CHAPTER 2

2. MULTIMODAL TRANSPORTATION

2.1 INTRODUCTION

Multimodal transportation (MMT) plays a key role in international logistics. Multimodal transport is commonly known as referring to the combination of two or more modes of movement of goods, such as road, rail, or sea (Muller 1995). The development of multimodal transportation has been followed by an increase in multimodal transportation research (Jose E. Florez et al., 2010). Multimodal Transportation refers to a transport system usually operated by one carrier with more than one mode of transport under the control or ownership of one operator. It involves the use of more than one means of transport such as a combination of truck, railcar, aeroplane or ship in succession to each other e.g. a container line which operates both a ship and a rail system of double stack trains. Multimodal transportation is the transportation of goods under a single contract but performed with at least two different means of transport. i.e. the carrier is liable for the entire carriage even though it is performed with several different means of transport (e.g. rail, sea and road).

The carrier, however, does not have to be in the possession of all of the means of transport and in practice usually is not. The carriage is often performed by using sub-carriers, in legal language often referred to as actual carriers. The carrier that is responsible or the entire carriage is referred to as a Multimodal Transport Operator...
(MTO). Multimodal Transportation is defined as follows: International multimodal transport means the carriage of goods by at least two different modes of transport on the basis of a multimodal transport contract from a place in one country at which the goods are taken in charge by the multimodal transport operator to a place designated for delivery situated in a different country (SU, et. al, 2006). Multimodal transport which uses two or more transportation modes, usually makes use of a third part logistics company. A third part logistics company is generally armed with Network planning system, decision support system and cargo tracking system. They usually depend on traditional and conventional methods, consequently giving rise to cost increase (Hyung R.C., et. al, 2006).

2.1.1. Overview of Multimodal Transportation

Multimodal Transport can be viewed as “the chain that interconnects different links or modes of transport – air, sea, and land into one complete process that ensures an efficient and cost-effective door-to-door movement of goods under the responsibility of a single transport operator, known as a Multimodal Transport Operator (MTO)”

In practice freight forwarders have become important MTOs as they have moved away from their traditional role as mere agents for the sender and accepting a much wider liability as carriers. Also large sea-carriers have evolved into MTOs as they provide their customers with so-called door-to-door services, i.e. the sea carrier offers transport from the sender's premises all the way to the receiver's premises instead of just offering more traditional tackle-to-tackle services or peer-to-peer services. MTOs that are not in the possession of a sea vessel are in common law countries, in the United States especially, referred to as
Non Vessel Operating Carriers (NVOC). Historically multimodal transport developed in connection with the so-called container revolution during the 1960s and ‘70s and today containerized transports are by far the most important multimodal consignments. One must however always bear in mind that multimodal transport is not equivalent to container transport and multimodal transport is just as feasible without any form of containers. With the advent of containerization in the late 1950s, MMT had been developed. Since then, certain important developments have influenced the modern development of multimodal transport (Sufian. A., et. al, 2005).

2.1.2. Multimodal Transportation

Multimodal Transportation is the combination of two or more means of transport to move passengers or goods from one source to a destination. The traveler can use either public (e.g., bus, taxi, metro, railway, and ship) or private vehicles (e.g., car, motorbike, bicycle, and walking). Multimodal journeys are becoming a real necessity in our society in order to guarantee a high level of mobility both inside cities and at the regional level. The concept of international multimodal transport covers the door-to-door movement of goods under the responsibility of a single transport operator. Although the concept might not be new, it developed with the container revolution initiated in the late 50’s by Malcolm McLean and his trucking operations (Bielli M., et. al 2006).

The emergence of the container technology and of the multimodal transport concept came from and facilitated growing international trade. Trade and transport are inextricably linked, efficient transport services are a prerequisite to successful trading. International transport generally implies the use of various transport links (interfaces and
modes), each link corresponding to a transfer, storage or transport operation either in the country of origin, in a transit country, or in the country of final destination. This situation has created a number of problems over the years, as more and more shippers are realizing that this new concept is involving the effective participation of various transport mode operators but does not always make clear who is responsible for delivering cargo at destination in safe conditions, according to agreed schedules (Luigi. M., et. al, 2009).

Considering the variety of cultures, languages and commercial practices at both ends of a trade, and the resulting complexity of assembling such an international transport operation, it would appear reasonable to a trader to let one qualified operator organize and be responsible and accountable for the entire transport chain (Hong K, et., al, 2006).

Beginning from the present unimodal transport conditions, transport operators have developed transport systems to fulfill customer’s requirements, offering competitive services and thereby making trade more efficient by offering multimodal transport services to their clients. Multimodal transport implies the safe and efficient movement of goods, where the MTO accepts the corresponding responsibility from door-to-door. With technological development of transport means and operations, as well as in communications, coupled with liberalization in the provision of services, more and more transport operators are able to provide such safe and efficient transport. These services are increasingly market-segment oriented rather than transport mode oriented. The absence of international rules governing the successive carriage of goods resulted in peculiar problems in the matter of carriers’ responsibility and the liability for loss or damage to the goods occurring in the course of a multimodal transport operation.
Understanding and solving transport problems is a process which generally starts with an analysis of the current state in order to deduct deficiencies (Markus Friedrich, 1998).

