Computer-controlled freight platforms for a time-tabled rail transport system
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1 PARTNERSHIP

The PLATFORM consortium, co-ordinated by IT Ingegneria dei Trasporti (ITR), is organised in a scientific committee, and an advisory board. The first is composed of the main partners, DFKI, ETRA, FIT and IDSIA, the second of ADL, CEMAT, CONTSHIP, DSP, ESL and NOVATRANS.

1.1 Co-ordinator

IT Ingegneria dei Transport SRL is a Rome-based transport consultancy founded in 1993. It specialises in transport system studies, transport planning, feasibility studies, models, planning of public transport networks, investigations of vehicle flows, and professional training. IT has participated as partner, subcontractor, and consultant in a number of European Commission transport research projects. The firm also develops software, and provides training, for a wide range of transport applications and is the only authorised reseller in Italy of the programs TransCAD® and MAPTITUDE® for transport models.

The five partners and several regular consultants are nearly all transport engineers, with the remainder architects or other experts. IT. maintains close ties with the departments of transport of the universities of Rome (DITS) and Perugia, and most members of the group have worked on European research projects as DITS contractors. All technical reports are edited, designed and produced in-house in English or Italian.

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1.2 Scientific Committee

DFKI

Founded in 1988, DFKI today is one of the largest non-profit contract research institutes in the field of innovative software technology based on Artificial Intelligence (AI) methods. DFKI is focusing on the complete cycle of innovation,
from world-class basic research and technology development through leading-edge demonstrators and prototypes to product functions and commercialisation. Based in Kaiserslautern and Saarbrücken, the German Research Center for Artificial Intelligence ranks among the important Centers of Excellence worldwide. An important element of DFKI’s mission is to move innovations as quickly as possible from the lab into the marketplace. Only by maintaining research projects at the forefront of science can DFKI have the strength to meet its technology transfer goals.

Within the five research departments in which DFKI is organised the one collaborating in the PLATFORM project is **Deduction and Multiagent Systems** (Director: Prof. Dr. Jörg Siekmann).

The Multiagent Systems Group in the department of Prof. Dr. Jörg Siekmann was established in 1991. The group has carried out fundamental research in the field of Distributed Artificial Intelligence and has applied the resulting ideas to many areas including transportation, finance, enterprise resource planning, electronic commerce and the control of synthetic characters in virtual worlds.

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**ETRA I + D**  
ETRA Investigación y Desarrollo, S.A. (ETRA I+D) is the hi-tech unit within ETRA Group, one of the leading industrial groups in Spain. Its mission is putting in the market the most advanced solutions and services either directly or through the 10 companies of the Group. The main market areas of ETRA Group are Spain, south central America, Southeast and the EU. The activity of the company started in the 1970s and it is centred in four main activity lines. The first line of activity - which was initially the dominant one - is urban and interurban traffic control; the second line of activity is transport, mainly fleet management. In 1982 the company launched its main product in this area: the S.A.E (AVL and Operation Aid System). The third main activity-line is related to public lighting systems and energy control, an area where, again, ETRA has achieved the market leadership. A new activity line is currently looking for new solutions to adapt and integrate the company’s existing and new products within the Information Society framework. New Technologies. The RTD mechanisms enabled by the Commission's Framework programmes are central to the innovation strategy of ETRA I+D. In fact, the company has participated in more than 20 EU projects since 1988, in the scope of the FP III and IV. The projects carried out fell mainly within DRIVE, ESPRIT, Transport Telematics, Value and DGVII Transport.
Research Programmes. The technologies addressed have included: computer vision, simulation, electronic information exchange, intelligent agents, artificial intelligence, dynamic scheduling, web technologies, software engineering methodologies, fault tolerance, advance modelling methodologies, etc.

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IDSIA  
IDSIA, Istituto Dalle Molle di Studi sull'Intelligenza Artificiale, was founded in 1988 to conduct basic AI research and to contribute to the advancement of the scientific and technological culture of the Italian-speaking Switzerland. On January 1st, 2000, IDSIA will become an Institute of the Swiss Italian University. Since its birth IDSIA has produced several publications in books, journals, and conference proceedings. Business Week Magazine ranked IDSIA among the world's top ten labs in Artificial Intelligence. IDSIA staff is around twenty people and comprises research directors, full time senior researchers, Ph.D. students, and a number of master thesis students.

The main research activities of the institute are: (i) the study of different metaheuristic approaches to solve combinatorial optimisation problems, (ii) basic and applied research on modelling, simulation and optimisation of transport systems, (iii) the development of learning algorithms that focus on collective behaviour and lifelong learning, and (iv) the development of neural network algorithms for generalisation starting from small training sets, based on information theory, statistics and complexity theory, applied to forecasting and image recognition.

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FIT  
Fit Consulting S.r.l. starts up in 1997 with a group of financial, investments and transport experts intending to introduce themselves to the market as a young and dynamic company, endowed with professionalism and seriousness. It guarantees then an effective service, by using the most advanced forms of service production

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and management. Therefore the aim is to offer the clients (SME and major enterprises, public and private bodies) professional specialised consultancy services in several fields.

The staff is entirely composed of personnel with qualifications in the specific intervention areas; particular attention is paid to constant contact and collaboration with academic and research institutions, so that it guarantees the correspondence between our services and the latest emerging qualitative standards.

