In this strategy, the load varies as the clusters are dropped or loaded with destinations being part of a single route.

b: Large Common Route Strategy – In this strategy, the clusters need not be delivered to their final destination but to the part until where the vehicle can offer cheaper transport i.e., can operate close to its full capacity. This opens up the possibility for other vehicles (smaller) to transport clusters on the non-overlapping routes.

c: Common Next Hop Strategy – This strategy identifies clusters having overlapping next hops.

Step 7: Offer transport with the calculated transportation cost to the selected cluster/s.

Step 8: If any of the cluster has already accepted transport from another vehicle then the vehicles offer will be rejected. In that case, the vehicle will have to offer transport to the next best cluster/s w.r.t. the *rcf* until the vehicles transport offer is accepted.

Step 9: End

6.5 Analysis of Designed Strategies and Decision Policies

The three strategies presented in section 6.3 are analysed using the scenario named “Single-Source with Multiple-Destinations (SSMD)” presented in Figure 6.4 which is nothing but a sub-set of a North-Germany roadmap. Later in this chapter, the results for this scenario are presented for the different strategies as well as for other scenarios such as “Multiple Sources with a Single Destination (MSSD)” and “Multiple Sources and Multiple Destinations (MSMD)” scenario.

Figure 6.4 presents the Single-Source with Multiple-Destinations scenario. The single source in this scenario is Bremen (represented in red colored text) and the other cities represented in black colored text represent the destinations – Hamburg, Luebeck, Lueneburg, Wismar and BadSegeberg. The numbers (in red color) written below the city name represents the cluster size of the cluster formed for that city at Bremen. For example, the numeral 30 that is written below the destination Hamburg represents a cluster with 30 packages destined to Hamburg. The weights (in black color) on the links represent the distance (in km) between the two cities.

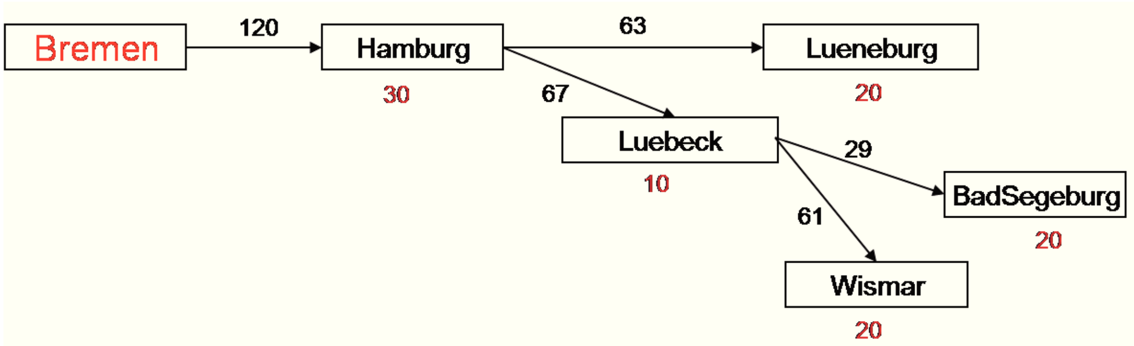

Figure 6.4: Scenario-SSMD: Source – Bremen; Destinations – Hamburg, Luebeck, Lueneburg, BadSegeberg and Wismar

6.5.1 Analysis of route correlation factor (*rcf*) based Decision Process

Before analyzing the simulation results, the author presents the theoretical calculations of the *rcf* for the SSMD scenario using different strategies to better understand the flow of the algorithm.

6.5.1.1 Scenario SSMD – *rcf* – Strategy based on Common Route

Table 6.2: Scenario SSMD – *rcf* using the Strategy: Common Route

Final Destination (Cluster size)	**Intermediate Destination (Cluster size)**	**Route Correlation Factor (*rcf*)**
Wismar (20)	Luebeck (10)	0.859
	Hamburg (30)	0.652
BadSegeberg (20)	Luebeck (10)	0.928
	Hamburg (30)	0.714
Luebeck (10)	Hamburg (30)	0.782
Lueneburg (20)	Hamburg (30)	0.792

For the scenario named Single-Source with Multiple Destinations (Figure 6.4) with the strategy based on common route, the *rcf* with respect to various destination pairs are presented in Table 6.2. For example, Hamburg lies on the route of all other destinations from source Bremen and therefore its correlation with all other destinations is calculated. It can be seen that BadSegeberg and Luebeck have highest correlation as these two destinations are the nearest to each other. For cluster destined to Hamburg, pairing with the cluster destined to Lueneburg represents the highest *rcf* value.

6.5.1.2 Scenario SSMD – *rcf* – Strategy based on Large Common Route

In the previous strategy, the *rcf* was calculated for destinations that were part of the same route. In this strategy, the correlation factor is calculated for combinations of destinations that may not fall on the same route but share a large common route. For example the set of destinations: Wismar and BadSegeberg have a common route until Luebeck. The *rcf* for the different set of destinations with this strategy is selectively summarized in Table 6.3.

Table 6.3: Scenario SSMD – *rcf* using Strategy: Large Common Route

Destination #1 (Cluster Size)	Destination #2 (Cluster Size)	Destination #3 (Cluster Size)	Route Correlation Factor (*rcf*)
Wismar (20)	Luebeck (10)	-	0.859
	Hamburg (30)	-	0.652
	BadSegeberg (20)	-	0.806
	Luebeck (10)	BadSegeberg (20)	0.861
BadSegeberg (20)	Luebeck (10)	-	0.928
	Hamburg (30)	-	0.714
Luebeck (10)	Lueneburg (20)	-	0.649
	Hamburg (30)	-	0.782
Lueneburg (20)	Hamburg (30)	-	0.792

6.5.1.3 Scenario SSMD – *rcf* – Strategy based on Common Next Hop

In this strategy, the transport route of clusters is broken into multiple hops with the vehicles preferring to transport clusters to the common next hop. Thus, for the scenario depicted in Figure 6.4, the vehicles will first transport clusters to Hamburg irrespective of their final destinations. After reaching Hamburg, further decisions will be taken, whether to take clusters with next hop Luebeck or Lueneburg and so on. This implies that the transport decision of the vehicle to pick the different clusters are revised at each vertex.

6.5.2 Analysis of Total Transportation Cost (*TTC*) based Decision Process

Similar to the previous case (analysis of *rcf*) this section presents the theoretical calculation of the *TTC* using the SSMD scenario with different strategies and its impact on the transport decision process. For example, if a vehicle transports the cluster of a single destination at a time, the cost offered in monetary unit (mu) by the vehicles to the clusters is presented in Table 6.4. From the transportation cost values obtained, it can be concluded that the preferable vehicle for transportation is the medium or small sized vehicle due to the smaller cluster size.

And also, it can be concluded that in order to maximize the capacity utilization of the vehicles it is not advantageous for the vehicle to transport clusters to a single destination at a time but rather share the transport capacity with clusters of various destinations. Thus, this section analyses the effect of route correlation factor as well as the transportation cost using the different strategies on the overall capacity utilization of the vehicles. As discussed, the first two strategies take into account the final destination and the route choice of the vehicle to calculate the route correlation factor and the transportation cost of different clusters. But in in the case of third strategy, the vehicles base their routing and transport decision (which route and set of clusters to pick) solely on the next hop.

Table 6.4: Scenario-SSMD – *TTC* Offer for Single Clusters

Destination (Cluster Size)	**T_L (50)** mu	**T_M (30)** mu	**T_S (20)** mu
Hamburg (30)	43.33	31.33	35.00
Lueneburg (20)	96.50	69.05	50.75
Luebeck (10)	197.00	140.90	103.50
Wismar (20)	129.00	91.80	67.00
BadSegeberg (20)	113.00	80.60	59.00

The cost offers calculated by the vehicles only take into account the distance the vehicle will have to travel from the source of the cluster to cluster's destination and not the distance which the vehicle might have to travel to reach the source of the cluster (empty trips back to the source). Since the vehicle will be transporting clusters of more than one destination, different costs will be offered to the different destinations. For example, if the large vehicle offers transport to clusters destined to Hamburg (30) and Lueneburg (20), then the large vehicle will travel with full load of 50 packages (2 clusters of size 30 and 20) until Hamburg. The transportation cost calculated per distance (km) for the common route i.e. until Hamburg will be shared by the two clusters in proportion to their size. The transportation cost for the next stretch from Hamburg to Lueneburg would have to be paid by the cluster destined to Lueneburg alone. The transportation cost per trip will be shared by the two clusters proportional to their cluster size. To simplify the calculations, in Table 6.5 the overall transportation cost is calculated per package and not cluster. There can be other arrangements to share the transportation costs between the clusters but they are not investigated in this thesis.

If the clusters that are transported together have a high route correlation factor then this will lead to higher sharing of the costs amongst the clusters and hence a decrease in the overall costs incurred per individual cluster.

6.5.2.1 Scenario SSMD – *TTC* – Strategy based on Common Route

As described previously, in this strategy the vehicle is able to calculate the correlation of all those destinations that lie on a common path and then make a decision as to which set of clusters to transport. The different cost offers that the vehicle can make to the clusters are depicted in Table 6.5.

Table 6.5: Scenario SSMD – *TTC* Offer using Strategy: Common Route

Vehicle Type (Load Capacity)	Source-Destination	Cost Calculation	Cost per package (mu)
T_L (50)	Bremen-Hamburg (30) Bremen-Lueneburg (20)	(((8+2)*120) + 100)/50 (((8+2)*120/50) + ((8+2)*63)/20) + 100/50	26.00 57.50
	Bremen-Hamburg (30) Bremen-BadSegeberg(20)	(((8+2)*120) + 100)/50 (((8+2)*120/50) + ((8+2)*96)/20) + 100/50	26.00 74.00
	Bremen-Hamburg (30) Bremen-Wismar (20)	(((8+2)*120) + 100)/50 (((8+2)*120/50) + ((8+2)*128)/20) + 100/50	26.00 90.00
	Bremen-Hamburg (30) Bremen-Luebeck (10)	(((8+2)*120/40) + 100)/40 (((8+2)*120/50) + ((8+2)*67)/10) + 100/40	32.50 99.50
T_M (30)	Bremen-Hamburg (30)	(((6+1)*120) + 100)/30	31.33
	Bremen-BadSegeberg (20)	(((6+1)*216) + 100)/20	80.60
	Bremen-Lueneburg (20)	(((6+1)*183) + 100)/20	69.05
	Bremen-Wismar (20)	(((6+1)*248) + 100)/10	91.80

T_M (30)	Bremen-Luebeck (10)	(((6+1)*187) + 100)/10	140.90
	Bremen-Luebeck (10) Bremen-BadSegeberg (20)	(((6+1)*187) + 100)/30 (((6+1)*187/30) + ((6+1)*29)/20) + 100/30	46.97 57.12
	Bremen-Luebeck (10) Bremen-Wismar (20)	(((6+1)*187) + 100)/30 (((6+1)*187/30) + ((6+1)*61)/20) + 100/30	46.97 68.32
T_S (20)	Bremen-Wismar (20)	(((4+1)*248) + 100)/20	67.00
	Bremen-BadSegeberg (20)	(((4+1)*216) + 100)/20	59.00
	Bremen-Lueneburg (20)	(((4+1)*183) + 100)/20	50.75
	Bremen-Luebeck (10)	(((4+1)*187) + 100)/10	103.50

6.5.2.2 Scenario SSMD – *TTC* – Strategy based on Large Common Route

In some scenarios, the transport topology might not always be directly connected (missing links between nodes). Thus, sometimes it may be helpful to figure out destinations that do not lie on the same path but still have a very large common path as compared to the non-common part of the transport distance. For a fork topology with long arm and short length teeth, this strategy will result in a combined transport of the clusters until the base of the forks. This strategy provides more flexibility in transport of the clusters to various destinations. By choosing clusters destined to destinations that do not lie on the same route, a larger vehicle may be used on the common path and then smaller vehicles can transport the individual clusters to their final destinations. Thereby, the transportation cost for the packages can be optimized and at the same time the profit of the vehicle can be maximized by virtue of operating near the full capacity load. The cost of packages for large common route strategy is depicted in Table 6.6.

Table 6.6: Scenario SSMD – *TTC* Offer using Strategy: Large Common Route

Destination	**T_L**	**T_M**	**T_S**	**Cost Calculation**	**Cost per package (mu)**
Lueneburg + Hamburg	Bremen-Hamburg-Lueneburg	-	-	Refer table 6.5	57.50
	Bremen-Hamburg	Hamburg-Lueneburg	-	25 + 24.55	49.55
		-	Hamburg-Lueneburg	25 + 18.25	43.25
BadSegeberg + Hamburg	Bremen-Hamburg-BadSegeberg	-	-	Refer table 6.5	74.00
	Bremen-Hamburg	Hamburg-BadSegeberg	-	25 + 36.10	61.10
		-	Hamburg-BadSegeberg	25 + 26.50	51.50

BadSegeberg + Luebeck	-	Bremen-Luebeck-BadSegeberg	-	Refer table 6.5	57.12
	-	Bremen-Luebeck	Luebeck-BadSegeberg	45.30 + 9.75	55.05
Wismar + Hamburg	Bremen-Hamburg-Wismar	-	-	Refer table 6.5	90.00
	Bremen-Hamburg	Hamburg-Wismar	-	25 + 47.30	72.30
		-	Hamburg-Wismar	25 + 34.50	59.50
Wismar + Luebeck	-	Bremen-Luebeck-Wismar	-	Refer table 6.5	68.32
	-	Bremen-Luebeck	Luebeck-Wismar	45.30 + 16.92	62.22
Luebeck + Hamburg	Bremen-Hamburg-Luebeck	-	-	Refer table 6.5	99.50
	Bremen-Hamburg	Hamburg-Luebeck	-	31.25 + 48.15	79.40
		-	Hamburg-Luebeck	31.25 + 34.75	66.00

6.5.2.3 Scenario SSMD – *TTC* – Strategy based on Common Next Hop

Table 6.7: Scenario SSMD – *TTC* Offer by Large Vehicle (T_L) using Strategy: Common Next-hop

Vertices Connection	**Cluster size**	**Cost Calculation**	**Cost per package (mu)**
Bremen-Hamburg	50	(((8+2)*120) + 100)/50	26.00
	30	(((8+2)*120) + 100)/30	43.33
	20	(((8+2)*120) + 100)/20	65.00
	10	(((8+2)*120) + 100)/10	130.00
Hamburg-Lueneburg	20	(((8+2)*63) + 100)/20	36.50
Hamburg-Luebeck	50	(((8+2)*67) + 100)/50	15.40
	30	(((8+2)*67) + 100)/30	25.67
	20	(((8+2)*67) + 100)/20	38.50
	10	(((8+2)*67) + 100)/10	77.00
Luebeck-BadSegeberg	20	(((8+2)*29) + 100)/20	19.50
Luebeck-Wismar	20	(((8+2)*61) + 100)/20	35.50

This strategy breaks the granularity of the destination based correlation into the smallest fragment, the common next hop. In this strategy, the vehicle is interested only in the clusters that have the same next hop. Thereby, the vehicles can have a lot of choice of clusters to transport on the common parts of the transport path. In the common next hop strategy, the vehicles calculate their transport cost for every stretch of link (road) between two cities with different loads (as a combination of cluster sizes). The costs for each size category of vehicles are presented in Tables 6.7 – 6.9. The drawback of this approach is that at every hop the clusters must be unloaded, a new set of clusters should be offered transport and finally the selected clusters shall be loaded on to the vehicle.

Table 6.8: Scenario SSMD – *TTC* Offer by Medium Vehicle (T_M) using Strategy: Common Next-hop

Vertices Connection	Cluster size	Cost Calculation	Cost per package (mu)
Bremen-Hamburg	30	(((6+1)*120) + 100)/30	31.33
	20	(((6+1)*120) + 100)/20	47.00
	10	(((6+1)*120) + 100)/10	94.00
Hamburg-Lueneburg	20	(((6+1)*63) + 100)/20	27.05
Hamburg-Luebeck	30	(((6+1)*67) + 100)/30	18.97
	20	(((6+1)*67) + 100)/20	28.45
	10	(((6+1)*67) + 100)/10	56.90
Luebeck-BadSegeberg	20	(((6+1)*29) + 100)/20	15.15
Luebeck-Wismar	20	(((6+1)*61) + 100)/20	26.35

Table 6.9: Scenario SSMD – *TTC* Offer by Small Vehicle (T_S) using Strategy: Common Next-hop

Vertices Connection	Cluster size	Cost Calculation	Cost per package (mu)
Bremen-Hamburg	20	(((4+1)*120) + 100)/20	35.00
	10	(((4+1)*120) + 100)/10	70.00
Hamburg-Lueneburg	20	(((4+1)*63) + 100)/20	20.75
Hamburg-Luebeck	20	(((4+1)*67) + 100)/20	21.75
	10	(((4+1)*67) + 100)/10	43.50
Luebeck-BadSegeberg	20	(((4+1)*29) + 100)/20	12.25
Luebeck-Wismar	20	(((4+1)*61) + 100)/20	20.25

6.6 Evaluation of Simulation Results

This section presents the simulation results for the different strategies discussed in section 6.1. After the clusters of the packages are complete (w.r.t. cluster size limit), the cluster-heads perform the route discovery for their respective destinations. After the route discovery process of the clusters, vehicles get the information about the various clusters generated at the different associated vertices in the logistical network.

To enhance the explanation of the individual strategies for the vehicles, the North-Germany roadmap (shown in Figure 6.5) is simplified to a "single-source with multiple-destinations" and "multiple-sources with a single-destination" and lastly a general scenario of "multiple-sources with multi-destination" is investigated. As mentioned earlier, there are 4 vehicles generated in the simulation scenario namely:

- Vehicle Large (T_L) with capacity = 50 packages
- Vehicle Medium -1 (T_M-1) with capacity = 30 packages
- Vehicle Medium -2 (T_M-2) with capacity = 30 packages
- Vehicle Small (T_S) with capacity = 20 packages

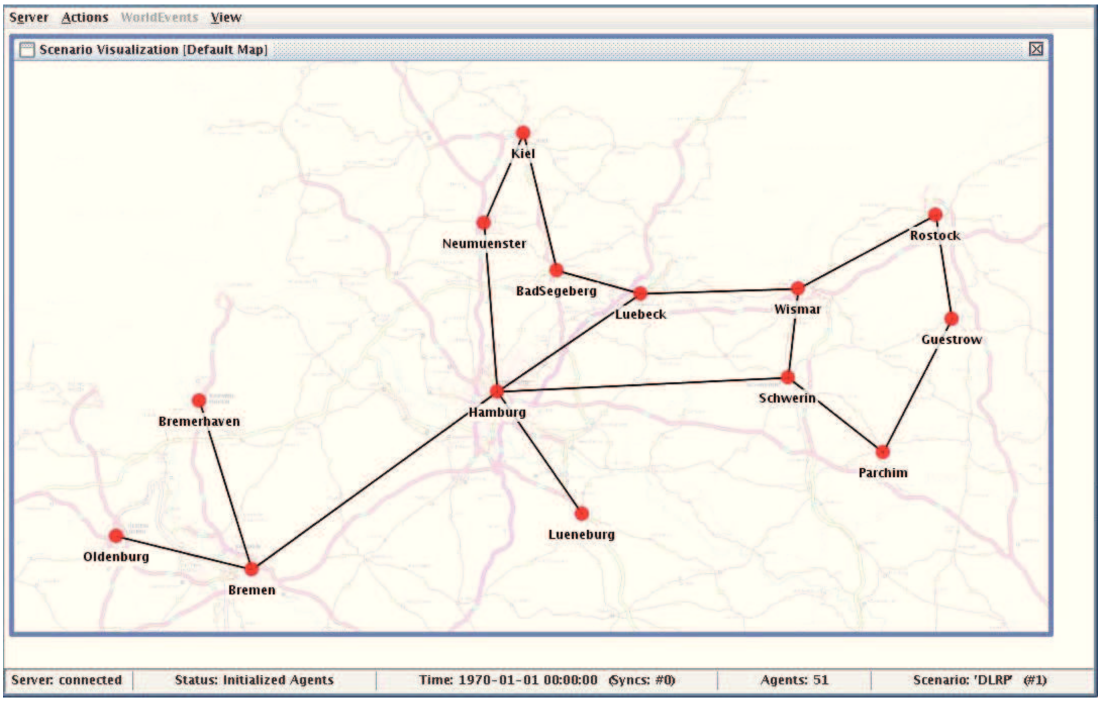

Figure 6.5: North Germany Road Map

6.6.1 Single Source with Multiple Destinations (SSMD)

The simulation scenario shown in Figure 6.4 assumes having a single source 'Bremen' and multiple destinations – 'Hamburg, Luebeck, Lueneburg, Wismar and BadSegeberg'. Simulation results for the 100 cluster scenario is presented in the Appendix B.

6.6.1.1 Scenario SSMD – Single Cluster per Vehicle

Vehicles perform routing based on the destination information of the clusters formed at the associated vertex. Based on the size of the cluster and its own capacity, the vehicle chooses the destination to travel and hence offers transport to that particular cluster. In the example scenario presented in Figure 6.4, there are clusters of size 30, 20, 20, 20 and 10 destined to Hamburg, Wismar, BadSegeberg, Lueneburg and Luebeck, respectively. Since, there are only 4 vehicles but clusters for 5 different destinations, the cluster destined for Luebeck is not picked by any vehicle in their first choice. The medium sized vehicle, T_M-1 is successful in offering transport to the cluster going to Hamburg and hence attains 100% capacity utilization. The large vehicle, T_L only gets to transport a cluster of 20 packages to Lueneburg but it was still a preferable choice due to the smallest distance as compared to the other remaining clusters of the same size. The other medium sized vehicle, T_M-2 selects cluster destined to BadSegeberg while the smallest truck picks up the cluster destined to Wismar. After delivering the clusters to Hamburg, T-M-1 travels back to Bremen and then transports the remaining cluster to Luebeck. The capacity utilization is depicted in Table 6.10. In addition, the incurred cost per package for the clusters is also depicted in Table 6.10.

Table 6.10: Scenario SSMD – Single Cluster per Vehicle: Simulation result for *rcf* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Cost per package to Destination (mu)
Large (T_L)	Bremen-Lueneburg	40%	96.50
Medium1 (T_M-1)	Bremen-Hamburg	100%	31.33
	Hamburg-Bremen	0%	-
	Bremen-Luebeck	33.33%	140.90
Medium2 (T_M-2)	Bremen-BadSegeberg	66.67%	80.60
Small (T_S)	Bremen-Wismar	100%	67.00

The results depicted in Table 6.11 (the transport decision based on the transportation cost) are different from the results depicted in Table 6.10 (transport decision based on only the cluster size). The transportation costs, the different vehicles will offer to the different cluster-heads based on their destination are depicted in Table 6.4. Based on these offers, it is clear that the large vehicle's price offers are very high w.r.t. the other vehicles. Therefore, no cluster-head accepts the large vehicle's price offer. The cluster destined to Hamburg gets the best offer from the middle-sized vehicles and it accepts the offer from vehicle T_M-1. The other 4 remaining clusters all have a better offer from the small vehicle, but since they have to be transported one after the other, the cluster destined to Wismar is transported first followed by the cluster destined to BadSegeberg. Eventually, the cluster destined to Lueneburg accepts the offer from the other middle-sized vehicle, T_M-2. Finally, the cluster for Luebeck is delivered by the small vehicle.

Table 6.11: Scenario SSMD – Single Cluster per Vehicle: Simulation result for *TTC* based decision policy

Vehicle Type	**Source-Destination**	**Capacity Utilization**	**Cost per package to Destination (mu)**
T_L	-	-	-
T_M-1	Bremen-Hamburg	100%	31.33
T_M-2	Bremen-Lueneburg	66.67%	69.05
T_S	Bremen-Wismar	100%	67.00
	Wismar-Bremen	0%	-
	Bremen-BadSegeberg	100%	59.00
	BadSegeberg-Bremen	0%	-
	Bremen-Luebeck	50%	103.50

6.6.1.2 Scenario SSMD – Strategy based on the Common Route

From the results of the previous section, it is clear that the vehicles were not operating near their full capacity and hence correlation based on the routes to the destinations of the clusters can be used to enhance the vehicle capacity utilization. In this scenario, vehicles also perform routing for the destinations of the clusters stored at the associated vertex. Based on the size of the cluster and its own capacity, the vehicle chooses the destination where it prefers to travel. After the choice of the destination and the route, the vehicle checks if there are other cluster destinations on the same route (which it can transport). Thus, the vehicle offers transport to all those clusters whose destinations are on the selected route. As explained in section 6.5, in the SSMD scenario there are clusters of size 30, 20, 20, 20 and 10 destined to Hamburg, Wismar, BadSegeberg, Lueneburg and Luebeck, respectively (as depicted in Figure 6.4).

The results based on the *route correlation factor (rcf)* are depicted in Table 6.12. In this scenario, the medium sized vehicle, T_M-1 is successful in offering transport to the cluster going to Hamburg and hence attains 100% capacity utilization. The smallest truck, T_S picks up the cluster destined to Wismar, there by attaining the 100% capacity utilization. The other medium sized vehicle T_M-2 selects clusters destined to Luebeck and BadSegeberg based on the correlation between the two destinations. Thus, the vehicle T_M-2 first transports both the clusters to Luebeck. Then, after unloading the clusters destined to Luebeck the vehicle transports the remaining cluster to its destination, BadSegeberg. The large vehicle, T_L only gets to transport the last remaining cluster of 20 packages to Lueneburg.

Table 6.12: Scenario SSMD – Common Route Strategy – Simulation result for *rcf* based decision policy

Vehicle Type	**Source-Destination**	**Capacity Utilization**	**Cost per package to Destination (mu)**
Large (T_L)	Bremen-Lueneburg	40%	96.50
Medium1 (T_M-1)	Bremen-Hamburg	100%	31.33
Medium2 (T_M-2)	Bremen-Luebeck	100%	46.97
	Luebeck-BadSegeberg	66.67%	57.12
Small (T_S)	Bremen-Wismar	100%	67.00

Table 6.13: Scenario SSMD – Common Route Strategy – Simulation result for *TTC* based decision policy

Vehicle Type	**Source-Destination**	**Capacity Utilization**	**Cost per package to Destination (mu)**
T_L	Bremen-Hamburg	100%	26.00
	Hamburg-Lueneburg	40%	57.50
T_M-1	Bremen-Luebeck	100%	46.97
	Luebeck-BadSegeberg	66.67%	57.12
T_M-2	-	-	-
T_S	Bremen-Wismar	100%	67.00

The investigated results (Table 6.13) for the cost-based transport decisions show that the smaller vehicle picks up the cluster destined to Wismar. The cluster destined to Hamburg and Lueneburg are offered the best price for transport by the large vehicle, T_L, (refer Table 6.5 for offered prices). Similarly, the combination of clusters destined to BadSegeberg and Luebeck are transported by the middle-sized vehicle, T_M-1 while the other mid-sized vehicle is unused.

6.6.1.3 Scenario SSMD – Strategy based on Large Common Route

As in the previous two cases, vehicles perform routing for the destinations of the clusters stored at the associated vertex. The decision on which clusters to be transported is made by the vehicle based on the choice of different routes for the destinations of various clusters. In this case, clusters can be selected whose routes share a large common path but may get separated later on the route (refer Eq.6.4).

The results based on the *route correlation factor (rcf)* for the strategy based on large common route is depicted in Table 6.14. The scenario under consideration for this case is depicted in Figure 6.4. As seen in the table the medium sized vehicle, T_M-1 is once again successful in offering transport to the cluster going to Hamburg and hence attains 100% capacity utilization. The large vehicle, T_L identifies through the routing information that the clusters travelling to BadSegeberg, Wismar and Luebeck all have a common route until Luebeck. Since, the sum of the 3 clusters equals the capacity of the large vehicle it is the best option for the large vehicle to operate at full capacity. Thereby, T_L first transports all the 3 clusters to Luebeck and then further carries on the cluster of 20 packages to BadSegeberg. The small vehicle, T_S decides to transport the cluster of 20 packages to Lueneburg whereas the other medium sized vehicle, T_M-2 picks up the clusters destined to Wismar at Luebeck.

Table 6.14: Scenario SSMD – Large Common Route Strategy – Simulation result for *rcf* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Cost per package to Destination (mu)
T_L	Bremen-Luebeck	100%	39.40
	Luebeck-BadSegeberg	40%	53.90
T_M-1	Bremen-Hamburg	100%	31.33
T_M-2	Bremen-Luebeck	0%	-
	Luebeck-Wismar	66.67%	60.75
T_S	Bremen-Lueneburg	100%	50.75

The results of transport decision strategy based on the transportation cost for large common route are depicted in Table 6.15. In this strategy, the transportation costs were calculated for the common path and the non-overlapping part separately. With this strategy, the larger vehicle may transport the goods over the overlapping route and then the other smaller vehicles (comparatively with cheaper price offer) could transport clusters to their final destinations.

From Table 6.15, it can be seen that the small vehicle transports the cluster destined for Wismar. In the meanwhile, the clusters destined for Luebeck and BadSegeberg are transported to Luebeck by medium-sized vehicle T_M-1. At Luebeck both the clusters are unloaded and the cluster destined to BadSegeberg is further transported by the small vehicle, T_S. The large vehicle transports clusters for Hamburg and Lueneburg until Hamburg. After unloading, both the clusters at Hamburg and the cluster destined to Lueneburg is transported by the medium-sized vehicle, T_M-2. Thus, in this strategy, the vehicles operate close to their capacity and are able to offer a quick and cheap transport to the cluster of packages.

Table 6.15: Scenario SSMD – Large Common Route Strategy – Simulation result for *TTC* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Cost per package to Destination (mu)
T_L	Bremen-Hamburg	100%	26.00
T_M-2	Bremen-Hamburg	0%	-
	Hamburg-Lueneburg	66.67%	49.55
T_M-1	Bremen-Luebeck	100%	46.97
T_S	Bremen-Wismar	100%	67.00
	Wismar-Luebeck	0%	-
	Luebeck-BadSegeberg	100%	55.05

6.6.1.4 Scenario SSMD – Strategy based on Common Next Hop

In this strategy, the vehicles offer transport based only on the common next hop of the route. The results for this strategy using the values of *route correlation factor (rcf)* and *total transportation cost (TTC)* are depicted in tables 6.16 and 6.17, respectively.

From table 6.16, it can be seen that the cluster destined to Wismar is delivered to Hamburg by the small vehicle, T_S while the medium-sized vehicle, T_M-1 transports the cluster destined for Hamburg. The rest of the clusters, destined for Lueneburg, Luebeck and BadSegeberg are transported by the large vehicle to Hamburg. Then the small vehicle transports the cluster for Wismar to Luebeck and finally from Luebeck to Wismar. The medium vehicle, T_M-1 takes the clusters for BadSegeberg and Luebeck to Luebeck and then delivers the BadSegeberg destined cluster. The other medium vehicle, T_M-2 takes the clusters to Lueneburg.

Table 6.16: Scenario SSMD – Common Next Hop Strategy – Simulation result for *rcf* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Total Cost per package per hop (mu)	Cost per package to Destination (mu)
T_L	Bremen-Hamburg	100%	26.00	26.00
T_M-1	Bremen-Hamburg	100%	31.33	31.33
	Hamburg-Luebeck	100%	19.97	44.97
	Luebeck-BadSegeberg	66.67%	15.15	60.12
T_M-2	Bremen-Hamburg	0%	-	-
	Hamburg-Lueneburg	66.67%	27.05	53.05
T_S	Bremen-Hamburg	100%	35.00	35.00
	Hamburg-Luebeck	100%	21.75	21.75
	Luebeck-Wismar	100%	20.25	77.00

Table 6.17: Scenario SSMD – Common Next Hop Strategy – Simulation result for *TTC* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Total Cost per package per hop (mu)	Cost per package to Destination (mu)
T_L	Bremen-Hamburg Hamburg-Luebeck	100% 100%	26.00 15.40	41.40
T_M-1	Bremen-Hamburg	100%	31.33	31.33
T_M-2	-	-	-	
T_S	Bremen-Hamburg Hamburg-Lueneburg	100% 100%	35.00 20.75	55.75
	Lueneburg-Luebeck	0%	-	-
	Luebeck-BadSegeberg	100%	12.25	57.65
	BadSegeberg-Luebeck	0%		
	Luebeck-Wismar	100%	20.25	65.65

From Table 6.17, it can be seen that due to the lower cost offer made by larger vehicle, the hop from Hamburg to Luebeck is covered by the clusters of Wismar, Luebeck and BadSegeberg over the large vehicle. The small vehicle transports the cluster to Lueneburg from Hamburg. The small vehicle happened to also transport the same cluster from Bremen to Hamburg and therefore the total cost incurred by this cluster is the sum of the two hops as depicted in the Table 6.17.

6.6.1.5 Scenario SSMD – Common Next Hop Strategy – Cluster Size Limit 5

Compared to the previous cases, the simulation for the common next hop strategy was re-run for a smaller cluster size of magnitude 5. Similar to all the other cases, in this case too the vehicles perform routing for the destinations of the clusters stored at the associated vertex and based on the different choice of routes for the destinations of various clusters; the decision of the target clusters and the corresponding route is made. As the cluster size is small, the clusters are completed well before the clustering time-out is reached and hence, start the routing process earlier. This allows the vehicles to offer transport to the various clusters with respect to a common next hop, irrespective of their final destination.