2.1.3. UNCTAD Field of Multimodal Transport

In pursuing its mandate, United Nations Conference on Trade and Development UNCTAD has achieved a number of recognized results in the field of multimodal transport: the elaboration of the Multimodal Transport Convention (1980), the elaboration of model multimodal container tariff rules, a constructive participation with the private sector towards the elaboration of new rules on multimodal transport documents, the monitoring on behalf of developing countries, the organisation of groups of experts to discuss issues on multimodal transport, the implementation of technical assistance activities as well as the creation of awareness on the subject through the organisation of workshops and seminars.

The Challenges ahead are two-fold: (i) with the globalization of production and the liberalization of services, developing countries and countries in transition, more than ever, need more than ever to increase their capabilities in offering reliable and cost-effective transport and logistics services, taking advantage of technological development through appropriate "leap-froging" into modern technologies and commercial practices; and (ii) there is a world-wide need for harmonization of the legal environment for multimodal transport, in particular considering the development of new forms of international transport (combined road/rail transport and short-sea shipping in Europe, for example).
The characteristics of multimodal mobility today are analysed, using an empirical analysis of the Dutch National Travel Survey. It is shown that multimodal transport is a niche market in transportation, which nevertheless plays a substantial role for specific trip types.

Furthermore, the main characteristics determining the share of multimodal travel will be established. These characteristics will then be used for a quantitative assessment of the future potential of multimodal mobility. Two approaches will be developed: one based on trip purpose and the other on trip type. Both will show that multimodal travel might increase substantially but will remain a niche market.

2.1.4. Objective of multimodal transportation

There are several kinds of resources, each one with different kinds of costs (e.g., moving truck empty is different from moving it loaded), different routes (either single mode routes, as all road, or multi-modal routes, as combining trucks with badge and/or rail), and with temporal and resource constraints (drivers have constraints on number of hours driving, for instance). The planning and design shall identify major origin and destinations within the area and determine appropriate alternative alignments to insure that linkages are provided (Jose E. Florez, 2010). The main goal of coordinating bodies is to gain an advantage from a particular transport facility while reducing its disadvantages. They should also consider all positive and negative aspects of various means of transport. For example, coordinating the operation of rail and water transport on
a particular route will reduce the cost of transportation compared to using water transport alone. The planning and design shall identify major origin and destinations within the area and determine appropriate alternative alignments to insure that linkages are provided.

It allows and support appropriate multi-modal uses of the road system, provide access to a wide variety of efficient, integrated and connected transportation opportunities, increase access to, and use of, alternatives to the single-occupant motorized vehicle, provide solutions to traffic congestion and pollution to improve transportation efficiency and quality of life, increase intermodal and non-highway freight shipments to improve efficiency in moving goods and people to promote effective use of existing infrastructure. A multimodal transportation company with centralized decision making can more quickly match transportation assets to changing shipper requirements, geographic markets, competitor strategies, production costs and transport technology. This ability cannot be overstated in a world where the demand for fuel is increasing exponentially. For example, railroads are 2 to 4 times more fuel efficient per ton-mile moved than trucks. Equally important in an environmentally conscious world is that central management can better control fuel pollutants emitted by the different modes comprising the multimodal firm (Clinton H. Whitehurst, 2005).

Multimodal Transportation System involves modal shift from private mode to public mode and vice versa. The modal change occurs at the point where public mode is to be alighted. Generally, MMT station acts as an interchange node. A good Multimodal
transportation system aims at achieving efficiency by the coordinated use of different modes with the following objectives: (i) to facilitate and improve passenger interface, (ii) to reinforce passenger/operators/developers focal point, (iii) to provide flexibility in the use of alternative mode choice, (iv) to solve time and cost effective analysis and (v) to evolve non-competing, coordinated system of various modes.

2.1.5. Mathematical Formulation

The need for a wider use of mathematical methods and models in transport arose because more goods had to be transported and rapid scientific and technological development brought about new possibilities in this area. This, in turn, gave a strong impetus to solve the problems of planning and management in transport by new more advanced methods. Mathematical models are used in the following main areas of transport now: drawing up optimal plans and controlling their fulfillment, solving the problems of mathematical programming in transportation including the following issues: ① drawing up an optimal plan of shipments; ② minimizing the expenses in transportation; ③ designing new traffic lines etc.

A mathematical model is aimed at optimizing multimodal transportation based on using various means of transport. The objective function of the model is used to determine the minimal costs and minimal time of delivery. The mathematical formulation is as follows:
where $C_{ij}$ is the cost (Lt) of delivering a container from the $i^{th}$ loading place to the $j^{th}$ place of destination ($i = 1 \div m, j = 1 \div n$);

$x_{ij}$ the number of containers (units) to be carried from the $i^{th}$ loading place to the $j^{th}$ place of destination ($i = 1 \div m, j = 1 \div n$);

$\bar{V}_k$ is the average cost of an hour of container transportation (Lt) ($k=1 \div l$);

$\bar{T}_k$ is the average cost of transport facility (Lt) in terms of the environment pollution ($k=1 \div l$);

$\bar{D}_k$ is the average insurance cost of cargo (Lt) carried by a particular kind of transport facilities ($k=1 \div l$);

The limiting conditions of the mathematical model for a balanced transportation problem are expressed in the following way:

$$Z_{\text{min}} = \min \left( \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} x_{ij} + \sum_{k=1}^{l} \bar{V}_k + \sum_{k=1}^{l} \bar{T}_k + \sum_{k=1}^{l} \bar{D}_k \right)$$

(1)
Moreover, where \( b_1, b_2, \ldots, b_m \) are containers (units) at destination places (demand).

