ARTICLE IN PRESS

Available online at www.sciencedirect.com

SCIENCE DIRECT®

ELSEVIER

European Journal of Operational Research xxx (2003) xxx–xxx

EUROPEAN JOURNAL OF OPERATIONAL RESEARCH

www.elsevier.com/locate/dsw

Towards the improvement of a combined transport chain performance

Athanasios Ballis, John Golias *

Department of Transportation Planning and Engineering, National Technical University of Athens, 5 Iroon Polytechneiou Str., 157 73 Zografou, Athens, Greece

Received 25 January 2001; accepted 18 July 2002

Abstract

Within the framework of the promotion of the environmental friendly modes, the European Commission has launched a number of research projects aiming at evaluating technical and organisational innovations that can improve the performance of the freight transport operations in the rail sector. The scope of this paper is to present a modelling approach focusing on the comparative evaluation of conventional and advanced rail-road terminal equipment. The set of models used, consists of an expert system for the terminal design, a model simulating terminal operations and a macro-model implementing rail operating forms and assigning freight flows in the transport network. This approach stems from the fact that the time savings due to efficient terminal transshipment can be used effectively only in combination with advanced rail operating forms.

Keywords: Modelling tools; Terminal design; Intermodal transport chain; Expert system; Simulation

1. Introduction

Creation of a European intermodal transport network is a high-priority objective of the European Community and one to which the European Commission has dedicated studies, specific legislation and very considerable funds [1]. Intermodal transport in Europe has registered a high rate of growth for many years since the beginning of its services. This growth was supported by a systematic promotion and subsidies received by various European countries. In the most recent years the growth trends of the past were not confirmed, and clear trends for the future are not self-evident [2]. Although in the strategic level the member states had expressed their willingness for a closer co-operation among their national railway organisations, this co-operation is still at an infant stage. However, as the liberisation of the railway market has allowed the participation of private operators, the focus is gradually moving from the improvement of the national network operations to the management of the international transport chain. In parallel, the European Commission has supported various research and pilot initiatives aiming

* Corresponding author. Tel.: +30-1-772-1276; fax: +30-1-722-1327.

E-mail address: igolias@central.ntua.gr (J. Golias).

0377-2217/03/$ - see front matter © 2003 Published by Elsevier Science B.V.
doi:10.1016/S0377-2217(03)00034-1

at the harmonization of infrastructure design standards, safety regulations, equipment specifications and operating procedures for both, intermodal terminals and network.

Intermodal terminals are the nodes of the freight transport network. Parameters like the terminal's location in relation to the spatial allocation of production and consumption centres, the existence of antagonistic terminals, the access to the major rail and road networks etc. affects significantly the cargo volume and the intermodal transport units (ITU) mixture served. Other parameters like the cost and availability of land are determined mainly by local conditions [3]. On the contrary, a number of parameters is determined by the terminal planner (or imposed by the terminal authorities). Among these parameters, the handling equipment plays a dominant role since it outlines the terminal layout and determines its limits and productivity [4].

Work on the comparative evaluation of alternative terminal designs (using conventional technologies) has been carried out both in the remote past [5–7] as well as in the recent years [8,9]. Selected issues (space, equipment optimisation etc.) have been further investigated [10,11]. The comparative evaluation of the innovative equipment that appeared lately [12] was performed mainly through research projects [13–17]. Attention was also given to specific operational issues [18,19].

The scope of this paper is to present a modelling approach focusing on the comparative evaluation of conventional and advanced rail-road terminal equipment. The typical rail-road terminal configuration and the associated service procedures are presented in Section 2. Since rail-road terminal productivity is strongly related to the rail-side operating conditions, the basic rail operating forms are presented in Section 3. The analysis is supported by a set of models. The description of the models and their interrelation are presented in Section 4, while the conclusions are drawn in Section 5.

2. Rail-road terminals

Rail-road terminals consist of a wide range of installations, ranging from simple terminals providing transfer between two or three modes of transport, to more extensive centres providing a number of value-added services such as storage, empties depot, maintenance, repair, etc. A typical rail-road terminal includes the following elements:

(a) Rail sidings for train/wagon storage, marshalling and inspection purposes.
(b) Transhipment tracks (also termed loading tracks) for the train loading/unloading operations.
(c) Storage or buffer lanes for ITUs.
(d) Loading and driving lanes for the trucks.
(e) Gates, internal road network.

In the simplest type of operation, the train arrives on the transshipment line, is serviced (unloaded and/or loaded) and remains there until departure. This type of operation enables almost exclusive direct transshipment between wagon and trucks without intermediate storage on the ground. The unloading and loading sequence is dictated mainly by the truck arrivals at the terminal [20].

Real-life operations are generally more complicated: If the number of incoming wagons per train exceeds the length of the track, the train has to be shared out over two (or more) tracks. Moreover, if the number of incoming trains (or train parts) exceeds the capacity of the transshipment tracks, certain trains have to be removed from the transshipment tracks after an unloading/loading phase of a few hours, in order to make space for new inbound trains. This procedure requires that the first pulse of wagons be completely unloaded, either onto the trucks or into the buffer lanes, in order to guarantee the availability of ITUs for customers. The empty wagons are then transferred to storage sidings and the next pulse of wagons can be marshalled into the transshipment tracks. After that, the empty wagons are composed to form the outgoing trains. A wagon pin adjustment procedure prepares the wagons to accommodate the new loading units. After the wagon's loading and the necessary inspections and brake tests, the train is ready to depart.

The requirements concerning rail-road terminal operations are increased by those corresponding to scheduled trains, train-to-train transshipments, increasing number of clients (private railways, intermodal operators) and complexity of data in the freight nodes (customs, hazardous goods) [21].

3. Rail operating forms

The intermodal transport situation in Europe is somewhat complex. However, for the purposes of this analysis, four different operating forms for railway transport have been identified (see Fig. 1).