Table 6.18: Scenario SSMD – Common Next Hop Strategy – Cluster Size Limit 5 – Simulation result for *rcf* based decision policy – vehicle capacity utilization

Vehicle Type	Source-Destination	Capacity Utilization	Cost per package per hop (mu)
T_L	Bremen-Hamburg	50%	52.00
T_M-1	Bremen-Hamburg	100%	31.33
	Hamburg-Luebeck	83.33%	22.76
	Luebeck-BadSegeberg	66.67%	15.15
T_M-2	Bremen-Hamburg	100%	31.33
	Hamburg-Luebeck	83.33%	22.76
	Luebeck-Wismar	66.67%	26.35
T_S	Bremen-Hamburg	100%	35.00
	Hamburg-Lueneburg	100%	20.75

In the example scenario (presented in Figure 6.4) for correlation based transport decision, vehicles T_S, T_M-1, T_M-2 and T_L take 4 (20), 6 (30), 5 (25) and 5 (25) clusters (packages) respectively to Hamburg as presented in Table 6.18. After reaching Hamburg, the vehicle T_S picks up the 4 clusters destined to Lueneburg. The medium sized vehicles, T_M-1 and T_M-2 take 5 clusters each to Luebeck. From Luebeck, T_M-1 and T_M-2 deliver clusters to BadSegeberg and Wismar, respectively. The total cost which the clusters had to pay to reach their respective destinations is depicted in Table 6.19.

Table 6.19: Scenario SSMD – Common Next Hop Strategy – Cluster Size Limit 5 – Simulation result for *rcf* based decision policy – cluster transport

Destination	Cluster No.	Vehicle	Cost per package (mu)	Total Cost per package until Hamburg (mu)	Cost per package to their Destination (mu)
Hamburg (30)	5, 6	T_L	52.00	(52*2 + 31.33*(2+1) + 35.00*1)/6 = 39.83	39.83
	4	T_M-2	31.33		
	2, 3	T_M-1	31.33		
	1	T_S	35.00		
Lueneburg (20)	4	T_L	52.00	(52*1 + 31.33*3)/4 = 36.49	36.497 + 20.75(T_S) = 57.24
	3	T_M-2	31.33		
	1, 2	T_M-1	31.33		
Luebeck (10)	2	T_M-1	31.33	(31.33 + 35.00)/2 = 33.17	33.165 + 22.76(T_M-1/2) = 55.93
	1	T_S	35.00		
BadSegeberg (20)	3, 4	T_L	52.00	(52*2 + 31.33*(1+1))/4 = 41.67	41.665+ 22.76(T_M-1/2)+ 15.15(T_M-1) = 79.58
	2	T_M-2	31.33		
	1	T_M-1	31.33		
Wismar (20)	3, 4	T_M-2	52.00	(31.33*2 + 35*2)/4 = 33.17	33.165 + 22.76(T_M-1/2)+ 26.35(T_M-2) = 82.28
	1, 2	T_S	35.00		

Table 6.20: Scenario SSMD – Common Next Hop Strategy – Cluster Size Limit 5 – Simulation result for *TTC* based decision policy – vehicle capacity utilization

Vehicle Type	Source-Destination	Capacity Utilization
T_L	Bremen-Hamburg	100%
	Hamburg-Luebeck	100%
T_M-1	Bremen-Hamburg	100%
T_M-2	-	-
T_S	Bremen-Hamburg	100%
	Hamburg-Lueneburg	100%
	Lueneburg-Luebeck	0%
	Luebeck-Wismar	100%
	Wismar-Luebeck	0%
	Luebeck-BadSegeberg	100%

The capacity utilization of the different vehicles for the transport decision based on the transportation cost is depicted in Table 6.20, while the total cost incurred by the clusters for transportation to their respective destinations is depicted in table 6.21. Since the large vehicle offers the lowest transportation cost when utilized to a full capacity, it can be seen that the clusters, even though they are smaller in size, prefer to be transported by the larger vehicle and hence are ready to wait until the large vehicle is fully loaded. Thus, the clusters (of different destinations) are first loaded onto the larger vehicle for transportation to the first hop i.e., Hamburg. The rest of the clusters at Bremen are transported to Hamburg with the medium-sized vehicle, T_M-1 and the small vehicle, T_S. The clusters that were transported by the small vehicle first chose the medium sized vehicle T_M_2 but since it was not fully loaded, the transportation cost offer was 47.00, much higher than the offer made by the small vehicle. Similar to the case where the first hop is Hamburg, in the case of next hop as Luebeck too, the clusters prefer the larger vehicle T_L while the small vehicle T_S delivers the cluster to Lueneburg from Hamburg. Later the small vehicle also delivers the clusters to Wismar and BadSegeberg from Luebeck one after the other.

Table 6.21: Scenario SSMD – Common Next Hop Strategy – Cluster Size Limit 5 – Simulation result for *TTC* based decision policy – cluster transport

Destination	**Cluster No.**	**Vehicle**	**Cost per package (mu)**	**Total Cost per package until Hamburg (mu)**	**Cost per package to their Destination (mu)**
Hamburg (30)	1, 2, 3	T_L	26.00	(26*3 + 31.33*2 + 35.00*1)/6 = 29.28	29.28
	4, 5	T_M-1	31.33		
	6	T_S	35.00		
Lueneburg (20)	1, 2	T_L	26.00	(26*2 + 31.33*2)/4 = 28.42	28.415 + 20.75(T_S) = 49.17
	3, 4	T_M-1	31.33		
Luebeck (10)	1	T_M-1	31.33	(31.33 + 35.00)/2 = 33.17	33.165 + 15.40(T_L) = 48.57
	2	T_S	35.00		
BadSegeberg (20)	1, 2, 3	T_L	26.00	(26*3 + 31.33)/4 = 27.33	27.332 + 15.40(T_L) + 12.25(T_S) = 54.99
	4	T_M-1	31.33		
Wismar (20)	1, 2	T_L	26.00	(26*2 + 35*2)/4 = 30.50	30.50 + 15.40(T_L) + 20.25(T_S) = 66.15
	3, 4	T_S	35.00		

6.6.1.6 Results Summary for SSMD Scenario

From the obtained results for the scenario depicted in Figure 6.4, it can be ascertained that the transportation cost based approach reduces the overall transportation cost incurred by the clusters when compared to the simple *route correlation factor* based approach (for all the different strategies). Since the transport cost calculation formula is inversely proportional to the carried load, the vehicles capacity utilization is inherent in the cost calculations. Therefore, the reduced transportation cost is obtained by maximizing the capacity utilization of the different available vehicles while offering transport to the clusters. Since the empty trips cost is not levied on the clusters, transportation cost based decisions may lead to more empty trips given the vehicle wants to make such a trip.

In comparison to the different strategies of utilization of the information about the correlation of routes to the destination, the strategies based on the common next hop and large common route perform better than the strategy that utilized the information of destinations that lie on the common route when empty trips are not considered, as seen in Table 6.22.

Table 6.22: Scenario SSMD – Overall Capacity utilization (OCU) for different strategies (excluding empty trips)

Strategy	Common Route	Large Common Route	Common Next Hop	Single Cluster per Vehicle
Correlation Factor	84.42%	93.49%	95.25%	67.86%
Transportation Cost	92.66%	96.75%	100%	83.86%

It is important to note the empty trips, the vehicles have to make in order to offer transport to all the clusters of packages. This holds true for all the scenarios discussed in this chapter, i.e., it is important to note that the vehicle bears the cost of the empty trips and does not levy it to the cluster of packages in its transportation offer. Thus, the decision to perform an empty trip in order to offer the transport to a cluster solely lies with the vehicle. To consider the empty trips made by the vehicles, the following performance metric has been defined to determine the overall capacity utilization, OCU for the different strategies.

$$OCU = 1 - \frac{\sum_{\text{all trips (including empty trips)}} \left(1 - \frac{\%Utilization\_per\_Route}{100}\right) * \text{Distance}}{\sum_{\text{all trips (including empty trips)}} \text{Distance}} \quad 6.7$$

Table 6.23 represents the overall capacity utilization (along with empty trips) of the different scenarios in percentage. In contrast to the results depicted in Table 6.22 (OCU excluding empty trips), Table 6.23 depicts that when empty trips are taken into account, the "Common Route" strategy has the highest percentage of OCU. This is due to the fact that the common route strategy only takes the clusters that have their destination on the route and thereby the number of empty trips required is less. On the other hand, the large common route strategy represents a fork-like topology and therefore results in multiple empty trips by the vehicle to the base of the fork. The common next hop strategy shows a relatively better performance when compared to the large common route strategy but not as good as the common route strategy. The common next hop strategy also results in higher number of loading and unloading process, as depicted in Table 6.24.

Table 6.23: Scenario SSMD – Overall Capacity utilization for different strategies (including empty trips)

Strategy	Common Route	Large Common Route	Common Next Hop	Single Cluster per Vehicle
Correlation Factor	84.42%	70.70%	80.29%	60.29%
Transportation Cost	92.66%	75.54%	78.48%	56.40%

Table 6.24: Scenario SSMD – Loading/unloading of clusters for different strategies

Vehicle	Amount of Loading/Unloading of Clusters (Packages)							
	Single Cluster per Vehicle		Common Route		Large Common Route		Common Next Hop	
	rcf	*TTC*	*rcf*	*TTC*	*rcf*	*TTC*	*rcf*	*TTC*
Large, T_L	1 (20)	0 (0)	1 (20)	2 (70)	2 (70)	1 (50)	1 (50)	2 (100)
Medium, T_M_1	2 (40)	1 (30)	1 (30)	2 (50)	1 (30)	1 (20)	3 (80)	1 (30)
Medium, T_M_2	1 (20)	1 (20)	2 (50)	0 (0)	1 (20)	1 (30)	1 (20)	0 (0)
Small, T_S	1 (20)	3 (50)	1 (20)	1 (20)	1 (20)	2 (40)	3 (60)	4 (80)

6.6.2 Multiple Sources with Single Destination (MSSD)

Similar to the single-source with multiple-destinations scenario, the road map of North Germany (Figure 6.5) is simplified to a multiple-sources with a single-destination (MSSD) scenario as depicted in Figure 6.6. In the investigated scenario, the single destination is Hamburg and the rest of the depicted cities are the sources for the packages in different numbers.

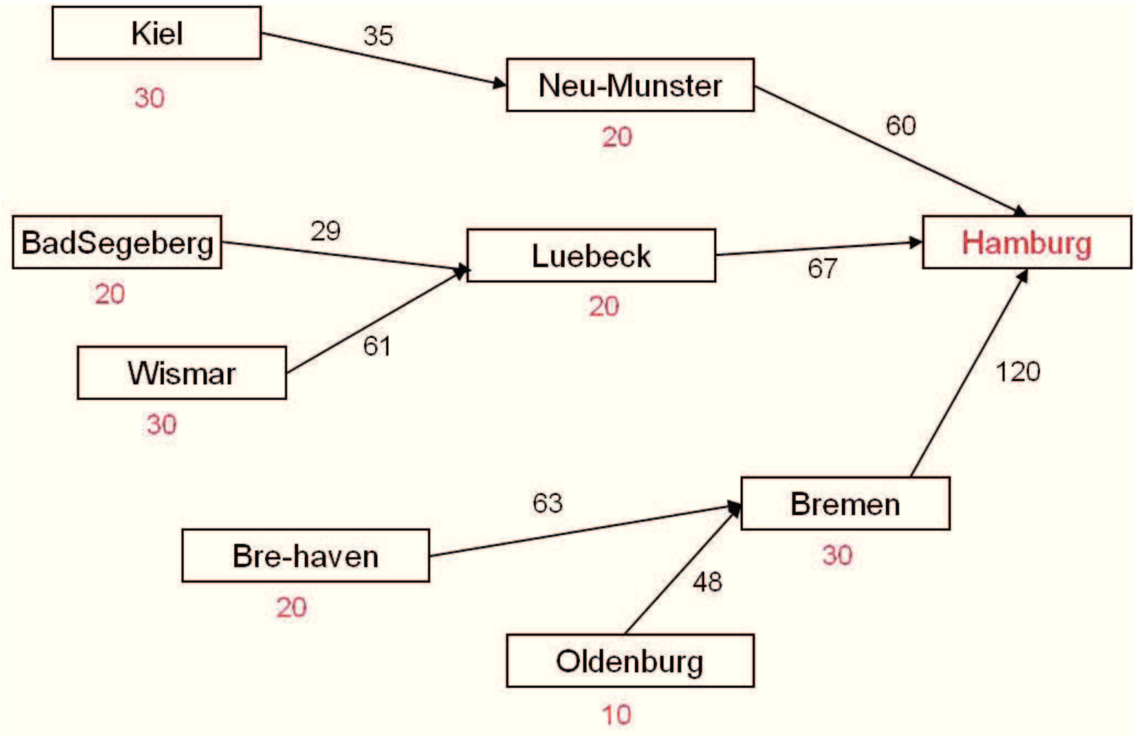

Figure 6.6: Multiple Sources with Single-Destination (MSSD) Scenario

6.6.2.1 Scenario MSSD – Strategy based on Common Route

For the scenario depicted in Figure 6.6, the large vehicle starts at Luebeck and it travels to Wismar to pick up the packages to be transported to Hamburg. On the way to Hamburg, it also picks up the clusters generated at Luebeck. The medium sized vehicle starts at Hamburg and it offers transport to the clusters formed at Bremen tobe delivered to Hamburg. The other medium vehicle starts at Bremerhaven and hence offers transport to the cluster at Bremerhaven. The small vehicle transports first the cluster formed at BadSegeberg to Hamburg and then further travels to Oldenburg to pick up the formed cluster. The clusters generated at Kiel and Neumuenster are transported by the large vehicle. The results based on the *route correlation factor (rcf)* for the strategy based on common route is depicted in Table 6.25.

Table 6.25: Scenario MSSD – Common Route Strategy – Simulation result for *rcf* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Total cost per package from Source to Final Destination (mu)
T_L	Luebeck-Wismar Wismar-Luebeck Luebeck-Hamburg	0% 60% 100%	- (61km) 39.07 15.40
	Hamburg-Kiel Kiel-Neumuenster Neumuenster-Hamburg	0% 60% 100%	- (95km) 29.00 14.00
T_M-1	Hamburg-Bremen Bremen-Hamburg	0% 100%	- (120km) 31.33
T_M-2	Bremerhaven-Hamburg	66.67%	69.05
T_S	BadSegeberg-Hamburg	100%	29.00
	Hamburg-BadSegeberg Oldenburg-Hamburg	0% 50%	- (96km) 94.00

For the transport decision based on the transportation cost offers by the different vehicles, the results are depicted in table 6.26. Though the clusters are formed at multiple sources, they are all destined to the same destination and therefore, the results are very similar to the approach based on the *route correlation factor* alone. There is only a small difference, i.e., the small vehicle transports packages from Bremerhaven instead of the medium-sized vehicle T_M-2 as the offer by the small vehicle appears before the cut-off time of the clusters decision at Bremerhaven.

Table 6.26: Scenario MSSD – Common Route Strategy – Simulation result for *TTC* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Total cost per package from Source to Final Destination (mu)
T_L	Luebeck-Wismar	0%	- (61km)
	Wismar-Luebeck	60%	39.07
	Luebeck-Hamburg	100%	15.40
	Hamburg-Kiel	0%	- (95km)
	Kiel-Neumuenster	60%	29.00
	Neumuenster-Hamburg	100%	14.00
T_M-1	Hamburg-Bremen	0%	- (120km)
	Bremen-Hamburg	100%	31.33
T_M-2	-	-	-
T_S	BadSegeberg-Hamburg	100%	29.00
	Hamburg-Bremerhaven	0%	- (183km)
	Bremerhaven-Hamburg	100%	50.75
	Hamburg-Oldenburg	0%	- (168km)
	Oldenburg-Hamburg	50%	94.00

6.6.2.2 Scenario MSSD – Strategy based on Large Common Route

Table 6.27: Scenario MSSD – Large Common Route Strategy – Simulation result for *rcf* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Total cost per package from Source to Final Destination (mu)
T_L	Luebeck-Wismar	0%	- (61km)
	Wismar-Luebeck	60%	39.07
	Luebeck-Hamburg	100%	15.40
	Hamburg-Kiel	0%	- (95km)
	Kiel-Neumuenster	60%	29.00
	Neumuenster-Hamburg	100%	14.00
T_M-1	Hamburg-Bremen	0%	- (120km)
	Bremen-Hamburg	100%	31.33
T_M-2	Bremerhaven-Bremen	66.67%	27.05
	Bremen-Oldenburg	0%	- (48km)
	Oldenburg-Bremen	33.33%	43.06
	Bremen-Hamburg	100%	31.33
T_S	BadSegeberg-Hamburg	100%	29.00

In this strategy, the vehicle offers transport to clusters formed at cities that do not lie on the same path. In the simulated scenario (depicted in Figure 6.6), the medium sized vehicle T_M-2 picks up the clusters at Bremerhaven and then travels to Oldenburg before delivering the two clusters at Hamburg. The rest of the behavior is similar to the one for the strategy with common route, as can be seen from Table 6.27.

Table 6.28: Scenario MSSD – Large Common Route Strategy – Simulation result for *TTC* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Total cost per package from Source to Final Destination (mu)
T_L	Luebeck-Wismar Wismar-Luebeck Luebeck-Hamburg	0% 60% 100%	- (61km) 39.07 15.40
	Hamburg-Neumuenster Neumuenster-Hamburg	0% 100%	- (60km) 14.00
T_M-1	Hamburg-Bremen Bremen-Hamburg	0% 100%	- (120km) 31.33
	Hamburg-Kiel Kiel-Neumuenster	0% 100%	- (95km) 25.50
T_S	BadSegeberg-Hamburg	100%	29.00
	Hamburg-Bremerhaven Bremerhaven-Bremen	0% 100%	- (183km) 52.08
	Bremen-Oldenburg Oldenburg-Bremen	0% 50%	- (48km) 65.33
T_M-2	Bremerhaven-Bremen Bremen-Hamburg	0% 100%	- (63km) 31.33

The results for the approach based on transportation cost are depicted in Table 6.28. The table shows that some of the results are similar to the earlier presented ones. The results show that the clusters generated at Bremerhaven and Oldenburg are transported to Bremen by the small vehicle in a sequential order. At Bremen, both the clusters are then loaded onto the medium-sized vehicle. Similarly, the cluster generated at Kiel is first transported to Neumuenster by the medium-sized vehicle, T_M-1 and then the large vehicle transport the cluster generated at Kiel to Hamburg along with the cluster generated at Neumuenster. Thus, for most of the sources the best utilization of vehicle capacity is obtained.

6.6.2.3 Scenario MSSD – Strategy based on Common Next Hop

This strategy results in a quite different behavior as compared to the previous two strategies. The results are listed in Table 6.29. The vehicles transport the clusters generated near to the city where they are stationed i.e., the large vehicle transports first the cluster from Wismar to Luebeck and then transports 2 clusters (generated at Wismar and Luebeck) to Hamburg. The medium-sized vehicle, T_M-1 travels to Bremen to transport the cluster to Hamburg whereas the other medium-sized vehicle, T_M-2 transports the packages from Bremerhaven to Bremen. T_M-1 then travels to Kiel to offer transport to the cluster formed there while T_M_2 travels to Oldenburg to transport clusters from Oldenburg to Bremen. Thus, T_M_1 transports the cluster from Kiel to Hamburg via Neumuenster and T_M-2 transports the clusters generated at Oldenburg and Bremerhaven to Hamburg via Bremen. In the meantime, the small vehicle transports the cluster generated at BadSegeberg to Luebeck and then further on to Hamburg before travelling to Neumuenster to transport the cluster formed at Neumuenster.

Table 6.29: Scenario MSSD – Common Next Hop – Simulation result for *rcf* based decision policy

Vehicle Type	**Source-Destination**	**Capacity Utilization**	**Total cost per package per Hop (mu)**	**Total cost per package from Source to Final Destination (mu)**
T_L	Luebeck-Wismar	0%	-	-
	Wismar-Luebeck	60%	23.63	39.03
	Luebeck-Hamburg	100%	15.40	15.40
T_M-1	Hamburg-Bremen	0%	-	-
	Bremen-Hamburg	100%	31.33	31.33
	Hamburg-Kiel	0%	-	-
	Kiel-Neumuenster	100%	11.5	28.83
	Neumuenster-Hamburg	100%	17.33	
T_M-2	Bremerhaven-Bremen	66.67%	27.05	58.38
	Bremen-Oldenburg	-	-	-
	Oldenburg-Bremen	33.33%	43.06	74.93
	Bremen-Hamburg	100%	31.33	
T_S	BadSegeberg-Luebeck	100%	12.25	34.00
	Luebeck-Hamburg	100%	21.75	
	Hamburg-Neumuenster	0%	-	-
	Neumuenster-Hamburg	100%	20.00	20.00

When the common next hop strategy is combined with the transportation cost based approach, the results change slightly when compared to correlation alone, as depicted in table 6.30. The clusters formed at Bremerhaven and Oldenburg is transported to their next hop Bremen by the small vehicle before the medium-sized vehicle, T_M-2, transports these two clusters from Bremen to Hamburg. Similarly, the other medium-sized vehicle, T_M-1, transports the cluster formed at Kiel to Neumuenster after transporting the cluster formed at Bremen to Hamburg. From Neumuenster, the large vehicle transports the cluster that was generated at Neumuenster and the other cluster that was transported from Kiel to Neumuenster.

Table 6.30: Scenario MSSD – Common Next Hop - Simulation result for *TTC* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Total cost per package from Source to Final Destination (mu)
T_L	Luebeck-Wismar	0%	-
	Wismar-Luebeck	60%	39.03
	Luebeck-Hamburg	100%	15.40
	Hamburg-Neumuenster	-	-
	Neumuenster-Hamburg	100%	14.00
T_M-1	Hamburg-Bremen	0%	-
	Bremen-Hamburg	100%	31.33
	Hamburg-Kiel	0%	-
	Kiel-Neumuenster	100%	25.50
T_M-2	Bremen-Hamburg	100%	31.33
T_S	BadSegeberg-Luebeck	100%	34.00
	Luebeck-Hamburg	100%	
	Hamburg-Bremerhaven	0%	-
	Bremerhaven-Bremen	100%	52.08
	Bremen-Oldenburg	0%	-
	Oldenburg-Bremen	50%	65.33

6.6.2.4 Results Summary for MSSD Scenario

From the results obtained for the scenario depicted in Figure 6.6 and the OCU values without considering the empty trips are depicted in Table 6.31, it can be seen again that the transportation cost based approach is able to maximize the capacity utilization of the vehicles and thereby reduce the overall transportation cost when compared to the *route correlation factor* based approach. Comparing the different strategies to utilize the information about the correlation of routes to the destination, here also the strategies based on the common next hop and large common path perform better than the strategy that utilized the information of destination lying on the same path. The overall capacity utilization including empty trips is shown in Table 6.32. The depicted percentage values were calculated using Eq. 6.7. In contrast to the single source multiple destination scenario, here the vehicle has to make more empty trips (as there are multiple sources but only a single destination). Hence, the OCU is much less for all the different strategies.

Table 6.31: Scenario MSSD – Overall Capacity utilization for different strategies (excluding empty trips)

Strategy	Common Route	Large Common Route	Common Next Hop
Correlation Factor	76.78%	86.33%	89.37%
Transportation Cost	84.51%	92.78%	92.78%

Table 6.32: Scenario MSSD – Overall Capacity utilization for different strategies (including empty trips)

Strategy	Common Route	Large Common Route	Common Next Hop
Correlation Factor	49.40%	56.86%	58.80%
Transportation Cost	47.34%	48.05%	39.77%

The number of times that the vehicle has to load or unload the clusters for the various strategies is depicted in Table 6.33. Since the clusters are scattered at multiple sources, there is not much difference in the total number of times the clusters are loaded or unloaded for the different strategies.

Table 6.33: Scenario MSSD – Loading/unloading of clusters for different strategies

Vehicle	Amount of Loading/Unloading of Clusters (Packages)					
	Common Route		Large Common Route		Common Next Hop	
	rcf	*TTC*	*rcf*	*TTC*	*rcf*	*TTC*
Large, T_L	4 (100)	4 (100)	4 (100)	3 (100)	2 (50)	3 (100)
Medium, T_M_1	1 (30)	1 (30)	1 (30)	2 (60)	3 (90)	2 (60)
Medium, T_M_2	1 (20)	0 (0)	3 (60)	1 (30)	3 (60)	1 (30)
Small, T_S	2 (30)	3 (50)	1 (20)	3 (50)	3 (60)	4 (70)

6.6.3 Multiple Sources with Multiple Destinations – A (MSMD–A)

To have a more realistic scenario, a scenario with multiple sources and multiple destinations was setup as shown in figure 6.7. In this case, there are several sources with three destinations: Bremen, Hamburg and Kiel. In order to differentiate the destinations of the packages generated at a city, the first letter of the destination city is written in front of the numbers i.e., for packages destined to Kiel the denotation is a prefix ‘K’.

6.6.3.1 Scenario MSMD–A – Strategy based on Common Route

This section presents the results obtained for the scenario that is depicted in Figure 6.7 for the common route strategy. The results depicted in Table 6.34 show that the large vehicle, T_L, transports the clusters formed at Wismar and Luebeck to Hamburg. The medium-sized vehicle, T_M-1, that is present at Hamburg transports the cluster formed to Kiel and then transports to Bremen the cluster formed at Kiel. Finally, T_M-1 transports the cluster from Bremen to Hamburg. The other medium-sized vehicle transports the cluster formed at Bremerhaven to Hamburg followed by the transport of the cluster from Oldenburg to Kiel and then finally transports the cluster formed at Neumuenster to Hamburg. The small vehicle transports the cluster generated at BadSegeberg to Hamburg and then transports the cluster from Bremen destined to Kiel. From Kiel the small vehicle then transports the cluster destined for Hamburg.

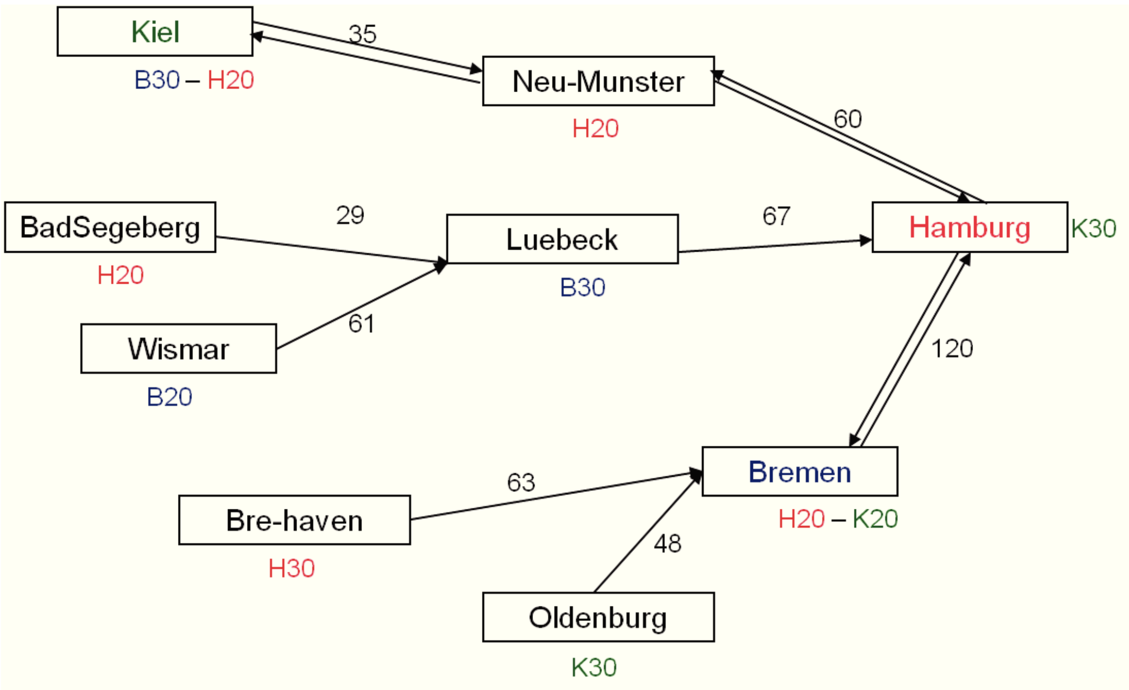

Figure 6.7: Multiple Sources with Multiple Destinations – A (MSMD–A) Scenario

Table 6.34: Scenario MSMD–A – Common Route – Simulation result for *rcf* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Total cost per package (mu)
T_L	Luebeck-Wismar	0%	(61km)
	Wismar-Luebeck	60%	69.90
	Luebeck-Bremen	100%	38.40
T_M-1	Hamburg-Kiel	100%	25.50
	Kiel-Bremen	100%	53.73
	Bremen-Hamburg	66.67%	47.00
T_M-2	Bremerhaven-Hamburg	100%	46.03
	Hamburg-Oldenburg	0%	(168km)
	Oldenburg-Kiel	100%	64.93
	Kiel-Neumuenster	0%	(35km)
	Neumuenster-Hamburg	66.67%	26.00
T_S	BadSegeberg-Hamburg	100%	29.00
	Hamburg-Bremen	0%	(120km)
	Bremen-Kiel	100%	58.75
	Kiel-Hamburg	100%	28.75

Table 6.35: Scenario MSMD–A – Common Route – Simulation result for *TTC* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Total cost per package (mu)
T_L	Luebeck-Wismar Wismar-Luebeck Luebeck-Bremen	0% 60% 100%	- (61km) 69.90 38.40
	Bremen-Oldenburg Oldenburg-Bremen Bremen-Kiel	0% 60% 100%	- (48km) 61.00 44.00
	Kiel-Neumuenster Neumuenster-Hamburg	40% 80%	37.50 17.50
T_M-1	Hamburg-Kiel	100%	25.50
	Kiel-Bremen	100%	53.73
T_M-2	Bremerhaven-Hamburg	100%	46.03
T_S	BadSegeberg-Hamburg	100%	29.00
	Hamburg-Bremen Bremen-Hamburg	0% 100%	- (120km) 35.00

Due to the distributed nature of the scenario, the *route correlation factor* based approach was able to obtain a very good result, achieving almost on all transports a 100% capacity utilization. But, the transportation cost offer based approach illustrates quite a different behavior which is depicted as results in Table 6.35. Here the cost drives all the decisions and therefore, the large vehicle is chosen to transport clusters generated at Oldenburg and Bremen to Kiel. After reaching Kiel, the large vehicle then transports the clusters generated at Kiel to Hamburg and on the way also transports the cluster formed at Neumuenster. The medium-sized vehicle, T_M-1, which is starting at Hamburg, transports the cluster to Kiel and then transports the cluster formed at Kiel to Bremen. The other medium-sized vehicle, T_M-2, transports the cluster generated at Bremerhaven to Hamburg. The small vehicle transports the clusters from BadSegeberg to Hamburg and then the cluster generated at Bremen to Hamburg.

6.6.3.2 Scenario MSMD–A – Strategy based on Large Common Route

The results for the r*oute correlation factor* based approach for the large common route strategy are depicted in Table 6.36. It is interesting to find that there is no difference in results when compared to the common route strategy due to the specific parameter values such as the cluster sizes. The favorable combinations for the scenario depicted in Figure 6.7 always happen to be of the destinations that lie on the same path.

Table 6.36: Scenario MSMD-A – Large Common Route - Simulation result for *rcf* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Total cost per package (mu)
T_L	Luebeck-Wismar	0%	- (61km)
	Wismar-Luebeck	60%	69.90
	Luebeck-Bremen	100%	38.40
T_M-1	Hamburg-Kiel	100%	25.50
	Kiel-Bremen	100%	53.73
	Bremen-Hamburg	66.67%	47.00
T_M-2	Bremerhaven-Hamburg	100%	46.03
	Hamburg-Oldenburg	0%	- (168km)
	Oldenburg-Kiel	100%	64.93
	Kiel-Neumuenster	0%	- (35km)
	Neumuenster-Hamburg	66.67%	26.00
T_S	BadSegeberg-Hamburg	100%	29.00
	Hamburg-Bremen	0%	- (120km)
	Bremen-Kiel	100%	58.75
	Kiel-Hamburg	100%	28.75

Though the results for the transportation cost based as depicted in Table 6.37 also shows similarities with the results presented in Table 6.35, but there is a minor difference. The medium-sized vehicle, T_M-2, transports the cluster generated at Oldenburg to Bremen. The final destination of this cluster is Kiel and therefore, the large vehicle transports it along with the cluster formed at Bremen to Kiel.

Table 6.37: Scenario MSMD–A – Large Common Route – Simulation result for *TTC* based decision policy

Vehicle Type	Source-Destination	Capacity Utilization	Total cost per package (mu)
T_L	Luebeck-Wismar Wismar-Luebeck Luebeck-Bremen	0% 60% 100%	- (61km) 69.90 38.40
	Bremen-Kiel	100%	44.00
	Kiel-Neumuenster Neumuenster-Hamburg	40% 80%	37.50 17.50
T_M-1	Hamburg-Kiel	100%	25.50
	Kiel-Bremen	100%	53.73
T_M-2	Bremerhaven-Hamburg	100%	46.03
	Hamburg-Oldenburg Oldenburg-Bremen	0% 100%	- (168km) 58.53
T_S	BadSegeberg-Hamburg	100%	29.00
	Hamburg-Bremen Bremen-Hamburg	0% 100%	- (120km) 35.00

6.6.3.3 Scenario MSMD–A – Strategy based on Common Next Hop

The results for both the *route correlation factor* approach and the transportation cost approach yield exactly the same results as depicted for the large common route strategy and hence are not depicted in this section. Therefore, this realistic scenario of multiple sources and multiple destinations clearly diminishes the differences between the different strategies but still points to the advantages of maximizing the vehicle capacity utilization and base the transport decision not merely on the correlation of the destinations but on the transportation cost that will be incurred by the clusters for the transport to their respective destinations.

6.6.3.4 Results Summary for MSMD–A Scenario

Table 6.38 and Table 6.39 show OCU values obtained while excluding and including the empty trips made by the vehicle, respectively.