If the condition (4) is not satisfied, then an imaginary place of loading or destination is introduced to obtain a balanced transportation problem.

\[
\sum_{j=1}^{n} x_{ij} \leq b_i \\
\sum_{j=1}^{n} x_{2j} \leq b_2 \\
\vdots \\
\sum_{j=1}^{n} x_{mj} \leq b_m
\]  

(2)

\[
\sum_{i=1}^{m} x_{i1} = a_1 \\
\sum_{i=1}^{m} x_{i2} = a_2 \\
\vdots \\
\sum_{i=1}^{m} x_{in} = a_n
\]  

(3)

\[ x_{ij} \geq 0, \quad \text{when } i = 1 + m \]
\[ j = 1 + n, \]

Moreover,

\[
\sum_{i=1}^{m} b_i = \sum_{j=1}^{n} a_j
\]  

(4)

where \( b_1, b_2, \ldots, b_m \) are containers (units) at destination places (demand).

If the condition (4) is not satisfied, then an imaginary place of loading or destination is introduced to obtain a balanced transportation problem.

\[ \sum_{k=1}^{i} \bar{x}_{kj} \text{ is the average cost of container delivery;} \]

\[ \sum_{k=1}^{i} \bar{p}_{kj} \text{ is the average cost of using a particular kind of transport facilities in terms of the environment pollution;} \]

\[ \sum_{k=1}^{i} \bar{D}_{kj} \text{ is the average cost of cargo insurance for a particular kind of transport facilities, i.e., all three components of an objective function depend on } x_{ij} \text{ which is the number of containers (units) carried from the } i\text{-th loading place to the } j\text{-th place of destination.} \]
For example, containers may be carried by rail, motor or sea transport, while the number of containers in a haul varies. Therefore, when calculating average expenses for different modes of transportation, the number of hauls should be taken into consideration (Olga Lingaitiene et al, 2006).

2.2. MULTIMODAL TRANSPORT

2.2.1. Definitions

The definition of multimodal transport is that two or more different modes are used for a single trip between which the traveler has to make a transfer and this technique is shown in Fig.2.1. A mode might be defined by vehicle type or by transport function. The part of the trip where a single mode is used is called a leg. Typical examples are a trip in which a bicycle is used to access the railway system, or a trip is which an urban bus is used for the leg between railway station and the final destination. The opposite of a multimodal trip, that is a unimodal trip, thus are trips in which only a single mode is used, that are by private car or by a regional train service.

![Diagram of multimodal transport](image)

Figure 2.1 Examples of unimodal trips (a, b) and a multimodal trip (c)(the transfer point is denoted by the bold T) (Van Nes R., 2002)
Although this definition seems to be quite simple, it deserves more discussion with regard to the four aspects: ① Transfers, ② Modes and transport services, ③ Trips instead of tours and ④ the role of walking. Transfers are an essential part of a multimodal trip.

In order to use two or more modes travelers have to change modes at transfer nodes. However, since transfers are also a common phenomenon in unimodal public transport networks, the definition of transfers needs to be more specific. In this thesis the term transfer is used for intermodal transfers that are transfers where travelers change transport service networks or modes. The inclusion of transport services is essential since it implies that a transfer from one transport service network to another transport service network having other characteristics is also an intermodal transfer. A typical example is the transfer from a regional bus to an urban bus. A transfer within a transport service network, between urban buses for instance, is then defined as an intramodal transfer. Intermodal transfers are special because they deal with different network types, which are designed separately by different operators or authorities, while for intramodal transfers usually one organisation is responsible for all these aspects.
Since a transfer implies extra travel time and/or travel costs while no distance is covered, the transfer itself has serious consequences for the transport services included in a multimodal trip. In order to be attractive compared to a unimodal transport service, the speed or the costs of a transport service in a multimodal trip should compensate for the delay and inconvenience of the transfer, as shown in Fig. 2.2. Multimodal transport requires fast or cheap transport services. In unimodal transport network design, the transfer penalty in terms of additional time and costs usually leads to a focus on maximizing direct trips, or on minimizing transfers. Furthermore, the operators will also try to minimize the negative impact of the remaining transfers in their networks. Such an approach is clearly not suitable in a multimodal context, since it would ultimately lead to unimodal networks only (Van Nes R., 2002).
Figure 2.3 Distinction in different types of modes