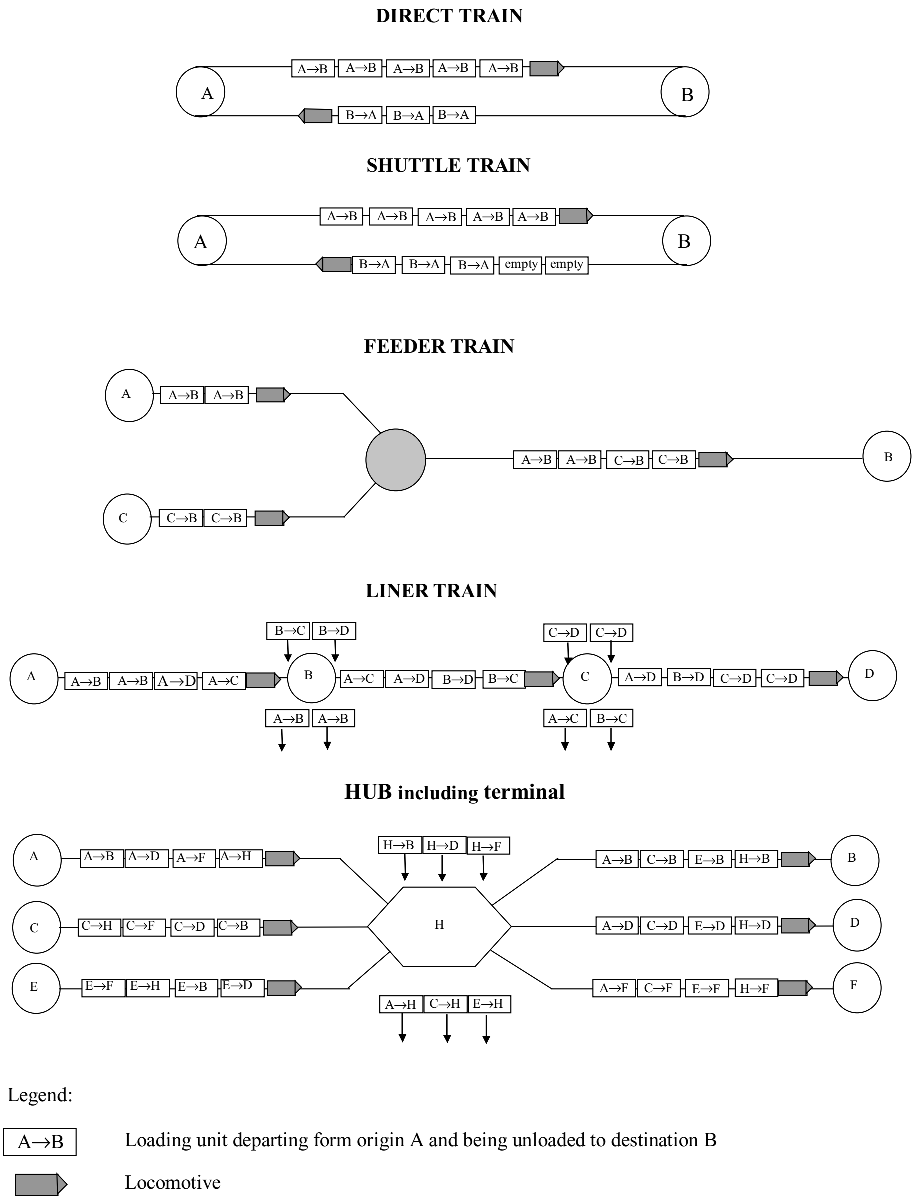

Fig. 1. Alternative rail operating forms.

(1) Direct train. These trains are running between two terminals without handling on the way and are the most economic and rapid operating rail mode. Two variants may be found: block trains (the number of wagons dependent on specific demand) or shuttle trains (fixed train formation). The latter includes also shuttle–shuttle form, which is characterised by a fixed composition of wagons, running twice a night between two terminals, thereby eliminating the need for a pair (one per direction) of wagon groups.

(2) Group trains or feeder systems. The aim of feeder systems is to link terminals of a region through—short—feeder links and fulfil the long distance transport in a complete train. If the demand is too small for economical services with direct trains, feeder systems can be a possible solution.

(3) Liner trains. They offer regular service and allow the integration of terminals with smaller demands in a network of intermodal transport. Today's understanding of liner trains means fixed compositions of wagons which are loaded and unloaded during the stop. An alternative can be a liner train which uncouples a number of wagons (instead of transships ITUs) in each terminal stop.

(4) Hub and spoke system. With such a system it is possible to offer more connections between medium and small terminals. The time used for train formation and bundling in the hub and for detours (compared to the shortest path between two terminals) reduces the possible transport distance in the available time window.

Moreover, a mixture of full load traffic and intermodal transport systems exists, that makes use of junctions and marshalling yards for the wagon sorting process. This rail form is still very common in Europe for small volumes or if private sidings have to be served.

4. Modelling approach—models and linking technique

Rail-road terminals and rail operating forms are two of the parameters that affect the effectiveness of the intermodal transport. Many other parameters exist like the structure of the existing network (in terms of origin/destination points and railway line capacities), the rolling stock capabilities, the interference with the passenger railway traffic (which normally have priority over the freight traffic) etc. The optimisation of the whole system, should unavoidably be based on numerous assumptions and despite its great academic importance, it is of limited value for many actors involved in the real world operations (e.g equipment manufactures, freight forwarders, terminal operators) that seem to prefer straightforward answers to their "what–if" scenarios.

The modelling approach followed in this research allows the user intervention in the design process, both in terminal design and rail form system selection, while on the other hand facilitates powerful tools (expert system support, simulation, freight flow market share functions etc.) that can produce quantitative results (investment cost, cost per loading unit transshipped, transport volume etc.). The improvement of the performance of a system under investigation (e.g a transport corridor that incorporates small, medium and large terminals) can be achieved through an optimisation procedure, which is based on a thorough investigation of the terminal performance by use of a micro-model. This model incorporates an expert system, that assists the user to form technically sound terminal designs and therefore to reduce the number of alternatives for further investigation, and a simulation model, that quantifies the performance of the produced terminal configurations. The outcome of the above investigation is a set of cost-versus-volume curves (see part 4.3). These curves are then used in a macro-model of the transport network, which calculates the volume of the rail freight flows in the network. Furthermore, an analytical model is used for the calculation of the cost of the pre- and post-haulage sub-system. [1] The presentation of the pre- and

[1] The micro-model was developed by the National Technical University of Athens (NTUA). The macro-model was developed by COHERANCE (Brussels) while the pre- and post-haulage model was developed by Eidgenossische Technische Hochschule (ETH)—Zurich IVT.

post-haulage sub-system analysis and modelling is outside the context of this paper.

4.1. Expert system

The micro-model consists of an expert system supported by a simulation module and a cost calculation module for the various terminal designs. The expert system produces alternative terminal designs using conventional and innovative transshipment equipment, rail access systems, identification, location and positioning devices, semi-automatic control, information systems, etc. The expert system identifies each of the above elements by "compatibility", "performance" and "cost" attributes. The "compatibility" and the "performance" attributes—through an interactive interface—enable the user to form technically sound terminal designs. Moreover, the "performance" attributes participate in the calculation of the equipment service cycle, thus enabling the quantification of the performance of each element in the terminal performance. An automatic information system—for example—that supports a reach-stacker [2] fleet is incorporated in the micro-model by the following attributes:

(a) "cost" attributes which are its purchase/installation cost and its maintenance cost,
(b) "performance" attribute expressed by time saving achieved in the equipment service-cycle due to implementation of the information system that results in the reduction of reshuffles i.e. container rearrangements in order to handle containers that are not at the top of the stack.

The detailed description of the characteristics and capabilities of the expert system are presented elsewhere [22]. Hereinafter, the expert system parameters and the associated set of rules are outlined.

The first parameter is the cargo volume of the terminal. This user selection determines the type of the available handling equipment/technologies. For example, a moderate terminal volume excludes the equipment dedicated to low volume as well as high cargo volumes. In Fig. 5 the effective volume ranges for various equipment/technologies are presented. Furthermore, the cargo volume in combination with other parameters (type of the equipment, ITU types transshipped, stacking capabilities etc.) determines the land requirements.

The second parameter of the expert system is the mixture of the loading unit types transshipped. In the real world the mixture of the existing loading unit types (namely containers, swap-bodies/inland containers and semi-trailers) is determined by the market conditions, which in turn are affected by the location of the terminal e.g. a rail terminal located nearby a port, is likely to serve very high percentages of containers. Therefore, through this parameter the user "describes" an important terminal characteristic. The associated selections affect the land requirements (the loading unit dimensions are taken into account) as well as the stacking capabilities (since only containers and a small proportion of the swap bodies and inland containers are stackable). The existence of semi-trailers, especially when in high percentages, excludes some equipment types or imposes requirements for additional apparatus or specialized rolling stock. This is due to the fact that some automatic equipment require man intervention in order to fix the king-pin support of the semi-trailer.