Table 6.38: Scenario MSMD–A – Overall Capacity Utilization for different strategies (excluding empty trips)

Strategy	Common Route	Large Common Route	Common Next Hop
Correlation Factor	94.69%	94.69%	94.69%
Transportation Cost	94.17%	95.63%	95.63%

Since this scenario is more generic with multiple sources and multiple destinations, the overall capacity utilization of the vehicles show less variation with respect to various investigated strategies. In addition the number of empty trips is also limited, which results in better overall performance.

Table 6.39: Scenario MSMD–A – Overall Capacity utilization for different strategies (including empty trips)

Strategy	Common Route	Large Common Route	Common Next Hop
Correlation Factor	76.34%	70.85%	70.85%
Transportation Cost	80.28%	75.70%	75.70%

Table 6.40: Scenario MSMD–A – Loading/unloading of clusters for different strategies

Vehicle	Amount of Loading/Unloading of Clusters (Packages)					
	Common Route		Large Common Route		Common Next Hop	
	rcf	*TTC*	*Rcf*	*TTC*	*rcf*	*TTC*
Large, T_L	2 (50)	6 (140)	2 (50)	5 (140)	3 (130)	8 (340)
Medium, T_M_1	3 (80)	2 (60)	3 (80)	2 (60)	6 (170)	5 (150)
Medium, T_M_2	3 (80)	1 (30)	3 (80)	2 (60)	7 (200)	3 (90)
Small, T_S	3 (60)	2 (40)	3 (60)	2 (40)	7 (140)	3 (60)

The number of times the vehicle has to load or unload the clusters is depicted in Table 6.40. It can be seen from the results that the common next hop strategy results in a pretty large number of cluster loading/unloading process when compared to the other two strategies.

6.6.4 Multiple Sources with Multiple Destinations – B (MSMD–B)

Taking into consideration the scalability issue, the simulation results for a large network with 100 clusters was analysed using the scenario presented in Figure 6.5.

Table 6.41: Scenario MSMD–B – Packages generated for different Source–Destination Pairs in a large scenario with 100 Clusters

Source/Destination	Bremen (B)	Hamburg (H)	Kiel (K)	Total packages per Source
BadSegeberg	0	30	20	50
Bremen	X	100	50	150
Bremerhaven	50	50	50	150
Hamburg	50	X	100	150
Kiel	100	100	X	200
Luebeck	0	20	10	30
Neu-Munster	30	30	0	60
Oldenburg	30	30	30	90
Wismar	40	40	40	120
Total per destination	**300**	**400**	**300**	**1000**

Table 6.41 represents the number of packages generated at various Source Nodes for a set of 3 destinations i.e., Bremen, Hamburg and Kiel. In total 8 vehicles were used for the transportation of goods in this scenario (2 vehicles with a capacity of 50 packages – T_L_1 and T_L_2; 4 vehicles with a capacity of 30 packages – T_M_1, T_M_2, T_M_3 and T_M_4; 2 vehicles with capacity of 20 packages, T_S_1 and T_S_2). The performance based on capacity utilization of the vehicles is presented in Table 6.42. The detailed tables for this scenario are depicted in Appendix B.

The '# Clusters' column in Table 6.42 depicts the number of clusters being transported for different destinations while, the column 'vehicles' represents various vehicles that are used for the transportation of the clusters from the source to the final destination. The vehicle may also transport clusters to intermediate destinations that lie on the route to the final destination. And in a similar way, the vehicle can also load clusters from intermediate destinations for destinations that

- lie on the route to the final destination,
- is the final destination itself or
- have the final destination on its route.

Table 6.42: Scenario MSMD–B – Common Route Strategy – Sequence of Cluster Transportation by various Vehicles and Capacity Utilization for *TTC* based decision policy

Vehicle	Source	Intermediate Destination 1 (ID1)	Intermediate Destination 2 (ID2)	Final Destination (FD)	# Clusters			Capacity Utilization
					ID1	ID2	FD	
T_S_1	Hamburg	-	-	Kiel			2	100%
T_S_2	Kiel	Hamburg	-	Bremen	1		1	100%
		Hamburg	-	Bremen			1	100%
T_M_1	Oldenburg	Bremen	Hamburg	Kiel	1	1	1	100%
		Bremen	Hamburg			1		100%
			Hamburg	Kiel			2	100%
T_M_3	Luebeck	Hamburg	-	Kiel	2		1	100%
		Hamburg	-	Kiel			2	100%
T_M_4	Neu-Munster	Hamburg	-	Bremen	1		2	100%
		Hamburg	-	Bremen			1	100%
T_M_2	Wismar	Hamburg	-	Bremen	1		2	100%
		Hamburg	-	Bremen			1	100%
T_L_2	BadSegeberg	Hamburg	-	Kiel	3		2	100%
		Hamburg	-	Kiel			3	100%
T_L_1	Bremerhaven	Bremen	Hamburg	Kiel	2	2	1	100%
		Bremen	Hamburg	Kiel		1	1	100%
			Hamburg	Kiel			1	60%
T_S_1	Kiel	Hamburg	-	-	2			100%
		Hamburg	-	Bremen			2	100%
T_M_3	Kiel	-	-	Bremen			3	100%
T_M_4	Bremen	-	-	Hamburg			3	100%
T_S_2	Bremen	Oldenburg	-	-	0			0%
		Oldenburg	Bremen	-		2		100%
			Bremen	Hamburg			2	100%
T_L_2	Kiel	-	-	Hamburg			5	100%
T_M_1	Kiel	-	-	Bremen			3	100%
T_M_2	Bremen	Bremerhaven	-	-	0			0%
		Bremerhaven	Bremen	Kiel		1	2	100%
			Bremen	Kiel			1	100%
T_L_1	Kiel	-	-	Hamburg	2 + 3Bremen			100%
T_M_4	Hamburg	-	-	Bremen			3	100%
T_L_2	Hamburg	-	-	Wismar			0	0%
T_S_1	Bremen	-	-	Kiel			2	100%
T_M_3	Bremen	-	-	Hamburg			3	100%
T_S_2	Hamburg	-	-	Oldenburg			0	0%
T_L_2	Wismar	-	-	Hamburg	3 + 2Bremen			100%
T_M_2	Kiel	Neu-Munster	-	-	0			0%
		Neu-Munster	Hamburg	Bremen		2	1	100%
			Hamburg	Bremen			2	100%
T_L_1	Hamburg	-	-	Wismar			0	0%
T_M_1	Bremen	Bremerhaven	-	-	0			0%

		Bremerhaven	-	Hamburg			3	100%
T_S_2	Oldenburg	-	-	Kiel			2	100%
T_M_4	Bremen	Oldenburg Oldenburg	- -	- Hamburg	0		 2	0% 66.67%
T_M_2	Bremen	Bremerhaven Bremerhaven	- -	- Bremen	0		 2	0% 66.67%
T_L_1	Wismar	-	-	Kiel			4	80%
T_M_2	Bremen	Bremerhaven Bremerhaven	- - Bremen	- Kiel Kiel	0		 2 1	0% 66.67% 100%

In Table 6.42, the first row depicts that the small vehicle, T_S_1 transports two clusters (each of size 10 packages) from Hamburg to Kiel with a capacity utilization of 100%. The other small vehicle, T_S_2 picks up the clusters destined for Hamburg and Bremen from Kiel. After delivering the cluster destined for Hamburg, it has enough free capacity to pick up another cluster at Hamburg which is destined for Bremen. Thus, in total the vehicle, T_S_2 delivers 3 clusters, 1 to Hamburg and 2 to Bremen. Therefore for this entry in the Table 6.42, Hamburg is depicted as the Intermediate Destination 1 and in the column '# Clusters' 1 is depicted for the number of clusters delivered to the Intermediate Destination 1 (ID1). For the Final Destination, '# Clusters' depicts the two clusters that were delivered to Bremen differentiating between the source of the individual clusters i.e., Kiel and Hamburg. Coming to the next vehicle T_M_1 with a capacity of 30 packages, it can be seen from Table 6.42 that at Oldenburg it picks a cluster each for Bremen, Hamburg and Kiel. Interestingly, at Bremen after delivering the cluster destined for Bremen, the vehicle successfully offers transport to a cluster destined to Hamburg. Therefore, from Bremen to Kiel via Hamburg, the vehicle has 2 clusters for Hamburg and 1 for Kiel. At Hamburg, the vehicle unloads the 2 clusters and is able to offer transport to 2 other clusters destined to Kiel making it again 3 clusters on board the vehicle for the the final stretch of the route from Hamburg to Kiel.

From Table 6.42, it can also be seen that the vehicles try to utilize their capacity for the trips they make by transporting clusters for destinations lying on a route. Since, the vehicles use the concept of correlation of routes and the transportation cost, the preferance is always given to more clusters of the same destination. Thus, inherently the overall implemented concept tries to minimize the number of times the vehicle has to load or unload on a route, while making sure that the transport is offered in quick time and with a higher capacity utilization.

Table 6.43: Scenario MSMD–B – Overall Capacity utilization for *TTC* based decision policy

Strategy	Common Route	Large Common Route	Common Next Hop
Excluding Empty Trips	96.49%	95.38%	95.94%
Including Empty Trips	83.02%	82.33%	82.55%

Table 6.44: Scenario MSMD–B – Loading/unloading of clusters for different strategies

Vehicle	Amount of Loading/Unloading of Clusters (Packages)		
	Common Route	Large Common Route	Common Next Hop
	TTC	*TTC*	*TTC*
Large, T_L_1	17 (170)	18 (180)	44 (440)
Large, T_L_2	18 (180)	18 (180)	40 (400)
Medium, T_M_1	12 (120)	14 (140)	24 (240)
Medium, T_M_2	18 (180)	16 (160)	33 (330)
Medium, T_M_3	11 (110)	14 (140)	21 (210)
Medium, T_M_4	12 (120)	14 (140)	16 (160)
Small, T_S_1	8 (80)	8 (80)	16 (160)
Small, T_S_2	9 (90)	9 (90)	16 (160)

Table 6.43 depicts the "Overall Capacity Utilization" of the three strategies that were introduced in this thesis and evaluated for the multiple source and multiple destination scenario with 100 clusters. In the investigated scenario, the three destinations lie on the path from Kiel to Bremen via Hamburg and for sources that do not lie on this path, Hamburg acts as the diverging point for the other two destinations. Therefore, it is more likely that the strategy that prefers the destinations on the same route should perform better and can be verified from Table 6.43. The common next hop approach is the next best as it starts similar to the large common route strategy and then later on follows the common route strategy pattern as all the clusters are formed and the vehicle can transport more clusters to the same destination. The performance of the individual strategies depends on the initial distribution of the vehicles in the scenario as well as that of the packages generated at different sources for various destinations.

Table 6.44 shows the number of times the clusters are loaded and unloaded from the vehicles. Due to the scattered sources all around the scenario, there is not much difference between the different strategies.

6.7 Conclusion

In this chapter the role of different parameters, such as the correlation of the routes to the different destinations and the total transportation cost was described with the help of different scenarios. Three different strategies were developed and investigated to illustrate the transportation cost incurred by clusters depending on the cluster size as well as on the distance of route to the destination. Based on these strategies two different parameters; correlated information of the route and the capacity utilization of vehicles were used for the transport decisions. Eventually, the simulation results were presented for the same.

Conclusion

From the obtained results for different possible transport logistic scenarios, it is clear that the transport decisions though very complex can be simplified by exploiting the available information in the logistical network. An example of such information is the preferred route, the distance to the destination and the intermediate destinations on the route, the cluster size and so on. Different scenarios presented depict the advantages of the ‘common route’, ‘common next hop’ and ‘large common route’ strategies and at the same time also underline the fact that the performance of a strategy may depend on the distribution of the sources and destinations in the logistical network along with the size of the clusters formed.

Additionally, the gain in reducing the overall transportation cost of the logistical network based on the transport decisions is presented. The model used by the vehicles to calculate the transportation cost of a cluster on a route takes into account the profit per unit distance as well as profit per trip so that the vehicle can maximize its profit. In addition, the vehicles can decide to travel empty trips in order to offer transport to formed cluster of packages. The cost of the empty trip in the implemented cost model is not levied on the clusters and hence is not considered by the vehicle while offering transport to the clusters. But, with different cost models the cost may be shared or negotiated with the cluster. As future work, different cost models for the vehicles may be considered where the empty trip cost may be shared or negotiated with the cluster. In order to be fair to the clusters the vehicle informs the clusters about the price offer when utilized to its full capacity. Thus, the clusters have the incentive to share the vehicle capacity to reduce the overall cost.

From the simulation results, it can be seen that the ‘common route’ strategy often performs the best as it makes sure that the selected clusters are transported to their respective desitinations. The ‘large common route’ strategy also performs well most of the time as it allows for clusters destined to a small region to be transported together even if their destinations do not lie on the same route. But ‘large common route’ strategy may lead small distances of transport with unsufficiently utilized capacity. The ‘common next hop’ strategy bases its decision on short hop distances and hence brings about large computational complexity along with the added risk or multiple loading and unloading process. The ‘common route’ strategy leads to minimal number of loading and unloading events and it can be identified as the best strategy that will yield good capacity utilization for the vehicles at a reasonable transportation cost.

Therefore, it can be concluded that the obtained set of solutions result in an efficient cooperative logistical network. Finding optimal combinations of clusters introduces high processing requirement and may even lead to scalability issues for large logistical network[RMS09] and therefore was not considered in this work.

CHAPTER **7**

7. Automated Negotiation in Logistics: Background

The previous chapters discussed the topics related to clustering, cluster-based routing and also the cluster based transportation issues like capacity utilization and transportation cost. In addition to that, in this chapter the author introduces the concept of automated negotiation. The idea behind the integration of the concept of automated negotiation in the cluster-based routing method is to bring about more flexibility in the transport decisions. Once the information regarding the transportation cost for the chosen route is known by the vehicles and the clusters, they can negotiate the transportation cost. Thus, this chapter introduces the concept of negotiation as well as strategies and protocols adapted for the dynamic and complex logistics network.

7.1 Introduction

Negotiation is a means for the negotiating entities to communicate to reach mutually beneficial agreements [Rai82, FU81, Pru81, You75 and Har56]. For example, the buyer would prefer a low price for the service it is purchasing and the seller prefers a high price for the service it is offering. In addition to attempting the best deal, the entities should need to ensure that the negotiation terminates before a certain deadline. In case of a logistics scenario, the vehicle would be the seller who is offering service of transportation to the packages who are the buyers of that service offered by the vehicles. Hence, one of the important aspects the package considers is the best price deal in the process of negotiation. In this process, the negotiation time deadline also plays a crucial role. Another crucial feature of negotiation is the negotiating strategy which is being deployed and the number of issues that have to be negotiated. In many applications such as transportation logistics, the bargaining is not only over the price of the service, but also takes into account issues such as delivery time, quantity and other product specific properties. Thus, negotiation strategies and protocols need to be set according to the scenario and the application domain.

However, at first the meaning of automated negotiations in general and issues associated with the negotiations are discussed to better fit in the logistics scenario. Thus, this chapter presents the basic definition of automated negotiation, classifications of negotiation in general and the negotiation strategies, protocols and issues (through a logistics scenario perspective). In addition, a negotiation model is presented that captures certain aspects of transportation logistics.

7.2 Automated Negotiation

Negotiation represents a key form of interaction seeking mutual benefit. The concept of automated negotiations is a very broad one. As discussed in [PRPJ06], the coverage of automated negotiation extends from unstructured exchange of messages to partial as well as completely structured systems like autonomous computers. As said in [FSJ02] –

"Automated negotiation is a key form of interaction in systems that are composed of multiple autonomous agents". The interactions between the negotiation entities aim to reach an agreement over a negotiation issue that is handled with iterative offers and counter offers. The negotiating entities may have common as well as conflicting interests which can result in further cooperation or compromises. In such situations, agents can gain mutual benefit from reaching agreements on an outcome from a set of outcomes, but need to compromise on some other outcomes in the set. More specifically, negotiation is a bargaining process in which a joint decision is made by two parties. At first contradictory demands are put forward and then gradually a point of agreement/disagreement is reached. A large number of automated negotiation models [Far00, JFLP01] are proposed in literature; ranging from auctions in which the agents' pricing decision problem is solved through showing the dominance of a truthful bidding strategy [VJ00], to models in which the agents argue for positions and aim to persuade their opponents of the value of particular actions [PSR98]. These models have been developed and applied to data allocation in information servers, resource allocation and task distribution. Apart from this, the application area in which automated negotiation has received considerable attention is in the field of electronic commerce [FWJ04]. In this particular application area, the aim of the software agents is to negotiate optimally with other agents on behalf of the seller and the buyer. Most of the current negotiation strategies are based on one-to-one negotiation between the seller of the services and the buyer of the services.

Transportation logistics is one of the challenging areas for application of automated negotiation [HRP05]. In addition the increasing dynamics and complexities in such networks result in an increased demand of distributed optimization techniques. The agent mediated negotiation competence has been investigated by various researchers [LC10]. As this thesis mainly focuses on the autonomous transport logistics using software agents, the negotiation is agent-mediated. The negotiating parties (packages and vehicles) are represented as software agents. In the logistics application domain, the negotiations between the agents representing the packages and the vehicles do not focus exclusively on price, but also allow the transportation of mutual beneficial clusters of packages which help the vehicles in better capacity utilization and hence more profit.

In general, negotiation is a process of communication that furthers cooperation and coordination. All the entities or interactive elements that seek mutual benefit must satisfy the fundamental requirement from either side. The negotiation involves offers and counter offers that have to be met or mutually agreed between the negotiating entities. Thus, the negotiation terminates either with an agreement or a disagreement.

In addition, the negotiation entities have to follow certain rules regarding negotiation [KL05]. In this regard, three broad factors that make negotiation more flexible and sophisticated are discussed in [Kraus01, JPSF01] and are presented as follows:

- What negotiation protocol will be used?
  For example; the set of rules which govern the interaction.
- What are the issues over which negotiation takes place?
  For example; the set of issues over which an agreement must be reached.
- And what reasoning model will agents employ?
  For example; the agents negotiation strategy which complies with the negotiation protocol to reach the negotiation objectives.

Considering the number of negotiation issues, in transportation logistics, negotiations mostly deal with the transportation costs, services etc. which eventually impact the customer satisfaction. For example, in a logistics scenario the issues are price, delivery date, the quantity as well as the route to be picked by the vehicle for transportation. Thus, the negotiation issues can be single or multiple depending on the application domain. In such cases, one of the approaches is to bundle all the issues and negotiate as a single issue. This will in turn help the negotiators in finding a trade-off among different issues but would demand a more complex negotiation that would result in additional computations [FSJ02, KR76]. The other approach is to negotiate sequentially. Though sequential negotiation reduces complexity, but the order in which the issues are negotiated has to be agreed upon. More information regarding the negotiation agenda and its outcome are presented in [Fers90].

7.3 Negotiation Model

The negotiation model basically consists of four components [RZ94]:

- Negotiation protocol: specifies the rules to be followed by the negotiating entities
- Negotiation strategies: specifies the sequence of actions (offers/responses)
- Information state of agents: information concerning the negotiation issues
- Negotiation equilibrium: strategy that brings about the stability to the system with a best response

The negotiation protocol defines the conditions under which the interaction between the negotiating entities takes place, what counter-offers are allowed etc. In general, the negotiation protocol is decided between the negotiating participants before the negotiation begins. It can be designed to handle a single issue or multiple issues either sequentially or as a single bundle of issues.

Similarly, the negotiation strategy defines the sequence of actions (offers or responses) the negotiators plan during the negotiation process. The different strategies may produce a different or same outcome with varying number of negotiation steps. For example, in some cases the negotiation can terminate after the first round of bidding or can continue until the negotiation time-deadline is reached. It implies that the outcome of a negotiation is crucial with respect to the negotiation strategy being used. Also, the choice of strategy is not only dependent on the negotiation scenario but also on the type of negotiation protocol.

The information state of the agents also plays a role in the negotiation process. Von Neumann and Morgenstern [NM47] introduced the concept in the field of game theory where they classified the games based on complete information and incomplete information. In the former category the players in the game know all the relevant information of all the players, rules and preferences defined by the utility function. In the latter case, each player has some private information which is unknown to other players. Therefore, the game begins with a probability distribution known to all players.

In addition to the negotiation protocol and the negotiation strategies to be followed by the participating entities, the negotiation mechanism also needs to be stable. The earliest concept that was developed for stable systems was the Nash equilibrium for games of simultaneous offers [Nash50]. In this equilibrium concept, various strategies are defined that result in system stability. More on this is described in [OR94].

With these points, many different models can be designed depending on the application domain. However, they all play a role in developing a negotiation model from a single-issue to multiple issues case. Thus, the classification of the negotiation with respect to the number of issues is also an important aspect to be discussed.

7.3.1 Negotiation Classification

Negotiation can be classified based on the number of issues as well as on the number of participating entities. Table 7.1 below presents the classification with respect to the transport logistics scenario. Negotiation can be single-issue, e.g., price for the service offered or can be multiple-issue depending on different factors such as price, delivery time of the packages, etc. It can be also classified as bi-lateral or multi-lateral depending on the number of participants negotiating in the scenario. For example, it can be a single package negotiating with a single truck or multiple packages negotiating with multiple trucks or a single truck. It can be mediated or non-mediated depending on the approach deployed in the logistics scenario. For example, in case of the semi-autonomous approach, it is mediated by the associated vertex which plays a key role in addition to the packages and the vehicles. And in case of the autonomous approach, it is not mediated, but the autonomous participants handle the negotiation independently. Similarly, the negotiation can be open or closed; in the sense that it can be an auction which is open to all interested participants or it can be closed like tenders in which each individual proposes its own price privately without the knowledge of other participant's price proposal.

Table 7.1: Negotiation Classification

Single Issue - Price	Multiple Issue - Price, delivery time etc
Bi-lateral - Single Pkg vs. Single Truck	Multi-lateral - Multi Pkg vs. Multi Truck
Mediated - Semi-autonomous (Associated Vertex)	Non-mediated - Autonomous
Open - Auction	Closed - Tenders

7.3.2 Negotiation Protocols

Negotiation has been a central subject in the research areas of economics and game-theory for many years. The field of multi-agent environments has also been involved in the negotiation modeling [MV99]. However, the most challenging task is to bring about useful results of formal negotiation protocols, while mapping and adjusting them to real-world applications. The choice of the specific negotiation protocol for a given domain depends on the specification of the domain. It depends on the number of agents in the system, the amount of information the agents are aware of each other and last but not least, what type of agreement that they need to reach.

Various negotiation protocols available in literature are studied and their applicability in the transport logistics scenario is analysed to best fit in the model presented in this thesis. But before going into detail on the available negotiation protocols in literature, certain parameters that can be used to evaluate different protocols are discussed [Kraus01] as follows:

- Negotiation Time: A delay in reaching an agreement causes an increase in the cost of communication and computation time and eventually on the time spent on the negotiation. It is preferable that less time is spent on negotiations to prevent deviation from the schedule. For example, in transport logistics delivery at the right time is one of the important aspect and thus, the negotiation time which takes into account all the predefined conditions needs to be considered.
- Efficiency: An efficient negotiation is the one which has an efficient outcome from the negotiation process. For example, for the cluster-based routing scenario in logistics, it is better that the cluster-head which is negotiating on behalf of all

other members opts out with an agreement which suits best for all members in its cluster.

- Simplicity: A simple and efficient negotiation process implies that the negotiation strategy can be fulfilled in a reasonable amount of time with less complexity. Particularly, in multi-agent automated systems it means that agents will be able to compute the strategy with less complexity and in preferred time schedule.

Researchers have been investigating on the negotiation protocols in economics, game theory and social sciences [LWJ00]. Particularly, auctions or bilateral negotiations are used in e-commerce applications. In automated auctions agents represent the users and are responsible for the negotiation. Depending on the auction type, agent negotiation can be one-to-one, one-to-many or many-to-one. Therefore, having a clear protocol is crucial in automated negotiation models. Wellman et al [WW01] asserts that different negotiation approaches are appropriate in different situations, and, thus, any generic approach should support a range of options required for negotiation.

7.3.3 Negotiation Issues

Negotiation is characterized by many issues. Hence, there can be single issue negotiation or multi issue negotiation models. Depending on the negotiation model (single or multiple issues) an issue is defined as a range of values and the negotiation outcome depends on the satisfaction level of these values. In microeconomics, they are defined in terms of preferences [CB03]. The preferences represent the order of the outcomes, which eventually are assumed to guide the behavior of the negotiating entities.

In many cases, the preferences are mapped to values of a utility. The higher the utility the greater is the preference of that issue. Thus, a utility function is a mapping from a space of outcomes onto utility values [Wilk08]. In other words, utility implies a variable indicating goal-attainment or satisfaction level. Within this range of values, a minimum, maximum as well as optimal values for the negotiation outcome are defined. Figure 7.1 depicts an example of a utility function for a single issue with respect to a buyer. The y-axis defines the utility values and the x-axis the prices. P_{opt} defines the optimum price defined by the buyer which in this case is the price that leads to a utility of 90%. P_{max} defines the maximum price by which the buyer can end the negotiation. For theoretic analysis of the negotiation process in this thesis, P_{opt} and P_{max} are termed as the reservation and acceptable price, respectively (refer section 7.3).

As seen in the Figure 7.1, as the price increases the utility decreases. It means that the buyer wants a lower price to buy the services from the seller and the utility function depicts the best value when the price is lower.

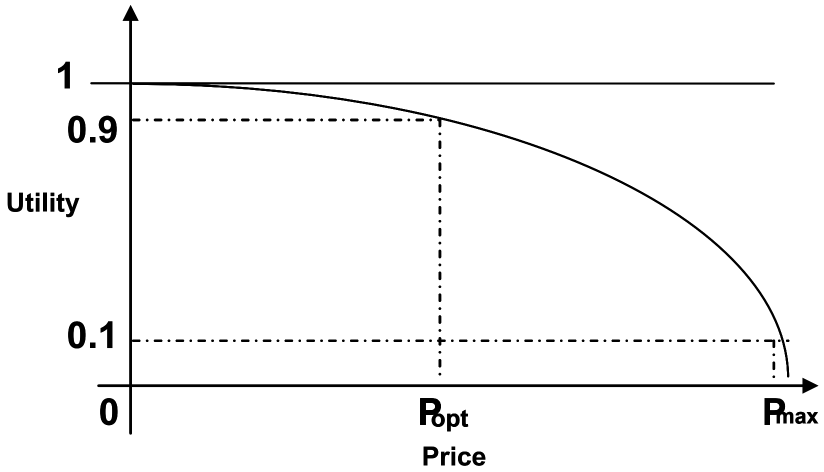

Figure 7.1: Utility Function for Single Issue w.r.t. Price Offered by the Buyer

There are many issues in logistics which can be considered for negotiation. One of the common issues in logistics for negotiation is the price. The price can be per package or per cluster. However, for the package it will be the total transportation cost while for the vehicle it is the base cost in addition to the cost based on the distance the vehicle is travelling for the transportation or the total time taken for transportation. The other important issue in logistics is the delivery time or the due date for the package to be delivered to the customer. For example, in case of the package the time constraint is very hard so it has to be delivered as per the time schedule and certainly on time, while for the vehicle it will be just on time as it looks for more capacity utilization on the route or journey it is travelling. The other issues that have to be dealt with both by the packages and the vehicles are the issue of delay penalty or fine. For the package, this means it should reach the customer/destination on time; else it has to bear the fine for late delivery. Similarly, for the vehicle, it can be a loss of credibility due to the delay or any mishap with the transportation or as part of the agreement. So these are some of the issues to be dealt in logistics for efficient negotiation. However, in this thesis the single issue of negotiation i.e., the price is analysed and its effect on the utility function with respect to the package (buyer of the service) and the vehicle (seller offering the service of transportation) is considered.

In case of multiple issues negotiated in a bundle, the utility function is based on the weighting factors. The weighting factors describe the relative importance for different negotiation issues. More on this is presented in [Wilk08] and was not further investigated in this thesis.

7.3.4 Negotiation Strategy

The main purpose of a negotiation is to reach an agreement on certain issues for a service offered by one negotiator to another negotiator. However, negotiation results depend on the strategies that the negotiating entities follow. These strategies involve exchange of initial offer, evaluation of the proposals and counter proposals etc. Thus, negotiation strategy denotes the way in which the negotiation offers fluctuate over time. This in turn depends on the tactics the negotiation strategy uses in the negotiation process. Tactics specify the way in which the offers and counter-offers are used in the process of negotiation. Various tactics that the negotiation strategy uses are presented in [FSJ98] and are discussed as follows:

- Time-dependent: In this type of tactic, the offers and responses are dependent on the criterion of time. It can be relaxed with time or impatient with time. Time is a major constraint in the negotiation behavior [KWZ95]. The negotiating entities have strict deadlines within which the negotiation must be completed. For example, if the entity has a time deadline within which it needs to decide on an agreement, then it should concede more rapidly as the deadline approaches. Considering the logistics scenario for the cluster-head (package) its due date is of utmost importance, hence, it would like to reach the negotiation agreement a bit faster compared to the vehicle which can go on steadily with the negotiation as its main goal is the maximum capacity utilisation/profit.
- Resource-dependent: This type of tactic is applied in a competitive environment where the negotiation process is based on the number of resources or participants. The quantity of a particular resource has a strong influence on the negotiation behavior. The appropriate evaluation of the remaining resources is an essential characteristic of a good negotiator as well. For example, considering the logistics scenario, if the number of vehicles are limited compared to the number of clusters of packages to be transported then each of the cluster-head packages would try to make the best proposals compared to all other participants, as it would prefer to reach the agreement faster and make a choice as soon as possible on the limited resources (vehicles). Another aspect would be the local resources like the capacity. Depending on the capacity with respect to the cluster size and the availability of the vehicle for the respective cluster-size, the cluster-head needs to decide on the best negotiation proposal.
- Behavior-dependent: This type of tactic is also referred to as intelligent or imitation tactic. This tactic is mostly employed when the negotiator is not under pressure to reach an agreement. It can use the imitative tactics for not being exploited by other negotiators. The imitation can also be dependent on the current or past experiences in dealing with the opponents and their strategies. Hence, this behavior tactic more or less depends on the degree of information available about the opponent. The imitation can be either positive or negative. More of this is depicted in the next section.

As discussed, various tactics can be used at various circumstances. [FWJ04] also describe the type of negotiators depending on the time tactic i.e., the negotiator whose utility value increases with time has the incentive to reach an agreement later and is termed the strong or patient negotiator while the one who follows a tactic to reach an agreement faster is referred as weak or impatient negotiation.

7.4 Theoretical Analysis for Negotiation in Logistics

In this section a single issue negotiation model based on price in a logistics scenario is presented and the optimal strategies by which the negotiation is successful are discussed and analysed. The theory and formulation in this section is adapted to a transport logistics scenario from the work presented in [FWJ04]. At first a negotiation protocol is analysed and its implications in a logistics scenario are explained with the help of results obtained.

7.4.1 Assumptions

Consider a logistics scenario wherein the clusters (packages) are negotiating with the vehicles on the transportation cost. The cluster-head is negotiating on behalf of the cluster members with the vehicle, thereby saving the associated communication costs for negotiation. The negotiation issue considered here is the price (p) that is offered by the vehicle for transportation. Before the beginning of the negotiation process, the participants calculate the range of values within which they will negotiate. This range starts with the most favorable price with which the negotiation will be initiated and hence it is termed as the "Initial Price, IP". The negotiation range ends at the least favorable price and is termed as the "Reservation Price, RP".

As it is an autonomous scenario wherein every entity is represented as a software agent, a general notion of an agent 'a' is presented. The range of values of price that are acceptable to an agent a where $a \in [c, v]$ is denoted by $[IP^a, RP^a]$. The price which is acceptable to both the cluster c and the vehicle v is defined in the interval $[RP^v, RP^c]$ which is termed as the 'zone of agreement'. It is also assumed that the cluster-head's initial price IP^c is smaller or equal compared to its reservation price RP^c while the initial price IP^v of the vehicle is larger or equal compared to its reservation price RP^v i.e.

$$IP^c \leq RP^c \qquad 7.1$$

and

$$IP^v \geq RP^v \qquad 7.2$$

It also means that, both IP^c and IP^v may lie outside the zone of agreement. Each of the negotiating participants, i.e., the vehicles and the cluster-heads, has a deadline which is denoted by $t^a \in t, t = \{0,1,...T^a\}$. The negotiation agents alternately propose the price offers at time steps t until the negotiation time deadline, T^a. These timesteps can be in any order of time units (seconds, minutes, etc.) depending on the negotiation scenario.

The price offered by cluster-head c at time t is given by $p^t{}_{c\to v}$. Negotiation is started as one of the agents (e.g., cluster-head) makes an offer. Hence, when the vehicle v receives the price offer from the cluster-head, it rates the offer using the utility function U^v. In case, the value of U^v for $p^t{}_{c\to v}$ at time t is greater than the value of the counter-offer made by the agent v in the next time period, t' i.e.

$$U^v\left(p^t{}_{c\to v}, t\right) \geq U^v\left(p^{t'}{}_{v\to c}, t'\right) \text{ for } t' = t + 1 \qquad 7.3$$

then the vehicle agent v accepts the offer at time t and negotiation agreement is successful, else, a counter-offer is proposed at next time period t'. Thus, the agent's action A^v at time t in response to $p^t{}_{c\to v}$ is given as

$$A^v(t, p^t{}_{c\to v}) = \begin{cases} \text{Quit} & \text{if } t > T^a \\ \text{Accept } p^t{}_{c\to v} & \text{if } U^v\left(p^t{}_{c\to v}\right) \geq U^v\left(p^{t'}{}_{v\to c}\right) \\ \text{Offer } p^{t'}{}_{v\to c} \text{ at } t' & \text{otherwise} \end{cases} \qquad 7.4$$

Eventually, the outcome of negotiation depends on the satisfaction level of negotiation issues (in this case, the price and the time) which can be measured using the utility function. Thus, the agent's utility is defined as a product of the following two von Neumann-Morgenstern utility functions [FWJ04, KR76],

$$U^a(p,t) = U^a_p(p) * U^a_t(t) \qquad 7.5$$

where, $U^a{}_p$ and $U^a{}_t$ are one-dimensional utility functions. $U^a{}_p$ is defined as:

$$U^a_p(p) = \begin{cases} RP^c - p \\ p - RP^v \end{cases} \qquad 7.6$$

for the cluster-head and the vehicle respectively.