With regards to the Transport Area, the company avails itself of its manager’s many years’ time experience gained as co-ordinator and expert of more than 40 national research and development projects and more than 15 ECC Pan-European projects. Because of the activities it has carried on FIT Consulting is able to enjoy a European network of companies which are specialised in the same sector, providing consultancy services at every different research level, with a group of young and dynamic experts.

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1.3 Advisory Board

The PLATFORM Advisory Board consisted of representatives of eight operators, or their associations, likely to use the project’s outcomes; they came from Italy (CEMAT, CONTSHIP), France (ESL, NOVATRANS), Spain (ADL) and Switzerland (DSP). The board was kept informed about the project’s achievements early enough to provide feedback to the consortium on their opinions, attitudes, needs and aspirations. Its representatives have been invited to the project’s meetings and dissemination events with adequate prior information to allow them to present and discuss their contributions systematically and thoroughly.

They have co-operated in the project also as peer reviewers of the documents produced during the project lifetime. This ensured internal quality control and provides high-level scientific and/or practical advice where required.
2 EXECUTIVE SUMMARY

The PLATFORM project addressed task 3.2/7, “Terminal control”, of the ITC work programme, 3rd Call for Proposals of the Transport Research Programme, Directorate General VII of the European Union. The project, with an initial duration of 18 months, later extended to 21 months, has implemented a simulation environment for the assessment of impacts produced by the adoption of different technologies and management policies to enhance freight intermodal terminal performances. The simulation environment can be used to analyse how to make combined transport competitive for long and even medium distance and thus lead to a substantial reduction of road-based transport.

The approach has been divided into three main phases:

- analyse operators’ requirements and produce guidelines for the implementation of the PLATFORM integrated simulation environment;
- design and implement the integrated simulation environment;
- validate the integrated simulation environment on the basis of data gathered from a real test terminal, and define a standard methodology for the evaluation of the simulation results.

This is the final report prepared for DG VII, summarising the entire project and its achievements.

The participants in the work which led to this report are:

- C. Epifani, A. Alessandrin (ITR);
- H. J. Bürcckert, P. Funk, G. Vierke (DFKI);
- R. Ferri, R. Font (ETRA I+D);

Experts from the operators represented in the Advisory Board contributed to the definition of the framework of the state of the art in intermodal terminals and to the identification of the users’ requirements.

The following elements were highlighted during the first phase of the project.

At present intermodal terminals are generally managed without the help of computer applications and information technologies: the terminal management highly depends on the policies adopted, peculiar of each terminal, which are
applied manually by the managers on the basis of their experience. However, in many cases there is no need of special co-ordination between the actors of the terminal, because they have sufficient resources in terms of tracks, equipment, human resources, etc.

The growth of freight transport shows an high trend for the short and medium term which cannot be met by the existing infrastructures and managing tools.

The European Intermodal Association established the working group Chantier Terminaux, which set the minimum requirements for the intermodal terminals of the future. These standards are the minimum dimensions of a terminal able to guarantee a sufficient traffic concentration and an independent economic management using the presently available techniques.

In any case Terminal operators prefer to introduce new management methodologies based on information technologies better than investing in new equipment or enlarging the area of the terminals.

The new freight transport concepts are strictly linked to the use of telematics for the management of deliveries and in the intensive use of automated and computerised means for treatment, sorting, storage and drawing of freight.

As a summary, a computer-controlled freight terminal should have the following features:

- fast loading/unloading devices;
- computer-aided positioning of the terminal equipment to optimise transfers and on-board devices to receive transfer instructions;
- intelligent gate procedures and automated guidance of trucks to reserved loading places;
- computer-based booking and dispatch systems for the reservation of transport capacity and for the allocations of loading time and position;
- telematic systems for terminal-to-truck and truck-to-terminal communication, which allows for automated booking and cancelling;
- electronic devices to automatically locate and register the ITU position in the yard (hand-held PCs used by crane operators and terminal managers).
- computer-aided yard allocation policies.

Since interventions on intermodal terminals involve large investments, it is necessary to develop in-depth feasibility studies to avoid useless money expenses. To give an answer to this problem, PLATFORM has implemented a simulation environment, for the assessment of the impacts produced by the adoption of different technologies and management policies to enhance intermodal terminal performances, and defined an evaluation methodology.

The architecture of the environment is based on the classification of simulation
objects as agents (terminal agents, forwarding agents, etc.) and components (yard areas in the terminal, the road and rail networks, etc).

Decision makers (simulation agents) and infrastructures (simulation components) are modelled as objects which store and exchange information on terminal inputs, states and outputs and perform actions according to their local behaviour. There is not a unique supervising agent which controls the whole simulation, but the simulation is the result of the interaction among the agents, each one equipped with local knowledge on its actions in response to the behaviour of other agents.

The PLATFORM simulation environment consists of two subsystems which simulate the intermodal transport task (ITT) of each intermodal transport unit (ITU) in an intermodal corridor:

- the intermodal transport planner, which operates the planning of the whole ITT for each ITU;
- the intermodal transport simulator, which operates the execution of the ITT for each ITU, including internal terminal operations.

The intermodal transport planner is based on three elements:

- the intermodal planning and execution units, planning the whole ITT of the ITU;
- the forwarding agents, planning and booking the ITU journey by truck;
- the booking agent, planning and booking the ITU journey by train.

The intermodal transport simulator is also based on three elements:

- the road simulation module, simulating the trip legs by truck provided by the forwarding agents;
- the terminal simulation module, simulating the loading/unloading of ITUs between trucks and trains as well as storing of ITUs in the intermodal terminal;
- the corridor simulation module, simulating the flow of trains between terminals.