The cost and availability of land are the additional expert system parameters. The cost of land value is used in the cost calculations scheme while the availability of the land, in combination with the terminal volume and the stacking capabilities of the loading units, excludes the handling equipment types that are land intensive.

Another parameter is the rail operating form (see Section 3) at the terminal. The selected form defines the train arrival pattern (and therefore the associated truck arrival patterns) used by the simulation model.

The length and access system of the transshipment tracks are the next parameters. Four options

[2] Reach Stacker = mobile equipment with a spreader on a beam that allows them to handle and stack containers one on the top of the other)

are included: short (450 to 550 m) or long (750 m) tracks both in combination with single or bilateral access. This selection determines the dimension of one of the terminal sides, the one that interfaces with the rail. It also determines (in combination with the equipment type and the operating rail form served) the number of the transshipment and waiting tracks of the terminal. Table 1 indicates the track configurations for a terminal serving direct trains on short tracks, (also called half-module) by use of gantry cranes. The table depicts an expert system rule that applies for all gantry crane based terminal designs (equipment configurations number 3 and 13 in Table 2). Other equipment configurations require different rules. In the moving train technique (equipment configurations number 5, 7, 10 and 14 in Table 2), for example, only one short transshipment track exists while all waiting trains are accommodated in waiting tracks. Moreover, a single-access system excludes the implementation of some technologies (e.g. the train coast in the terminal with momentum technology).

Table 1
Number of transshipment and waiting tracks for a terminal with short tracks, equipped with gantry cranes, that serves direct train operating forms

Volume (units per day)	Number of transshipment tracks	Number of waiting tracks
250	4	0
500	4	4
750	2×4	2×2

Terminals with short rail interface have lower infrastructure cost but higher operating cost since the long trains must be split in two parts to be accommodated in the short transshipment tracks. Furthermore, additional effort is put for the handling equipment that have to "clear the train" before the two train parts swap between transshipment and waiting trucks. Therefore, the length of transshipment tracks affects the infrastructure cost (land, total transshipment/waiting track length) as well as the handling equipment productivity.

The final parameter is the equipment type that allows for a selection among a number of handling systems incorporating reach stackers, gantry cranes of various productivities, as well as four innovative handling equipment/technologies. The technical description of this equipment can be found elsewhere [23]. Furthermore, the user can adopt appropriate additional add-on devices (semi-automatic control for conventional cranes, coast with momentum access system, pre-planning support etc.) that although they increase the

Table 2
Alternative handling technologies evaluated by the micro-model

a/a	Module size	Equipment configuration
1	Half module	Two reach stackers operating at 15 ITUs/h
2	Full module	Two reach stackers operating at 15 ITUs/h
3	Half module	One gantry crane operating at 22 ITUs/h
4	Full module	One gantry crane operating at 22 ITUs/h
5	Full module	Moving train technique–One crane–Single area variant
6	Full module	Two gantry cranes operating at 24 ITUs/h
7	Full module	Moving train technique–One crane–Basic variant
8	Full module	Three gantry cranes operating at 24 ITUs/h
9	Full module	Three gantry cranes operating at 28 ITUs/h
10	Full module	Moving train technique–Two cranes–Single area variant
11	Two full modules	Two reach stackers operating at 15 ITUs/h
12	Two full modules	Two gantry stackers operating at 24 ITUs/h
13	Half module	Two gantry stackers operating at 24 ITUs/h
14	Full module	Moving train technique–Two cranes–Basic variant
15	Two full modules	Three gantry cranes operating at 24 ITUs/h
16	Full module	Unidirectional bridges
17	Full module	Bi-directional rolling gantry crane

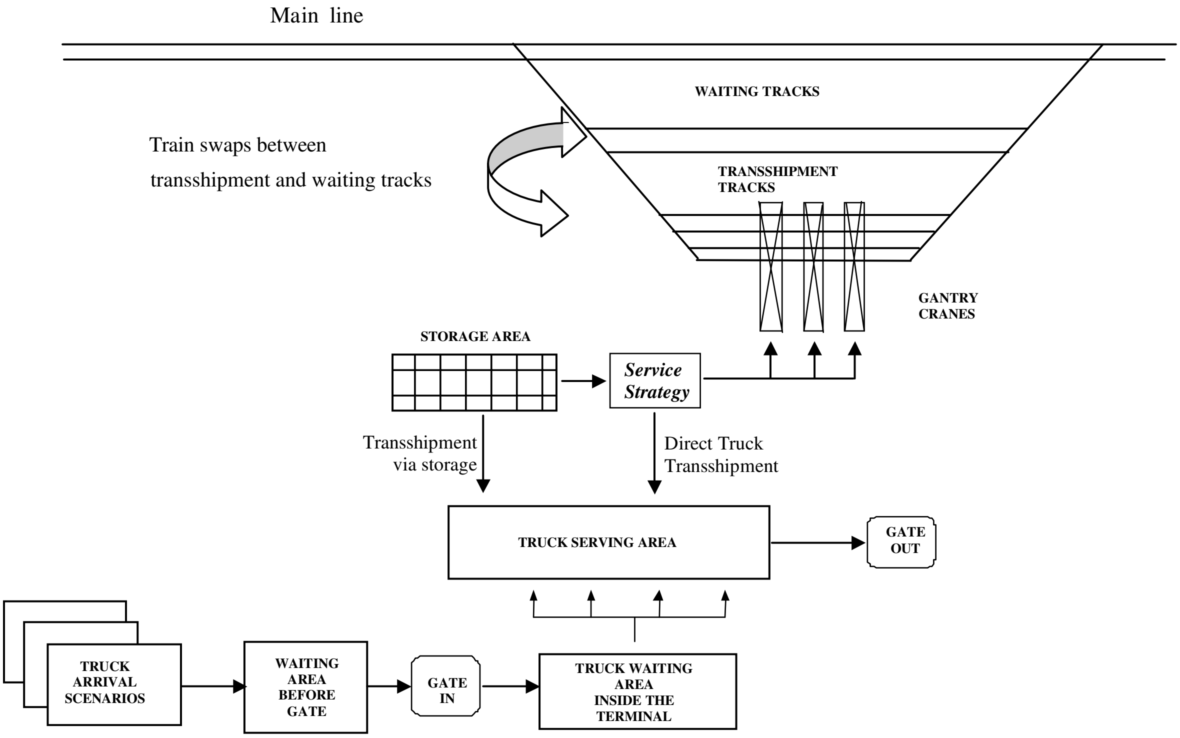

Fig. 2. Key elements of the simulated terminal.

investment cost, allow for an improvement of the equipment service cycle time.

4.2. Micro-model

The simulation module converts the equipment service cycle into train/vessel and truck service times, which are then compared to specific quality of service criteria. The model simulates both the railside and the roadside of the terminal. Fig. 2 presents the key elements of the simulated terminal.