$U^a{}_t$ is defined as $U^a{}_t(t) = (\delta^a)^t$ where δ^a is the discounting factor i.e., when $\delta^a < 1$ the agent is impatient and loses utility with time and when $\delta^a > 1$ the agent is patient and gains utility with time.

As discussed in the previous section, the tactics for generating offers and counter-offers also play an important role as both the negotiating agents have a deadline that is time-dependent. Thus, the factor deciding the next offer value is time t. The tactics (see previous section) which decide the next price-offer to be made is dependent on t and T^a.

The negotiation offers lie in the interval $[IP^a, RP^a]$. The offer proposal made between the negotiation entities at time t where $(0 \le t \le T^a)$ is modeled as a function ϕ^a depending on time as follows:

$$p^t_{c \to v} = IP^c + \phi^c(t)(RP^c - IP^c) \quad 7.7$$

$$p^t_{v \to c} = RP^v + (1 - \phi^v(t))(IP^v - RP^v) \quad 7.8$$

Various time-dependent functions can be defined with different values of $\phi^a(t)$ (see [FSJ98] for more details). However, $\phi^a(t)$ always lies in the range of 0 and 1 i.e. $\phi^a(0) = k^a$ and $\phi^a(T^a) = 1$, where k^a lies in the interval [0,1] and determines the initial offer. $\phi^a(t)$ is defined as the negotiation decision function (NDF):

$$\phi^a(t) = k^a + (1 - k^a)\left(\frac{t}{T^a}\right)^{\psi} \quad 7.9$$

At the beginning of the negotiation process, NDF will give the initial value k^a i.e. the constant and when the time deadline approaches it will approach the value 1 and hence the price offer will approach the reservation price, RP^a. Thus, by varying k^a along 0 and 1, the initial price can be varied between IP^a and RP^a respectively. Normally in the negotiation process, the value $k^a = 0$ is set so that the initial price offer is IP^a.

The NDF defines various numbers of possible tactics for different values of ψ. Depending on the value of ψ the next section presents the different patterns of curves of negotiation tactics. These tactics are analysed with respect to an autonomous logistics scenario.

7.4.2 Negotiation Tactics

In this section the author presents the graphical descriptions of the negotiation tactics as described in the previous section and discusses their implications on the logistics application. Figure 7.2 gives the negotiation tactics for price offers made by the cluster of packages (buyer of the service of transportation) to the vehicle (seller of the service of transportation). As the cluster is the one that buys the service, it would relatively prefer a low price. As seen in the figure, three different tactics are presented based on different values of ψ (refer Eq. 7.9), namely Conceder, Linear and Boulware.

- Boulware [Rai82]: In this tactic, the ψ value is greater than one. It implies that initially a lower value is offered by the package to the vehicle and maintained until the time deadline is almost exhausted. When the deadline is nearly reached the price offer concedes up to its reservation value. Figure 7.2 shows the Boulware tactic for ψ =30.0, 5.0 and 2.0 respectively.
- Conceder [Pru81]: For this tactic ψ is less than one and close to zero. In this case, the package offers a very high price very quickly. Since there is not much scope to increase the offer further due to the limiting reservation price the consequent offers are minimally increased until the deadline is reached. Figure 7.2 also shows different curves for the conceder tactic with similar characteristics for different values of ψ.
- Linear: This tactic is the balanced approach with ψ=1. The price increases linearly with respect to time.

Analyzing these tactics, it can be concluded that a negotiator is more patient in case of $\psi > 1$ i.e. one that follows the Boulware tactic and more impatient in case $\psi < 1$ and nearing to zero i.e., one that follows the Conceder tactic. Thus, the counter offer depends on the initial price offer at which the negotiation starts and the reservation (final) price beyond which the negotiation does not concede and the value ψ which identifies the tactic to generate offers from the initial price towards the reservation price. Thus, these variables form an integral part of the agent's strategy.

Figure 7.3: Vehicle Negotiation Strategy Behavior presents the negotiation tactics with respect to the vehicle. The vehicle offers service of transportation to the packages/clusters. In other words, the vehicle would prefer a high price.Figure 7.3: Vehicle Negotiation Strategy Behavior also displays the 3 tactics discussed earlier in Figure 7.2. However, looking into the behavior of the tactics, it can be concluded that if the resources are limited, i.e., if vehicles (sellers) are less compared to the number of the clusters (buyers), the Boulware approach seems best, wherein the vehicle can wait for the cluster of packages to become impatient and makes a better price proposal (relatively higher price) to attract the vehicle. On the other hand, the Conceder tactic seems to be more advantageous for the clusters due to large number of buyers. Thus, the clusters have a higher probability of being considered for transportation and also have the chance of reaching the final agreement relatively faster in time.

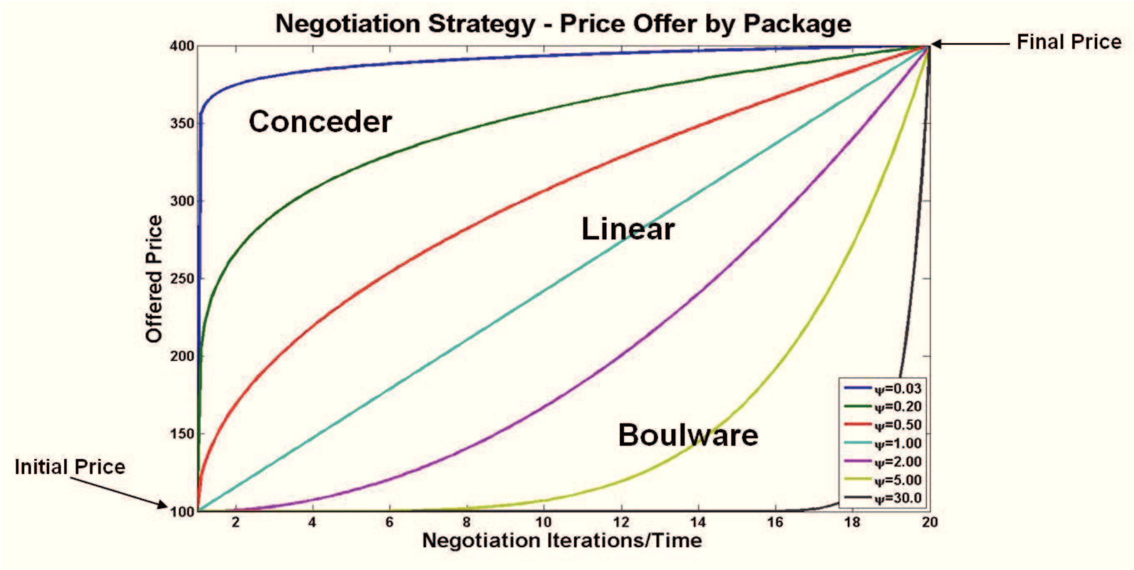

Figure 7.2: Package Price Offer w.r.t. Negotiation Time for Varying Ψ (Eq. 7.7)

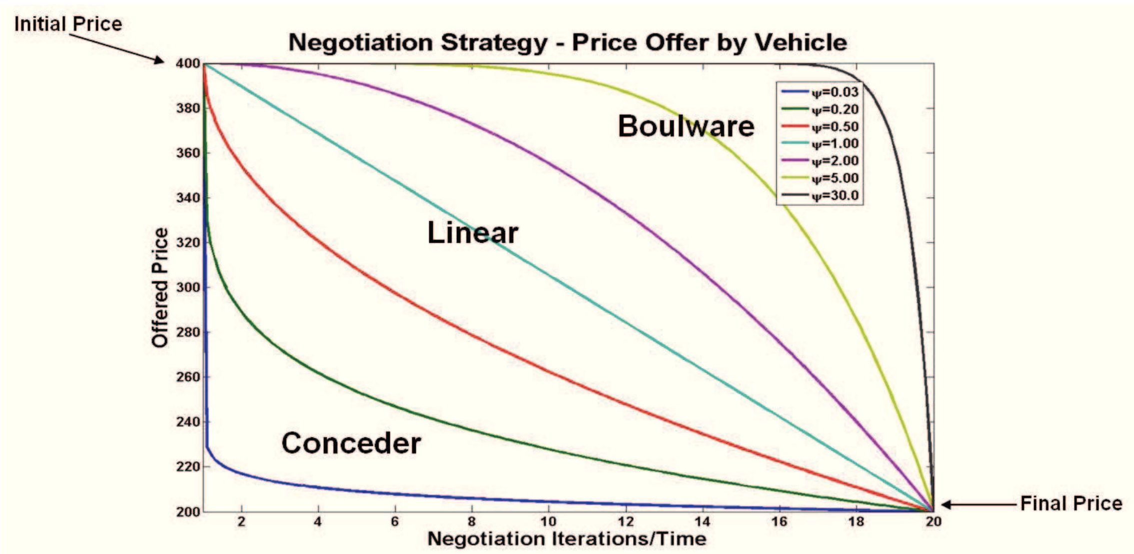

Figure 7.3: Vehicle Price Offer w.r. Negotiation Time for Varying Ψ (Eq. 7.8)

As discussed in Section 7.3.4, the outcome of negotiation also depends on the Behavior-dependent strategy. In this case, there can be positive imitation (the opponents follow the same strategy w.r.t., eachother) or negative imitation (opponents follow the opposite strategies w.r.t., eachother) again based on same as well as different time-constraints.

7.4.3 Negotiation Strategy with same Time-constraint

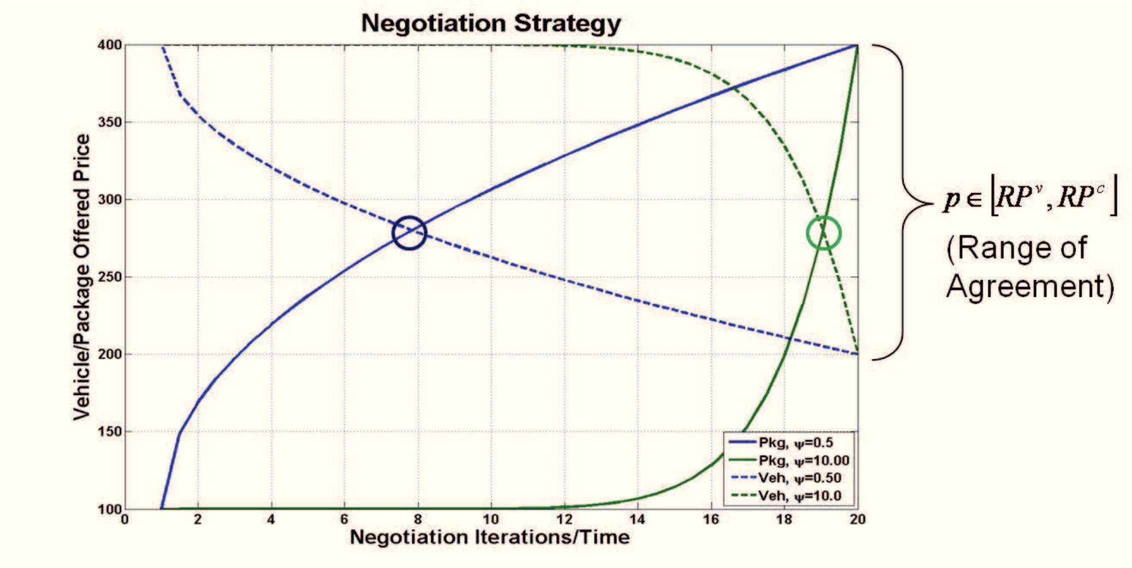

Figure 7.4: Vehicle/Package Price Offer w.r.t. Negotiation Time for Varying Ψ with Same Time Constraints (Positive Imitation)

Figure 7.4 depicts the characteristics of a behavior-dependent negotiation tactic with positive imitation for both packages and vehicles. For a behavior-dependent negotiation strategy, the negotiator should have either some form of a priori information of the opponent or its own belief on how the opponent is negotiating. This prior information could be based on the past experiences with this particular opponent or obtained due to the exchange of initial and reservation price information at the start of the negotiation process as per the negotiation protocol in use. Positive imitation implies that the packages and the vehicles follow the same tactic, i.e, as one changes the offered price with a larger amount (conceder tactic), the other also changes the counter offer price by a large amount (conceder tactic). Negotiating in this way results in reduced time of negotiation as the agreement is reached faster. It is also assumed that both the negotiating entities, i.e., both the packages (buyer) and the vehicles (seller) have the same time constraint. The solid line represents the behavior for the packages and dotted lines represent the vehicles behavior. As seen in the figure, looking onto the blue lines, the negotiation is successful at a much earlier point in time (see the blue circle) compared to the green lines (green circle). This implies that negotiation is successful in less time if both the vehicles and the packages follow the Conceder tactic, whereas the negotiation takes a longer time in case they follow the Boulware tactic. However, the price at which the agreement is successful is the same in both the cases. This is especially advantageous for the packages, because they have to be delivered urgently, hence, settle with the best price in less time. But the packages can also opt for the Boulware approach in case they have no hard constraints on the due date of delivery, wherein they don't have too much of time limitation and can increase the price steadily. And similarly, the vehicles that are relatively less bothered with time can steadily continue the negotiation to best maximize its capacity utilization.Thus, it can be concluded that a positive imitation strategy with Conceder tactic is a better option. Additionally, in the case of Conceder tactic the negotiation agreement is reached earlier in time and with a relatively satisfactory price.

Figure 7.5 depicts the behavior dependent strategy for both the vehicles and the packages with negative imitation. The assumption in this case is similar to the previous case wherein both the parties have the same time constraints. As seen in the figure, when the package follows the Conceder tactic the vehicle follows the Boulware tactic and vice versa. Thus, it can be observed that the negotiation agreement is successful at a relatively low price (see green circle) but a rather delayed point of time (near to the deadline time) in case of the package following the Boulware tactic and the vehicle following the Conceder tactic. However, in the vice versa case wherein the vehicle following the Boulware tactic and the package following the Conceder tactic, the resultant price is relatively higher at point of time a successful negotiation agreement is reached (see blue circle). But, in this case the agreement is at an earlier time-point compared to the previous case.

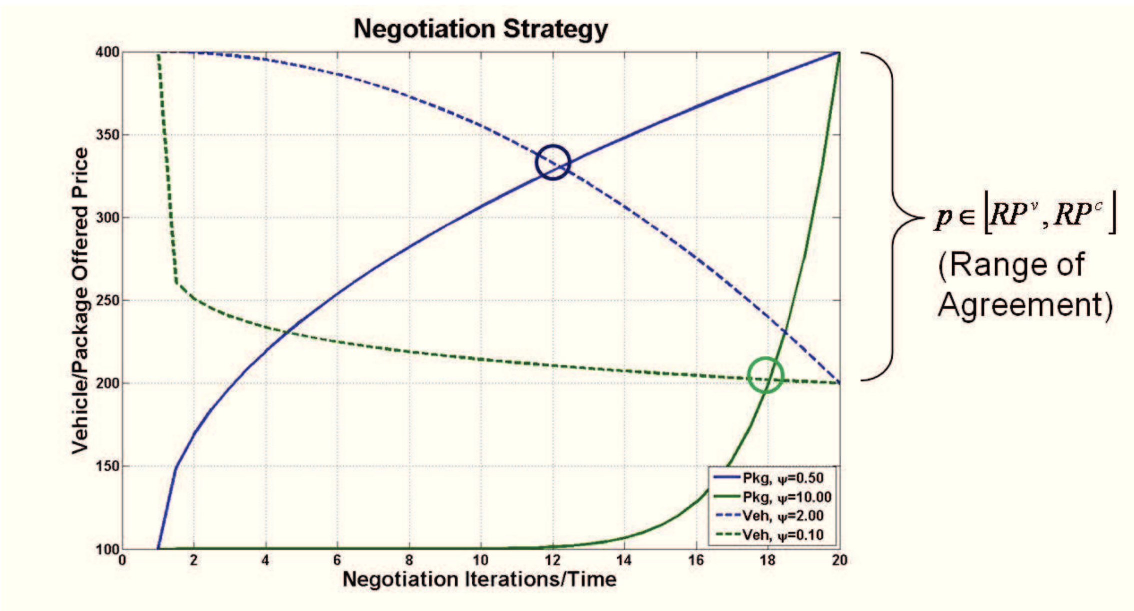

Figure 7.5: Vehicle/Package Price Offer w.r.t. Negotiation Time for Varying Ψ with Same Time Constraints (Negative Imitation)

Thus, it can be concluded that, if the negotiation parties apply the negative imitation strategy, it is advantageous to the party that follows the Boulware tactic to reach an agreement.

7.4.4 Negotiation strategy with different Time-constraint

Figure 7.6 and Figure 7.7 depict the behavior dependent negotiation strategy with positive as well as negative imitation with the assumption of different time constraints for both the packages and the vehicles. As seen in the Figure 7.6, if both the parties follow the same strategy with the Conceder tactic, negotiation is successful, whereas if both of them follow the Boulware tactic, then as the time constraint of one (in this case, the vehicle) is short compared to the other (packages) the negotiation enters a conflict zone with no chances of reaching a successful negotiation agreement. Thus, it can be concluded that though Boulware tactic may be the preferred tactic of the negotiating agents as they want to get a favorable agreement but this tactic can also result in a case where the negotiation ends without any agreement.

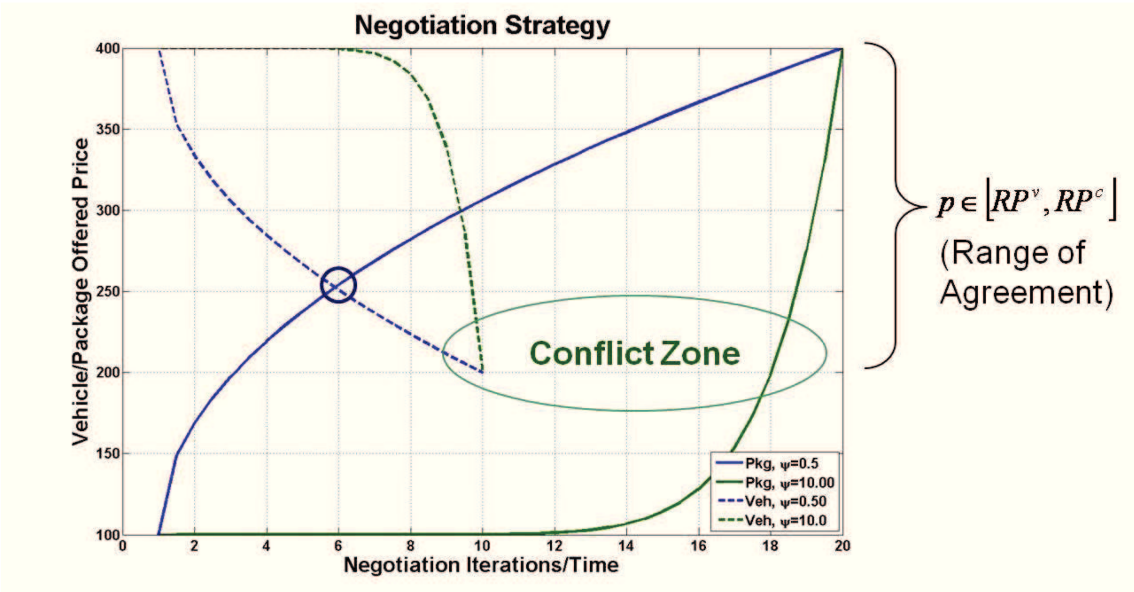

Figure 7.6: Vehicle/Package Price Offer w.r.t. Negotiation Time for Varying Ψ with Different Time Constraints (Positive Imitation)

Figure 7.7 depicts the negative imitation behavior case and shows that the party with the smaller time-constraint can manage to have a successful and favorable negotiation agreement with the Boulware tactic. Thus, it can be concluded that for realistic assumptions of different time constraints of the negotiating parties, there are chances of negotiation being unsuccessful if careful strategy planning is not done.

7.4.5 Negotiation Outcome

The outcome of the negotiation depends on both agents' strategies. The optimal negotiation strategy depends on the information about the negotiation parameters. The negotiation strategy of the negotiation entities determines the way the offers and counter-offers are handled. Thus, for example in case of a logistics scenario, the vehicle

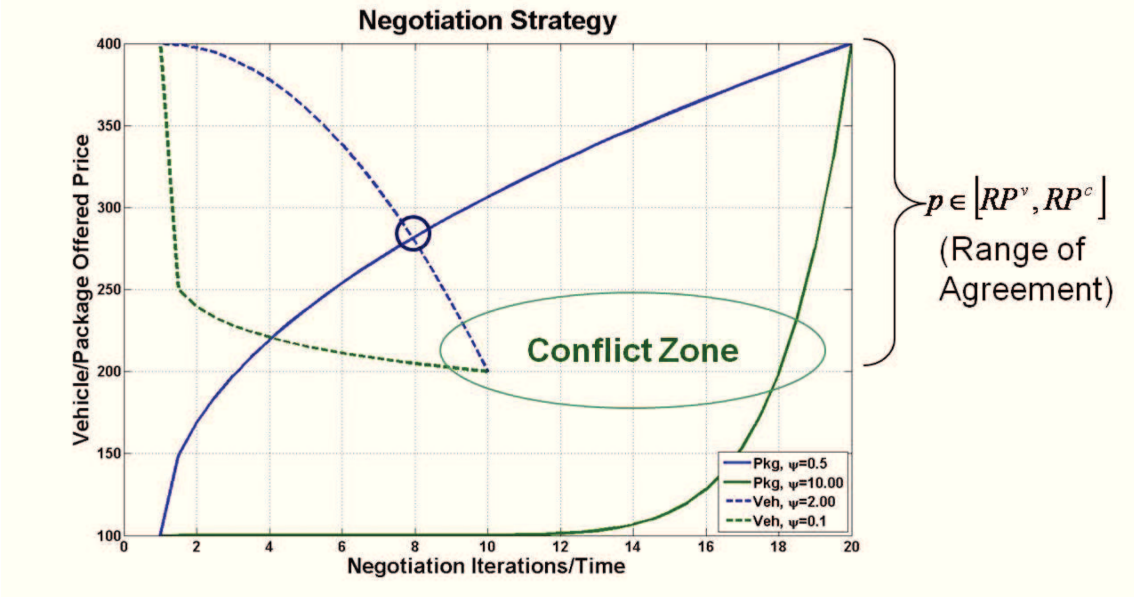

Figure 7.7: : Vehicle/Package Price Offer w.r.t. Negotiation Time for Varying Ψ with Different Time Constraints (Negative Imitation)

agent's strategy S^v is defined as a quadruple with elements such as the initial price IP^v by which the vehicle starts the negotiation, the reservation price RP^v beyond which negotiation does not concede, time T^v at which the final price is offered and the value ψ^v.

$$S^v = \langle IP^v, RP^v, T^v, \psi^v \rangle \quad 7.10$$

Different strategies can be defined for different values of the four variables. For example: if a cluster makes an initial offer at vehicle's reservation price (RP^v) and offer final price as its own reservation price, RP^c at time T & uses extreme Boulware NDF then,

$$S^c = \langle RP^v, RP^c, T, B \rangle \quad 7.11$$

Note that the ψ value can take any of the tactics Boulware (B), Conceder (C) and Linear (L) NDFs respectively. Thus, the negotiation can be successful or unsettled or in a conflict, depending on the four variables defined in each of the negotiator's strategy.

However, the negotiation outcome (O_n) is an element of $\langle (p,t), \widehat{C} \rangle$ where, (p,t) denotes the price and the time of agreement, where $p \in \lfloor RP^v, RP^c \rfloor$ and $t \in [0, \min(T^c, T^v)]$ and $\widehat{C}$ denotes the conflict outcome.

Depending on the different strategies the resultant outcome of negotiation is analysed in the following figures. Figure 7.8 presents the time, behavior and resource dependent strategy with the same time constraint. The dotted lines represent the vehicle strategy and the solid lines the package (cluster) strategy for different values of ψ (holds for all figures).

Figure 7.8: : Vehicle/Package Price Offer w.r.t. Negotiation Time for Varying Ψ with Same Time Constraints (Positive Imitation)

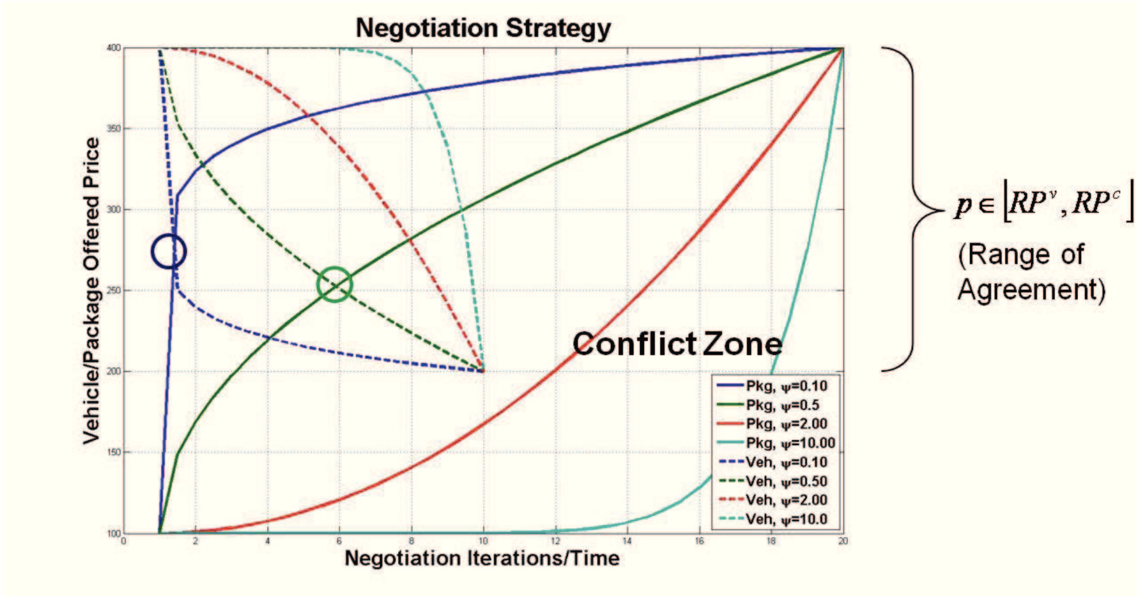

Figure 7.9: : Vehicle/Package Price Offer w.r.t. Negotiation Time for Varying Ψ with Different Time Constraints (Positive Imitation)

As seen in the Figure 7.8, the range of price agreement is between the reservation price of both the vehicle and the package. Figure 7.9 presents the time, behavior and resource dependent strategy with different time constraint. It is assumed that the time-deadline of the vehicle is less than the time-deadline of the package. Contradictory to the previous figure, it can be observed that there is no possibility of agreement resulting in a conflict zone in all the cases, except for the case of low values of ψ like 0.1 and 0.5, where there is negotiation agreement quiet earlier in time with reference to the negotiation time deadline. In this case, it is advantageous for the package with lower preferred price but the vehicle is in loss as it expects a higher price offer.

Figure 7.10: : Package Price Offer w.r.t. Negotiation Time for Varying Ψ (Mixed Negotiation Strategy)

The mixed strategies (Figure 7.10 – 7.13) showcase the numerous possibilities to design a strategy for negotiation. For example, a strategy like Boulware strategy can be too inclined to get an acceptable price in the negotiation process but at the expense of failing to reach an agreement in negotiation. And on the other hand, the Conceder strategy is too impatient to reach a negotiation agreement even though it might be with an unfavorable price. The mixed strategies allow the negotiators to break the whole negotiation process into small rounds with different strategies for these different small rounds. Figures 7.10 to 7.11 depict results for two such rounds where the strategy may change from Boulware to Conceder or vice versa at the middle of the negotiation process by inverting the ψ value. For a negotiator following the linear strategy, there is no difference in this type of mixed strategy.

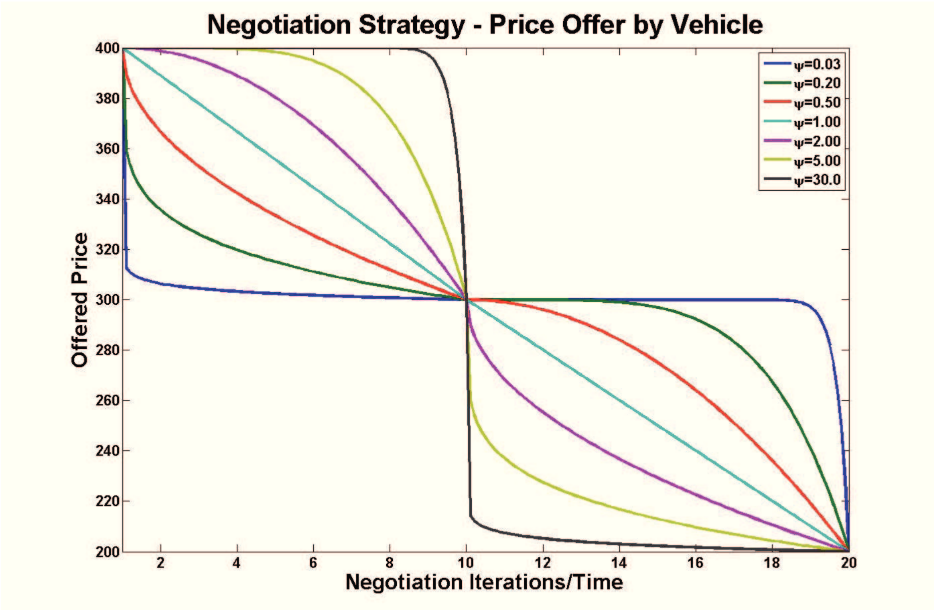

Figure 7.11: Vehicle Price Offer w.r.t. Negotiation Time for Varying Ψ (Mixed Negotiation Strategy)

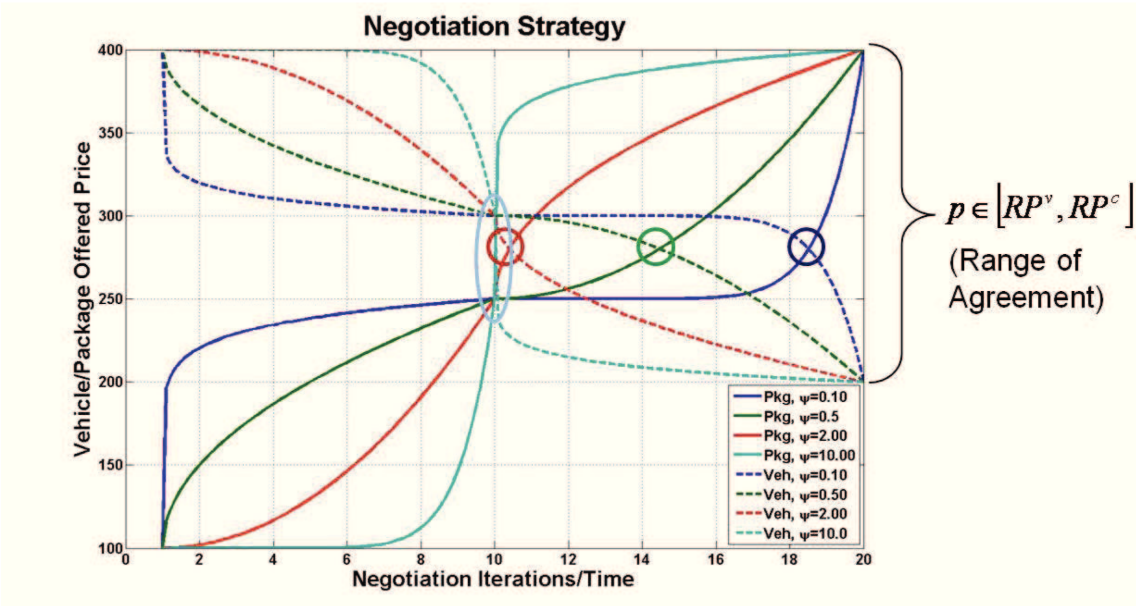

Figure 7.12: Vehicle/Package Price Offer w.r.t. Negotiation Time with Same Time Constraints (Mixed Negotiation Strategy)

Figure 7.12 and Figure 7.13 presents the mixed strategies for packages (solid line) and vehicles (dotted lines) with same as well as different time constraints. It can be observed that both the vehicles and packages have a possibility of reaching a negotiation agreement for a satisfactory mutual price offer. For example, Figure 7.13 presents the case wherein the time deadline of the vehicle is less than the package. As opposed in the previous case (Figure 7.9) even though the opponent's deadline is smaller, it can be observed that there is a possibility of entering the range of agreement with satisfactory mutual price offer.