Modes and transport services are terms that are closely related and at the same time have different meanings. A typical example of the usage of the term mode is in the mode-choice model in which the traveler's choice such as cycling, car, and public transport is modeled. In this context the term mode is usually associated with the vehicle used. In the case of public transport, however, the term mode is related to the service characteristics and not specifically to vehicle types such as bus, tram, metro, and train. Multimodal transport thus concerns transfers between private transport modes, between private transport and public transport services, and between functionally different types of public transport services; and this distinction in mode types is illustrated in Fig 2.3.
It can be noted that for public transport services the vehicle mode might be ambiguous: For example bus, might be a vehicle mode for urban public transport services as well as for regional and national public transport services. The definition of multimodal transport should ideally be based on tours (Fig. 2.4) as suggested by Egeter et al (1994) and not on trips. Anyway there is a difference between a multimodal trip and a multimodal tour. A tour in which bus is used in the first trip, and in which the return trip is made as car passenger, consists of two unimodal trips. Although such a tour might be called a multimodal tour (Fig 2.5), it is clear from this example that a multimodal tour is unlike a multimodal trip where two or more modes are used in a single trip. Both concepts, multimodal tours and multimodal trips have their own characteristics. Multimodal transport network design is strongly related to multimodal trips and tours become essential in describing travelers’ behavior (Van Nes R., 2002).

Figure 2.5 Examples of unimodal and multimodal tours.
(a) Unimodal tour consisting of 2 unimodal trips
(b) Multimodal tour consisting of 2 unimodal trips
(c) Multimodal tour consisting of 2 multimodal trips
(d) Multimodal tour consisting of a multimodal and a unimodal trip
On the other hand, this example illustrates that the concept of tours is relevant for the assignment of trips on a multimodal network. It is not very logical, for instance, that the return trip in this example could be made as a car driver. For trips starting at home there may be more vehicle modes available than for trips starting at other locations. Furthermore, it must be taken into account that a private mode used for the first trip of the tour, should be returned to the home address. A typical example is that a traveler, who used a car as an access mode for the train, should return at the end of his tour to the railway station where the car was parked. Walking is nearly always part of a trip and this is obvious in the case travelers have to walk to and from the stops of the public transport system, but using the car also requires walking to and from the parking place, although these distances might be short. Walking can thus be considered as a universal component at the start and the end of any trip, and is therefore not considered as a separate mode in the definition of a multimodal trip. Travelers who walk to the bus stop, ride the bus, and walk from the stop to their destination thus make a unimodal trip. In the case that a bicycle is used to access the bus system, however, the trip will be defined as a multimodal trip in which two services and two modes are used. The only exception to this rule is when walking can be seen as the main mode of the trip, that is, when walking is the mode used to cover the largest distance of the trip. This might occur if travelers use a bicycle or a car to access a shopping centre or a recreational area such as a park. The distance walked might then exceed the total distance covered by bicycle or car.
2.2.2. Assignment problem

Assignment Method was developed by D. Konig, a Hungarian Mathematician and is therefore known as the Hungarian Method of Assignment Problem. In order to use this method, one needs to know only the cost of making all the possible assignments, with minimum cost. Assigning a job becomes a problem because each job requires different skills and the capacity or efficiency of each person with respect to these jobs can be different. This gives rise to cost differences. If each person is able to do all jobs equally efficiently then all costs will be the same and each job can be assigned to any person. The cost elements are given and are a square matrix and requirement at each destination is one and availability at each origin is also one. In addition we have number of origins which equals the number of destinations hence the total demand equals total supply. There is only one assignment in each row and each column.

Assignment Problem, a classical combinatorial optimization problem is attempted in a novel manner using an agent/resource allocation based model known as a Computational Ecology. Algorithm that reduces to an iterative weighted normalisation process is obtained that converges to the optimal or near optimal assignment of a given positive square benefit matrix. It consists of finding a maximum weight matching in a weighted bipartite graph. (F.Vermaak and M.A. Van Wyk, 2010). There are a number of agents and a number of tasks. Any agent will be assigned to perform any task, incurring some cost that may vary depending on the agent-task assignment. It is required to perform all tasks by assigning exactly one agent to each task in such a way that the total cost of the assignment is minimized. Numerical experiments comparing the
performance of the inexact and exact penalty function methods will be completed (Vyacheslav and V. Kalashnikov 2008).

Besides its theoretical significance, its frequent appearance in the areas of distributed control and facility allocation, where the problems size and the cost for global computation and information can be highly prohibitive, gives rise to the need for local solutions that dynamically assign distinct agents to distinct tasks, while maximizing the total assignment benefit (Michael M.Zavlanous, 2008). Deeper and more complete investigations on service assignment problem for both shareable and non-shareable cases could also lead to interesting conclusions (XuanTung Hoang and Dongman Lee and Younghee Lee, 2008).

**Basic Assumptions of the Assignment Problem**

Based on the definition of an Assignment Problem, the applications need to be formulated in a way that satisfies the assumptions: The number of assignees and the number of tasks are the same. Each assignee is to be assigned to exactly one task. Each task is to be performed by exactly one assignee. There is a cost $C_{ij}$ associated with assignee $i (i=1,2,3,...n)$ performing task $j (j=1,2,3,...n)$. The objective is to determine how all $n$ assignments should be made to minimize the total cost. Any problem satisfying all these assumptions can be solved extremely efficiently by algorithms designed specifically for Assignment Problems. The first three assumptions are fairly restrictive. Many potential applications do not quite satisfy these assumptions. However, it is often possible to reformulate the problem to make it fit (Hiller / Lieberman, 2001).
2.2.3. Multimodal Transport and the Layer Model

The layer model provides a framework to analyse the transportation system. The basic model consists of three layers, activities, transport services and traffic services and two markets between them (fig.2.6). The first phase explains transport market between activities and transport services and second phase explains traffic market between transport services and traffic services (Schoemaker et al, 1999). Multimodal transport is related to the second layer: transport services; Transport services determine the quality of the whole trips from door to door, which is influenced by the vehicle, the network, and all service attributes. Transport services include private transport as well as public transport. The differences between the various transport services depend on the characteristics of all the three components and on who is responsible for the quality of those components.