The trains' properties (arrival time, number of ITUs to be loaded/unloaded, scheduled departure times) are defined by a "train arrival scenario" which is produced prior of the simulation by a special generator that incorporates information of operating characteristics of real terminals. Various train arrival scenarios are produced in order to cover a wide range of volumes (from 100 to 1200 ITUs per day). For each train arrival scenario, a nonstationary Poisson process (empirical data following the German experience) is used to generate the associated truck arrivals. The simulated rail-side operations include train swaps between transshipment and waiting tracks as well as the truck service procedures (where the terminal working hours, the equipment service discipline and the terminal's train–truck appointment system are taken into account). The thorough presentation of the simulation model is included elsewhere [23].

4.3. Cost versus volume curve production

Fig. 3 shows the methodology used to produce a typical cost-versus-volume curve. A design is considered as acceptable, if all trains are served on time (according to their time table) and in addition if the 95% of the associated trucks are served within 20 minutes.

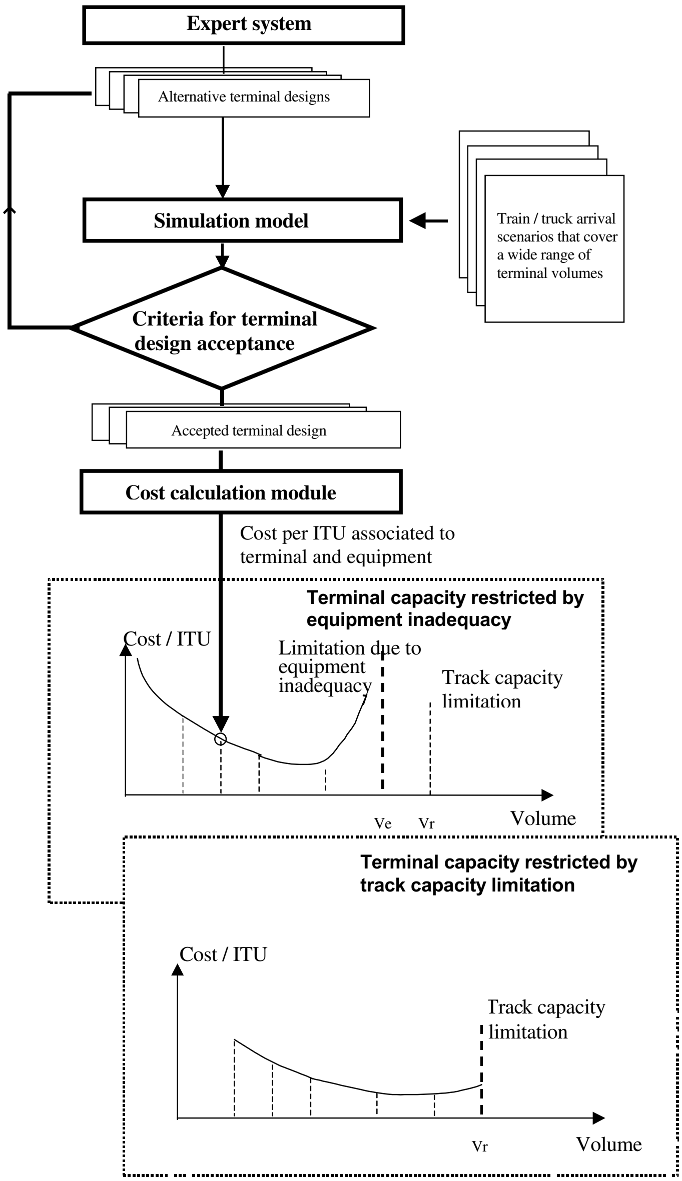

Fig. 3. Method used to produce a typical cost-versus-volume curve.

This criterion agrees with the results of a relevant EC research project [24] and was confirmed by many terminal operators. The elements of the accepted design (area, equipment, personnel etc.) as well as the truck dwell times are "fed" into the cost calculation scheme to produce the "cost per ITU transshipped" for the specific cargo volume, technological solution and operating conditions. The replication of the computational procedure for a series of cargo volumes produces a cost-versus-volume curve associated to a technological solution operating under specific operating conditions.

Two types of cost-versus-volume curves are identified: "U" type curves indicating that the terminal capacity is restricted by the equipment inadequacy and "L" type curves indicating that the terminal capacity is restricted by the capacity limitations of the tracks. It must also be noted that when the terminal capacity is restricted by equipment inadequacy (see relevant case in Fig. 3) the cost/ITU curve presents two asymptotic points: the first at zero volume level and the second at maximum load capacity.

4.4. Terminal investment strategies

A typical intermodal transport chain includes many actors (sender, forwarder, main haulage operator, terminal operator, pre- and post-haulage operator/company etc.). Nevertheless, the present analysis may be considered as having the terminal operator cost as the primary target of the optimisation procedure. However, it is foreseen that the enhancement of the efficiency of the terminals will be swift to the whole transport chain not only as a price per handling reduction but also as an increase of the combined transport share due to the implementation of advanced rail operating forms that could be implemented thanks to the potential of the technological advances at the terminals.

One might expect that a terminal operator aims to operate his terminal at the minimum point of the cost/ITU curve or to a point that maximises the terminal's profit. Nevertheless, the current terminal practice is following other rules. The conflict mainly concerns the terminal (server) which aims at the maximisation of its investment/equipment utilisation while, on the other hand, the trucks (users) request limited service time. This limited service time is interpreted as "new configuration, more handling equipment" or as "new technology, more productive handling equipment". The lower part of Fig. 4 illustrates the cost element associated to the terminal decision that "swifts" from its current technology/configuration into another more suitable for higher volumes technology/configuration when the volume reaches a certain value, say V_1.

The term "technology/configuration" is used hereinafter to describe terminal designs that are based on different equipment technologies or alternatively terminal designs that are enhancing their capabilities by increasing the number of equipment and/or upgrading the terminal configuration (e.g. full modules instead of half modules, more transshipment tracks etc.) or even terminal designs that implement both options.

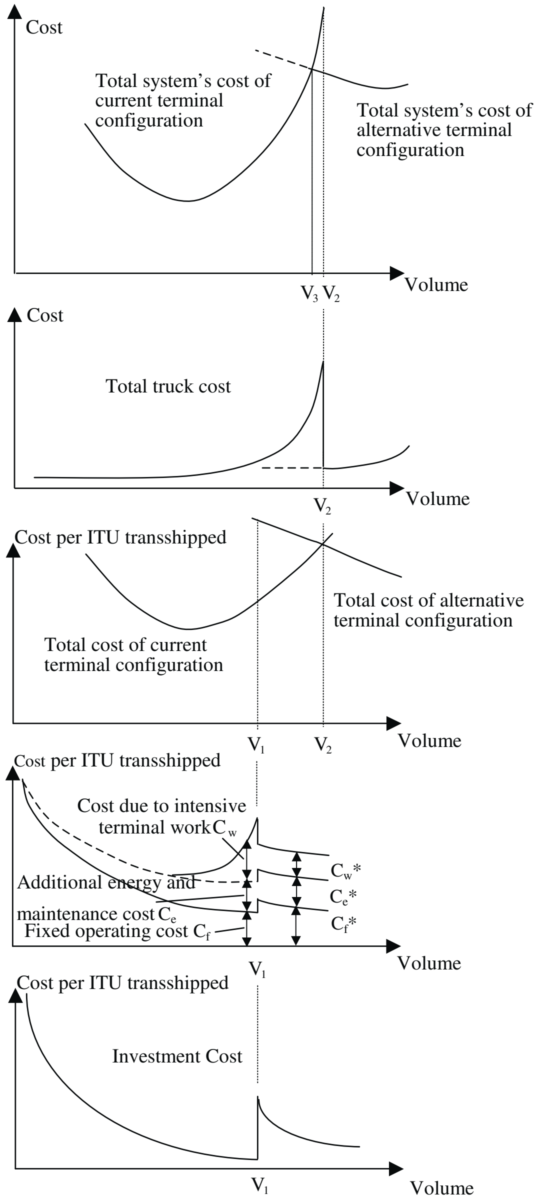

Fig. 4. Cost elements associated to alternative terminal configurations.