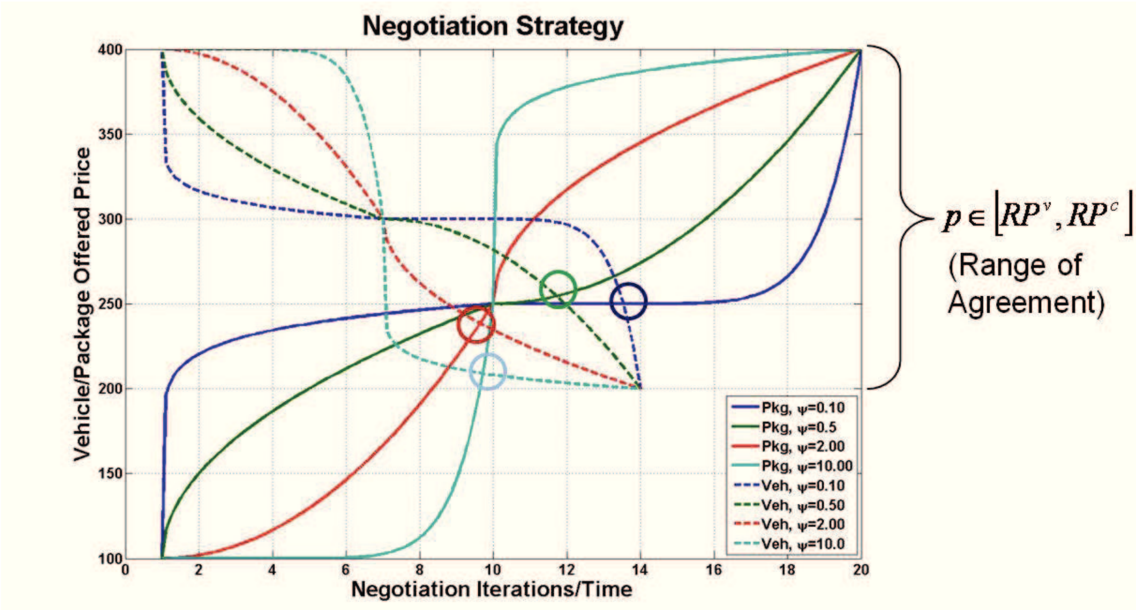

Figure 7.13: Vehicle/Package Price Offer w.r.t. Negotiation Time with Different Time Constraints (Mixed Negotiation Strategy)

Figure 7.14 and Figure 7.15 present the behavior dependent mixed strategy (with positive imitation) comparing the vehicle and the package strategy with similar values of ψ. By observing the curves it can be concluded that this strategy best works for the vehicle as the agreement is best reached at the higher price approximately near to the preferred reservation price of the vehicle. But Figure 7.15 presents the vehicle strategy with smaller deadline than that of the package. In this case as observed the agreement is reached at ψ =0.5 (both vehicle and package) while there is conflict in the later case.

Conclusion

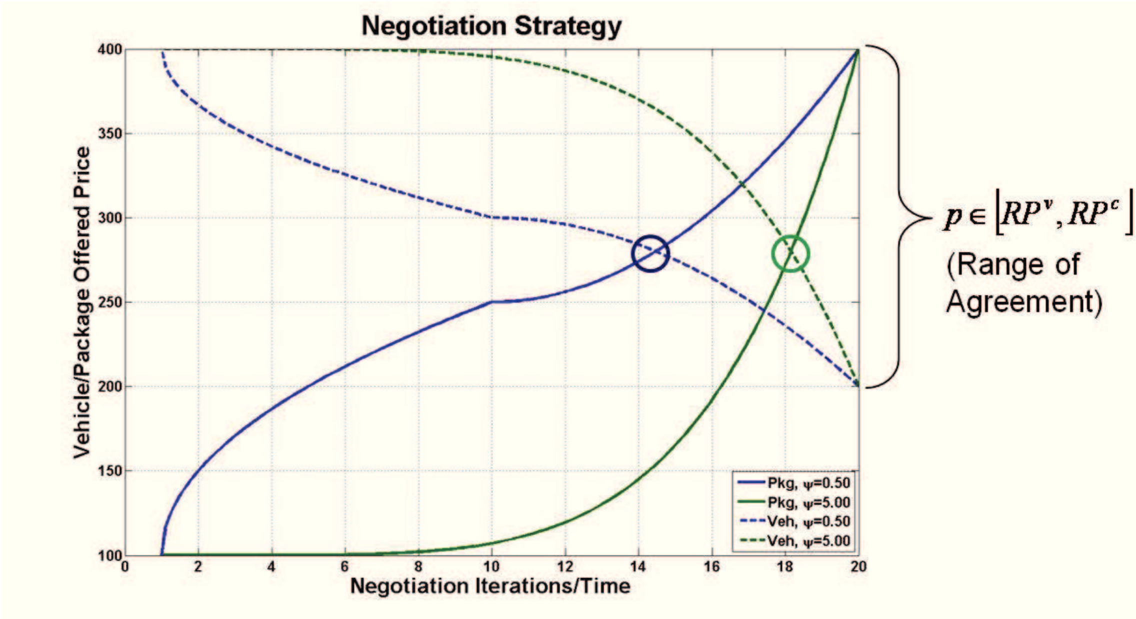

Figure 7.14: Vehicle/Package Price Offer w.r.t. Negotiation Time with Same Time Constraints (Mixed Negotiation Strategy with Positive Imitation)

Figure 7.15: Vehicle/Package Price Offer w.r.t. Negotiation Time with Different Time Constraints (Mixed Negotiation Strategy with Positive Imitation)

7.5 Conclusion

This chapter introduced the concept of automated negotiation, issues for negotiation as well as the strategies and tactics used during the negotiation process particularly in transport logistics scenarios. As there are various possibilities of choosing the negotiation issues in logistics, this thesis concentrated on the issue of price and time. Time and price play a crucial role in logistics and hence, these issues were analysed and their behaviour with respect to different negotiation tactics (namely Conceder, Boulware and Linear) used by the transport goods (packages) and vehicles were explained.

A negotiation model for a logistics network was presented. Based on the negotiation model, the results were obtained that explained the different possibilities of employing different negotiation tactics in different scenarios. For example, a scenario with different time constraints of negotiating parties results in chances of negotiation terminating without an agreement. Similarly, results were depicted for the mixed negotiation strategies used by the vehicles and the transport goods. These results concluded that the mixed strategies with same as well as different time constraints have a higher possibility of reaching a mutual negotiation agreement on price.

Thus, this chapter presents the approach of negotiation in a transport logistics scenario and depending on the requirement of the logisitic entities, proposes the various strategies by which a negotiation can reach to a stage of agreement.

8. Implementation of Negotiation Strategies in PlaSMA

As already discussed in Chapter 7, automated negotiation is a process by which two or more agents communicate and try to reach a mutually acceptable agreement on the issue of negotiation. This chapter discusses the implementation and integration of the automated negotiation protocols and strategies in the cluster-based routing simulation scenarios. The negotiation strategies analysed are the one's which the clusters and vehicles use during the negotiation process. Thus, based on the results obtained in this chapter the reader gets an impression of the best negotiation strategies to be followed both by the clusters and vehicles to reach an agreement on the transportation cost. Also, their implications on the overall performance of the logistics network in terms of reaching an agreement in the negotiation process are discussed.

The viability of negotiation is demonstrated through a prototypical implementation in the simulation tool PlaSMA. In addition, a discussion of the overall approach and the underlying algorithms with the emphasis on the motivation of using cluster-based negotiation is analysed.

8.1 Automated Negotiation for cluster-based DLRP

The negotiation process is viewed as a set of software agents in a logistics environment which interact in order to reach an agreement over an issue. Agents like the packages or the vehicles participating in the negotiation can interact with each other via the intermediate broker such as the associated vertex or directly among themselves. However, this thesis concentrates only on negotiation of transportation cost (termed also as price) between the cluster-head and the vehicle. This type of negotiation with only a single issue for negotiation and between two entities is termed as single-issue based bi-lateral (between a cluster and vehicle) negotiation.

In this section the implementation of single-issue bi-lateral automated negotiation in the simulation tool PlaSMA is presented. In the single-issue model, transportation cost is chosen to be the issue that has to be negotiated between the vehicle and the cluster (represented by the cluster-head). In this model, the associated vertex does not play any role but only initiates the information exchange between the cluster-head and the vehicle.

The route selection by the different entities in a logistical network may depend on various criteria. For the single-issue model this routing decision is based on the transportation cost criteria. Once the cluster has identified the best possible route to its respective destination, announces the same to the vehicle present at the vertex. The vehicle based on the route information of the cluster initiates its own routing discovery process for the proposed destination.

Based on the selected route, the cluster-head and the vehicle propose the preferred price for the transportation to each other in different negotiation steps. Before the negotiation begins, both the cluster-head and the vehicle calculate a set of 3 price values which will guide the negotiation offers made by them. The 3 different pre-determined costs for negotiation are as follows:

- Reservation Price (RP) – It is the least favorable price that can be offered during the negotiation for the transportation.
- Acceptable Price (AP) – It is the price with sufficient utility with which the negotiation can be terminated.
- Initial Price (IP) – It is the first price offer in the negotiation process.

8.2 Negotiation Protocol for cluster-based DLRP

In a negotiation process, the negotiating entity issues a proposal to inform the opponent about the intention, requirements and constraints about the service it needs to buy or sell. The proposal is evaluated, modified and returned as counter offer. Several counter offers can be encountered by the two negotiation parties until a final agreement is reached. Thus, the negotiation protocol is one of the basic elements to be defined when initiating the negotiation process. The negotiation protocol involves the sequence of actions to be followed during the negotiation process. The negotiation protocol implemented in this thesis is adapted and modified from the one proposed in [SHH00]. The protocol is a finite state machine with states and transitions.

Figure 8.1 presents the state transition diagram for both the cluster and the vehicle (it is the same for both). As seen in the figure, the negotiating entity is in *Init* state at the start of the negotiation process. From that state, it can either move into the offer received state (*Offer_rec*) or into the offer sent state (*Offer_sen*) respectively. For example, after being in the *Offer_rec* state it can send an accept, reject, counter-offer or terminate message and move on in the following states: *Offer_acc*, *Offer_rej*, *Offer_sen* or *Terminate*, respectively. *Terminate* is the state wherein the negotiation is terminated successfully or unsuccessfully.

In the implemented protocol, the vehicle starts the negotiation process. It computes the initial bid and sends the price proposal to the cluster and waits for the response from the opponent (cluster). If the cluster accepts the offer, the negotiation is successful and the negotiation is terminated. Else if the price offer is rejected and the vehicle receives the rejection message it computes a *counter-offer* and again waits for the response. Another case can be that a new price offer is proposed by the cluster. Depending on the received price offer proposed by the cluster the vehicle can either make a counter-offer, accept the offer and in some cases can also reject the offer. Thus, the negotiation process continues and terminates when a mutual decision is reached or if the negotiation time-out is encountered by either of the parties or both.

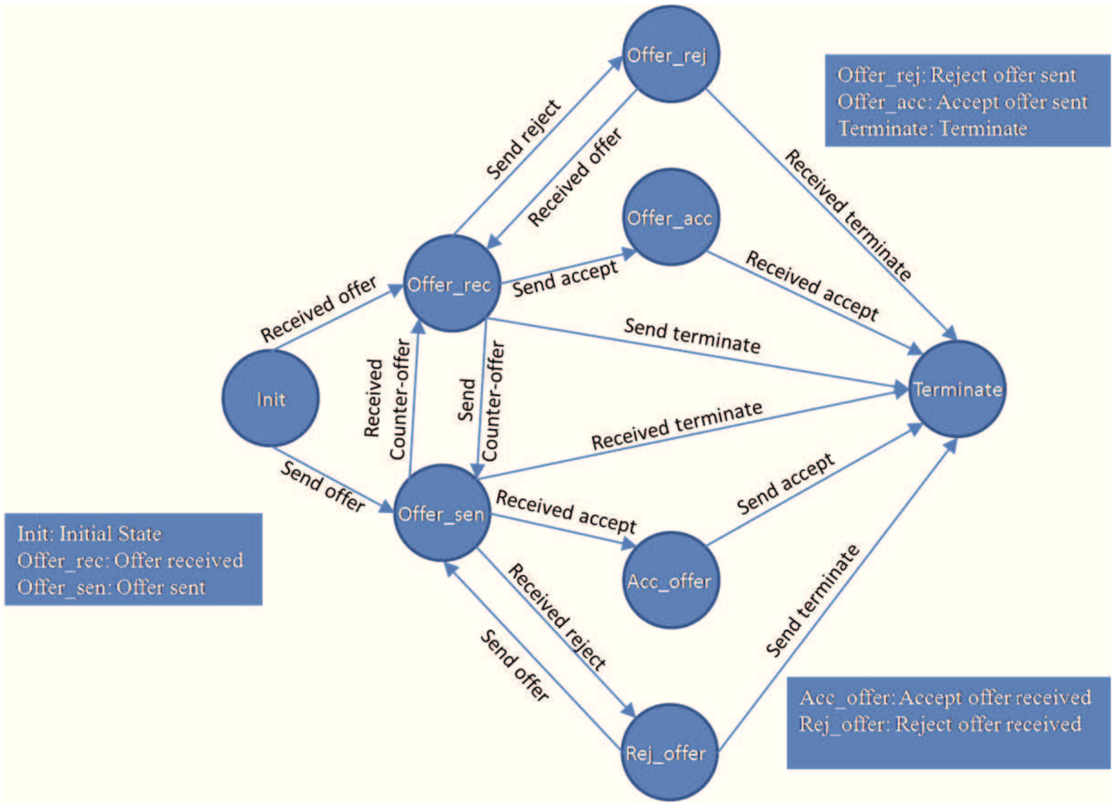

Figure 8.1: Single-issue Bi-lateral Negotiation Protocol Model based on [SHH00]

The protocol in this thesis has been used for the single-issue bi-lateral negotiation model i.e., for the negotiation of transportation cost between a cluster and a vehicle. However, this protocol can also be used for multi-lateral negotiation wherein the clusters may negotiate with a number of different vehicles simultaneously by sharing the cost offers in parallel during a negotiation step. This implies that the negotiation protocol can be applied independently multiple times depending on the number of opponents.

8.3 Negotiation Strategy

The strategy of the negotiating entities during a negotiation scenario is very critical for the outcome of the negotiation. This thesis in particular adapts the strategy that is based on the work proposed in [FWJ04]. The negotiation is assumed to be between the clusters (buyer) and the vehicles (seller). The assumptions are that the vehicle is constrained by the cost and the number of days within which it needs to transport the clusters, while the cluster is constrained by its utility and the number of days within which it needs to get delivered (due-date). As the vehicle is selling its services, it prefers a higher price while the cluster (buyer) prefers a lower price. In addition, neither the cluster nor the seller has information about the constraints of the other. The negotiation entities, i.e. the clusters and the vehicles, make alternative bids with the vehicle to bid first. An agreement is reached when the received offer has a higher utility than the counter offer for that negotiation step. If a deal cannot be reached within or before one of the negotiating parties runs out of time, i.e., the negotiation time-out is reached, the negotiation terminates unsuccessfully. The various scenarios with different time constraints and strategies for clusters and vehicles are presented in the next section. However, the outcome of the negotiation depends on both agents' strategies. Since both agents use a time-dependent strategy, an agent always proposes a strategy that offers its own reservation price at its deadline.

The negotiation predicates used are explained as follows:

- *Negotiation Step (S)*: The step of the negotiation. For example, when a cluster or vehicle sends an offer and in turn receives another offer, then the negotiation step is increased by one.
- *Counter-offer:* The offer which a cluster or vehicle receives from the opponent.
- *Negotiation Time (T)*: The timeout for negotiation to terminate
- *Utility (U)*: Utility of the cluster or vehicle if it buys or sells the service

As discussed in Chapter 7, the negotiation strategy used by the negotiating entities depends on the negotiation tactics they deploy in the negotiation process. It can be a time-dependent, resource-dependent or a behavior dependent strategy. In this thesis, mainly the time-dependent strategy is discussed though partially it also takes into account the resources as well as the behavior of the negotiating entities. It means that depending on the number of clusters and the behavior (high or low bid) proposed by the opponents, the negotiators can either start with a very high price or very low price or can change the strategy in between.

Depending on the different negotiation tactics used by the negotiating entities, four basic strategies are defined as presented in Table 8.1. Strategy *S1* defines the state in which both the vehicle and the cluster follow the *Boulware* tactic. Strategy *S2* is the one in which the vehicle follows the *Boulware* and the cluster follows the *Conceder*. Similarly, strategy S3 corresponds to the vehicle following the *Conceder* and the cluster following the *Boulware* tactic and strategy S4 represents both the vehicle and the cluster following the *Conceder* tactic. By introducing these strategies, the author analyses as to which strategy holds good for successful negotiation or the advantages associated following a particular strategy depening on the requirements of the negotiating entities.

Table 8.1: Negotiation Strategy of the Vehicle and Cluster

Vehicle/Cluster	Boulware	Conceder
Boulware	S1	S2
Conceder	S3	S4

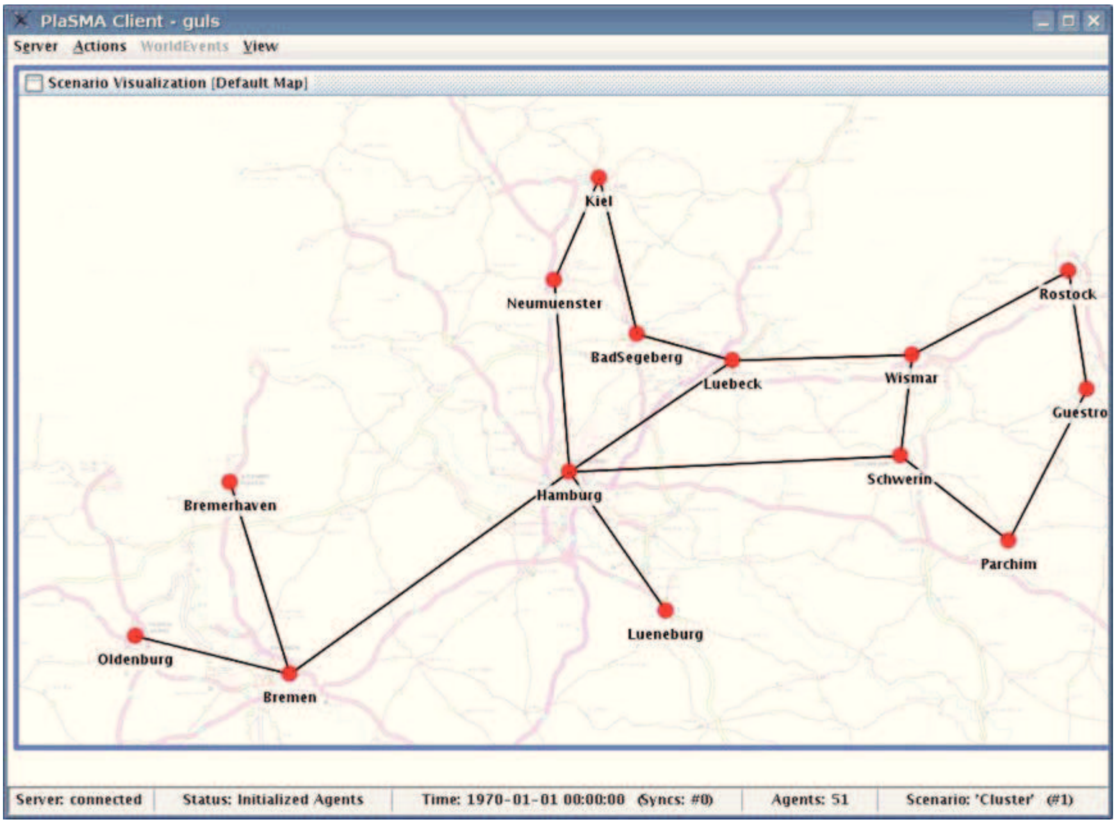

Figure 8.2: Simulation Scenario for Negotiation

8.4 Negotiation Scenarios

The scenario (Figure 8.2) used in Chapters 5 and 6 for analyzing the cluster-based DLRP approach is also used here in further analyzing the effect of automated negotiation. As discussed, different clusters of packages are formed based on their respective destinations. Once the clusters are formed, the routing process is started where in the cluster-head and the vehicles start the route discovery process. However, the vehicles do not have a preferred destination if they are idle or empty. Therefore, they obtain the information of the available clusters from the associated vertices. Based on the cluster information and their destinations, the vehicle starts the route discovery process. After the route discovery process both the vehicle calculates the transportation price based on the distance to the preferred destination and the desired profit (discussed in Chapter 6).

Thus, the negotiation scenario basically consists of the cluster (single) and the vehicle (single) negotiating on the single negotiation issue, i.e., the price for the transport service offered. The vehicle is the negotiating entity that is offering the transportation service to the cluster for its transport to the required destination. The formulation for calculating the offers and counter offers using the price range described in Table 8.2 are calculated using equations 7.7 and 7.8. Two basic strategiess with respect to the time-deadline of the negotiating parties are proposed in this thesis. Following are the two scenarios:

- Strategy 1: Same Negotiation Time-out (SNT)
- Strategy 2: Different Negotiation Time-out (DNT)

In case of SNT, both the cluster and the vehicle have the same negotiation time-out value, and in case of DNT, the cluster or the vehicle have different time-outs (one has larger negotiation time-out value compared to the opponent).

8.5 Simulation Results

This section discusses the simulation results obtained by implementing the strategies in the scenario discussed in the previous section. The general assumption which can be made is that the cluster is a buyer who wants to buy the transport service and the vehicle is the seller, selling its transportation services. For the illustrated results, the negotiation is considered at Bremen, between a medium-sized vehicle, T_M-1 and a cluster of 10 packages destined to Hamburg. The reservation prices, acceptable prices and the initial prices for both, the vehicle and the cluster are presented in the Table 8.2. The values presented are in reference to the cost calculation done in chapter 6. The utility to obtain the acceptable price is set to be 300 for both, the cluster and the vehicle. The acceptable price is calculated using Eq. 7.6.

Table 8.2: Price values of clusters and vehicles for Negotiation

Prices	**Cluster Price Values**	**Vehicle Price Values**
Reservation Price (*RP*)	600	200
Acceptable Price (*AP*)	300	500
Initial Price (*IP*)	100	1000

8.5.1 Same Negotiation Time-out (SNT) Scenario

Figure 8.3 and Figure 8.4 show the flowcharts of a negotiation protocol for cluster and vehicle, respectively. In the presented negotiation protocol, the negotiator either accepts or sends counter offers as a response to received offers until the negotiation equilibrium is found or the negotiation time-out is reached.

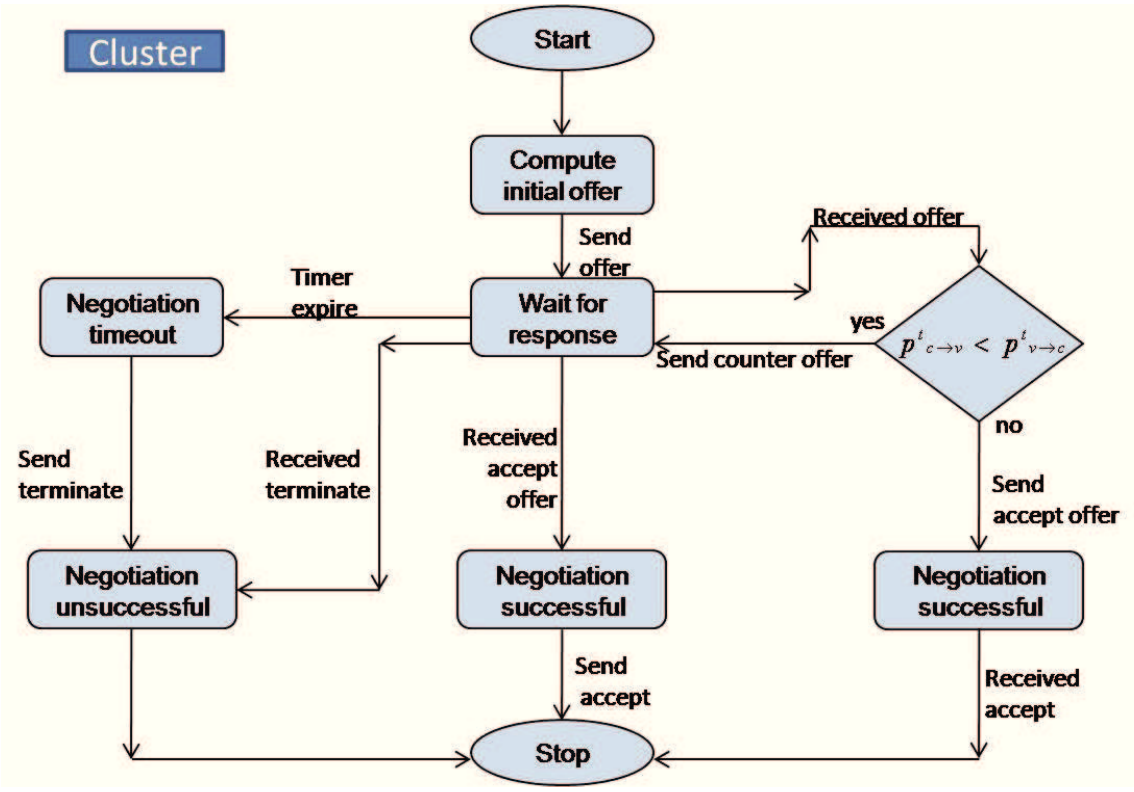

Figure 8.3: Flowchart of Cluster Negotiation Protocol Model

Figure 8.5 and Figure 8.6 present the simulation results obtained for the Single-issue bi-lateral negotiation between the cluster and the vehicle for the Same Negotiation Time-out scenario (i.e. 20 negotiation iterations) following the strategy S1 and S4. As seen in the figures in general, the x-axis corresponds to the Negotiation Iteration/Time-out and y-axis for the Offered Price. The blue and black solid lines represent the price offered by the cluster and the vehicle, respectively. The dotted line for both the cluster and vehicle represents the *RP* offer, i.e., for the cluster the *RP=600*, and for vehicle *RP=200* respectively. As seen in Figure 8.5 according to S1 both the cluster and the vehicle follow the Boulware strategy, i.e., it can be termed the waiting strategy, wherein the price offer is gradually increased from low to higher value. As soon as the zone of agreement is reached, each of the negotiation opponents counter-checks the offers and makes a proposal. Hence, as seen in the figure, at the 18th negotiation iteration when the vehicle sends the price-offer to the cluster, the cluster compares that price to its counter-offer and since its counter-offer is better than the price offered by the vehicle (it prefers a lower price) it sends the new price offer to the vehicle. Similarly, the vehicle counter checks this price-offered by the cluster with the next value it will like to propose (i.e., at the 19th iteration) and since the price-offer it will be offering in the next time iteration (19th iteration) is of lesser value than the cluster-offered price, it will accept the price offered by the cluster (i.e. the price offer at 18th iteration). Thus, the negotiation ends successfully with the price offered by the cluster and the vehicle contented with this price-offer.

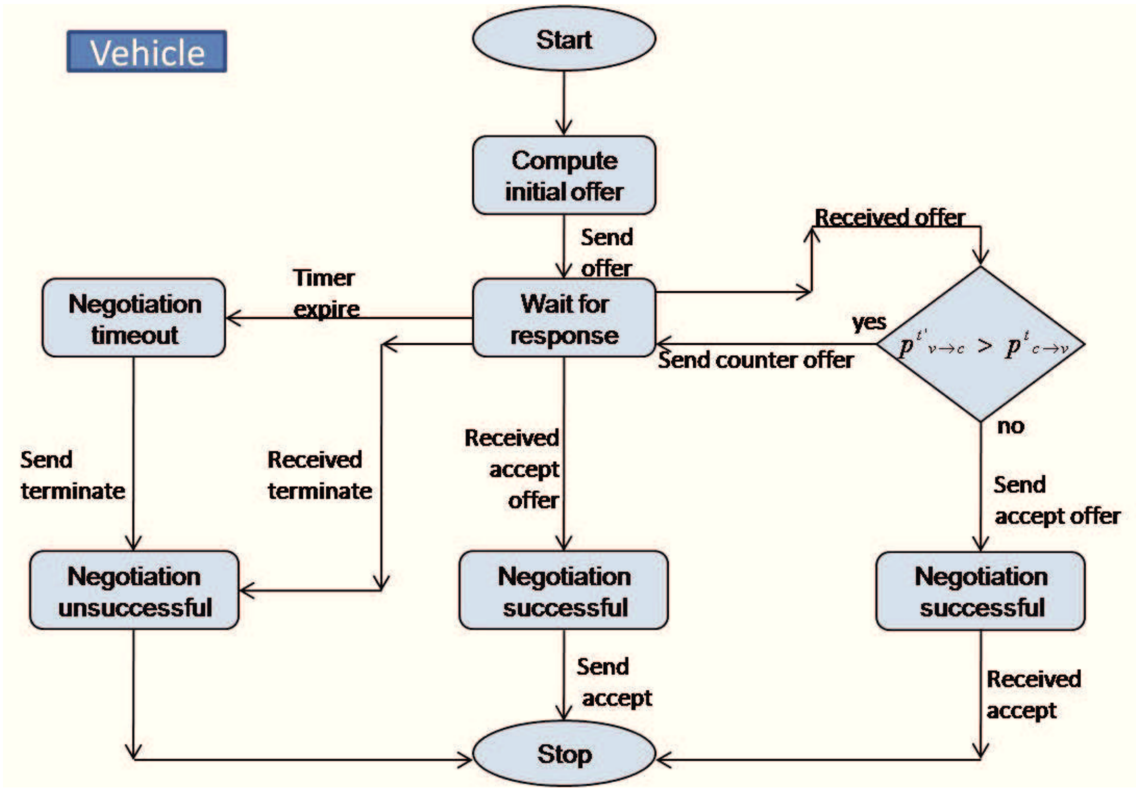

Figure 8.4: Flowchart of Vehicle Negotiation Protocol Model

Figure 8.6 represents the SNT scenario following the strategy S4. In this case, both the cluster and the vehicle are following the Conceder strategy. Due to the impatient strategy, the increment in price offer is higher initially and gradually reduces for the following negotiation steps. As seen at the 4th negotiation iteration, the vehicle offers a price to the cluster and the cluster in turn compares it to the price it is offering at the next time-instance, i.e. at the 5th iteration, and sends the new price offer at the 4th iteration. The vehicle in turn compares this new price offer with its next iteration price-offer and finds that the price offered by the cluster is better than its present counter-offer (i.e. at 5th iteration) and accepts the price offer made by the cluster. Thus, the negotiation is terminated successfully at the price offer of around 450.

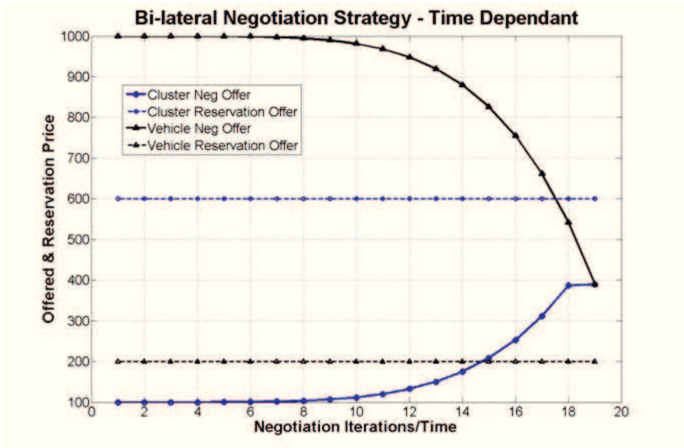

Figure 8.5: Vehicle/Cluster Price Offer w.r.t. Negotiation Time with Reservation Price of 200 and 600 respectively with Strategy S1 and Same Negotiation Time

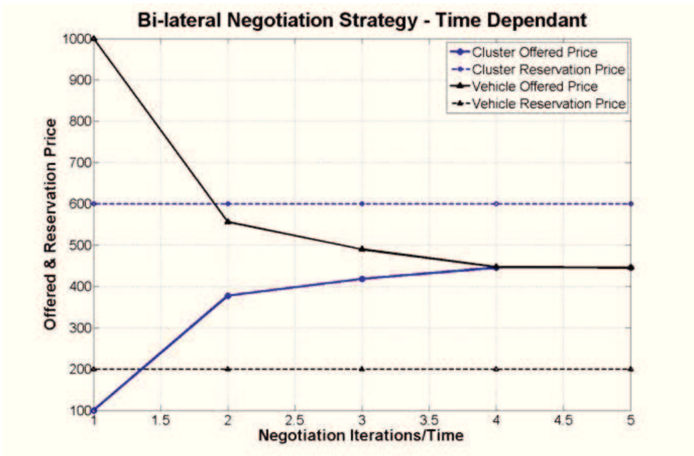

Figure 8.6: Vehicle/Cluster Price Offer w.r.t. Negotiation Time with Reservation Price of 200 and 600 respectively with Strategy S4 and Same Negotiation Time

Figure 8.7 and Figure 8.8 present the simulation results for the SNT scenario with strategies S2 and S3 respectively. As seen in Figure 8.7, the strategy followed is S2. In this case, the vehicle is following the Boulware tactic and the Cluster the Conceder tactic. Hence, as seen in this case, the negotiation almost terminates at the point at which the negotiation iterations time-out i.e., the 18th iteration. In this case also the vehicle agrees to the offer made by the cluster at the 18th iteration time with a price offer of 599. But, the special factor in this case is that this strategy, i.e. S2, is best suited for the vehicle as it gets a better negotiation deal (as it prefers a higher price-offer) compared to the cluster (which prefers a lower price).