In the case of private transport such as private car, the concept of a transport service is less clear. The main point is that the driver provides transport for himself: the driver as service provider and the passenger are the same person. The car-driver

![Figure 2.6 Layer model of the transportation system](image)

Figure 2.6 Layer model of the transportation system
determines the quality of the vehicle and of the service during the trip, while the authorities determine the quality of the network used. Multimodal transport implies that more than one transport service is used for making a trip, being combinations of private transport and public transport services or combinations of public transport services. This can be illustrated, if the layer for transport services is split into the various elements (fig.2.7). Transport service integrator, which decides or helps to decide which transport services are used for a specific trip. This might be a single transport service resulting in a unimodal trip or a combination of transport services leading to multimodal trip. Transport services are thus competing as well as working together; The role of transport service integrator is usually performed by the traveller himself, but can also be performed by a third party such as a travel agency or the Transvision Company in the case of the Odessey-card. Upon request of the card-holder, Transvision arranges the whole trip using services such as rent-a-car (with or without a chauffeur), train, taxi, and Traintaxi, including all financial aspects;

![Multimodal transport and the layer model](image)

**Figure 2.7** Multimodal transport and the layer model

Transport services, the single or unimodal transport service such as urban, regional, or national public transport services, and private transport services as private
car and bicycle, which determine travel time and travel costs. A transport service consists of service components and transport means, which are provided and operated; Service components, which include all components, not related to the transport means, such as in the case of public transport services: the service network, ticketing, and providing information. In the case of private transport the traveller himself takes care of these aspects; Transport means, the vehicles used to provide transportation. They should be provided for and should be operated for the specific services; Operating transport means, which is taken care of by the driver and might be performed by either the traveller himself, a fellow traveller, or by a professional driver; Providing transport means, which can be done by the traveller himself, by a rental service, or by a public transport company. For a specific part of the trip providing transport means might include parking in the case of private vehicles. Table 2.1 shows the transport service provider.

Table 2.1  Examples of parties involved in providing a transport service

<table>
<thead>
<tr>
<th>Transport service integrator</th>
<th>Service components</th>
<th>Providing transport means</th>
<th>Operating transport means</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unimodal transport</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private car</td>
<td>Traveller</td>
<td>Traveller</td>
<td>Traveller</td>
</tr>
<tr>
<td>Car passenger</td>
<td>Traveller / (Car driver)</td>
<td>Car driver</td>
<td>Car driver</td>
</tr>
<tr>
<td>Public transport Service</td>
<td>Traveller</td>
<td>Public Transport company</td>
<td>Public Transport Company</td>
</tr>
<tr>
<td><strong>Multimodal Transport</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private car / Bicycle*</td>
<td>Traveller Transvision</td>
<td>Traveller Railway company/ Car driver/ Traveller</td>
<td>Traveller Railway company / Car driver / Taxi company / Rental service</td>
</tr>
</tbody>
</table>

* For instance a bicycle that is transported with the private car.
This more detailed description of the layer Transport services clearly shows three typical features of multimodal transport. The role of the Transport service integrator becomes more apparent. Combination of transport services requires at least good information on the transport services that are available. Furthermore, dedicated arrangements might be needed to assure a comfortable trip. The multimodal transport requires for the traveller to transfer between different transport services. This implies a change of trip characteristics, which might have a negative influence on the attractiveness of multimodal transport. Furthermore, since each transport service involves different parties co-ordination might become a critical element.

Share of the multimodal transport compared to unimodal transport and the modes used in a multimodal trip are the two characteristics of multimodal mobility. The mode of transport determines multimodal transport usage. These factors can be used to make an assessment of the future potential of multimodal mobility. In order to answer these questions, an analysis was made of the Dutch National Travel Survey (CBS (1996)). This survey collects travel-data for more than 70,000 households annually, leading to data on about 600,000 trips. Since multimodal trips might have rare sequences of services and modes a combination is made of the surveys for 1995, 1996, and 1997. In this way there are more observations available for some particular combinations of modes, for instance, car driver as a main mode. The main mode is defined as the mode that is used to cover the largest distance of the trip, while the other modes used in the trip are classified as access and egress modes.
2.2.4. Descriptive Characteristics of Multimodal Trips

Table 2.2 shows the modal split for all trips with a distinction between unimodal and multimodal trips. The first observation that can be made is that the share of multimodal trips is small: 2.9% of all trips are multimodal. Compared to the period ten years earlier, this share has increased by 25%. This is mainly due to the fact that in 1990 the Students Public Transport Card was introduced, leading to a substantial increase in public transport usage for this part of the population. If students are not included in the comparison, the share of multimodal transport would be 2.1%, an increase of 10% in ten years.