A graphical user interface allows for customising the simulation, for selecting the important parameters, views and maps, and for inspection of the input and output data of the simulation.

The PLATFORM evaluation methodology has been applied to the outputs supplied by the simulation of different scenarios of development in intermodal terminals: it can be properly regarded as a before-after appraisal: it is applied to the choice among alternative scenarios of development, a typical situation for the before procedures, and is also run on simulation outputs considered as measurements, which is typical of the after procedures.

PLATFORM, with its evaluation methodology, is mainly addressed to terminal
managers, forwarders, rail operators and authorities. The first three categories are commercial operators whose main goal is to increase their profits while minimising costs: the best evaluation technique for their exigencies is the *Cost-Benefit Analysis* based on the evaluation of the *Net Present Value*. Authorities are mainly concerned with community welfare and other non-monetary impacts, therefore the most suitable technique is *Multi-Criteria Analysis*: the procedure chosen for PLATFORM is one of the simplest available methods which descend directly from the so-called *Conjunctive Model*.

Depending on the preferences expressed by intermodal operators throughout Europe, the increase in the productivity of their terminals will be investigated in tandem with project scenarios to be compared with the do-nothing scenario, each containing the scenarios of the previous levels:

- present situation;
- adoption of computer-aided management;
- adoption of new transhipment equipment.

The CEMAT terminal of Verona, Quadrante Europa, has been used as the test site. It has been described and simulated applying to it the three scenarios defined in Deliverable 5a: present situation, adoption of computer-aided management and adoption of new transhipment technologies.

The first simulation scenario, the reconstruction of the present situation, is used for calibration. The results of this first simulation are compared with those measured by CEMAT during the surveys carried on in the IQ project. The adjacency of the simulation results to the measured data validated the simulator.

The second scenario is simulated applying to the present state of the Verona terminal the intermodal transport planner; simulating the adoption of a computer-aided management. This scenario is evaluated with the PLATFORM methodology applying Cost-Benefit Analysis for three actors (terminal manager, rail operator and forwarder) and the Conjunctive method (a Multicriteria) for the Authorities.

The “adoption of new transhipment technologies”, the third scenario, is reproduced with the terminal simulator increasing the performances of the transhipment equipment. The features of the simulator are used to compare this scenario with the do-nothing one.

It is shown that the adoption of faster transhipment devices is not useful if it is not supported by the adoption of computer-aided management and that the adoption of these last systems is cost-effective for every actor in the chain.

The CBAs and MCA highlighted a high convenience for every actor involved in the chain in adopting computer-aided management. The only foreseen limitation to the effectiveness of such a policy, albeit not negligible, is the necessity of a coral adoption of the necessary devices by every single forwarder and every terminal to make the system working.
It emerges clearly that the path to follow for the improvement of the intermodal transport passes through the adoption of computer-aided management to create truly integrated “computer-controlled freight platforms”.

PLATFORM itself represents a first step in this direction since the tools developed can be used as off-line instruments by lower and medium level management to analyse and evaluate different policies.

The entire PLATFORM environment can help the high-level management and the decision makers of the intermodal transport chain to evaluate high-level policies aimed at improving the intermodal transport.

PLATFORM is already working as an off-line tool but in the next future it is possible to develop on that base a terminal oriented on-line tool able to chose in every situation the optimal management policy, to drive the operations and to communicate with the trucks arriving to pick-up or delivery ITUs.
3 OBJECTIVES OF THE PROJECT

Freight transport in Europe has sharply increased in the last decade and is expected to increase in the near future. Increasing congestion, environmental problems and social impact of pure road transport makes intermodal transport play an important role in the development of the European countries.

“The efficiency of Europe’s transportation system has become severely strained. A major reason for this is an imbalance in the use of transport services. The reliance on road transport, where shippers are able to benefit from low-priced, high-quality services should particularly be mentioned in this respect. In the period 1970–1995, inland freight transport in the European Union doubled. In 1970 road transport accounted for 50% of the carriage of total inland freight. In 1995, this share had already increased to 73%. A further increase is forecasted … The increase of road transport in the EU has led to considerable congestion problems which are estimated to cost a total of 120 BECU per annum or approximately 2% of the Union’s GDP. Over the past few years, awareness has grown that transport is a component of logistics organisation and that modal choice is determined by supply chain requirements.” [59]

Most of the European transport companies are small or medium-sized enterprises widely focusing on road transportation. They are working in a highly competitive framework, made more acute by the low-cost competitors from Eastern Europe during the last years. Rail transportation is yet too much inefficient, in order to be competitive, at least for distances below 700 km.

“The growing demand for the transport of people and goods in Europe presents transport users, operators and public authorities with increasing problems, notably concerning cost-effectiveness, congestion and environmental impact. Whereas, in the past, we have tended to think about specific modes of transport — road, rail, air and waterborne — there is now growing recognition that sustainable mobility is about inter-connecting transport systems which have to provide a door-to-door service. This is what I call intermodality.” [60]

Intermodal terminals are the added-value elements of this mode of transport, whose overall efficiency is in close relation with the productivity of these transport centres.

The PLATFORM project addresses task 3.2/7, “Terminal control”, of the ITC work programme, 3rd Call for Proposals of the Transport Research Programme, Directorate General VII of the European Union. The project has implemented a simulation environment for the assessment of impacts produced by the adoption
of different technologies and management policies to enhance freight intermodal terminal performances.