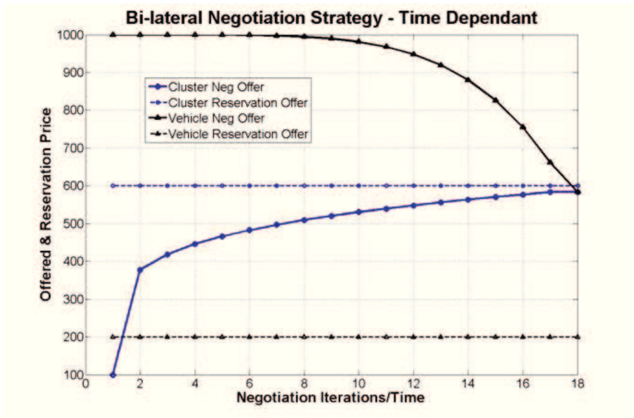

Figure 8.7: Vehicle/Cluster Price Offer w.r.t. Negotiation Time with Reservation Price of 200 and 600 respectively with Strategy S2 and Same Negotiation Time

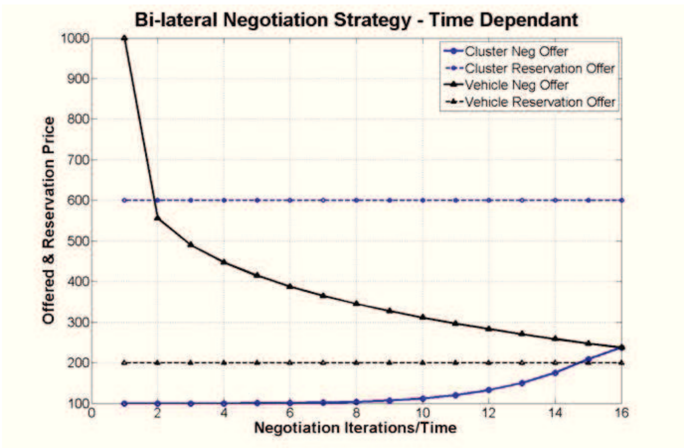

Figure 8.8: Vehicle/Cluster Price Offer w.r.t. Negotiation Time with Reservation Price of 200 and 600 respectively with Strategy S3 and Same Negotiation Time

Similarly, in case with negotiation following the strategy S3 (Figure 8.8) i.e., the vehicle following the Conceder tactic and the cluster following the Boulware tactic, the best negotiation deal is in favor of the cluster (relatively lower price) compared to the vehicle (as the price is really low for its demand). Here, the vehicle's offer at the 16th negotiation iteration is accepted by the cluster.

8.5.2 Different Negotiation Time-out (DNT) scenario

If the negotiating parties have different negotiation time-out values, due to the specific strategies employed by the parties the negotiation process may not always terminate in a successful negotiation even though there exists a region of agreement i.e., $\left[RP^v, RP^c\right]$.

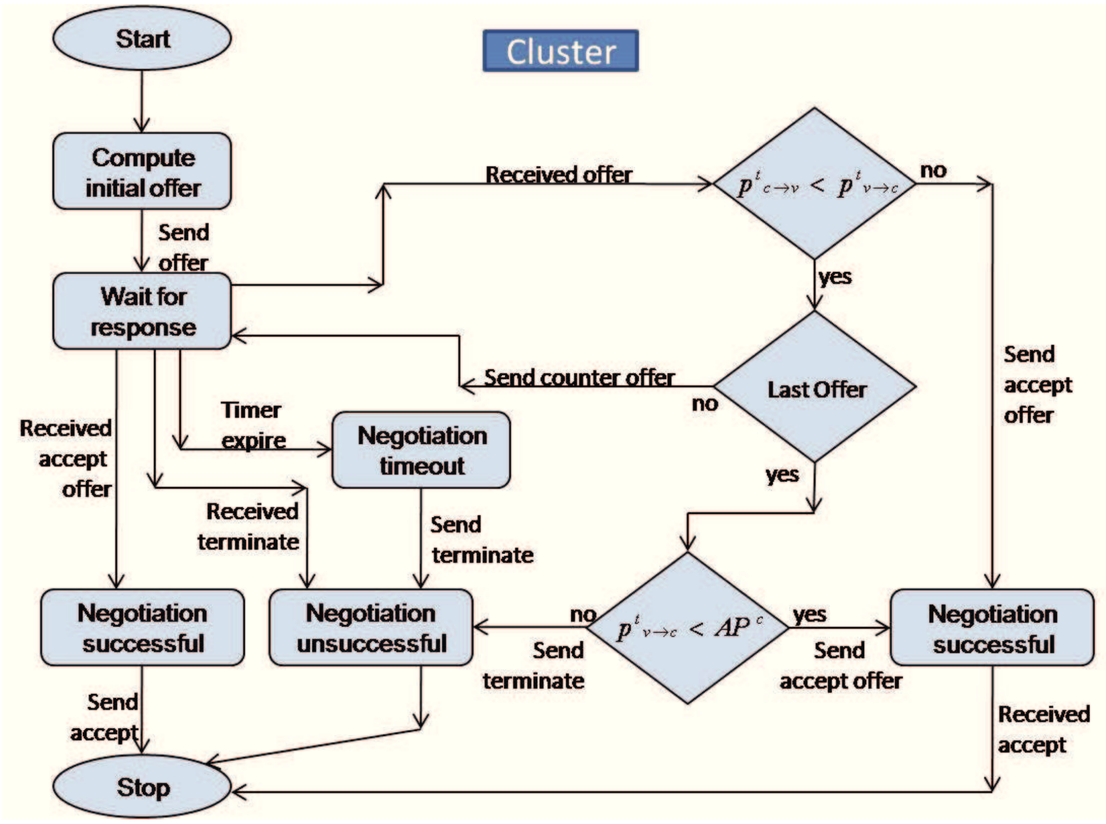

Figure 8.9: Flowchart of Cluster Negotiation Protocol Model with Acceptable Price

Therefore, in order to achieve a successful negotiation termination, an acceptable value (which results in a sufficient utility) is identified in addition to the reservation price at the starting of the negotiation process. When any of the negotiation parties sends the last offer, then it informs the other party about it being the last offer. Thus, the other party compares this last offer with the utility of acceptable level and if the received offer has the same or better utility then it will be accepted otherwise the negotiation will terminate without any success. The flowchart explaining the protocol model for the cluster and the vehicle is presented in Figure 8.9 and Figure 8.10 respectively.

Figure 8.12 and Figure 8.12 present the simulation results for the DNT scenario. The cluster/vehicle is following the S1 and S2 strategies respectively with the negotiation iteration time-out for the cluster is 10 and for the vehicle it is 20. However, as concluded in Figure 7.9 of Chapter 7, the negotiation cannot terminate in the zone of agreement. Hence, a new type of offer termed *Acceptable Offer* is defined for this case, which is the price that provides a sufficient utility factor. Hence, in case of the vehicle the *Acceptable Offer = 500* with a utility value of 300 ($AP^v - RP^v$) and for the cluster the *Acceptable Offer =300* also with a utility value of 300 ($RP^c - AP^c$).

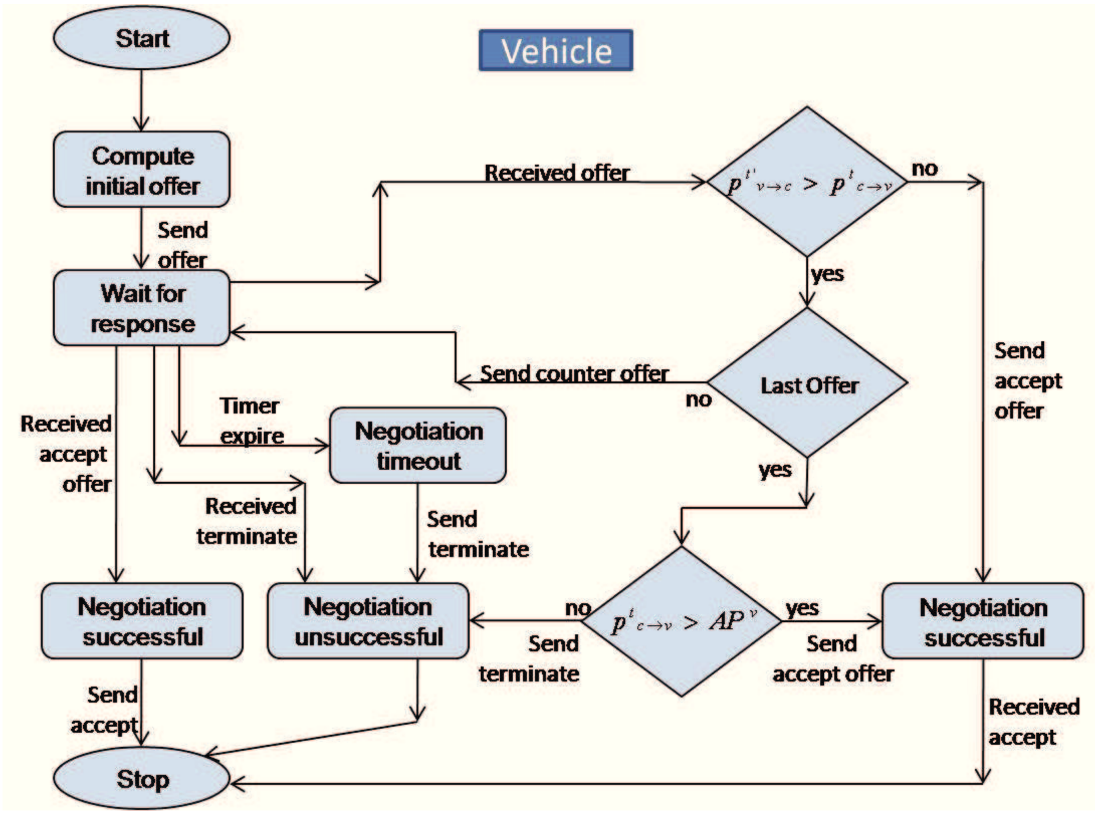

Figure 8.10: Flowchart of Vehicle Negotiation Protocol Model with Acceptable Price

As seen in the Figures 8.11 and 8.12, negotiation terminates only when the negotiation iteration time-out of the cluster is reached. At that instant of iteration, when the cluster offers the price it will also notify the vehicle with a flag that it is the last offer from its side as it has reached the negotiation time-out limit. At that point, the vehicle compares the price offer and since it is giving better utility value (i.e., 400 as the sufficient utility value defined by the cluster is 300, refer Eq. 7.6) it will accept the price offer. In case if the utility value would be less than 300 the vehicle would reject the offer. Similar is the case in the results obtained in which the vehicle/cluster is following the strategy S2. The results always end in a successful negotiation because $AP^v < RP^c$.

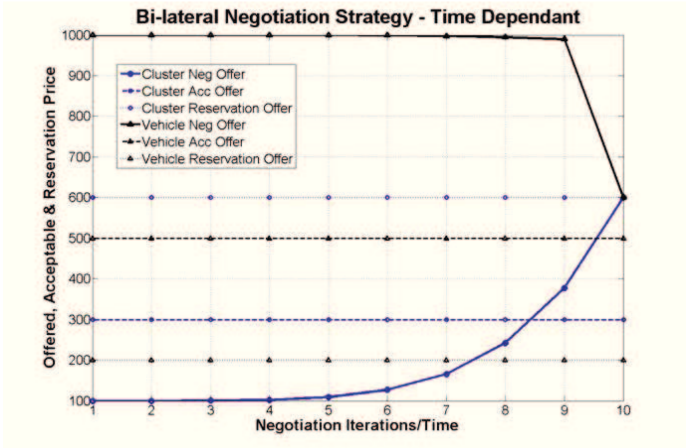

Figure 8.11: Vehicle/Cluster Price Offer w.r.t. Negotiation Time with Reservation Price of 200 and 600 and Acceptable Price Offer of 500 and 300 respectively with Strategy S1 and Different Negotiation Time

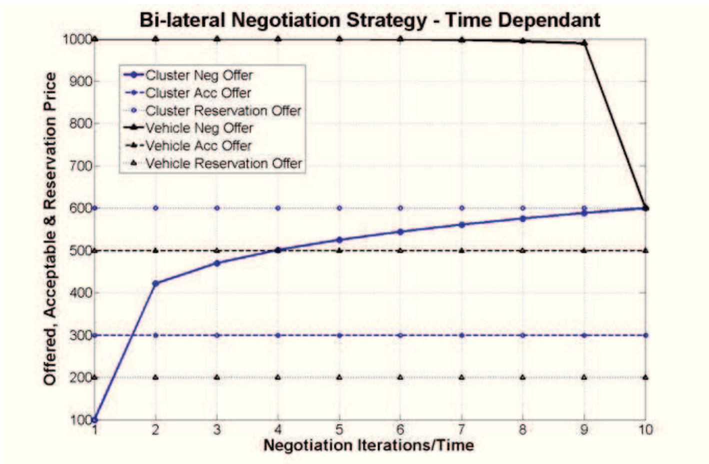

Figure 8.12: Vehicle/Cluster Price Offer w.r.t. Negotiation Time with Reservation Price of 200 and 600 and Acceptable Price offer of 500 and 300 respectively with Strategy S2 and Different Negotiation Time

Figure 8.13 and Figure 8.14 present the simulation results for the DNT case with the vehicle having a lower negotiation iteration time-out compared to the cluster (i.e. the vehicle has a negotiation iteration time-out equal 10 and the cluster 20 respectively). In this case too, the vehicle sends out the last price offer when the negotiation time-out is reached with a flag to the cluster. Then, the cluster checks whether the price offered by the vehicle would provide it sufficient utility value and since it finds that the utility is more than 300 (sufficient utility value for the cluster) it will end the negotiation successfully accepting the offer made by the vehicle.

Thus, it can be concluded that the negotiation will always terminate successfully if the following condition is true $RP^{v} < AP^{c}$.

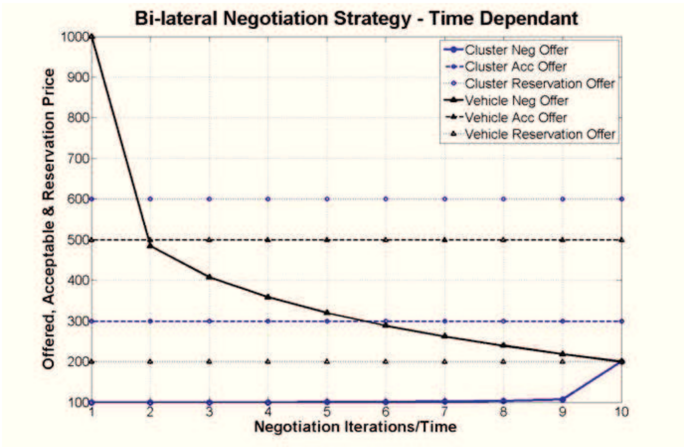

Figure 8.13: Vehicle/Cluster Price Offer w.r.t. Negotiation Time with Reservation Price of 200 and 600 and Acceptable Price Offer of 500 and 300 respectively with Strategy S3 and Different Negotiation Time

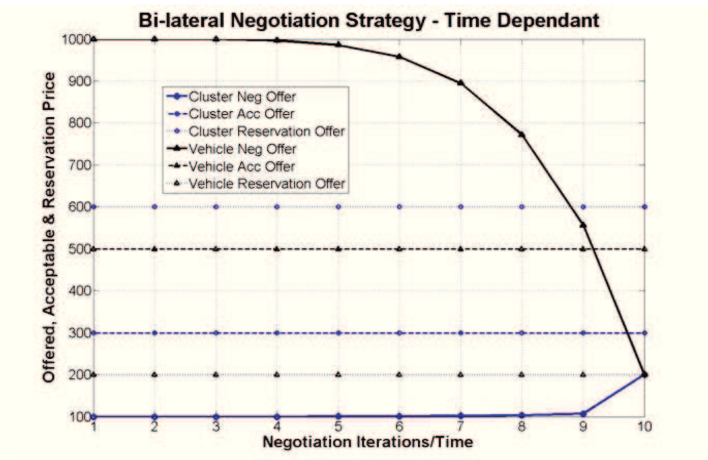

Figure 8.14: Vehicle/Cluster Price Offer w.r.t. Negotiation Time with Reservation Price of 200 and 600 and Acceptable Price Offer of 500 and 300 respectively with Strategy S1 and Different Negotiation Time

8.5.3 Same Negotiation Time-out (SNT) with reject strategy

In the negotiation protocol explained earlier in this chapter, the negotiators also have a possibility to reject an offer made by the opponent. Different negotiators may have different strategies on when and which offers to reject and to which offers to respond with a counter-offer. For the implemented model, the negotiators do not actively negotiate if the offered price is beyond the acceptable limit i.e., the reservation price. Thus, any offer that lies out of the 'zone of agreement' will be rejected. Figure 8.15 and Figure 8.16 depict the flowchart for this implemented model for cluster and vehicle, respectively.

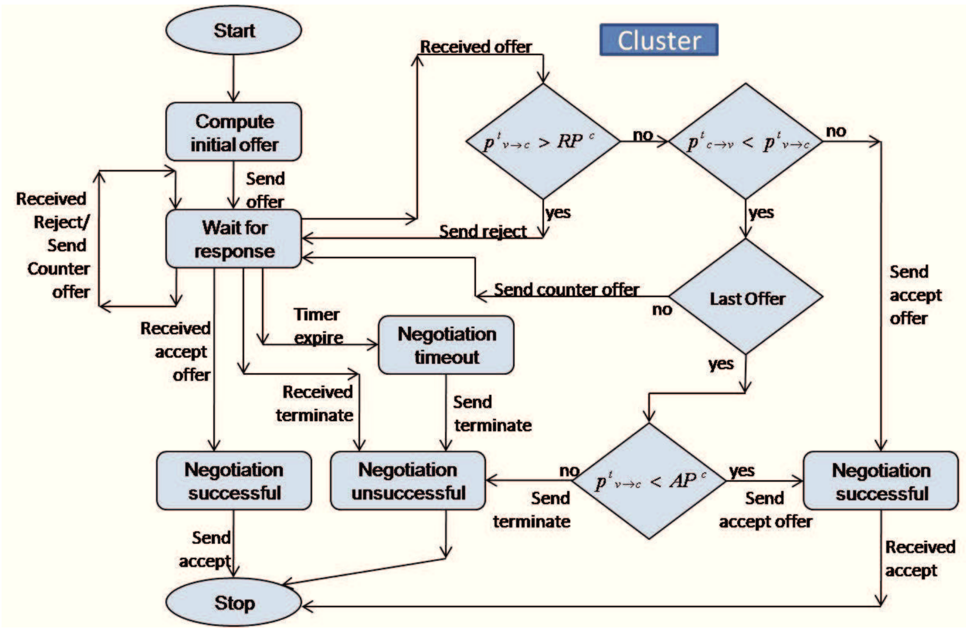

Figure 8.15: Flowchart of Cluster Negotiation Protocol Model with Reject

Figures 8.17 – Figure 8.20 present the simulation result with the special case termed *Reject.* In the simulation results presented, the cluster always follows the Boulware tactic whereas the vehicle's tactic changes from Boulware to Conceder. In this case, as compared to the previous case, instead of accepting and proposing the counter offers, the negotiating entities can reject the offers made by the opponents that lie outside the zone of agreement. The negotiation starts only when the price offer (made by both parties) enters the zone of agreement range. As it can be seen in the simulation result shown in Figure 8.17, the vehicle is proposing the price-offer and the offer is continuously rejected by the cluster until the 17th iteration wherein the vehicle proposes a price offer which is within the zone of agreement. Then the usual negotiation procedure starts wherein counter offers are proposed and compared with the offer to be generated in the next iteration and hence, depending on that the negotiation is successfully terminated. Thus, the negotiation is successful at 19th iteration with the vehicle accepting the offer made by the cluster. Similar, is the case for the simulations shown in Figure 8.18, where the vehicle is following a moderate Boulware tactic with a larger ψ value as compared to extreme Boulware tactic depicted in Figure 8.17.

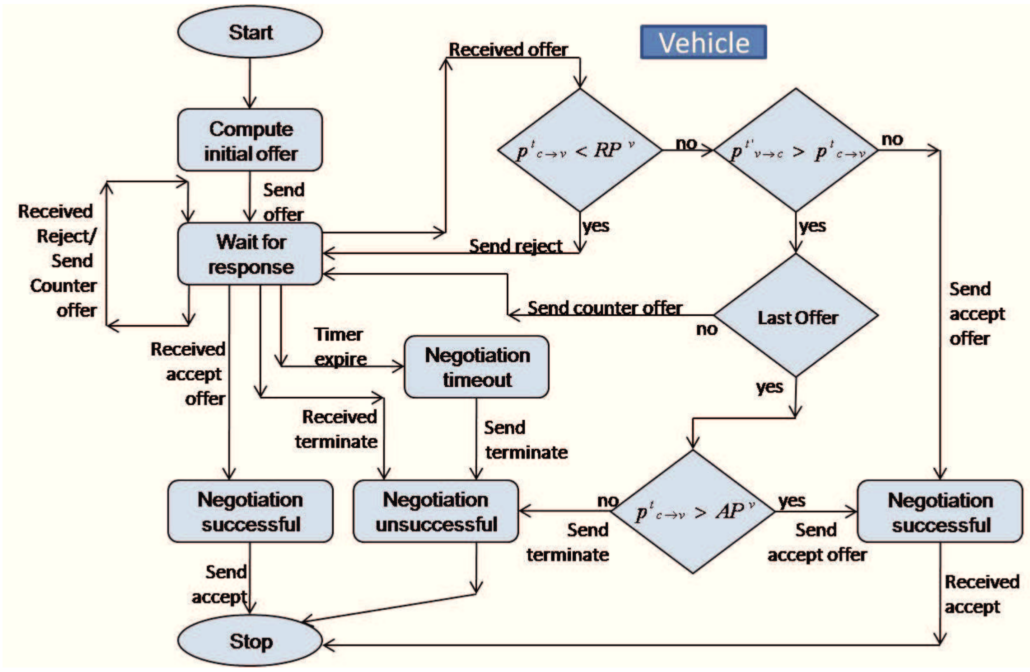

Figure 8.16: Flowchart of Vehicle Negotiation Protocol Model with Reject

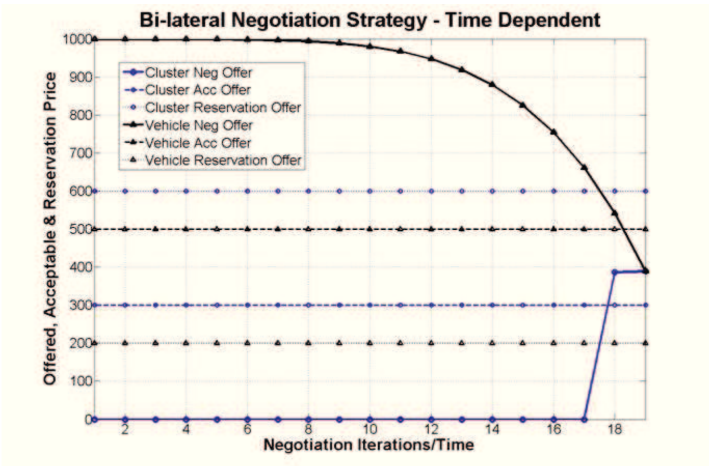

Figure 8.17: Vehicle/Cluster Price Offer (Reject Option) w.r.t. Negotiation Time with Reservation Price of 200 and 600 and Acceptable Price Offer of 500 and 300 respectively with Strategy S1 (Extreme Boulware Tactic) and Same Negotiation Time

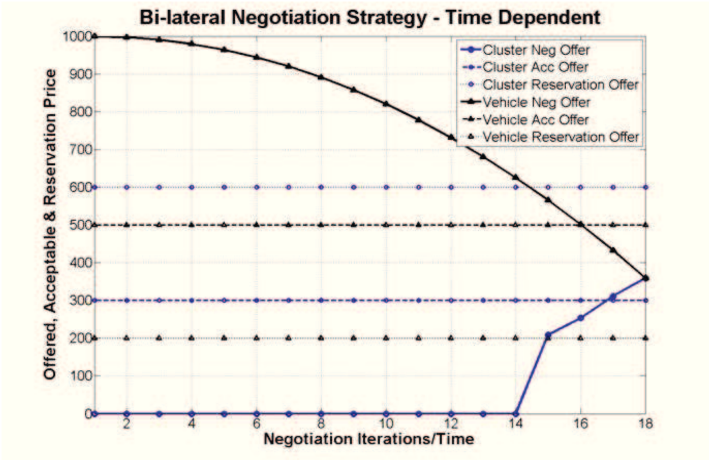

Figure 8.18: Vehicle/Cluster Price Offer (Reject Option) w.r.t. Negotiation Time with Reservation Price of 200 and 600 and Acceptable Price Offer of 500 and 300 respectively with Vehicle Moderate Boulware and Cluster Extreme Boulware Tactic for Same Negotiation Time

In Figure 8.19, the vehicle is following the linear tactic and its initial offers are rejected by the cluster. But, when the vehicle offer is within the zone of agreement the clusters counter-offer does not fall in the zone of agreement and hence the vehicle rejects it. Similar behavior is seen when the vehicle follows the conceder tactic in Figure 8.20.

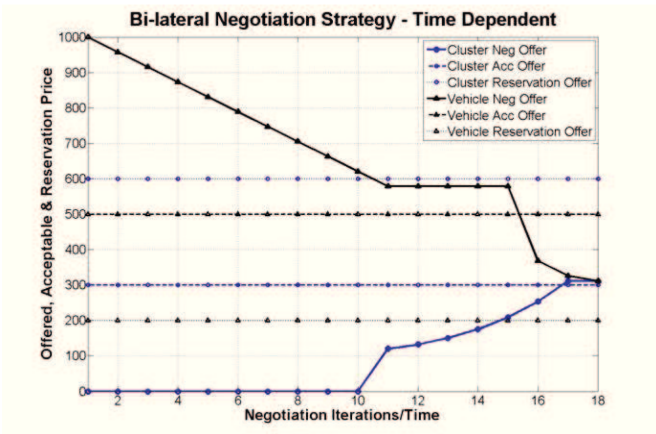

Figure 8.19: Vehicle/Cluster Price Offer (Reject Option) w.r.t. Negotiation Time with Reservation Price of 200 and 600 and Acceptable Price Offer of 500 and 300 respectively with Vehicle Linear and Cluster Moderate Boulware Tactic for Same Negotiation Time

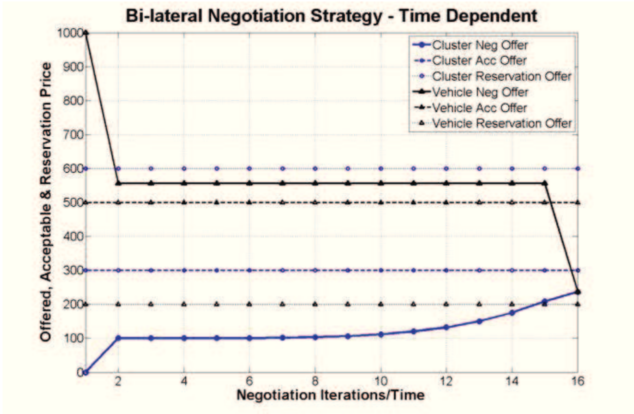

Figure 8.20: Vehicle/Cluster Price Offer (Reject Option) w.r.t. Negotiation Time with Reservation Price of 200 and 600 and Acceptable Price Offer of 500 and 300 respectively with Vehicle Extreme Conceder and Cluster Extreme Boulware Tactic for Same Negotiation Time

8.6 Conclusion

This chapter presents the implementation of an automated negotiation protocol for single issue bi-lateral negotiation model in PlaSMA. Various negotiation strategies are discussed and their performance is evaluated using different scenarios. As concluded in the previous chapter, the negotiation terminates within the region of agreement if both cluster and vehicles have the same time-out while in case of a scenario with different time-outs it might not be possible for the negotiation to terminate successfully. To overcome this problem a strategy with an acceptable price range is introduced. The acceptable price range is determined by defining a new price level (termed the acceptable price) by both the clusters and the vehicles. When the negotiating party sends the last offer (i.e., immediately before the negotiation time-out ends) it informs the opposite party about it. The other party compares this last offer with the utility of acceptable price and if the received offer has the same or better utility then it will be accepted. Otherwise the negotiation is terminated without success. Thus, it allows for the negotiations to end successfully if a good enough solution can be reached by the end of the negotiation time. Since, the acceptable price is not known by the opponent in the negotitation process, it is highly unlikely that the negotiating party would like to introduce a false last offer. As in this case, the negotiating party could terminate the negotiation process and hence resulting in its own loss.

Lastly, one more strategy named reject strategy was introduced with different and same negotiation time-out scenarios. In this approach, as compared to the previous approach, instead of accepting and proposing the counter offers, the negotiating entities can reject the offers made by the opponents that lie outside the zone of agreement. The negotiation starts only when the price offer (made by both parties) enters the zone of agreement range. The flexibility to reject an offer can be more helpful in cases where the negotiation is multi-lateral, i.e. there are multiple negotiators as in that case a party may select a small set of negotiators to actively negotiate and reject the others. In addition, the reject offer can imply to the opponent that its offer would not lead to quick negotiation equilibrium and hence the opponent should change the value more aggressively. In order to keep the negotiation process fair to all participants, in general the reservation price may be registered at a central entity like an associated vertex or even shared with all the participants. For the implemented strategy, it was assumed that all the parties follow the protocol honestly.

9. Conclusion and Outlook

This thesis presents the concept of cluster based routing and negotiation using software agent system in the transport logistics network. The goal is to bring about more autonomous decision making capability by the entities in the logistics network thereby enhancing the paradigm of autonomous cooperation in logistic networks.

9.1 Research Contributions

In this section, some of the significant research contributions of the work described in this thesis are highlighted:

Concept of clustering autonomous entities in logistics: The novel concept of clustering autonomous logistics entities is introduced. A short literature survey on the concepts of autonomous cooperation, software agents, role of software agents in autonomous cooperation of logistics entities are reviewed and presented. An algorithm termed algorithm for cluster establishment (ACE) is studied and enhanced for efficient cluster formation (refer Appendix A). Also a theoretical analysis on the correlation factor and its dependency on the clusters formed in the network is presented. Various clustering approaches namely Centralized, Semi-Autonomous and Autonomous are analysed and their advantages and disadvantages in the logistics network are discussed.

Design, implementation and enhancement of the cluster-based routing approach: The concept of clustering is deployed for a distributed routing approach termed cluster-based DLRP. The concept of DLRP and motivation for introducing the cluster-based DLRP is described in this thesis. In addition to this an analytical enhancement of the branching factor in the routing process is presented. A performance evaluation in this regard is presented and analysed using simulation scenarios based on the geographical map of Germany. The simulation and analytical results match each other for the various scenarios that were considered. As seen by the simulation and analytical results, cluster-based routing results in reducing the communication traffic by a significant amount.

Design and implementation of the correlation based transport decision: The transport decision based on the concept of correlation of the selected routes by the clusters and the vehicle is introduced. In this regard, two logistics transport decision criteria named capacity utilization of the vehicles and transportation costs incurred by the goods are considered. For the implemented protocol, the vehicles obtain the information about the various clusters formed from its current position to identify the best possible set of clusters for transportation, similar to the legacy DLRP. Based on the various strategies, the resultant effect on both the capacity utilization and the transportation cost for different scenarios are analysed. From the presented results, it can be seen that the correlation of routes and transportation cost based decision process enhances the capacity utilization of the vehicles. Since, clusters are transported together they also share the vehicle's transportation cost. Thus, the overall transportation cost incurred by the clusters is also significantly reduced.

Concept of automated negotiation in logistics: The concept of autonomous negotiation within the cluster based routing environment is introduced. Various negotiation issues, strategies and protocols to be considered in the logistics networks are analysed. Thereby a negotiation model for the logistics network using the clusters of transport goods and vehicles is presented. As time plays a prime factor in logistics various negotiation strategies based on time, resources and behavior are analysed. The analytical results considered various scenarios, using different negotiating strategies and their effects in reducing the negotiation time and cost. Obtained analytical results give an impression of which strategy to be used by the negotiators to reach a favourable agreement.

Design and implementation of negotiation strategies in transport logistics scenario: The last part of the thesis deals with the implementation of the negotiation strategies for the cluster-based DLRP transport solution implemented in PlaSMA. The negotiation strategies deal with the negotiation of the transportation cost calculated by the cluster and the vehicle based on the selected route. In this regard, a single-issue bi-lateral automated negotiation model is presented in detail. Also, the negotiation protocol and strategy for cluster-based DLRP is presented. Various negotiation scenarios are introduced and simulated. The simulation results give an impression of the negotiation strategies to be used with respect to a transport logistics network and the effect on transportation cost and negotiation time under various circumstances.

9.2 Outlook

In this section, the future research suggestions that would enhance and complement the thesis are presented.

In this thesis, the cluster based routing method was introduced. The clustering model implemented was mainly involved with clustering of transport goods with respect to different destinations or the common route the vehicles are traveling to deliver the goods. However, future research can concentrate on other parameters of the goods such as common type-of-goods or common time-of-delivery etc. This would additionally put constraints on the operation of the clustering algorithms for better performance optimization of the transportation domain.

This thesis concentrated on the semi-autonomous approach wherein the decisions (clustering and routing) were partially handled both by the distribution centers (vertices) as well as transportation goods and vehicles. Future research could be implementing a more autonomous scenario where all the decisions are handled by or between the transport goods and the vehicles without any involvement of a centralized entity like the distribution center. A performance evaluation on the comparison between and semi-autonomous and autonomous scenarios could better help in distinguishing the advantages and disadvantages more elaborately.

Additionally, other than the transport goods, many other logistical entities may also be clustered for example; vehicles, distribution centers and even cities. This broader scale clustering may open a new set of optimization problems to further improve the autonomous transportation system e.g., inter/intra-cluster transportation domains.

For the overall optimization of the transport in a logistics network, correlation of routes was considered by the vehicles. Different strategies were used to identify favorable combinations. The results show some empty trips that the vehicles have to make in order to offer transport to some goods. In the current work, this cost was not considered by the vehicle and hence it was not levied on the goods. Other cost models for considering the empty trips as well as for calculating the transportation cost can be further investigated.