When an existing "technology/configuration" is replaced by another (with a higher capacity), various cost alterations occur: The investment cost is usually increased since the technology/configuration that can cope with higher volumes incorporates more expensive equipment and/or more land and civil engineering works.

The operating cost can be increased or decreased depending on the relevant alteration of its three components: fixed operating cost, additional energy and maintenance cost, cost due to intensive terminal work. The fixed operating cost element C_f (minimum personnel, energy for lighting, fixed equipment maintenance etc.) can be increased or decreased according to the degree of automation of the new equipment/configuration.

If the new technology/configuration has the same/similar degree of automation with the existing technology/configuration then the fixed operating cost is expected to be increased due to the additional personnel associated to the increased number of equipment. On the contrary, when the new technology/configuration offers a higher degree of automation, the fixed operating cost is expected to be reduced due to savings in personnel. The additional energy and maintenance cost element Ce concerns mainly the associated variable energy and maintenance costs of the terminal equipment (energy per ITU handling, replacement of ruined parts, tires, increased consumption of lubricants, types etc.). These cost elements are expected to be increased when technologies/configurations capable of handling higher ITU volumes are introduced, since they usually include more and/or fast equipment requiring more energy as well as more maintenance due to more sophisticated devices/control etc.

The cost element associated to intensive terminal work C_w is usually generated when the terminal exceeds its static capacity and therefore trains swap between waiting and transshipment tracks and "clear the train" operations are required, leading to additional manpower ad/or overtimes, indirect ITU handling etc. This cost element is expected to be decreased since the new equipment/configuration posses enchased capabilities that reduce or eliminate the above terminal inefficiencies.

The composition of investment and operating cost into total terminal cost curves for each technology/configuration (see middle graph in Fig. 4) enables the identification of the break-even point at the specific volume (V_2), where the existing technology/configuration should be abandoned in favour of the alternative. Nevertheless, this volume is usually associated to very high truck costs.

If the total system cost (total terminal cost plus truck sub-system cost) is taken into account, the break-even point corresponds to a different volume (V_3). However, this is only of theoretical value, since the cost for new investment/equipment has to be covered solely by the terminal while the benefits are spread to both terminal and trucks (see the upper part of Fig. 4). For the same reason, other reasonable compromises (e.g. the limit of 70–80% for the equipment utilisation "suggested" for some queuing systems) do not lead to agreement between "server" and "users". The power play is mainly defined by the market response. If the trucks are captive to the specific terminal, they have to accept long service times. If, on the contrary, other options exists (e.g. other terminals in the area or transport by road instead of combined transport) the terminal has to offer a high level of service (that includes short service time) to attract the trucks. The experts (interviewed for the purposes of this research) pointed out that there are two reasonable thresholds that could be adapted in the procedure of upgrading the existing conventional terminal configuration: the 250 and the 500 TUEs/day. This rule of thumb was originated from the conventional German and French terminal configurations but it seems that can be also applied for many proposed advanced technologies/configurations.

The perception of the data presented in Fig. 5 reveals that the 250 TEUs/day threshold is imposed by the equipment inadequacy that leads to high terminal and truck costs. The threshold of 500 TEUs/day corresponds to the maximum capacity of the track sub-system. The L type curves of the technical solutions investigated in the 250–500 volume range indicated that the handling equipment has not reached their limits and posses reserved capacity.

It should be noted that the threshold similarly between conventional and advanced systems is due to the fact that the advanced systems take into account the existing rail operating forms and terminal operating conditions.

Table 2 introduces the basic characteristics of the technologies investigated within the framework of this research while Fig. 5 shows the overall outcome of the modelling and cost calculation procedure, namely the cost-versus-volume curves. Each curve is associated to a technological solution and includes infrastructure, equipment, maintenance, energy, personnel and truck waiting time costs. In addition, a "minimum cost envelope" is produced (based on the assumption of a hypothetical terminal that "swaps" between technologies/configurations at the break-even points of the total cost of the alternative systems, indicating also the volume areas where each technology is cost effective. It should be mentioned that apart from the technological solutions investigated in this work, others also exist, but the current research was restricted to technologies for which detailed cost and performance information were available. Nevertheless, the research is currently extended aiming at the investigation of a much wider spectrum of technological solutions [17].

An overview of the curves in Fig. 5 indicates that:

(1) Each design is effective for a certain cargo volume range and is restricted by its capacity limitations. The terminal's capacity limitations are imposed mainly by the capacity limitations of the sidings/transshipment track sub-system rather than by the handling equipment given that there are technical solutions to provide the required support for the handling operations.

(2) Relatively high costs are related as expected to low volumes (irrespectively of the equipment technologies). These costs decrease as volumes increase but an asymptotic trend is observed at the level of 30 Euros per ITU. However, comparison