PLATFORM’s main objective was to implement a more cost-effective way to manage freight-traffic flows through the enhancement of terminal management and the integration of existing telematic systems.

The PLATFORM approach addressed rail–road terminals for rail–road transfer based on a computerised control and management system. A smooth organisation for pre-haulage and end-haulage, as well as the completely computerised management of terminal services, has been demonstrated through computer simulation of the transport flow (modelling input and output streams of both rail and road) and the terminal services. The system for the management of integrated rail–road transport has been developed and tested in selected demo terminals on a corridor available to Consortium member.
4 MEANS USED TO ACHIEVE THE OBJECTIVES

PLATFORM approach has been divided into three main phases:

- analyse operators' requirements and produce guidelines for the implementation of the PLATFORM integrated simulation environment;
- design and implement the integrated simulation environment;
- validate the integrated simulation environment on the basis of data gathered from a real test terminal, and define a standard methodology for the evaluation of the simulation results.

4.1 The market requirements

A properly functioning freight transport system is one of the most important conditions for the efficiency of trade and industry. The increase in road traffic has created a situation in our streets that threatens the proper functioning of the transport system and the entire economic traffic. Therefore measures are urgently needed to ensure the full operation of transport services and to reduce the environmental impact of motor vehicles.

The traditional policy for the organisation of intermodal transport at regional level aimed to ease the construction of terminals for medium- and long-distance services and the localisation of storage and distribution centres in the peripheral areas of urban agglomerates.

At present the reorganisation of the intermodal transport requires the design of a network of logistic platforms, based on a hierarchical structure and on functional connections between main centres and satellite centres (hub and spoke). The system should take into account the requirements of, on the one hand, the medium- and long-distance traffic and, on the other, the urban and regional traffic.

The urban and regional commercial traffic is mainly carried out by single operators, who are able to achieve only small improvements by using operational logistics. This one-dimensional logistics allows each operator to establish a system of vehicle scheduling for point-to-point circuits and to reduce operational expenditures on a company basis. The problems arising in these systems result in a high share of dead kilometreage that can be reduced only by collecting new freight on the delivering route.

A first improvement can be achieved through the local co-operation among
operators: they can remain independent contractors while a central organisation is responsible for logistics. Freight demand can be served better by the concept of *two-dimensional logistics*: the share of road dead kilometrage can be reduced, without losing market shares, and the capacity of the vehicles will be better used, especially if delivery and collection are combined.

The concept of *three-dimensional logistics* is more successful in the regional context: this can be seen as the basic pattern of regional freight traffic, which will form the core of the overall system based on integrated logistic platforms. This concept aims at an optimal freight delivery and collection system based on different terminals as logistic centres. As there will be traffic among the terminals also, the entire system must be optimised.

The *four-dimensional logistics* is related to a complete co-ordination of freight transport. Point of transhipment is the dominant logistic platform. Direct trains (trailer trains) will operate between all logistic platforms. The logistic PLATFORM organises and carries out the transhipment including a possible short-time storage (buffer) as well as the regional delivery and collection. Such an organisation needs close co-operation of all operators within the freight centre.

Consequently the ideal case of freight transport can be outlined as in figure 4.1:

- Urban and regional freight distribution and collection is based on logistics platforms, which must be located where they will best serve the area to be supplied.

- These logistic platforms will serve as points of transhipment between short- and long-distance haulage, and between road and railway traffic; if
there is any link to the railway system, the transport between logistic platforms should use the railway.

The share of the railways, especially in urban areas where many railway links still exist, could rise in the future, if new technologies are developed to avoid the expensive and time-consuming formation of conventional trains.

Costs and frequency of the intermodal services are the two main variables to be considered from the customer perspective. They are related to distance and volume.

Figure 4.2 illustrates the relationship between costs and distance, in comparison with road transport. The curve for road-only transport begins a little later, since the distance for this mode of transport is always shorter. The line for combined transport includes trucking to the terminal, loading, combined transport, unloading and trucking to the customer. For distances beyond the break-even point (A) combined transport is more profitable.

Also the frequency of service depends on distance. For combined transport distances up to 250 km should be served every day, up to 700 km three times a week, up to 1200 km two times a week, beyond 1200 km once per week may suffice. It must be underlined that also suitable arrival times are important.

![Figure 4.2. Costs of intermodal transport and road-only transport with respect to travel distance](image)
The possibility of operating shuttles depends on the volume: a minimum of 20,000 ITUs, more or less, per year are needed to operate such a service. The consequence is that terminals must generate and attract enough cargo in order to achieve balanced freight flows.

The new freight transport concepts are linked to the use of telematics for the management of deliveries, to the centralisation and hierarchic organisation of the logistic platforms (hub and spoke) and in the intensive use of automated and computerised means for treatment, sorting, storage and drawing of freight.
The friction costs, which the intermodal terminal operators are facing as a result of the interaction of rail and road transport, could be reduced by smooth integration and fully computerised organisation of the terminal and feeder services with telematic system and Artificial Intelligence technologies.

The basic scheme of the physical infrastructures required by a computer-controlled freight terminal is illustrated in figure 4.3:

- fast loading/unloading devices;
- computer-aided positioning of the terminal equipment to optimise transfers and on-board devices to receive transfer instructions;
- intelligent gate procedures and automated guidance of trucks to reserved loading places;
- computer-based booking and dispatch systems for the reservation of transport capacity and for the allocation of loading time and position;
- telematic systems for terminal-to-truck communication, which allows for automated booking and cancelling;
- computer-aided yard allocation policies.