Finally in this thesis, negotiation strategies were studied that concentrated on the negotiation of the transportation cost between the vehicles and the clusters of transport goods. Various negotiation time dependent tactics were analysed and presented. Future research can concentrate on more constraints on negotiation strategies. In addition, only a bi-lateral negotiation model was considered in this thesis. A future aspect could be in analyzing the negotiation strategies for multi-issue, multi-lateral negotiation in an autonomous logistics network, though this would make the entire process very complex. In addition, the role of cluster size in the negotiation process can be investigated.

Appendix A: Cluster Formation Algorithm

Special mobile agent platforms are required on each host to provide a safe environment for the execution of mobile agents, and also offer services for the agents residing on the host. A brief overview of the well-known mobile agent platforms is presented.

A.1. Cluster Formation Algorithm

In this section, an algorithm for cluster-formation in multi-agent systems is described. A large number of centrally controlled algorithms for discovering clusters exist in the literature, the majority of which focus on finding clusters with various properties of the data set. For example, a multi-dimensional data set may result in clusters of widely different sizes or odd cluster shapes making it difficult to define the similarity function. Nevertheless, this thesis needs to account for specifics of a transport logistics network application. Consider a certain communication infrastructure (where each entity is connected with respect to the common information they share) e.g., in a logistics network; the common destination of transport goods or dynamic impact scenarios such as density of the cluster vary in time and space. Therefore the goal is not a new clustering method per se, but rather a clustering technique in a dynamic, decentralized setting.

In short, the focus is on evaluating inter-agent communications required by a decentralized clustering algorithm, dynamically adapting changes of the data and changes in relationships and actions. For example, an agent may send a message with information about itself to other agents or delegate some task to a cluster-head or declare independence announcing itself as new cluster-head based on the clustering heuristics defined.

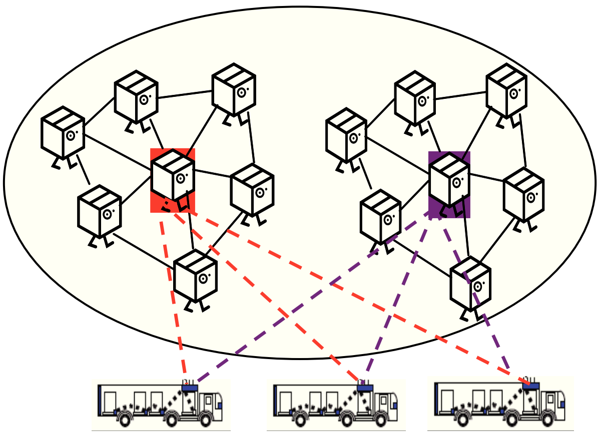

Figure A.1: Transport Logistics Cluster-Head Package-agents communicating with the Vehicle-agents [Src: SWB+07]

Eventually, the paradigm shift of making the entities more autonomous and intelligent in transport logistics has paved the way for integrating the decentralized algorithms so that the decision making process devolves to the level of an individual item in the logistic chain. Thus, the various concepts and algorithms applied or used in modeling the information and communication networks can be integrated in the logistic processes. Clustering as such is a well known research topic in various application areas. Therefore, one of the goals of this work is to introduce the clustering concept in the autonomous logistics network.

Clustering as defined by [JMF99] is a means of generating similar groups of entities such that the items within the cluster are more strongly related to each other than to those in different clusters. Particularly in an autonomous logistics scenario, the key aspect of clustering is to reduce the communication volume, which may result in a large latency period to take decisions for software agents (transport goods etc) (proved in Chapter 4). Logistic components may have common aims, for example, there can be several goods that are at the same location and have the same destination. In such a case, it can be sensible to form communities of those components and determine a community leader that acts on behalf of all members, refer Figure A.1. It is expected that thereby, the required communication among the logistic components can be optimized. As time plays the prime factor in logistics, it is important to take the right decision at the right time with right information shared in less time.

Keeping in mind the above concepts, various algorithms proposed for communication networks (e.g. sensor networks, ad hoc networks) for clustering can be deployed and adapted to logistic scenarios. Various algorithms/protocols have been proposed in literature for clustering. This work proposes the mapping of algorithms used for clustering of sensor networks to the clustering problem of logistic entities like the transport goods with the use of software agent framework [SWB+07]. In this thesis the transport goods are also referred to as packages. Every package (transport good) is autonomous (represented by an agent) enough to take decisions by communicating and contributing to the cluster formation process.

A clustering algorithm studied for an autonomous logistic scenario is the algorithm proposed by Chan & Perrig [CP04] termed as Algorithm for Cluster Establishment (ACE). The proposed algorithm incurs communication overhead as each agent communicates with a set of neighboring agents in order to achieve the desired global objective of cluster formation and cluster-head selection. The algorithm proposed in [CP04] is presented in brief termed ACE. In this work the ACE algorithm was enhanced to Enh-ACE-a and Enh-ACE-b [SWB+07]. In this proposed work, the algorithm is mainly used for clustering of packages which are already grouped based on a similarity measure within a distribution center.

A.1.1. ACE algorithms applied to a Logistic Scenario

The ACE algorithm is applied to a general logistic scenario as shown in Figure A.2, wherein the clustering method is applied to entities like packages that are represented as package agents (PAs). These PAs are assumed to be stored at the distribution center (DC) and need to be distributed to various destinations.

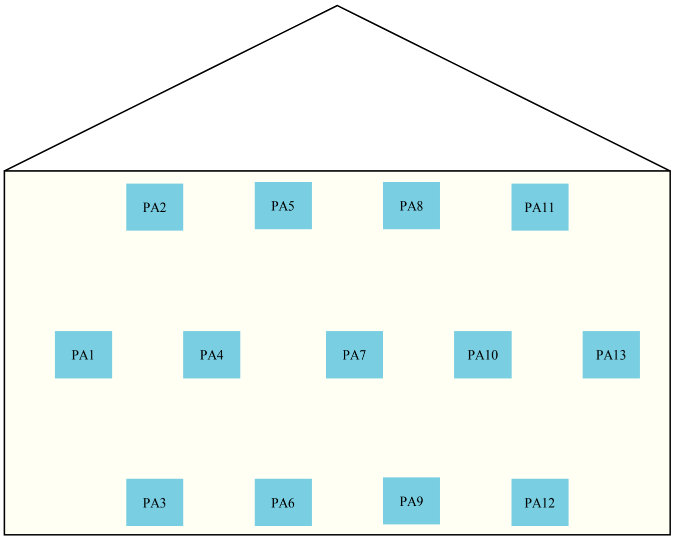

Figure A.2: An example of a logistics scenario with stored packages (PAs) within the distribution center

In this model, the package agents (PAs) are defined by their characteristics like destination, type etc. and thus, these characteristics can be used for the purpose of clustering, as a set of items. Each agent can only communicate to another agent within the local (physical) neighborhood and hence can establish a limited number of *links* to other agents. These links represent communication channels and thus, define the neighborhood of an agent. The aim of the clustering algorithm is for the agents to rearrange these links and to select some of them to form *connections* and *connected links* between themselves, generating a graph of connections corresponding to a clustering.

The creation of initial links is a bootstrapping problem; it is assumed that they are derived from the placement of agents, or some other application-dependent source, and are modeled as a random network. Thus, in the scenario each agent starts out as a cluster of a single item with links to randomly chosen neighbor agents. As the algorithm progresses, agents pick some of their links to become *connected links* based on the similarity of the agents (similarity with respect to properties; for example, same destination). Agents joined by a path of connected links form a single cluster.

The clustering of PAs is done based on the same type of packages and the common destination point of their delivery. The PAs are connected by various links characterized with respect to their properties and thus, clustering is done based on the common properties of the agents, e.g. a common or nearby destination. Assuming there are some packages in one of the distribution centers, the connections between the packages indicates the similarity in their geographical location.

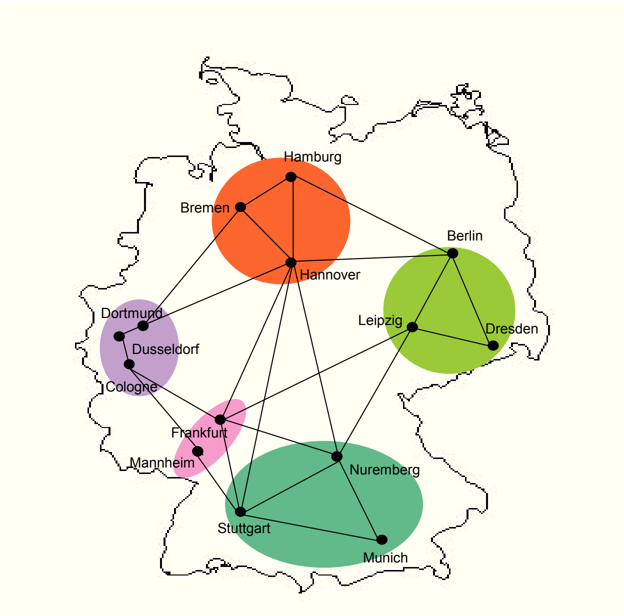

Figure A.3 Map of Germany with road network connections

Referring to Figure A.2, different packages stored at the distribution center will have different destinations with respect to the map of Germany presented in Figure A.3. For example, if the distribution center is located at Bremen and PA1 is destined to Munich then PA1 will look for packages destined to the nearby area. PA1 finds that PA3 is to be delivered to Nuremberg so it makes the connection with it. Similarly PA5 needs to be delivered to a nearby location to Munich so eventually the connection is made with it. While PA4 needs to be delivered to Frankfurt and since Frankfurt lies on the route to Munich, PA4 will be connected to both the PAs related to Munich as well as the ones that needs to be delivered in the region of Frankfurt, e.g., PA6 which is to be delivered to Manheim. Hence, in this way the PAs can communicate to PAs of other destinations and generate connections between them. Eventually, a cluster-head is selected which acts like an information pool to all the neighboring PAs. The main advantage of this clustering approach is that the negotiation between various PAs is faster and additionally the vehicles can efficiently decide which PAs to transport based on the information they get from the cluster-head. For example, instead of the vehicles travelling to some distant DC for delivering the goods and returning back to the DC they already started, they rather collect clusters from the DC's falling on their way to the distant DC. This eventually, results in the process of saving time and increasing revenue.

Various algorithms which result in efficient clustering are presented in the following sub-sections.

A.1.1.1 ACE

During the clustering process, out of all the PAs, one PA is randomly picked. The selected PA's available choice of actions depends on what state it is currently in. If the selected PA is already a cluster member but is not the cluster-head then, it does nothing and the algorithm picks another PA randomly.

If the selected PA is unclustered, it polls its neighboring *cluster members* and counts the number of loyal followers, *L* (members which are still unclustered and ready to be a part of the selected PA's cluster). If the selected PA finds that the count exceeds a certain *threshold* (*f_min*= 1) it declares itself the cluster-head and then assigns its cluster-id to its followers, making them a part of its cluster.

But, in case when the selected PA is already a cluster-head, the selected PA checks if its cluster members have more loyal followers (if given a chance to be cluster-head) than itself. In that case, it will transfer its status of cluster-head to the cluster member PA which has most loyal followers. Thus, the cluster member of the selected PA with the highest number of loyal followers of its own becomes the new cluster-head and defines its new cluster by assigning its followers a new cluster-id. When a member of the cluster looks for possible loyal followers then it searches for the unclustered neighbors as well as the neighbor members of the cluster of which it is already a part. While checking for the better cluster-head the present cluster-head re-counts its own possible loyal followers because since the last count, a new neighbor might have come up or an old loyal follower might not exist anymore and so on.

Appendix A: Cluster Formation Algorithm

Algorithm ACE: Original ACE algorithm

Procedure Package agents can have three possible states – *Unclustered, Clustered or Cluster-head*

If an *Unclustered* package agent wants to become a cluster-head then its *loyal followers* are the neighboring package agents that are *Unclustered* and want to become part of its cluster. If a *Clustered* or *Cluster-head* polls for its *loyal followers* then *loyal followers* are the *Unclustered* and *Clustered* (of the same cluster) neighbor package agents.

The number of *loyal followers* is termed as numLoyalFollowers

f_min is the minimal size of a cluster that can be formed

<u>Start of the Algorithm</u>

Randomly Pick a Package Agent (*PA*) and it is termed as a Selected Package Agent (*SPA*)

Check for the status of the selected package agent

If (*SPA* = *Unclustered*) then

poll for *loyal followers*

If (numLoyalFollowers >= f_min) then

SPA announces itself to be the C*luster-head* and sends a message to all its loyal

followers wherein all the loyal followers status changes from *Unclustered* to

Clustered with the *SPA's* Cluster ID

Else

the *SPA* remains as *Unclustered*

End If

Else If *SPA* = *Cluster-head* then

Current_head = *SPA*'s ID

Current_numLoyalFollowers = SPA's numLoyalFollowers

For all *i* where *i* is a potential new *Cluster-head* i.e., members of the *SPA*'s cluster

including the *Cluster-head*

polledFollowerCount = *Poll_for_numLoyalFollowers* (*i*, *SPA*'s *Cluster ID*)

If (*polledFollowerCount* > *Current_numLoyalFollowers*) then

Best_head = *i's ID*

A.1. Cluster Formation Algorithm

Best_numLoyalFollowers = polledFollowerCount

Cluster_changed = TRUE

End If

End For

If (*Best_head* ≠ *Current_head*) then

Best_head announces itself to be the new C*luster-head* and hence its loyal followers change their *ID*s to be that of *Best_head*'s *Cluster ID*

Current_head relieves itself of its *Cluster-head ID* and takes the *Best_head's Cluster ID*

If there is any *PA's* that was part of the *Current_head*'s cluster but are no longer a part of the new cluster then their status is reversed to the *Unclustered* status

Else If (*Cluster_changed*) then

Re-define the current C*luster-head's* cluster as there is a new member added to the old cluster

Else the current cluster remains unchanged

End If

End If

End Procedure

Figure A.4 depicts the flowchart of the cluster formation based on the ACE algorithm.

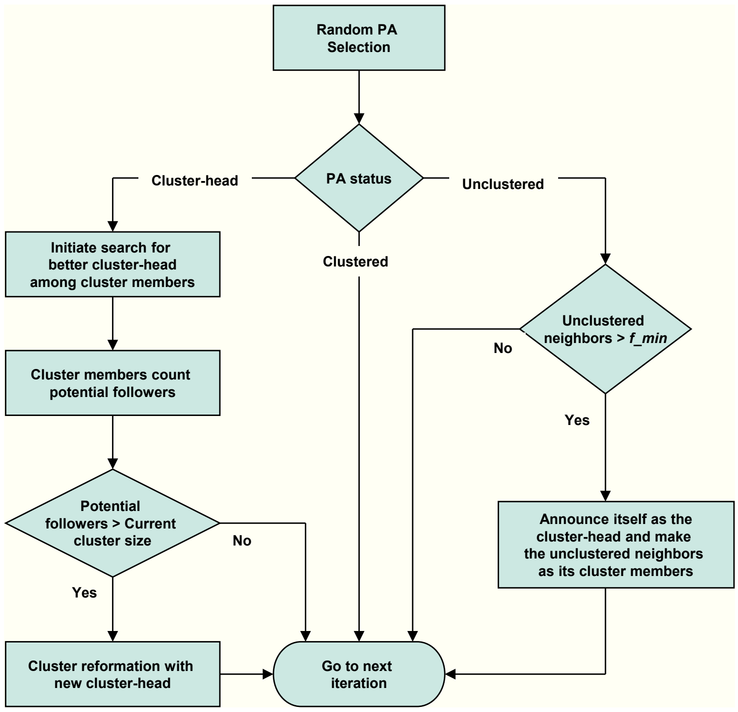

Figure A.4: Cluster formation by ACE Algorithm

A.1.2. Enhanced ACE Algorithms

In the following the ACE algorithm is enhanced by the author into two versions termed *Enh-ACE-a* and *Enh-ACE-b* respectively [SWB+07]. The motivation for the enhancements is to minimize the processing complexity by reducing the number of iterations to obtain efficient clusters (cluster-head with largest number of followers).

A.1.2.1. Enh-ACE-a

In this enhanced version of the ACE algorithm, the procedure is the same with the introduced changes presented in the steps below:

Step 1: It was observed that in ACE, the search for a better cluster-head was confined to the present cluster-head's cluster only and was not extended to all its neighbors. So, the first idea was to extend the search to all the neighbors of the present cluster-head, irrespective if the neighbor was a part of its cluster or not. Therefore, in this step if the PA is already a cluster-head then it will poll all its neighbors (even those which are members of another cluster). The reasoning can be that though this neighbor is not a follower currently but still has a connection to it i.e., it has connections with more than one cluster and might be a good choice for the cluster-head.

Step 2: If any of the polled neighbors has more loyal followers than the selected cluster-head, then it announces itself as the candidate for the new cluster-head. Taking this into account, the old cluster-head will abandon its position and make the polled neighbor with maximum loyal followers the new cluster-head. The new cluster-head would then announce to all its loyal followers the status of it being the cluster-head.

Step 3: If any of the polled neighbors which was a part of any other cluster and is not the new cluster-head then, this particular neighbor node will become a part of the cluster whose cluster-head polled this neighbor node. This implies that the polled neighbor node *changes its loyalty* and be a part of another cluster. The reasoning can be that the polled neighbor was given a chance to be the new cluster-head and hence, it repays by being a loyal follower (a member) of the cluster.

Algorithm Enh-ACE-a*:* Modified ACE Algorithm (Change of loyalty and larger set polled to search for a new cluster-head by an existing cluster-head)
Procedure: Package agents can have three possible states – *Unclustered, Clustered or Cluster-head* If an *Unclustered* package agent wants to become a cluster-head then its *loyal followers* are the neighboring package agents that are *Unclustered* and want to become part of its cluster. If a *Clustered* or *Cluster-head* polls for its *loyal followers* then *loyal followers* are the *Unclustered* and *Clustered* (of the same cluster) neighbor package agents. The number of *loyal followers* is termed as numLoyalFollowers *f_min* is the minimal size of a cluster that can be formed Start of the Algorithm Randomly Pick a Package Agent (*PA*) and it is termed as a Selected Package Agent (*SPA*) Check for the status of the selected package agent If (*SPA* = *Unclustered*) then

poll for *loyal followers*

If (*numLoyalFollowers* >= *f_min*) then

SPA announces itself to be the C*luster-head* and sends a message to all its loyal

followers wherein all the loyal followers status changes from *Unclustered* to

Clustered with the *SPA's Cluster ID*

Else the *SPA* remains *Unclustered*

End If

Else If (*SPA* = *Clusterhead*) then

Current_head = SPA's ID

Current_numLoyalFollowers = SPA's numNeighbors*

(*After this iteration the current cluster-head will have all its neighbors as its loyal followers if it remains to be the cluster-head)

For all *i* where *i* is a potential new *Cluster-head* i.e., all neighbors of the *SPA*

including the *Cluster-head*

polledFollowerCount = *Poll_for_numLoyalFollowers* (i, *SPA*'s *Cluster ID*)

If (*polledFollowerCount* > *Current_numLoyalFollowers*) then

Best_head = *i*'s *ID*

Best_numLoyalFollowers = polledFollowerCount

Cluster_changed = TRUE

End If

End For

If (*Best_head* ≠ *Current_head*) then

Best_head announces itself to be the new *Cluster-head* and hence its loyal

followers change their *ID*s to be that of *Best_head*'s *Cluster ID*

Current_head relieves itself of its *Cluster-head ID* and takes the *Best_head's*

Cluster ID

If there are any *PA's* that were part of the *Current_head*'s cluster but are no longer a part of the new cluster then their status is reversed to the *Unclustered* status

Else If (*Cluster_changed*) then

Re-define the current C*luster-head's* cluster as there is a new member added to the

old cluster

Else the current cluster remains unchanged

End If

End If

End Procedure

Figure A.5 depicts the flowchart of the cluster formation based on the Enh-ACE-a algorithm.

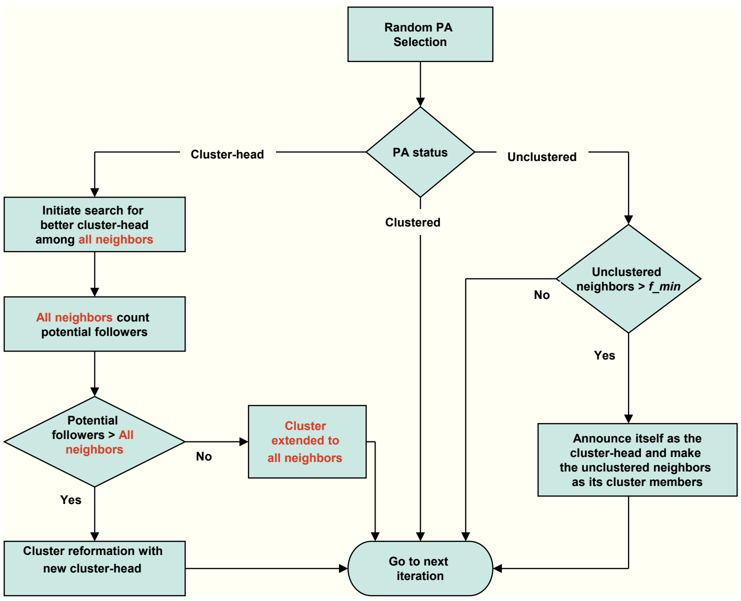

Figure A.5: Cluster formation by Enh-ACE-a Algorithm

A.1.2.2. Enh-ACE-a

This algorithm is same as Enh-ACE-a except for the only change in the third step. If the polled neighbor is part of another cluster and is not the new cluster-head, then the neighbor is not allowed to change its cluster i.e., *no change of loyalty*. This approach is an intermediate approach with respect to ACE and Enh-ACE-a.

Appendix A: Cluster Formation Algorithm

Algorithm Enh-ACE-b*:* Modified ACE Algorithm (No change of loyalty and larger set polled to search for a new cluster-head by an existing cluster-head)
Procedure Package agents can have three possible states – *Unclustered, Clustered or Cluster-head* If an *Unclustered* package agent wants to become a cluster-head then its *loyal followers* are the neighboring package agents that are *Unclustered* and want to become part of its cluster. If a *Clustered* or *Cluster-head* polls for its *loyal followers* then *loyal followers* are the *Unclustered* and *Clustered* (of the same cluster) neighbor package agents. The number of *loyal followers* is termed as numLoyalFollowers *f_min* is the minimal size of a cluster that can be formed Start of the Algorithm Randomly Pick a Package Agent (*PA*) and it is termed as a Selected Package Agent (*SPA*) Check for the status of the selected package agent If *SPA = Unclustered* then Poll for *loyal followers* If (*numLoyalFollowers >= f_min)* then *SPA* announces itself to be the C*luster-head* and sends a message to all its loyal followers wherein all the loyal followers status changes from *Unclustered* to *Clustered* with the *SPA's Cluster ID* Else the *SPA* remains as *Unclustered* End If Else If *SPA* = *Clusterhead* then *Current_head = SPA's ID* *Current_numLoyalFollowers = SPA's numLoyalFollowers* For all *i* where *i* is a potential new *Cluster-head* i.e., all neighbors of the *SPA* including the *Cluster-head* *polledFollowerCount* = *Poll_for_numLoyalFollowers* (*i*, *SPA*'s *Cluster ID*) If *polledFollowerCount* > *Current_numLoyalFollowers* then *Best_head* = *i*'s *ID* *Best_numLoyalFollowers = polledFollowerCount* *Cluster_changed = TRUE*

A.1. Cluster Formation Algorithm

End If

End For

If *(Best_head* ≠ *Current_head)* then

Best_head announces itself to be the new *Cluster-head* and hence its loyal followers change their *ID*s to be that of *Best_head*'s *Cluster ID*

Current_head relieves itself of its *Cluster-head ID* and takes the *Best_head's Cluster ID*

If there any *PA's* that were part of the *Current_head*'s cluster but are no longer a

part of the new cluster then there status is reversed to the *Unclustered* status

Else If (*Cluster_changed*) then

No new cluster is made and at the same time no changes are made to the pre-existing clusters i.e., the PA's that were polled to become the *Cluster-head* do not change their loyalty (remain loyal to their old *Cluster-head*)

End If

End If

End Procedure

The Figure A.6 depicts the flowchart of the cluster formation based on the Enh-ACE-b algorithm.

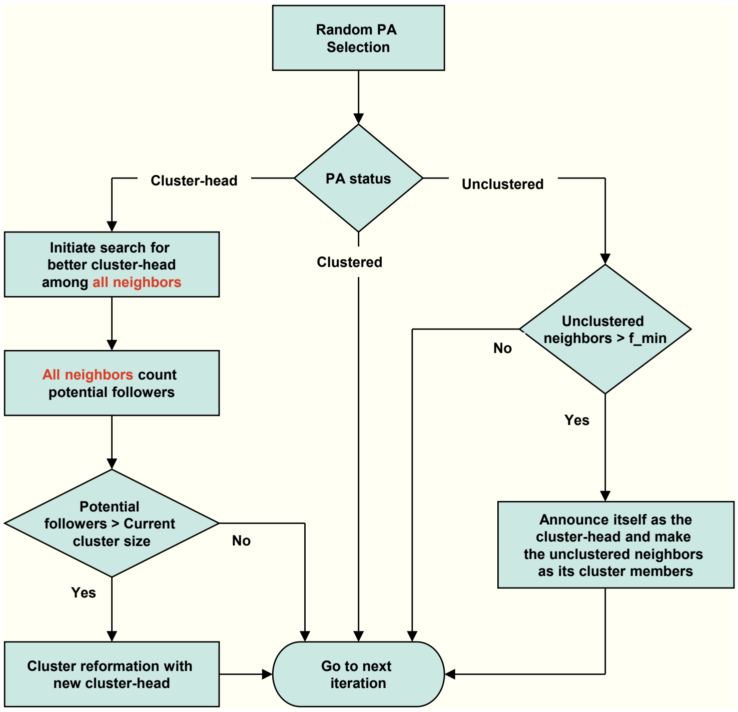

Figure A.6: Cluster formation by Enh-ACE-b Algorithm

A.1.3. Result and Conclusion

The Figures A.7, A.8 & A.9 depict the resultant clusters formed by the respective algorithms. The dark filled boxes represent the cluster-heads (cluster-heads) and the lightly filled boxes as their loyal members.

As observed the resultant clusters formed by ACE are three clusters with one package (PA3) remaining unclustered, refer Figure A.7 whereas the algorithm Enh-ACE-a and Enh-ACE-b result in two clusters (same) but the number of computations in Enh-ACE-b is one more compared to Enh-ACE-a, as shown in Figures A.8 and A.9.

A.1.3. Result and Conclusion

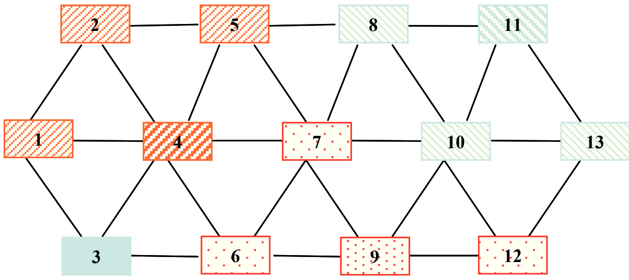

Figure A.7: Scenario: ACE

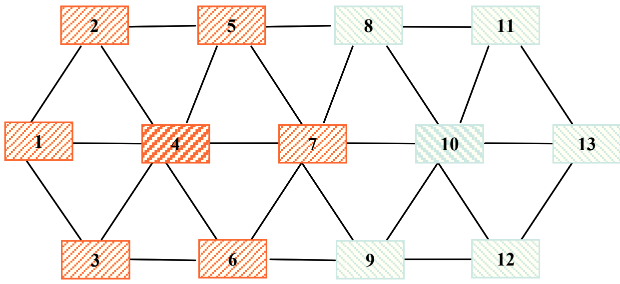

Figure A.8: Scenario: Enh-ACE–a

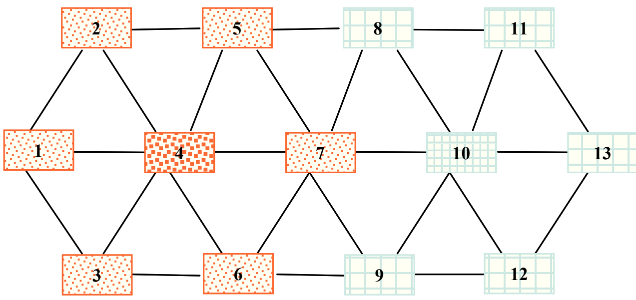

Figure A.9: Scenario: Enh-ACE–b

The random sequences in which the PAs are selected in each case are presented in Table A.1. It can be observed that the action is only taking place for those selected package agents, which are cluster-heads or unclustered. These package agents are represented in bold font in Table A.1. For ACE the number of action points (selected PAs) is 11 and for Enh-ACE-a and Enh-ACE-b the number of action points is 8 and 9 respectively.

Thus, to speed up the process, PAs should be selected from the set of unclustered or cluster-head PAs only rather than from the complete set of PAs.

Table A.1: Sequence of selected package agents (PAs)

ACE	SPA's Sequence: **2 11 9** 5 8 **9 2 6** 3 3 5 12 12 **11** 8 3 13 7 8 **10** 6 2 8 10 **9** 8 **4 6** 13 4 (30 iterations)
Enh-ACE-a	SPA's Sequence: **2 11 9** 5 8 **9 2** 6 3 3 5 12 12 **11** 8 3 13 7 8 **10** 6 2 8 10 9 8 **4** 6 13 4 (30 iterations)
Enh-ACE–b	SPA's Sequence: **2 11 9** 5 8 **9 2 6** 3 3 5 **12 12 11** 8 3 13 7 8 10 6 2 8 10 9 8 4 6 13 4 (30 iterations)

The method of clustering logistic entities can be advantageous in many folds. The method of clustering can increase the profit margin of the organization due to the planned organized movement of vehicles for load collection based on the idea of clusters of packages for particular destination. This helps in dealing with the dynamics involved within the scenario in certain cases. The selected cluster-head acts as an information pool for its cluster and hence bring the information near the package agents, reducing the latency and bandwidth demand. The optimal selection of the cluster and cluster-head goes a long way in reducing communication as well as transport costs on the whole.

This can also aid the routing problem giving a better option for the vehicle to take an appropriate route based on the clustering done. On the way, the vehicle can pick and drop packages as well as if the packages and vehicles negotiate in an optimal way. The algorithm presented offers a method of effective clustering with limited communication overhead.

Appendix B: Transport based on Route Correlation and Transportation Cost

From the investigations presented in Chapter 6, it was concluded that the strategy wherein the choice of clusters to be transported together was based on the common route gave the best performance results. To investigate the scalability issues of such an implementation, a larger simulation was run for 100 clusters with 10 as the cluster size.

B.1. Single Source and Multiple Destinations

This section presents the results for multiple destinations with single or multiple sources with the simulation scenario being the same as was used for investigations presented in Chapter 6, refer Figure 6.4 & 6.7, respectively.

B.1.1. Strategy based on common Route

Single Source: Bremen

Multiple Destinations: Hamburg-300, Lueneberg-250, Luebeck-200, BadSegeberg-150 and Wismar-100

Clustersize 10, # of clusters 100, Total number of packages generated 1000

Simulation Time 10 days (14400min.), Packet generation rate 100packages/day

cluster formation timeout 1 day (1440min.), vehicle waiting time 2 days.