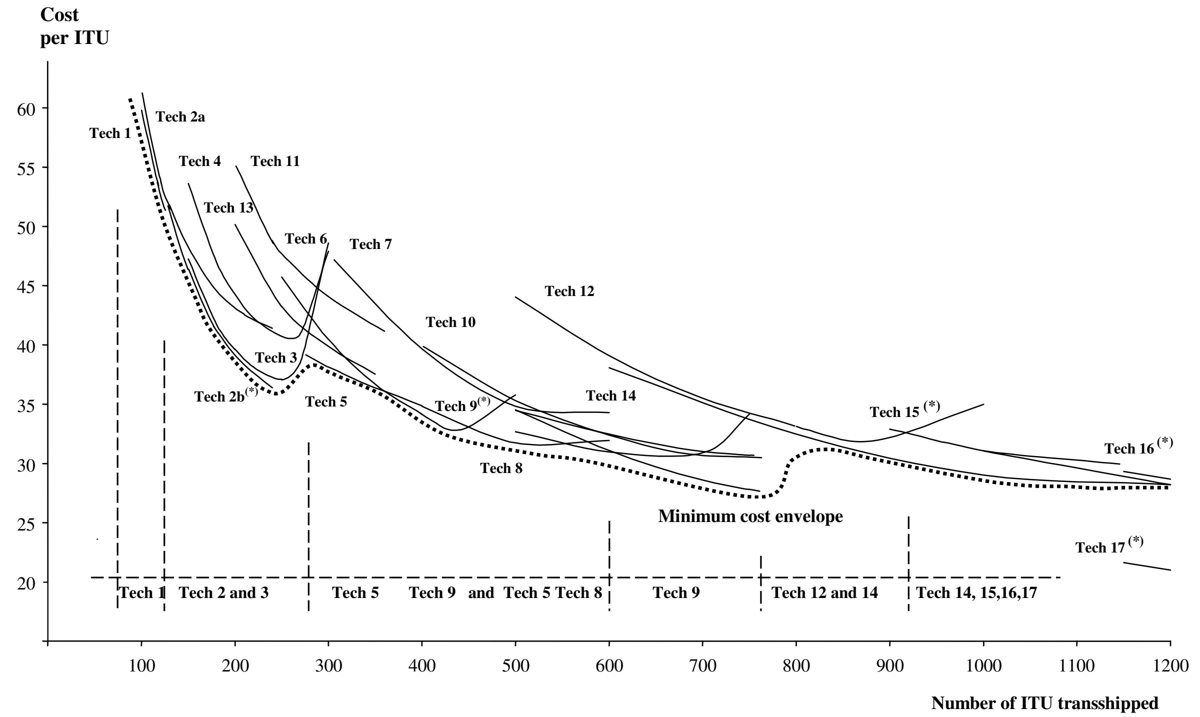

Fig. 5. Pattern of the cost versus volume curves, shape of the minimum cost envelope and efficient ranges for alternative technologies (the asterisk indicates that the equipment configuration requires a truck appointment system).

with a "real life" situation might lead to astonishing results. The calculated cost is about double the "price" accepted by the market. This is explained by the fact that the model takes into account the investment cost that accounts for about 50% of the total terminal cost. This means that under today's pricing system the terminal covers only its operating cost. The infrastructure is considered as "heritage" from the era of the state-owned railways while the expenses for the purchase of the newer equipment, fully or partly covered by state subsidies, represent the social cost that the community pays for the survival of this environmental friendly mode. Nevertheless, it seems that in Europe, the state-subsidy period has reached to an end for the sake of the liberalization."

The importance of the quality of service offered by the combined transport terminals (qualification, security, flexibility for last minute changes, short cut-off time, etc.) is recognized as an important factor associated to the attractiveness of the combined transport. The associated effects are in fact taken into account through the market share functions of the macro-model (see Section 4.5).

4.5. The macro-model

The macro-model was developed to analyse the attractiveness of the multi-modal transport chain on a scale that may range from a multi-regional to a European one. It allows the user to define networks, forms of operation, costs and delay calculation rules, as well as a range of transshipment terminals. Fig. 6 presents the main elements composing the macro-model as well as its relation with the expert system modelling blocks. A freight demand is defined between regions and the model computes the flows carried by each operating form simulated in the model.

The model uses a "geographical data query" developed in the context of a EU research programme [27] that contains the freight demand among the different regions considered. This freight can be accommodated by different modes (including the combined transport) depending on cost, time and quality of service characteristics. The micro-model makes use of market share functions to represent this market behaviour. In the first step, the regions (where an operating system can be implemented) and the corridors between these regions are defined. If more than one terminals exist in a region, the catchment area of each terminal is defined by assuming that a percentage of the containerised cargo of the region, (or even from neighbouring regions), can be dedicated to the selected terminal. In the second step, the (proposed) rail operating forms are "built" using a route specification and taking into account the total flow allocated to the route or the link belonging to the route.

In the last step, the solver procedure tries to determine the optimum flow allocation for the operating forms and the optimum choice of terminal at the transshipment nodes in order to minimise the global operating cost within the constraints of the model. As the costs depend on link flows and the distribution of flows in the network depends on the costs, the model allows for an iterative procedure in which the final flows, should converge with the flows used for the calculation of cost values from the "minimum cost" envelope curve.

The model consists of several interacting components:

- The operating forms module generates itineraries using the networks available with respect to particular operating forms. The operating forms are defined by a set of building rules, a set of minimum running constraints and cost and delay calculation rules. The building rules are used in the generation process. The running constraints are used in the allocation process according to the following principle: if one of the running constraints is not respected, the form is no longer eligible for flow allocation;
- The cost and delay module computes the cost for each itinerary generated by the operating forms module by applying the cost and delay calculation rules for the freight volume of the itinerary. The handling costs for terminal operations depend on the flows allocated to the terminal in question. The terminal costs used by the macro-model are calculated through the "minimum cost envelope" curve. This combination has two important advantages:

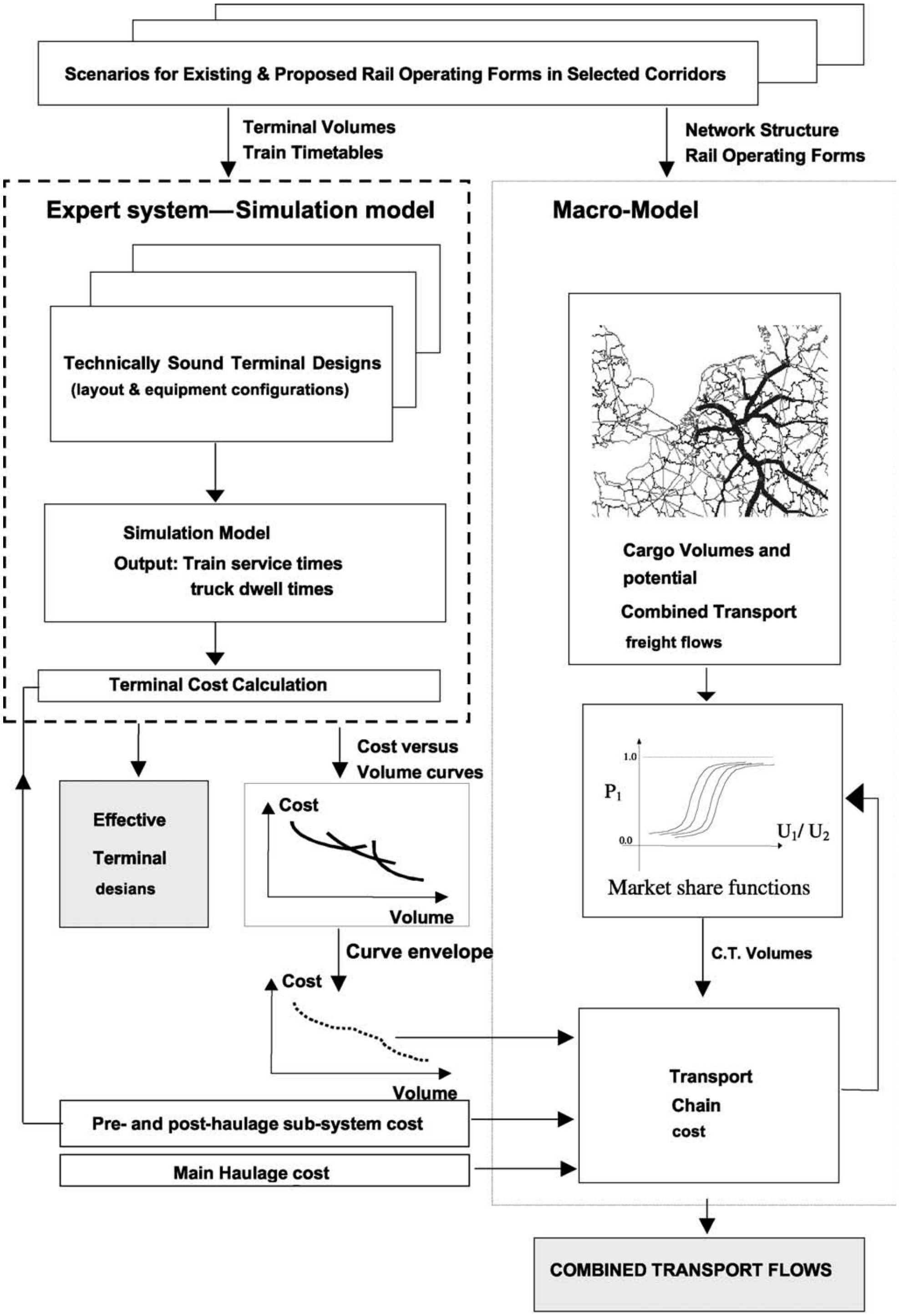

Fig. 6. Global modelling structure.