The loading/unloading systems impose planning and scheduling requirements for the arrival of trucks and trains. Therefore the terminal has to control the time of arrival of the trucks, the time of arrival of the trains, the exact position of the load in the yard or on the transport networks and the identification of the ITUs. In addition, a tool for dynamic rescheduling of trucks and reallocation of ITUs on the trains is required.

Communication facilities between trucks and the control centre should be considered in order to plan the loading/unloading of trains and the efficient use of equipment and space. The control centre should be able to exchange messages with the truck drivers.

It would be desirable that the system be available on a network accessible to the gate system and the control centre as well as to the clients and the forwarding companies. It is important that these systems exploit the characteristics supported by the Internet and offer their services through this means.

### 4.2 The simulation environment

An intermodal transport along an intermodal corridor, from the origin to the destination via intermodal terminals, can be divided into three legs (figure 4.4).

The *initial leg* describes the trip from the customer to the starting intermodal terminal by truck. This leg is managed by a dispatching company.

The second leg, the transport from terminal to terminal by train, which is called the *main leg*, is managed by the intermodal terminals.
The third and final leg by truck, the transport from the ending terminal to the receiver, is again managed by a dispatching company.

A typical intermodal transport, like the one described above, takes place on a network, characterised by rail and road links and a number of intermodal terminals.

Several negotiation and planning activities are involved (figure 4.5). The negotiation chain is triggered by a customer (C1) requesting the transport of an ITU from C1-town to C2-town. This transport will be an intermodal transport.

C1 announces the order in an order negotiation protocol, which is an instance of the Contract Net Protocol (CNP). Usually in a CNP, the manager can announce the order to several partners in order to get the best bid; this possibility is indicated by the other (greyed) recipients of the order. For the sake of simplicity, attention will be focused on one of these partners only, namely forwarder F1.

In order to plan the intermodal transport, F1 has first to find out the train connection. Since trains have more or less fixed scheduling, the main leg is a fixed part of the trip, constraining the initial and the final leg. Both of these parts of the intermodal transport offer more flexibility, since the transportation is managed by truck.

For the main leg, F1 contacts the booking agent at the nearest intermodal terminal. This contact is a nested CNP, within the main leg negotiation. In order to initiate the negotiation, the forwarder needs to extract the relevant information from the given order. It creates a main leg order, which contains:

- ITU data, such as type, weight, size, wagon requirements, etc.;
- main leg destination; F1 needs the corridor; in particular it needs to know that a trip from C1-town to C2-town will require an intermodal transport (truck-train-truck) via IT1 and IT2;
Figure 4.5. The intermodal transport planning phase

- earliest arrival time at the terminal gate; this time will be calculated using some kind of heuristics or looked up in a distance table; since it is still the negotiation phase and a plan is not yet available for the transport, the forwarder needs to use an estimated time;

- desired pick-up time at the main leg destination; again, this time has to be estimated by the forwarder.

This order is conveyed to the intermodal terminal. Again, the recipients of the order could be more than one terminal, if there are different intermodal transport routes possible. From now on the attention will be focused on one terminal agent only (IT1).
The terminal agent of IT1 tries to find a train suiting the desired time constraints as well as the requirements for the ITU type. If it finds a train, which still has a free ITU specific wagon type, it reserves this and communicates the respective time information back to F1 in a main leg plan.

With this main leg plan F1 can now initiate the planning of the initial and the final leg. For the initial leg it conveys a specific order to its fleet, the initial leg order, which contains the arrival time at the terminal gate; internal negotiation will result in the initial leg plan. For the final leg plan, F1 extracts a final leg order and conveys it to forwarders at C2-town, may be working in close co-operation with F1. Here again, only one forwarder is considered, even though the CNP used in this negotiation allows for more contractors.

If all the legs of the intermodal transport have been successfully planned, F1 announces the pick-up time for the ITU in question to C1.

The PLATFORM simulation environment consists of two subsystems which simulate the transport of each ITU in an intermodal corridor: the intermodal transport planner (ITP), which operates the planning of the whole intermodal transport task (ITT) for an ITU, and the intermodal transport simulator (ITS), which operates the execution of the ITT for each ITU, including internal terminal operations.

The ITP is based on three elements:

- the intermodal planning and execution units (IPnEUs);
- the forwarding agents;
- the booking agent.

The IPnEUs plan the whole ITT, splitting it into its three legs. They contact the specialised agents for planning and booking of these legs.

The forwarding agents execute the planning and booking of the ITU journey by truck: these agents are responsible for the planning of delivery to and pick-up from terminals. Each forwarder is modelled through a forwarding agent. At each terminal a road network area broker agent co-ordinates the planning of the forwarding agents of the area around the terminal. All these agents are realised by instances of the TELETUCK system.

The booking agent execute the planning and booking of the ITU journey by train. This agent is asked for free capacity at the time-scheduled trains. A booking solver checks which bookings are possible. The booking agent chooses the best solution and makes the reservation.

The ITS is based on three elements:

- road simulation module (RSM);
- terminal simulation module (TSM);
The RSM simulates the trip legs provided by forwarders, i.e. the transport of the ITU by truck. According to the schedules for delivery and pick-up of the ITUs at the two terminals, the flow of trucks between each terminal and the customers at its local region is simulated.