Most multimodal trips (72%) consist of two legs, that is, two vehicle modes are used. 26% of multimodal trips contain three legs, and only 2% of multimodal trips consist of four or more legs. When looking at the main mode, that is, the mode used to cover the largest distance, train is the most important mode accounting for 59.2% of all multimodal trips. The second mode is bus, having 14.5%, followed by a group having a share of 6 to 7%: car passenger (7.3%), tram/metro (6.4%), and car driver (6.2%). Interestingly, walking is the main mode for 3.7% of all multimodal trips. Private modes are the main mode for 17.2% of all multimodal trips (Van Nes R., 2002).
Table 2.2 Distinction between unimodal and multimodal trips (1995-1997)

<table>
<thead>
<tr>
<th>Main mode</th>
<th>All trips (%)</th>
<th>Unimodal (%)</th>
<th>Multimodal (%)</th>
<th>Percentage multimodal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car driver</td>
<td>36.2</td>
<td>36.0</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Car passenger</td>
<td>13.1</td>
<td>12.9</td>
<td>0.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Train</td>
<td>2.1</td>
<td>0.4</td>
<td>1.7</td>
<td>80.5</td>
</tr>
<tr>
<td>Tram/Metro</td>
<td>0.9</td>
<td>0.7</td>
<td>0.2</td>
<td>20.4</td>
</tr>
<tr>
<td>Bus</td>
<td>2.0</td>
<td>1.6</td>
<td>0.4</td>
<td>21.2</td>
</tr>
<tr>
<td>Bicycle</td>
<td>27.6</td>
<td>27.5</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Walking</td>
<td>16.0</td>
<td>15.9</td>
<td>0.1</td>
<td>0.7</td>
</tr>
<tr>
<td>Other</td>
<td>2.1</td>
<td>2.1</td>
<td>0.0</td>
<td>1.7</td>
</tr>
<tr>
<td>All modes</td>
<td>100.0</td>
<td>97.1</td>
<td>2.9</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Multimodal travel is dominant for the train, accounting for 80% of all train trips. The share of multimodal trips drops to about 20% for bus and tram/metro each. For the private modes it ranges between 1.5% for car passenger and 0.6% for car driver and bicycle.

Figure 2.8 Modal share of the home-based and the activity-based legs of multimodal trips, excluding walking (NTS 1995-1997)
A characteristic mentioned in the discussion on trips or tours, is the difference in vehicle availability between the home-based part and the non-home-based or activity-based part of the trip (fig.2.8). The modal split for the access and egress legs of the multimodal trips, excluding the percentages for walking which are 24.5% and 51.3% respectively. As expected, private modes, especially cycling, play an important role for the home-based part of the trip, accounting for 49% of the access/egress trips. For the activity-based part of the trip, this share drops to 17%. It is interesting to note that for the activity-based leg the importance of the car passenger and tram/metro modes is larger, while that for bus is equal. The share of taxi is limited to 1% for the activity-based part of the trip. Of course, these percentages are typical for the situation in the Netherlands, especially with respect to the role of the bicycle. For commuters to Chicago, for instance, Davidson & Yang (1999) reported 50% car drivers and 15% car passengers as access modes for rail transport services, while walking accounts for 83% of the egress modes. This description of multimodal trips gives some insight into the main characteristics, but does not provide an explanation.

2.2.5. Factors determining the share of multimodal travel

The most explanatory variables included in the National Travel Survey are ordinal variables; discriminant analysis has been used to assess the main factors that determine multimodal travel (SPSS (1998)). In order to account for the contribution of the availability of vehicle modes at the home-based part of the trip a selection was made of trips starting at home. The explanatory variables included
variables related to the traveller, such as age, education, and vehicle availability, and variables related to the trip itself, type of origin and destination area, trip purpose, and trip length. Three factors proved to be dominant in discriminating between unimodal and multimodal trips. Trip distance: longer travel distances have more multimodal trips; Type of destination area: multimodal trips are oriented to the main cities and especially the city centers, trip purpose: the main trip purposes for multimodal trips are work and education.

Using these three factors 83% of the multimodal trips could correctly be classified. Trip distance is the dominant variable: directly accounting for classifying 78% of all multimodal trips. Inclusion of additional variables led to very small improvements in the classification results. Personal characteristics had only a minor influence, with the exception of the availability of the Students Public Transport Card. As already stated in the previous section, the availability of such a card has a strong positive relationship with multimodal trip making. These three main factors will be discussed in more detail, followed by some other factors such as car availability and the impact of tours. The importance of trip length can clearly be seen from Fig 2.9 and Fig 2.10, which show the trip length distribution and the differences in trip lengths with respect to the number of legs per trip.
Figure 2.9  Trip length distribution for all trips and for multimodal trips (each trip types adds up to 100%)

Figure 2.10  Trip length characteristics in relation to the number of legs per trip (NTS 1995-1997)
The average total trip length of multimodal trips is 45 kilometers, more than 4.5 times the average unimodal trip length. Multimodal transport thus accounts for more than 12% of all kilometers travelled. Multimodal transport appears to be viable for trips longer than 10 kilometers and becomes an interesting alternative for trips longer than 30 kilometers, having a modal share of approximately 15%. There is, however, a large difference in the distances with respect to the main modes used in the multimodal trip. Short trip lengths are found for the main mode walking (6 kilometers) and tram/metro (14 kilometers). For these main modes intra-urban trips are dominant. Bus and both car modes have medium trip lengths, varying between 26 kilometres (bus) and 42 kilometers (car passenger). It is interesting to note that for the main mode of car driver the trip length distribution includes short trips (intra-urban) as well as very long trips. The average trip length of a multimodal trip by train is 58 kilometers.