Table B.1: Source: Bremen; Clustersize 10, # of clusters 100, Total number of packages generated 1000

Cluster Head	**Vehicle**	**Destination/Distance**	**Utilization**
Load_Bremen_1	T_S_1(50%)	Hamburg/120km	-
Load_Bremen_2	T_S_2(50%)	Lueneburg/183km	-
Load_Bremen_3	T_M_1(33.33%)	Luebeck/187km	-
Load_Bremen_5	T_M_1(66.67%)	BadSegeberg/216km	-
Load_Bremen_7	T_M_2(33.33%)	Wismar/248km	-
Load_Bremen_38	T_S_1(100%)	Hamburg/120km	100%
Load_Bremen_42	T_S_2(100%)	Lueneburg/183km	100%
Load_Bremen_43	T_M_1(100%)	Luebeck/187km	100%/ 33.33%
Load_Bremen_70	T_M_2(66.67%)	Hamburg/120km	66.67%/ 33.33%
Load_Bremen_80	T_M_3(33.33%)	Lueneburg/183km	-
Load_Bremen_81	T_M_4(33.33%)	BadSegeberg/216km	-
Load_Bremen_96	T_M_4(66.67%)	Luebeck/187km	66.67%/ 33.33%

Appendix B: Transport based on Route Correlation and Transportation Cost

Load_Bremen_99	T_L_1(20%)	Wismar/248km	-
Load_Bremen_101	T_M_3(66.67%)	Hamburg/120km	-
Load_Bremen_120	T_M_3(100%)	Lueneburg/183km	100%/ 66.67%
Load_Bremen_134	T_L_1(40%)	Hamburg/120km	-
Load_Bremen_81	T_L_2(20%)	BadSegeberg/216km	-
Load_Bremen_156	T_L_1(60%)	Luebeck/187km	-
Load_Bremen_165	T_S_1(50%)	Lueneburg/183km	-
Load_Bremen_166	T_L_1(80%)	Hamburg/120km	-
Load_Bremen_201	T_L_1 (100%)	Hamburg/120km	100%/ 40%/ 20%
Load_Bremen_202	T_S_1(100%)	Lueneburg/183km	100%
Load_Bremen_203	T_S_2(50%)	Wismar/248km	-
Load_Bremen_204	T_L_2(40%)	BadSegeberg/216km	-
Load_Bremen_205	T_L_2(60%)	Luebeck/187km	-
Load_Bremen_236	T_M_1(33.33%)	Hamburg/120km	-
Load_Bremen_242	T_M_1(66.67%)	Lueneburg/183km	-
Load_Bremen_205	T_L_2(80%)	Luebeck/187km	-
Load_Bremen_269	T_L_2(100%)	BadSegeberg/216km	100%/ 60%
Load_Bremen_272	T_S_2(100%)	Hamburg/120km	100%/ 50%
Load_Bremen_284	T_M_1(100%)	Lueneburg/183km	100%/ 66.67%
Load_Bremen_303	T_M_2(33.33%)	Hamburg/120km	-
Load_Bremen_304	T_M_2(66.67%)	Luebeck/187km	-
Load_Bremen_306	T_M_4(33.33%)	Wismar/248km	-
Load_Bremen_324	T_M_3(33.33%)	BadSegeberg/216km	-
Load_Bremen_327	T_S_1 (50%)	Lueneburg/183km	-
Load_Bremen_334	T_M_2(100%)	Hamburg/120km	100%/ 33.33%
Load_Bremen_353	T_M_3(66.67%)	Luebeck/187km	-
Load_Bremen_334	T_M_3(100%)	Hamburg/120km	100%/ 66.67%/ 33.33%
Load_Bremen_327	T_S_1 (100%)	Lueneburg/183km	100%
Load_Bremen_401	T_M_4(66.67%)	Hamburg/120km	-
Load_Bremen_402	T_S_2(50%)	Lueneburg/183km	-
Load_Bremen_403	T_M_4(100%)	Luebeck/187km	100%/ 66.67%/ 33.33%
Load_Bremen_405	T_M_1(33.33%)	BadSegeberg/216km	-
Load_Bremen_407	T_S_1(50%)	Wismar/248km	-
Load_Bremen_438	T_M_1(66.67%)	Hamburg/120km	100%
Load_Bremen_442	T_S_2(100%)	Lueneburg/183km	100%
Load_Bremen_443	T_M_1(100%)	Luebeck/187km	100%/ 66.67%/

B.1. Single Source and Multiple Destinations

			33.33%
Load_Bremen_470	T_S_1(100%)	Hamburg/120km	100%/ 50%
Load_Bremen_480/	T_L_1(20%)	Lueneburg/183km	-
Load_Bremen_481/	T_M_2(33.33%)	BadSegeberg/216km	-
Load_Bremen_496/	T_M_2(66.67%)	Luebeck/187km	-
Load_Bremen_499/	T_M_3(33.33%)	Wismar/248km	-
Load_Bremen_501/	T_M_2(100%)	Hamburg/120km	100%/ 66.67%/ 33.33%
Load_Bremen_520/	T_L_1(40%)	Lueneburg/183km	-
Load_Bremen_534/	T_L_1(60%)	Hamburg/120km	-
Load_Bremen_581/	T_M_4(33.33%)	BadSegeberg/216km	-
Load_Bremen_556/	T_M_3(66.67%)	Luebeck/187km	-
Load_Bremen_565/	T_L_1(80%)	Lueneburg/183km	-
Load_Bremen_566/	T_L_1(100%)	Hamburg/120km	100%/ 60%
Load_Bremen_601/	T_M_3(100%)	Hamburg/120km	100%/ 66.67%/ 33.33%
Load_Bremen_602/	T_S_2(50%)	Lueneburg/183km	100%
Load_Bremen_603/	T_S_1(50%)	Wismar/248km	-
Load_Bremen_604/	T_M_4(66.67%)	BadSegeberg/216km	-
Load_Bremen_605/	T_M_4(100%)	Luebeck/187km	100%/ 66.67%
Load_Bremen_636/	T_L_2(20%)	Hamburg/120km	-
Load_Bremen_642/	T_S_2(100%)	Lueneburg/183km	100%
Load_Bremen_605/	T_L_2(40%)	Luebeck/187km	-
Load_Bremen_669/	T_L_2(60%)	BadSegeberg/216km	
Load_Bremen_672/	T_L_2(80%)	Hamburg/120km	-
Load_Bremen_684/	T_M_1(33.33%)	Lueneburg/183km	-
Load_Bremen_703/	T_L_2(100%)	Hamburg/120km	100%/ 40%/ 20%
73/Load_Bremen_704/	T_S_1(100%)	Luebeck/187km	100%/ 50%
74/Load_Bremen_706/	T_S_2(50%)	Wismar/248km	-
Load_Bremen_724/	T_M_2(33.33%)	BadSegeberg/216km	-
Load_Bremen_727/	T_M_1(66.67%)	Lueneburg/183km	-
Load_Bremen_734/	T_M_1(100%)	Hamburg/120km	100%/ 66.67%
Load_Bremen_753/	T_M_2(66.67%)	Luebeck/187km	-
Load_Bremen_734/	T_S_2(100%)	Hamburg/120km	100%/ 50%
Load_Bremen_727/	T_M_3(33.33%)	Lueneburg/183km	-
Load_Bremen_801/	T_M_2(100%)	Hamburg/120km	100%/ 66.67%/ 33.33%
Load_Bremen_802/	T_M_3(66.67%)	Lueneburg/183km	-
Load_Bremen_803/	T_M_4(33.33%)	Luebeck/187km	-
Load_Bremen_805/	T_M_4(66.67%)	BadSegeberg/216km	-
Load_Bremen_807/	T_S_1(50%)	Wismar/248km	-

Load_Bremen_838/	T_M_4(100%)	Hamburg/120km	100%/ 66.67%/ 33.33%
Load_Bremen_842/	T_M_3(100%)	Lueneburg/183km	100%
Load_Bremen_843/	T_L_1(20%)	Luebeck/187km	-
Load_Bremen_870/	T_S_1(100%)	Hamburg/120km	100%/ 50%
Load_Bremen_880/	T_M_1(33.33%)	Lueneburg/183km	-
Load_Bremen_881/	T_L_1(40%)	BadSegeberg/216km	-
Load_Bremen_896/	T_L_1(60%)	Luebeck/187km	66.67%/ 33.33%
Load_Bremen_899/	T_S_2(50%)	Wismar/248km	-
Load_Bremen_901/	T_L_1(80%)	Hamburg/120km	80%/ 60%/ 20%
Load_Bremen_920/	T_M_1(66.67%)	Lueneburg/183km	
Load_Bremen_934/	T_M_1(100%)	Hamburg/120km	100%/ 66.67%
Load_Bremen_981/	T_M_2(33.33%)	BadSegeberg/216km	-
Load_Bremen_956/	T_M_2(66.67%)	Luebeck/187km	66.67%/ 33.33%
Load_Bremen_965/	T_M_3(33.33%)	Lueneburg/183km	33.33%
Load_Bremen_966/	T_S_2(100%)	Hamburg/120km	100%/ 50%

B.2. Multiple Sources and Multiple Destinations

Multiple Sources: Bremen, Oldenburg, Bremerhaven, Hamburg, Luebeck, Wismar, Nuemuenster, Kiel
Multiple Destinations: Hamburg, Bremen, Kiel

Clustersize 10, # of clusters 100, Total number of packages generated 1000
Simulation time 5 days (7200min.), Packet generation rate 40 packages/day
Cluster formation timeout 1 day, Vehicle waiting time 2 days.

Table B.2: MSMD-B - Source-Destination Pairs

Source/Destination	**Bremen (B)**	**Hamburg (H)**	**Kiel (K)**	**Total per Source**
BadSegeberg	0	30	20	**50**
Bremen	X	100	50	**150**
Bremerhaven	50	50	50	**150**
Hamburg	50	X	100	**150**
Kiel	100	100	X	**200**
Luebeck	0	20	10	**30**
Neu-Munster	30	30	0	**60**
Oldenburg	30	30	30	**90**
Wismar	40	40	40	**120**
Total per destination	**300**	**400**	**300**	**1000**

B.2. Multiple Sources and Multiple Destinations

Table B.3: Source-Bremen; Clustersize 10, # of clusters 15, Total number of packages generated 150

Cluster	Cluster-Head	Vehicle	Destination/Distance
Cluster_Hamburg_1	Load_Bremen_1	T_M_1	Hamburg/120km
Cluster_Kiel_1	Load_Bremen_2	T_L_1	Kiel/215km
Cluster_Hamburg_2	Load_Bremen_16	T_L_1	Hamburg/120km
Cluster_Hamburg_3	Load_Bremen_31	T_M_4	Hamburg/120km
Cluster_Kiel_2	Load_Bremen_32	T_M_2	Kiel/215km
Cluster_Hamburg_4	Load_Bremen_47	T_M_4	Hamburg/120km
Cluster_Hamburg_5	Load_Bremen_61	T_M_4	Hamburg/120km
Cluster_Kiel_3	Load_Bremen_62	T_S_1	Kiel/215km
Cluster_Hamburg_6	Load_Bremen_77	T_S_2	Hamburg/120km
Cluster_Hamburg_7	Load_Bremen_91	T_S_2	Hamburg/120km
Cluster_Kiel_4	Load_Bremen_92	T_S_1	Kiel/215km
Cluster_Hamburg_8	Load_Bremen_106	T_M_3	Hamburg/120km
Cluster_Kiel_5	Load_Bremen_121	T_M_2	Kiel/215km
Cluster_Hamburg_9	Load_Bremen_122	T_M_3	Hamburg/120km
Cluster_Hamburg_10	Load_Bremen_138	T_M_3	Hamburg/120km

Table B.4: Source: Bremerhaven; Clustersize 10, # of clusters 15, Total number of packages generated 150

Cluster Head	Vehicle	Destination/Distance
Load_Bremerhaven_1	T_L_1	Hamburg/ 183km
Load_Bremerhaven_2	T_L_1	Kiel/278km
Load_Bremerhaven_3	T_L_1	Bremen/ 63km
Load_Bremerhaven_30	T_L_1	Hamburg/ 183km
Load_Bremerhaven_32	T_M_2	Kiel/278km
Load_Bremerhaven_33	T_L_1	Bremen/ 63km
Load_Bremerhaven_61	T_M_1	Hamburg/ 183km
Load_Bremerhaven_62	T_M_2	Kiel/278km
Load_Bremerhaven_63	T_M_2	Bremen/ 63km
Load_Bremerhaven_90	T_M_1	Hamburg/ 183km
Load_Bremerhaven_92	T_M_2	Kiel/278km
Load_Bremerhaven_93	T_M_2	Bremen/ 63km
Load_Bremerhaven_121	T_M_2	Kiel/278km
Load_Bremerhaven_122	T_M_2	Bremen/ 63km
Load_Bremerhaven_138	T_M_1	Hamburg/ 183km

Appendix B: Transport based on Route Correlation and Transportation Cost

Table B.5: Source: Oldenburg; Clustersize 10, # of clusters 9, Total number of packages generated 90

Cluster-Head	Vehicle	Destination/Distance
Load_Oldenburg_1	T_M_1	Hamburg/ 168km
Load_Oldenburg_2	T_M_1	Bremen/ 48km
Load_Oldenburg_3	T_M_1	Kiel/263km
Load_Oldenburg_30	T_M_4	Hamburg/ 168km
Load_Oldenburg_32	T_S_2	Kiel/263km
Load_Oldenburg_33	T_S_2	Bremen/ 48km
Load_Oldenburg_61	T_M_4	Hamburg/ 168km
Load_Oldenburg_62	T_S_2	Kiel/263km
Load_Oldenburg_63	T_S_2	Bremen/ 48km

Table B.6: Source: Kiel; Clustersize 10, # of clusters 20, Total number of packages generated 200

Cluster-Head	Vehicle	Destination/Distance
Load_Kiel_1	T_S_2	Hamburg/95km
Load_Kiel_2	T_S _2	Bremen/215km
Load_Kiel_21	T_S _1	Hamburg/95km
Load_Kiel_22	T_M_3	Bremen /215km
Load_Kiel_41	T_M_3	Bremen /215km
Load_Kiel_42	T_S_1	Hamburg/95km
Load_Kiel_61	T_L_2	Hamburg/95km
Load_Kiel_62	T_M_3	Bremen/215km
Load_Kiel_81	T_L_2	Hamburg/95km
Load_Kiel_83	T_M_1	Bremen/215km
Load_Kiel_101	T_M_1	Bremen/215km
Load_Kiel_102	T_L_2	Hamburg/95km
Load_Kiel_121	T_M_1	Bremen/215km
Load_Kiel_122	T_L_2	Hamburg/95km
Load_Kiel_141	T_L_2	Hamburg/95km
Load_Kiel_142	T_L_1 (Kiel-Hamburg) T_M_4 (Hamburg-Bremen)	Bremen/215km
Load_Kiel_161	T_L_1	Hamburg/95km
Load_Kiel_162	T_L_1 (Kiel-Hamburg)	Bremen/215km

B.2. Multiple Sources and Multiple Destinations

	T_M_4 (Hamburg-Bremen)	
Load_Kiel_180	T_L_1	Hamburg/95km
Load_Kiel_182	T_L_1 (Kiel-Hamburg) T_M_4 (Hamburg-Bremen)	Bremen/215km

Table B.7: Source: Neu-Munster; Clustersize 10, # of clusters 6, Total number of packages generated 60

Cluster-Head	Vehicle	Destination/Distance
Load_Neu-Munster_1	T_M_4	Hamburg/ 60km
Load_Neu-Munster_3	T_M_4	Bremen/ 180km
Load_Neu-Munster_21	T_M_2	Hamburg/ 60km
Load_Neu-Munster_22	T_M_4	Bremen/ 180km
Load_Neu-Munster_41	T_M_2	Bremen/ 180km
Load_Neu-Munster_42	T_M_2	Hamburg/ 60km

Table B.8: Source: Wismar; Clustersize 10, # of clusters 12, Total number of packages generated 120

Cluster-Head	Vehicle	Destination/Distance
Load_Wismar_1	T_M_2	Bremen/ 248km
Load_Wismar_2	T_M_2	Hamburg/ 128km
Load_Wismar_3	T_L_1	Kiel/223km
Load_Wismar_30	T_L_2	Hamburg/ 128km
Load_Wismar_32	T_L_1	Kiel/223km
Load_Wismar_33	T_M_2	Bremen/ 248km
Load_Wismar_61/	T_L_2	Hamburg/ 128km
Load_Wismar_62	T_L_1	Kiel/223km
Load_Wismar_63	T_L_2 (Wismar-Hamburg) T_M_2 (Hamburg- Bremen)	Bremen/ 248km
Load_Wismar_90	T_L_2	Hamburg/ 128km
Load_Wismar_92	T_L_1	Kiel/223km
Load_Wismar_93	T_L_2	Bremen/

	(Wismar-Hamburg) T_M_2 (Hamburg-Bremen)	248km

Table B.9: Source: BadSegeberg; Clustersize 10, # of clusters 5, Total number of packages generated 50

Cluster-Head	Vehicle	Destination/Distance
Load_BadSegeberg_1	T_L_2	Hamburg/96km
Load_BadSegeberg_2	T_L_2	Kiel/191km
Load_BadSegeberg_19	T_L_2	Hamburg/96km
Load_BadSegeberg_26	T_L_2	Kiel/191km
Load_BadSegeberg_36	T_L_2	Hamburg/96km

Table B.10: Source: Luebeck; Clustersize 10, # of clusters 3, Total number of packages generated 30

Cluster-Head	Vehicle	Destination/Distance
Load_Luebeck_1	T_M_3	Hamburg/67km
Load_Luebeck_2	T_M_3	Kiel/162km
Load_Luebeck_17	T_M_3	Hamburg/67km

Table B.11: Source: Hamburg; Clustersize 10, # of clusters 15, Total number of packages generated 150

Cluster-Head	Vehicle	Destination/ Distance
Load_Hamburg_1	T_S_1	Kiel/95km
Load_Hamburg_3	T_S_2	Bremen/120km
Load_Hamburg_16	T_S_1	Kiel/95km
Load_Hamburg_31	T_M_1	Kiel/95km
Load_Hamburg_32	T_M_4	Bremen/120km
Load_Hamburg_47	T_M_1	Kiel/95km
Load_Hamburg_61	T_M_3	Kiel/95km
Load_Hamburg_62	T_M_2	Bremen/120km
Load_Hamburg_77	T_M_3	Kiel/95km
Load_Hamburg_91	T_L_2	Kiel/95km
Load_Hamburg_93	T_S_1	Bremen/120km
Load_Hamburg_106	T_L_2	Kiel/95km
Load_Hamburg_121	T_S_1	Bremen/120km
Load_Hamburg_122	T_L_2	Kiel/95km
Load_Hamburg_138	T_L_1	Kiel/95km

B.2. Multiple Sources and Multiple Destinations

Table B.12: Sequence of Cluster Transportation by various Vehicles – Multiple Source Multiple Destination – B (MSMD-B): Common Route Strategy

Vehicle	Source	Intermediate Destination 1 (ID1)	Intermediate Destination 2 (ID2)	Final Destination (FD)	# Clusters			Capacity Utilization
					ID 1	ID 2	F D	
T_S_1	Hamburg	-	-	Kiel			2	100%
T_S_2	Kiel	Hamburg Hamburg	- -	Bremen Bremen	1		1 1	100% 100%
T_M_1	Oldenburg	Bremen Bremen	Hamburg Hamburg Hamburg	Kiel Kiel	1	1 1	1 2	100% 100% 100%
T_M_3	Luebeck	Hamburg Hamburg	- -	Kiel Kiel	2		1 2	100% 100%
T_M_4	Neu-Munster	Hamburg Hamburg	- -	Bremen Bremen	1		2 1	100% 100%
T_M_2	Wismar	Hamburg Hamburg	- -	Bremen Bremen	1		2 1	100% 100%
T_L_2	BadSegeberg	Hamburg Hamburg	- -	Kiel Kiel	3		2 3	100% 100%
T_L_1	Bremerhaven	Bremen Bremen	Hamburg Hamburg Hamburg	Kiel Kiel Kiel	2	2 1	1 1 1	100% 100% 60%
T_S_1	Kiel	Hamburg Hamburg	- -	- Bremen	2		 2	100% 100%
T_M_3	Kiel	-	-	Bremen			3	100%
T_M_4	Bremen	-	-	Hamburg			3	100%
T_S_2	Bremen	Oldenburg Oldenburg	- Bremen Bremen	- - Hamburg	0	 2	 2	0% 100% 100%
T_L_2	Kiel	-	-	Hamburg			5	100%
T_M_1	Kiel	-	-	Bremen			3	100%
T_M_2	Bremen	Bremerhaven Bremerhaven	- Bremen Bremen	- Kiel Kiel	0	 1	 2 1	0% 100% 100%
T_L_1	Kiel	-	-	Hamburg	2 + 3Bremen			100%
T_M_4	Hamburg	-	-	Bremen			3	100%
T_L_2	Hamburg	-	-	Wismar			0	0%
T_S_1	Bremen	-	-	Kiel			2	100%
T_M_3	Bremen	-	-	Hamburg			3	100%
T_S_2	Hamburg	-	-	Oldenburg			0	0%
T_L_2	Wismar	-	-	Hamburg	3 + 2Bremen			100%
T_M_2	Kiel	Neu-Munster Neu-Munster	- Hamburg Hamburg	- Bremen Bremen	0	 2	 1 2	0% 100% 100%
T_L_1	Hamburg	-	-	Wismar			0	0%
T_M_1	Bremen	Bremerhaven	-	-	0			0%

		Bremerhaven	-	Hamburg			3	100%
T_S_2	Oldenburg	-	-	Kiel			2	100%
T_M_4	Bremen	Oldenburg	-	-	0			0%
		Oldenburg	-	Hamburg			2	66.67%
T_M_2	Bremen	Bremerhaven	-	-	0			0%
		Bremerhaven	-	Bremen			2	66.67%
T_L_1	Wismar	-	-	Kiel			4	80%
T_M_2	Bremen	Bremerhaven	-	-	0			0%
		Bremerhaven	-	Kiel			2	66.67%
			Bremen	Kiel			1	100%

Table B.13: Sequence of Cluster Transportation by various Vehicles – Multiple Source Multiple Destination - B (MSMD-B): Large Common Route Strategy

Vehicle	Source	Intermediate Destination 1 (ID1)	Intermediate Destination 2 (ID2)	Final Destination (FD)	# Clusters			Capacity Utilization
					ID 1	ID 2	F D	
T_S_1	Hamburg	-	-	Kiel			2	100%
T_S_2	Kiel	Hamburg	-	Bremen	1		1	100%
		Hamburg	-	Bremen			1	100%
T_M_1	Oldenburg	Bremen	Hamburg	Kiel	1	1	1	100%
		Bremen	Hamburg			1		100%
			Hamburg	Kiel			2	100%
T_M_3	Luebeck	Hamburg	-	Kiel	2		1	100%
		Hamburg	-	Kiel			2	100%
T_M_4	Neu-Munster	Hamburg	-	Bremen	1		2	100%
		Hamburg	-	Bremen			1	100%
T_M_2	Wismar	-	-	Hamburg	1Hamburg + 1Bremen + 1Kiel			100%
T_L_2	BadSegeberg	Hamburg	-	Kiel	3		2	100%
		Hamburg	-	Kiel			3	100%
T_L_1	Bremerhaven	Bremen	Hamburg	Kiel	2	2	1	100%
		Bremen	-	Kiel			2	100%
			Hamburg	Kiel			2	100%
T_S_1	Kiel	Hamburg	-	-	2			100%
		Hamburg	-	Bremen			2	100%
T_M_3	Kiel	-	-	Bremen			3	100%
T_M_2	Hamburg	-	-	Bremen			2	66.67%
T_M_4	Bremen	-	-	Hamburg			3	100%
T_S_2	Bremen	Oldenburg	-	-	0			0%
		Oldenburg	Bremen	-		2		100%
			Bremen	Hamburg			2	100%
T_L_2	Kiel	-	-	Hamburg			5	100%
T_M_1	Kiel	-	-	Bremen			3	100%
T_M_2	Bremen	Bremerhaven	-	-	0			0%
		Bremerhaven	Bremen	Kiel		1	2	100%

B.2. Multiple Sources and Multiple Destinations

			Bremen	Kiel			1	100%
T_L_1	Kiel	-	-	Hamburg	2 + 3Bremen			100%
T_M_4	Hamburg	-	-	Bremen			3	100%
T_L_2	Hamburg	-	-	Wismar			0	0%
T_S_1	Bremen	-	-	Kiel			2	100%
T_M_3	Bremen	Bremerhaven Bremerhaven	- -	- Hamburg	0		 3	0% 100%
T_S_2	Hamburg	-	-	Oldenburg			0	0%
T_L_2	Wismar	-	-	Hamburg	3 + 2Bremen			100%
T_M_2	Kiel	Neu-Munster Neu-Munster	- Hamburg Hamburg	- Bremen Bremen	0	 2	 1 2	0% 100% 100%
T_L_1	Hamburg	-	-	Wismar			0	0%
T_M_1	Bremen	Bremerhaven Bremerhaven	- -	- Bremen	0		 2	0% 66.67%
T_S_2	Oldenburg	-	-	Kiel			2	100%
T_M_4	Bremen	Oldenburg Oldenburg	- - Bremen	- Hamburg Hamburg	0		 2 1	0% - 100%
T_M_2	Bremen	Bremerhaven Bremerhaven	- -	- Kiel	0		 2	0% 66.67%
T_M_1	Bremen	-	-	Hamburg			3	100%
T_L_1	Wismar	-	-	Hamburg	3Kiel + 1Bremen			80%
T_M_3	Hamburg	-	-	Kiel			3	100%
T_M_4	Hamburg	-	-	Bremen			1	33.33%

Table B.14: Sequence of Cluster Transportation by various Vehicles – Multiple Source Multiple Destination - B (MSMD-B): Common Next Hop Strategy

Vehicle	Source	Intermediate Destination 1 (ID1)	Intermediate Destination 2 (ID2)	Final Destination (FD)	# Clusters			Capacity Utilization
					ID 1	ID 2	F D	
T_S_1	Hamburg	-	-	Kiel			2	100%
T_S_2	Kiel	Hamburg Hamburg	- -	Bremen Bremen	1		1 1	100% 100%
T_M_1	Oldenburg	Bremen Bremen	Hamburg Hamburg Hamburg	Kiel Kiel	1	1 1	1 2	100% 100% 100%
T_M_3	Luebeck	Hamburg Hamburg	- -	Kiel Kiel	2		1 2	100% 100%
T_M_4	Neu- Munster	Hamburg Hamburg	- -	Bremen Bremen	1		2 1	100% 100%
T_M_2	Wismar	-	-	Hamburg	1Hamburg + 1Bremen + 1Kiel			100%
T_L_2	BadSegeberg	Hamburg Hamburg	- -	Kiel Kiel	3		2 3	100% 100%

Appendix B: Transport based on Route Correlation and Transportation Cost

T_L_1	Bremerhaven	Bremen	Hamburg	Kiel	2	2	1	100%
		Bremen	Hamburg	Kiel		1	1	100%
			Hamburg	Kiel			2	80%
T_S_1	Kiel	Hamburg	-	Bremen	1		1	100%
		Hamburg	-	Bremen			1	100%
T_M_3	Kiel	Hamburg	-	Bremen	1		2	100%
		Hamburg	-	Bremen			1	100%
T_M_2	Hamburg	-	-	Bremen			2	66.67%
T_M_4	Bremen	-	-	Hamburg			3	100%
T_S_2	Bremen	Oldenburg	-	-	0			0%
		Oldenburg	Bremen	-		2		100%
			Bremen	Hamburg			2	100%
T_L_2	Kiel	-	-	Hamburg			5	100%
T_M_1	Kiel	-	-	Bremen			3	100%
T_M_2	Bremen	Bremerhaven	-	-	0			0%
		Bremerhaven	Bremen	Kiel		1	2	100%
			Bremen	Kiel			1	100%
T_L_1	Kiel	-	-	Hamburg	2 + 3Bremen			100%
T_M_4	Hamburg	-	-	Bremen			3	100%
T_L_2	Hamburg	-	-	Wismar			0	0%
T_S_1	Bremen	-	-	Kiel			2	100%
T_M_3	Bremen	-	-	Hamburg			3	100%
T_S_2	Hamburg	-	-	Oldenburg			0	0%
T_L_2	Wismar	-	-	Hamburg	3 + 2Bremen			100%
T_M_2	Kiel	Neu-Munster	-	-	0			0%
		Neu-Munster	Hamburg	Bremen		2	1	100%
			Hamburg	Bremen			2	100%
T_L_1	Hamburg	-	-	Wismar			0	0%
T_M_1	Bremen	Bremerhaven	-	-	0			0%
		Bremerhaven	-	Hamburg			3	100%
T_S_2	Oldenburg	-	-	Kiel			2	100%
T_M_4	Bremen	Oldenburg	-	-	0			0%
		Oldenburg	-	Hamburg			2	66.67%
T_M_2	Bremen	Bremerhaven	-	-	0			0%
		Bremerhaven	-	Bremen			2	66.67%
T_L_1	Wismar	-	-	Kiel			4	80%
T_M_2	Bremen	Bremerhaven	-	-	0			0%
		Bremerhaven	-	Kiel			2	66.67%
			Bremen	Kiel			1	100%

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A		
	AC	Autonomous Cooperation
	ACE	Algorithm for Cluster Establishment
	ACK	Acknowledgment
	ACL	Agent Communication Language
	AODV	Ad hoc On-demand Distance Vector Routing
C		
	CRC	Collaborative Reserach Center
	CSCMP	Council of Supply Chain Management Professionals
	CU	Capacity Utilization
D		
	D	Destination
	DC	Distribution Center
	DLRP	Distributed Logistics Routing Protocol
	DNT	Different Negotiation Timeouts
F		
	FCFS	First Come First Serve
	FCM	Fuzzy C-Means
	FIPA	Foundation for Intelligent Physical Agents
G		
	GPS	Global Positioning System
	GIS	Geographical Information System
I		
	ID	Identification
	IEEE	Institute of Electrical & Electronics Engineers
J		
	JADE	Java Agent Development Environment
L		
	LEACH	Low-Energy Adaptive Clustering Hierarchy
	LORA_CBF	Location Routing Algorithm with Cluster Based Flooding
M		
	MA	Multi Agent
	MABs	Multi Agent Based Simulation
	MANET	Mobile Ad hoc NETwork
	MAP	Mobile Agent Platform

LIST OF ABBREVIATIONS

N		
	NDF	Negotiation Decision Function
O		
	OCU	Overall Capacity Utilization
	OR	Operations Research
P		
	PA	Package Agent
	PDP	Pick-up and Delivery Problem
	PlaSMA	Platform for Simulation of Multi-Agents
Q		
	QoS	Quality of Service
R		
	RFID	Radio Frequency Identification
S		
	SCM	Supply Chain Management
	SNT	Same Negotiation Timeouts
	SFB	Sonderforschungsbereich
	SPA	Selected Package Agent
T		
	TSP	Travelling Salesman Problem
	TTC	Total Transportation Cost
	TTL	Total Time to Live
V		
	VRP	Vehicle Routing Problem

List of Symbols

A^s	Seller agent action
A^c	Cluster agent action
A^v	Vehicle agent action
Acc_offer	Accept offer received
AP^c	Acceptable price of cluster
AP^v	Acceptable price of vehicle
a	Software agent
$\hat{a}$	Opponent agent
a_n	Number of software agents
B	Boulware function
b	Average branching factor
bre	Bremen
b_a	Buyer agent
$\sum_{i=0}^{l} b^i$	Total number of route requests in the network
b^l	Branching factor for *l* hops
$b_k^{\ w}$	Weighted average of branching factor
c	Clusters
Coc	Coefficient of correlation
$Count\_off$	Counter offer
C	Conceder function
$CComplete$	Cluster complete message
$CHAnn$	Cluster-head announcement message
$CHInfo$	Cluster-head information message
$CRegAck$	Cluster register acknowledge message
$CRegReq$	Cluster register request message
CU	Capacity Utilization
Cl_{size}	Cluster size
C_{intra}	Intra cluster communication
C_{extra}	Extra cluster communication
CP	Cluster prototype
d	Distance
d_{oi}	Distance between destination *i* and distribution center *o*

LIST OF SYMBOLS

d_{ij}	Distance between destination *j* and distribution center *i*
d_{jk}	Distance between destination *k* and distribution center *j*
$e^{1/\kappa}$	Exponential distribution function
f	Hop limit
$f_{\min}$	Minimum cluster size
FP^b	Final price of buyer
FP^s	Final price of seller
$G_0(x)$	Generating function of *x*
gue	Guestrow
H	Entropy
$H(a_i^u)$	Entropy of unique information of i^{th} agent
$H(PA)$	Entropy of package agent
$H(PA \cap \overline{PA_i})$	Entropy of whole network of packages excluding i^{th} package agent
ham	Hamburg
i	Number of immediate neigbors
IP^b	Initial price offer of the buyer
IP^s	Initial price offer of the seller
IP^c	Initial price offer of the cluster
IP^v	Initial price offer of the vehicle
Init	Initial state
j	Number of hops
k	Exact degree
k_a	Constant value between (0,1) to initiate negotiation price offer
l	Route length
$l_{\min}$	Minimum threshold
L	Linear function
m	Route path
$m_{\max}$	Maximum number of paths
M	Optimum number of packages
N	Total number of vertices
N_k	Number of vertices having degree *k*
$N_{clusters}$	Number of clusters
N_{dests}	Number of destinations

LIST OF SYMBOLS

N_{packs}	Number of packages
N_{route}	Total message count for one routing process
$Nego\_ite$	Negotiation iterations
n	Number of alternative routes
$n_k^{\ w}$	Weighted average of neighbors
nv_j	Number of neighboring vertices j
OCU	Overall capacity Utilization
O_n	Negotiation outcome
o	Distribution center
$Offer\_rec$	Offer received
$Offer\_rej$	Offer reject sent
$Offer\_sent$	Offer sent
$Offer\_acc$	Accept offer sent
p	Price offer
p_k	Probability distribution function with degree k
P_{tr}	Profit from single trip
$p_{\max}$	Maximum price offer
p_{opt}	Optimum price offer
$p^t{}_{s\to b}$	Price offer from seller to buyer at time t
$p^{t'}{}_{b\to s}$	Price offer from buyer to seller at time t'
$p^t{}_{c\to v}$	Price offer from cluster to the vehicle at time t
PA	Package agent
P	Profit
Q	Generic objective function
q	Total number of vertices
R	Number of route requests
rcf	Route correlation factor
RP^b	Reservation price of buyer
RP^c	Reservation price of cluster
RP^v	Reservation price of vehicle
RP^s	Reservation price of seller
Rej_offer	Reject offer received

LIST OF SYMBOLS

RANN	Route announcement message
RegAck	Registration acknowledge message
RegReq	Registration request message
RREQ	Route request message
RREP	Route reply message
S	Seller
s	Number of sources
SPA	Software package agent
S^a	Negotiation strategy of agent *a*
S^c	Negotiation strategy of cluster *c*
S^v	Negotiation strategy of vehicle *v*
t	Time
t'	Next time iteration
t_{nv_i}	Total number of vertices *i*
$t_{nv_l}^{\ w}$	Weighted average of neighbors
tot_dist_{ind}	Total distance travelled individually
T^a	Negotiation time deadline of agent *a*
T_c	Transport cost/km
TTC	Total transport cost
T_L	Truck large
T_M-1	Truck medium -1
T_M-2	Truck medium-2
T_S	Truck small
T_iter	Total number of time iterations
U	Utility
U^s	Utility of the seller
U^b	Utility of buyer
U^v	Utility of vehicle
$U^a{}_p(p)$	Utility function of price for an agent
$U^a{}_t(t)$	Utility function of time for an agent
U_m	Partition matrix
v	Vehicle
w	Weight factor

LIST OF SYMBOLS

w^{bre}	Weight at vertex Bremen
w^{gue}	Weight at vertex Guestrow
w^{ham}	Weight at vertex Hamburg
w^{q}	Weight at vertex q
X	Data set
Y	Negotiation steps
Z	Interconnected objects
δ	Discounting factor
$\phi^{q}(t)$	Negotiation Decision Function (NDF)
κ	Constant

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