The TSM simulates loading and unloading of ITUs between trucks and trains as well as storing of ITUs in the intermodal terminal. Equipment, platforms, yard areas and gate procedures are simulated in order to demonstrate the functionality of the terminal and potential for improvement.

The CSM simulates the flow of trains between terminals. According to the timetables, flow of trains from and to the terminals is simulated focusing especially the train flow within the chosen corridor.

A graphical user interface (GUI) allows for customising the simulation, for selecting the important parameters, views and maps, and for inspection of the input and output data of the simulation.

In the following sections the GUI, the ITS, the ITP and the interaction among them are described in more detail. Distinguished parts of the source code are given in appendix together with a user manual for the simulators. A demonstrator prototype of PLATFORM will be available on CD-ROM and on the PLATFORM web site for non-commercial usage only. It will be also used for demonstrations and for scenario evaluations to be reported in the final project deliverable. A commercial system could be developed for interested parties.

4.3 The evaluation methodology

The evaluation techniques belong to two different categories: monetary and non-monetary methods. Monetary methods can be used when the impacts of different alternatives can be, for the greater part, expressed in monetary terms. Non-monetary methods must be used when it is required to simultaneously assess technical, socio-economic, environmental and other impacts not directly expressible in monetary terms.

The four most used techniques are the following:

- Cost-Benefit Analysis (CBA);
- Cost Effectiveness Analysis (CEA);
- Multi-Criteria Analysis (MCA);
- Goal Achievement Matrix (GAM).

CBA requires the identification of all the effects of a project on the individual welfare of all members of the community. It requires these effects to be measured in monetary terms so that costs and benefits can be aggregated and compared.
In CBA, costs and benefits are systematically presented in a balance sheet. Costs are compared with benefits, resulting in the conclusion whether the project should be implemented or not on the basis of forecasts, along the useful life of the project, of some or all of the following indicators: Internal Rate of Return (IRR), Net Present Value (NPV), Benefits-to-Costs Ratio (BCR), Pay-Back Period (PBP).

There are two types of CBA, financial and socio-economic.

Financial CBA measures efficiency from a private point of view. The financial implication of each alternative should be forecast over its useful life and for a period long enough to permit understanding of its likely medium- to long-term impacts. This analysis gives essential information about inputs and outputs in physical terms, their prices and the overall structure of inflows and outflows. The key question is whether the project has sufficient return on investment. A positive outcome means that the project is profitable to an investor, but negative values of the main indicators do not necessarily indicate that the alternative is not in keeping with the project objectives, since there may occur a positive socio-economic appraisal of such an alternative.

The efficiency score of a project from a national point of view is investigated by the socio-economic CBA: all benefits and costs to society (including the so-called third parties) are taken into account. This kind of analysis aims to go above and beyond a purely financial appraisal, first by trying to take into account all of the welfare-related effects of investment, whenever they occur and whoever is affected, and second by attempting to correct for the distortions introduced by market failure in the form of externalities, government intervention or absence of markets (these distortions are not mutually exclusive). In some cases there are external social costs and benefits which, while easy to identify, are difficult to estimate in money value (this may often include environmental impacts): these aspects should be properly described and appraised, possibly with recourse to some qualitative-quantitative method.

CEA has all the features of CBA, but does not require all costs and benefits to be expressed in monetary terms. Usually CEA is applied if valuation of benefits is problematic, and can be described as an analysis to decide:

- which alternative can be realised the most efficiently (costs minimisation), given a fixed amount of intended (societal) effects;
- how much of the intended (societal) effects can be achieved (effect maximisation), given a fixed budget.

Like CBA, CEA can be applied in financial and socio-economic terms. But in contrast to CBA, CEA does not tell whether benefits outweigh costs and hence which alternative is most desirable from an efficiency point of view: CEA only provides a ranking among alternatives.

Evaluating transport initiatives can often be a rather complicated procedure, as it usually demands simultaneously taking into account several impacts of technical,
socio-economic, environmental and political nature, which are not all easily expressible in commensurate terms, if at all. There may not be market prices, or it may not be possible to elicit from private citizens money value, for some public objectives, but for the decision makers there is always an opportunity cost implicit in the choices that are forced upon them by the budget constraint. In order to estimate these opportunity costs, in terms of forgone investments in other directions, it is necessary to consider some recourse to the MCA. In such cases, MCA techniques give the decision maker the opportunity to accommodate a wide range of non-monetary impacts, as well as to admit interactions between impact scores, which are not necessarily linear. The basic concept is to elicit from decision makers their preferences among projects on the basis of the importance given to the impacts. In other words, MCA techniques aim at providing a flexible way of dealing with qualitative multidimensional effects of transport initiatives.

The GAM method is an appraisal tool that can measure the extent to which a given project achieves its explicit goals. This method allows a potential decision-maker to select from a series of alternative projects the most appropriate one for implementation, with respect to each project’s rate of success in the pre-defined goals.

Each of these techniques has its pros and cons and is better applicable in certain situations than in others.

The purely CBA and the purely MCA are at the extremes of a spectrum of approaches to appraisal. CBA employs exclusively monetary valuations and has generally more objective and explicitly defined criteria, while MCA employs weights from a variety of sources, with a high degree of subjective assessment and decision-maker judgement likely to be involved.