1. It enables the simultaneous consideration of many terminal-handling technologies.
2. It indicates the network nodes (terminals) where each technological solution is appropriate.

Therefore, the system moves towards its optimum status since each terminal is equipped with the technological solution that gives the minimum cost per ITU transshipped. The accuracy of this optimisation procedure is strongly dependent on the accuracy of the modelling tools as well as on the realism of the relevant cost and cargo flow data. Moreover, it assumes that terminal antagonism on the local/national level (when a national transport chain is considered) as well as on the international level (when—for example—the European transport chain is considered) will not affect significantly the optimum conditions of the whole system. This may be considered unrealistic but the usefulness of the methodology remains, given that it indicates the proper structure and the optimum operation for the whole (national or international) network.

- The allocation module allocates flows to itineraries with the aim of minimising the global transport costs within the applicable operating constraints. A maximum market share value limits flow allocations for the proposed itineraries;
- The market share module is a function estimated and calibrated according to the current market as regards the cost and delay ratio between road transport and the competing intermodal transport. The estimation process allows some qualitative parameters to be taken into account as well.

The accuracy/representativeness of the market share function is very important for the total modelling precision but unfortunately the required level is very difficult to be achieved. For the purposes of this work, three techniques are considered: The random utility approach, a fuzzy logic based approach and finally expert opinions for specific transport corridors and rail/truck price differences. The first two methods can provide scientific background but it is very difficult to be implemented due to two major "difficulties": the lack of adequate traffic volume/cost data and the quantification of the quality-of-service information.

In relation to the above, it is worth mentioning that the cost issue in combined transport has always been a "grey" area. There is no universally accepted cost methodology in the railway sector and very little information is available in relation to the breakdown of operating costs. In many cases the rail prices include large overheads, internal cross-subsidies or are determined according to the highest price that the market can bear. As a sequence, data concerning market share in relation to corresponding cost are scarcely available. Even in the case that such data exist, any market share function should be very carefully developed as it may suffer the disadvantage that it is based on market share and cost values in which cost is not calculated in exactly the same way.

However, relative efforts towards eliminating this kind of disadvantages, have led to the derivation of acceptable market share functions. Such functions were developed in certain cases. During the investigation of the Germany–Italy–Greece corridor [25], an appropriate market share function was developed and used for the analysis of the relevant cargo flows. The function is the outcome of Logit analysis, which is commonly used in transport mode choice. The choice was found to be dependent on the transport cost and the trip time required for each alternative mode available. Market share functions of similar form but with different parameter values reflecting the particularities of each of the combined transport market of each country were developed on the basis of German market data and were used in projects concerning Central Europe [26,27]. These later functions are also used for the needs in a number of case studies (Duisburg–Rotterdam, Duisburg–Hamburg, Duisburg–Frankfurt/Main and Rotterdam–Cologne–Rhine–Basle) where the above presented modelling procedure was implemented.

The quantification of the quality of service information is another issue where no straightforward answers exist. The lower level of service that the combined transport retains in comparison with the road alternative, form a significant "barrier". Various quality criteria have been identified (reliability, flexibility, monitoring, security, convenience, qualification) [14].

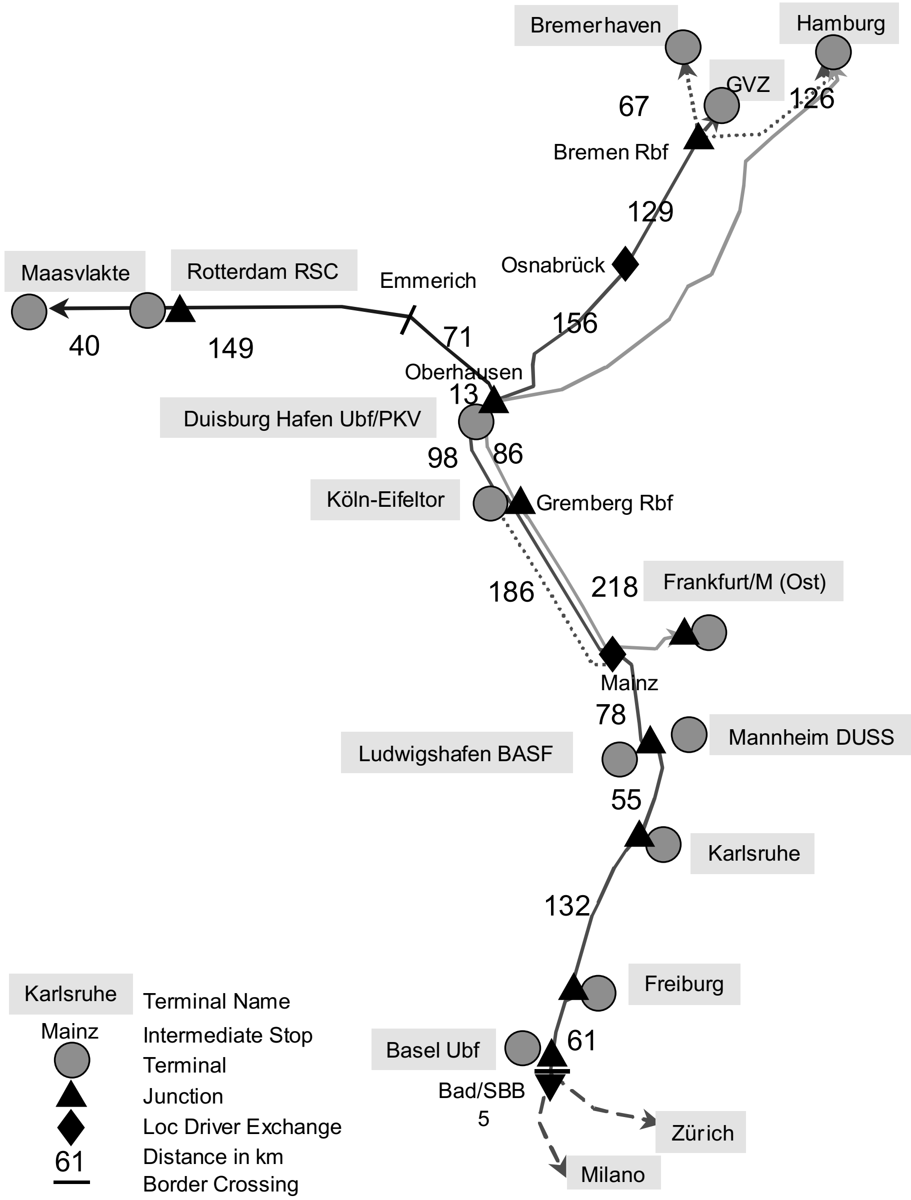

Fig. 7. Case study corridors investigated by use of the micro- and macro-models (*Source* [16]).