Figure 2.11  Average leg lengths of multimodal trips by main mode for the home-based leg (left-hand side), the main mode, and the activity-based leg (right-hand side) (NTS 1995-1997)
If multimodal trips are split into legs, there are three interesting characteristics that can be observed (Fig 2.11). First, the differences in leg lengths between the main mode and access and egress modes suggest a hierarchical relationship between the networks of these modes. The network of the main mode is suited for long distance travel, while the networks for the access and egress modes are used for short distances. Second, the average length of the home-based leg, shown on the left, is slightly smaller than the length of the activity-based leg shown on the right, with the exception of the main modes walking, tram/metro, and car driver. Third, the access and egress legs for the main modes car driver and car passenger are substantially larger than those for public transport. In fact, these trips can be distinguished in trips having relatively short access distances, especially by bicycle, and trips having very large access distances, for instance car passenger and car driver respectively in more rural areas. These latter trips are responsible for the relatively high average access distances. Furthermore, the percentage of multimodal trips having a home-based leg, is relatively low for the main mode car driver (28%), while for all other main modes the percentage of home-based legs is larger than that for the activity-based legs. In the case of the main mode train the percentages for both leg types add up to 134%, indicating a relatively high share of trips having three legs or more.

The third discriminating factor for multimodal travelling is trip purpose. As can be seen in Table 2.3, multimodal transport plays an important role for work and especially for education trips. The latter illustrates, again, the strong relationship between the Student Public Transport Card and multimodal transport. Multimodal
transport appears less interesting for trip purposes such as shopping, touring and picking-up or dropping off passengers.

Table 2.3  Trip purposes with distinction between unimodal and multimodal trips S

(1995-1997)

<table>
<thead>
<tr>
<th></th>
<th>All trips (%)</th>
<th>Multimodal (%)</th>
<th>Percentage multimodal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
<td>17.7</td>
<td>31.4</td>
<td>5.3</td>
</tr>
<tr>
<td>Social</td>
<td>15.6</td>
<td>14.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Education</td>
<td>4.6</td>
<td>21.4</td>
<td>14.0</td>
</tr>
<tr>
<td>Shopping</td>
<td>24.5</td>
<td>9.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Business, private</td>
<td>2.2</td>
<td>1.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Business, work</td>
<td>3.1</td>
<td>2.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Recreation</td>
<td>12.4</td>
<td>11.2</td>
<td>2.7</td>
</tr>
<tr>
<td>Touring</td>
<td>4.3</td>
<td>1.4</td>
<td>10.0</td>
</tr>
<tr>
<td>Personal care</td>
<td>3.1</td>
<td>1.3</td>
<td>1.2</td>
</tr>
<tr>
<td>Pick-up/drop-off</td>
<td>6.9</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td>Other</td>
<td>5.6</td>
<td>4.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

The importance for the work trips is to be expected. This trip purpose has a strong orientation to the centers of the main cities. Given the availability of the Students Public Transport Card the high share of multimodal trips for the trip purpose education is also not surprising. Similarly, the short distances related to shopping explain the low share of multimodal transport for this trip purpose. Such explanations, however, can not easily be found for the results for social and recreation trip purposes. The fact that the share of multimodal transport for the work and education trips is higher than average leads to four observations. First, it is interesting to note that even though these trips
have at least one transfer, they have a high trip-frequency, which implies that the penalty of a transfer seems to be acceptable. At least the overall benefits prevail over the discomfort of the transfer. Second, these trips are usually made in peak periods, periods in which the quality of public transport in terms of time-accessibility is usually the best. Third, the trip-frequency related to these trip purposes indicates that sufficient knowledge of the transport system may be expected to be available. Finally, it should also be noted that during the periods when most of these trips are made, the quality of the car system is worst due to congestion and that parking is often difficult and expensive.

**Important Factors**

The discriminate analysis not only showed the main factors determining multimodal mobility, it also showed the factors that are not decisive for multimodal travelling. There are, however, two characteristics that need further discussion, namely car availability and the availability of a railway station. Furthermore, given the theoretical importance of tours, special attention is given to multimodal travel in complex tours. Car availability, defined as having a driver’s license and having a car in the household, has no substantial impact on multimodal mobility. If a distinction is made between travelers who have a car available and those who do not, the same discriminating factors resulted. It has been found, however, that more than 50% of the travelers making a multimodal trip had no car available, which is nearly twice the share for all travelers. Interestingly, this percentage is not influenced by the availability of Students Public Transport Card. A comparison for car availability between the characteristics of unimodal trip makers and multimodal trip makers, showed that in the case of multimodal
trips car availability dropped substantially for the following characteristics: ① Travelers between 25 and 65 years, and especially for travelers between 30 and 50 years ② Travelers who are participating in the labor market ③ Travelers having a relatively high level of education ④ Travelers having a relatively high personal income.