The CBA basic rule for accepting a project is that its NPV, all impact values included, should be positive. Alternative criteria are that IRR is greater than the discount rate or that BCR is greater than the unit. These last two criteria do not consider the absolute value of the NPV of a project. They should thus be used with caution in comparisons of projects of different sizes and exclusive of each other: when there is no budget constraint, the project with the highest NPV must always be chosen (that means the project that reaches the highest possible level of utility).

CBA is substantially the most powerful technique to evaluate the profitability of an investment but, despite its extensions and adjustments, is unable to give full account of the value of some impacts. An example is the cost of electricity, which has its own monetary value but has a completely different social cost since a waste of energy means undesired impacts such as greenhouse effect and global warming.

MCA techniques give the user the possibility of weighting the various impacts differently in order to consider subjectively their importance, but do not give as output a tangible monetary value such as the PBP of the investment or the NPV.
The different exigencies of the various actors make the choice of the evaluation technique a subjective matter.

The PLATFORM evaluation methodology has been applied to the outputs supplied by the simulation of different scenarios of development in intermodal terminals: it can be properly regarded as a before-after appraisal. On the one hand, it is applied to the choice among alternative scenarios of development, typical situation for the ex-ante procedures. On the other, it is run on simulation outputs considered as measurements, which is typical of the ex-post procedures.

The evaluation of a project on the entire intermodal transport chain involves various actors and makes a global appraisal difficult. This kind of project is therefore usually evaluated from the point of view of only one actor. The methodologies developed under APAS for nodal centres for goods [10], for example, were focused on the nodal centres of the intermodal freight transport chain and, even if all the different actors were considered, the evaluation was determined only from the terminal manager’s point of view.

Since the PLATFORM simulation environment reproduces the entire chain, the different scenarios can include technological and managerial innovations in every chain leg. Therefore every actor in the chain can use PLATFORM to evaluate different interventions.

Shippers normally decide only for freight shipping. They are not really interested in how the intermodal chain works, but do care how much they are going to spend for shipping and whether the transport chain answers their needs in terms of reliability, flexibility and safety. These actors will not directly use PLATFORM, but the optimisation of the chain in terms of performances and costs, derived from the application of the PLATFORM results, should convince them to send more freight via intermodal transport.

PLATFORM, and its evaluation methodology, is therefore addressed to the other actors of the intermodal chain (the questionnaire circulated among several major companies to state objectives and relevant impacts to be analysed is reported in the appendix): terminal managers, forwarders, rail operators, authorities.

The first three categories are commercial operators and have the main goal of increasing their profits while minimising costs. The best evaluation technique for their exigencies is the CBA. On the contrary authorities are mainly concerned with community welfare and other non-monetary impacts. The most suitable technique is therefore MCA.

Terminal operators may use PLATFORM to analyse the impacts produced by almost every terminal enhancement: new equipment, storage areas and rail tracks, additional personnel as well as innovative management procedures and telematics technologies. Their goal is to improve the productivity of the terminal, which means to increase the total number of ITUs handled and train arrivals/departures. This implies reducing the unit costs for handling ITUs and the total travel time and improving the quality of the service.
Forwarders may use PLATFORM to investigate how to enlarge their market share and increase the level of the service they provides. Their main goals are to lower the costs of handling ITUs (improvements in reliability and flexibility of the terminal services which can produce a reduction of time in the terminal during delivery and pick-up of the transport units) and to optimise the use of resources on the road legs (usage of trucks, ITUs and drivers at origin and destination).

Rail operators may use PLATFORM to optimise the use of railway resources and to decide if more train paths might be given to a terminal. Their main goals are to supply better service (in terms of travel time reduction and punctuality), to increase the productivity of rolling stock and personnel, to increase safety levels by reducing the number of manoeuvres per train, to state if there is enough time space to serve new trains in the terminal.

Last but not least, authorities may use PLATFORM to analyse projects regarding intermodal transport terminals. They are mainly interested in reducing the costs of transport (comprising accident costs), the external effects of heavy vehicles on the road network, the energy consumption, the intrusion of terminals in the territory (reduction of space usage).

Each single evaluation process will be used to compare the simulation results of alternative scenarios of development, or with-project scenarios, against the present situation, or do-nothing scenario, measured or simulated as well.
5 SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE PROJECT

5.1 The graphical user interface

The PLATFORM graphical user interface (GUI) allows the user to define an intermodal environment, access the different modules of the simulation environment, access the results of a simulation.

An intermodal environment is formed by the following elements: customers, forwarders, intermodal terminals, rail links and road links. The PLATFORM user must define all these elements before he can simulate a given terminal or a given corridor and obtain any results. The GUI will allow the user to change any of these components at any time and run the simulation in order to analyse and compare different scenarios in terms of investments in infrastructures and equipment or change of management methods.

Once all the elements have been input and the databases updated with the customised data, the user will launch the appropriate simulation depending on the elements selected through the interface.

The simulation allows for modelling the flow of ITUs from origin to destination along a corridor and the operations of an individual terminal. This involves the simulation of the selected terminal or the entire corridor, comprising the dispatching of ITUs on the road networks associated with the corridor. The results will be obtained separately for the terminals, the forwarders and the corridor.

5.1.1 Description of the graphical user interface

The user starts the system by double-clicking the PLATFORM icon on the Windows NT desktop. This will produce the control window, through which all the processes are initiated and the results viewed.

The control window comprises a menu bar at the top and a main window where the user can define the intermodal environment. Two tool bars have been added performing all the operations of the main menu and a set of powerful tools for the use of electronic maps and their layers.