According to a study of the mode choice in the freight sector, consignors are switched from road to rail and inland navigation only if the transport cost is 30–50% lower [28,29].

Case studies undertaken in the framework of the IMPULSE Project have shown the potentiality (for short and medium distances) of some advanced handling systems in combination with specific train operation forms. Fig. 7 presents a European corridor where some terminals are assumed to be equipped with an advanced automated handling system and shuttle–shuttle train operating forms are assumed to be in service. The resulted indicated that such a system can be cost effective [16].

5. Conclusions

This work proposes a set of models for the investigation of selected innovative handling technologies and advanced operating forms that could lead to a more efficient operation of the combined terminals and the whole transport chain.

The modelling tool set consists of a micro-model (expert system supported by a simulation module) for the comparative evaluation of alternative terminal designs and finally a macro-model for the investigation of the transport chain. Moreover an analytical model for the pre- and post-haulage subsystem analysis was developed and used.

The analysis of conventional and advanced terminal configurations performed by the micro-model revealed that each design is effective for a certain cargo volume range and is restricted by capacity limitations. These limitations are mainly imposed by the capacity limitations of the sidings/transshipment track sub-system rather than by the handling equipment adequacy. Cost-versus-volume curves were calculated for various conventional and advanced terminal designs and the ''minimum cost'' envelope was formulated.

It was also rather clear that advanced technological solutions should be coupled with ''advanced'' rail operating forms and proper truck booking systems. The effects of the efficient terminal operation in conjunction with advanced rail operating forms can be investigated by use of a macro-model which uses the above mentioned ''minimum cost'' envelope as cost function. This linking technique enables the simultaneous consideration of many terminal-handling technologies while it indicates the terminals where each technological solution is appropriate. Since each terminal is equipped with the technological solution that gives the minimum cost per ITU transshipped the whole system moves towards its optimum status. This approach is strongly depended of the accuracy of the modelling tools and is based on the assumption that terminal antagonism in local/national level as well as in international level will not affect significantly the optimum conditions of the whole system. This may be considered as a rather unrealistic assumption.

However, the proposed methodology remains a useful tool towards establishing the proper structure and ensuring optimum operation for a national or an international—like the common European—network. It is of course clear that the formulation and adoption of a commonly accepted strategy for the combined transport, is a prerequisite for the application of the proper optimisation procedure. Despite today's uncertainty, the adoption of a ''central'' strategy seems to be the ''shape of thinks to come''.

Acknowledgements

The authors acknowledge the valuable contribution of the two anonymous reviewers for their comments and suggestions.

References

[1] European Commission, Directorate General for Energy and Transport, COST 328 Integrated Strategic Transport Infrastructure Network in Europe, Final Report, 1998, ISBN 92-828-4573-7.
[2] European Commission, Market of Intermodal Transport, IMPULSE project documentation, Deliverable D2, 1997.
[3] R.A. Staley, Land use constrains in locating intermodal terminals, Transportation Research Record 907 (1983) 1–4.
[4] A Ballis, Advanced Intermodal Terminals, Final Conference IMPULSEs for Intermodal Freight Transport, Brussels, Belgium, 1999.
[5] H. Lacey, The interrelationship of terminal design and equipment selection. ICHCA-USA Intermodal Containerization and Marine Terminal Development Conference, New York, USA, 1980.
[6] H. Erwin, Analysis and comparison of rail and road Intermodal freight terminals that employ different handling techniques, Transportation Research Record 907 (1983) 8–13.
[7] T. Derry, Straddle carriers vs rubber-tyred gantry, in: J. Immer (Ed.), Cargo Handling, Work Saving International, Washington, 1984, pp. 287–294.
[8] L. Ferreira, J. Sigut, Measuring the performances of intermodal freight terminals, Transportation Planning and Technology 17 (3) (1993) 269–280.
[9] SNCF Etude d'Analyse de la valeur sur le project de terminal de transport combiné de Vaires. Rapport de results, 1998.
[10] M. Taleb-Ibrahimi, B. De Castilho, C.F. Daganzo, Storage space vs. handling work in container terminals, Transportation Research 27B (1) (1993) 13–32.

[11] L. Ferreira, J. Sigut, Modelling intermodal freight terminal operations, Road and Transport Research 4 (4) (1995) 4–15.
[12] J. Woxenius, Inventory of transshipment technologies in Intermodal transport. Report for International Road Transport Union IRU, Geneva, 1997.
[13] European Commission—DG VII, Future optimum terminals for intermodal transport Doc. SIMET Project, Euret/411/95, Brussels, 1995.
[14] European Commission—DG Transport, market of intermodal transport, Deliverable D2.IMPULSE Research Project, Brussels, 1997.
[15] European Commission—DG Transport, New generation terminal and terminal-node concepts in Europe, Deliverable D2, TERMINET project, Brussels, 1997.
[16] European Commission—DG Transport, Cost effectiveness of intermodal transport, Deliverable D13/14, IMPULSE Research Project, Brussels, 1999.
[17] European Commission, DG-TREN, State of the art of conventional and innovative techniques in Intermodal transport, Innovative Technologies for Inter-modal Transfer Points (ITIP) project, Deliverable D1, 2000.
[18] N. Krishnamurthy, R. Batta, M. Karwan, Developing conflict-free routes for automated guided vehicles, Operations Research 41 (6) (1993) 1077–1089.
[19] N. Bostel, P. Dejax, Models and algorithms for container allocation problems on trains in a rapid transshipment shunting yard, Transportation Science 32 (4) (1998) 370–379.
[20] P. Boese, Applications of computer model techniques for railroad intermodal terminal configuration, equipment and operational planning, Transportation Research Record 907 (1983) 45–52.
[21] K.-U. Sondermann, A. Ballis, Intermodal pilot plants underlying logistic systems in Europe, 2nd EUROSIL Workshop, Athens, Greece, 1999.
[22] C.Abacoumkin, A. Ballis, Development of an expert system for the evaluation of new technologies in the combined transport area, 13th Conference of the Hellenic Research Society, Piraeus, Greece, 2000.
[23] A. Ballis, J. Golias, Comparative evaluation of existing and innovative rail-road transport terminals, Transportation Research Part A 36 (2002) 593–611.
[24] A. Ballis, J. Golias, C. Abacoumkin, A comparison between conventional and advanced handling systems for low volume container maritime terminals, Maritime Policy and Management 24 (1) (1997) 73–92.
[25] J. Golias, G. Yannis, Determinants of combined transport market share, Transport Logistics 1 (4) (1998) 251–264.
[26] R. Happel, Macro-Model Development, Dornier Deutsche Aerospace, 1993.
[27] C.E.C Directorate General for Transport, Impact de l' organization du trafic et des nouvelles technologies de transbordements sur le transport combiné en Europe, Doc.Euret/407/94, 1994.
[28] NEI, NEA, Vervoerwijzekeuze in het goederenvervoer, Rotterdam, Rijswijk, NEI, NEA, 1990.
[29] C. Bagchus, R.B. Kuipers, Autostrada del mare, European Shortsea Shipping, First European Research Roundtable Conference on Shortsea Shipping, Lloyd's of London Press LTD, 1992, pp. 52–65.