For all these groups the percentage of travelers having no car available is two or three times larger in the case of multimodal trip makers. This is exactly the opposite of what might be expected for these groups, since they generally have a relatively high level of car availability. Apparently, there is a group of travelers who make an explicit choice to have no driver’s license or no car, and thus choose public transport. This public transport oriented group of travelers, however, provides no discriminating characteristics for classifying multimodal trips. It might have been expected that, due to the importance of train in multimodal trip making, the availability of a railway station should also have been a discriminating factor. It is found, however, that railway station availability is of secondary importance if area type is also considered. Two remarks can be made with respect to this finding. First, there is a correlation between railway station availability and area type. Second, the variable area type is more detailed than a binary variable indicating whether a railway station is available or not. Furthermore, area type also stands for other characteristics, such as urban densities with respect to workplaces and urban facilities, and the availability of service modes to reach destinations that are further away from the railway station.

It is usually assumed that unimodal transport is perfectly suited for more complex tours, that is, tours having two or more activities: unimodal transport offers the
flexibility needed for complex tours. Table 2.4, however, shows that there is certainly no
evidence to support this assumption. The share of tours consisting of at least one
multimodal trip is even larger for more complex tours than for common tours consisting
of two trips. In a way it seems to work the other way around. Common trips are easily
made using unimodal transport and if travelers have to plan their trips, either due to
the high trip frequency such as in the case of commuter trips, or in the case of
complex tours, multimodal transport becomes a more interesting alternative. Another
possible explanation might be that the complexity of multimodal trips makes it
interesting to combine activities in a complex tour, which is made more attractive by
the concentration of activities around major stations.

<table>
<thead>
<tr>
<th>Table 2.4 Share of multimodal trips per tour type (NTS 1995)</th>
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<tbody>
<tr>
<td>Percentage of all tours</td>
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<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>1 trip tours</td>
</tr>
<tr>
<td>Simple tours (2 trips)</td>
</tr>
<tr>
<td>Complex tours (&gt; 2 trips)</td>
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<tr>
<td>All tours</td>
</tr>
</tbody>
</table>

2.3 MULTIMODAL TRANSPORT NETWORK

2.3.1. Network characteristics

Network characteristics can be seen from two points of view: that of the network
user (travelers) and that of the network investor or network operator. The main
characteristics of any transportation network from the traveler’s point of view are travel
costs and travel time, with the latter determined by network characteristics such as
space accessibility, time accessibility and network speed (Van Nes R., 2002). These network characteristics can be described using the following definitions:

- **Space accessibility**: the number and distribution of access points where the traveller can enter and leave the network. Typical examples are bus stops, motorway ramps, and airports;

1. **Time accessibility**: the distribution of opportunities per unit of time for the traveller to use the network. This characteristic is very common for public transport or airline services and can be described by timetables or service frequencies. For private transport the time accessibility is usually unlimited;

2. **Network speed**: the average speed while travelling on the network, which is determined by the network structure and the design speed. Since speed is independent of the distance travelled, it is preferred to the perhaps more obvious alternative of travel time.

3. In this thesis travel quality will usually be described by travel time, thereby neglecting other characteristics such as travel costs or all other service related characteristics. Furthermore, transport networks determine primarily travel times, while the other characteristics have only an indirect relationship with the transport network itself. It is evident that from the investor’s or operator’s perspective costs are the main network characteristic. The following costs can be distinguished:

4. **Investment costs** - especially the costs of building the physical network, which is related to type of infrastructure and total length of the network;

5. **Maintenance costs** - that is the costs for maintaining the quality of the infrastructure, which is, again, related to the length of the network;
6. **Operating costs**—these costs are especially related to transport service networks and include costs such as operating the vehicles. These costs are determined by the length of the transport service network and the frequency with which these services are offered.

<table>
<thead>
<tr>
<th>Table 2.5 Relationship between network category and network characteristics</th>
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<tbody>
<tr>
<td><strong>Traveller</strong></td>
</tr>
<tr>
<td>Space accessibility</td>
</tr>
<tr>
<td>Transport service network</td>
</tr>
<tr>
<td>Traffic service network</td>
</tr>
</tbody>
</table>

The characteristic that all these investor or operator costs have in common is the network density, which can be defined as the total network length per unit of area (Table 2.5). It clearly shows that time accessibility and operating costs are strongly related to transport service networks and that investment and maintenance costs are mostly related to traffic service networks. It should be noted that in the case of transport service networks investment and maintenance costs may also exist, but these costs mostly relate to the fleet used to provide the services. In the case of public transport services having dedicated infrastructure, however, investment and maintenance costs of infrastructure also become an important phenomenon.
2.4. SUMMARY

Multimodal transportation involves the use of more than one means of transport such as a combination of truck, railcar, aeroplane or ship in succession to each other. International multimodal transport means the carriage of goods by at least two different modes of transport on the basis of a multimodal transport contract from a place in one country at which the goods are taken in charge by the multimodal transport operator to a place designated for delivery situated in a different country. Intensive Research has been carried out in Netherlands in designing Multimodal transport networks including public and private transport. A good Multimodal transportation system aims at achieving efficiency by the coordinated use of different modes. The objective function of the mathematical model is used to determine the minimum cost and minimum time of delivery of goods over a multimodal transport system.