The GUI works based on the concept of maps and layers. A map is composed of layers, each of them representing an intermodal environment or base cartography.
An intermodal environment can be geographically described on the basis of a map layer representing the rail and/or road networks, which is loaded at the beginning of the operations and is used for editing purposes. Either way, this is done from the New or Open menu item under File on the top menu bar (figure 5.1). The PLATFORM environment will not provide a tool to make changes on networks, which must be edited using other software packages.

Once the user has loaded a network layer, he will be able to activate an existing layer with an intermodal environment or to create a new one as a new layer in the map, always starting from the same road network layer.

An intermodal environment is composed of nodes and leaves. Network nodes are intermodal terminals, network leaves are local road networks connecting the forwarders operating on the network.

The simulation environment allows modelling a corridor or a terminal in a network: the user must define the corridor or the isolated terminal and the GUI allows the user to enter the components interactively. This edition can be realised starting from an existing map or creating a new map. Anyway, each time the intermodal environment is created or changed, the Start Edition menu item must

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1 At present the PLATFORM prototype can load only the Europe map road topology supplied with it.
be clicked under Map in the main menu bar. When this option is activated, the user will be allowed to introduce on the map new elements by activating the buttons of the first tool bar.

The button must be selected on the tool bar to introduce a new terminal. The terminal is introduced over the electronic map by clicking in the position where the terminal is located. A dialogue box will appear asking the user to select an existing database to be associated to the terminal or a new one, which will have the default data, previously introduced in a template terminal database. The default database name is NewTerminal.mdb.

The button must be selected on the tool bar to introduce a new forwarder. The new forwarder is introduced over the electronic map by clicking in the position where the forwarder is located. A dialog box will appear asking the user to introduce the forwarder’s name and the terminal to which it will be associated. Then the user must select an existing database to which the forwarder data will be associated.

The button must be selected on the tool bar to introduce a new rail link. The new link is introduced over the electronic map by clicking the origin terminal and dropping to the destination terminal.

Once the user has introduced any element, it can be erased by means of the erase button.

Figure 5.2. Starting and stopping edition
Once all the elements have been introduced, the user must stop the edition in order to customise interact all the data of the intermodal environment defined. This can be done using the Stop Edition menu item must be clicked under Map in the main menu bar (figure 5.2).

The first time an intermodal environment is created, the user will be asked to save the layer file (*.bml) where all the data will be saved. Terminals and forwarders introduced have initial data that must be customised by the end user.

All the elements introduced in an intermodal environment can be edited by means of the GUI to enter or change the related data.

The user will define the general data of the road network (e.g. customers, orders as shown respectively in figures 5.3 and 5.4), that are applicable for the entire intermodal environment and will be used jointly with the specific scenario by the road simulator, through the Edit menu.

The equipment, its characteristics and special data for routing will be introduced to define forwarders: each specific forwarder can be activated (figure 5.5) and its characteristics opportunely changed (e.g. drivers, loading spaces as shown respectively in figure 5.6 and 5.7).

Terminals will be described (figure 5.8) in details in terms of infrastructures, equipment and simulation characteristics (e.g. gates, cranes, trucks, trains, work shifts as shown in figure from 5.9 to 5.13).

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![Figure 5.3. Editing orders](image)

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Figure 5.4. Editing customers

Figure 5.5. Editing forwarders
Figure 5.6. Editing forwarders drivers

Figure 5.7. Editing forwarders loading spaces
Figure 5.8. Editing terminal data

Figure 5.9. Editing gates
Figure 5.10. Editing cranes

Figure 5.11. Editing trucks
Figure 5.12. Editing train timetable and composition

Figure 5.13. Editing work shifts
5.1.2  Choice of the active elements and simulation

The user will have the possibility of activating a single terminal or a corridor to perform the simulation.

The simulation process can be triggered just for one terminal. Leaving apart the data for the rest of the terminals.

The user will activate a terminal just by clicking the right button on it. Then the user will have the option of activating or deactivating the terminal depending on the current state.

The prototype imposes a limit: a corridor can be established only among two terminals. These two terminals will be the active terminals and the other terminals will be passive for the simulation.

The simulation will get as input a number of parameters (e.g. travel time) that will be defined in the trains timetable database. The other terminals are used only to represent the flow of ITUs between the active terminals and the rest of the network.

The user will activate a corridor simply by clicking the right button on the link selected (figure 5.14). Then the user will have the option of activating or deactivating the link depending on the current state.

Figure 5.14. Activating/deactivating a corridor
Once all these data are introduced, the corridor is activated highlighting the rail link in a different colour.

Again, clicking the right button, the user may deactivate the active corridor.

The simulators are launched by selecting the Simulate option from the main menu bar where the simulators will be highlighted depending on the element selected in the control window. When launched a special window or visible item will show that the simulation is in progress (figure 5.15).

5.1.3 Results

The simulation gives the results separately for each element: terminals, forwarders, corridor. Once the simulation ends, the user must select the Results option from the main menu bar.

By selecting the terminal option the user is shown a dialog box with a list of the terminals defined in the intermodal environment; the user must select one terminal in this list. As an example, figure 5.16 shows the results for the Verona terminal. The results given by the simulation are the following:

- summary of the terminal resources (number of rail tracks, total length of the rail tracks, number of gantries, number of lifters);
- summary of the crane operations per train;

Figure 5.15. Simulation in progress
Figure 5.17. Terminal simulation results

Figure 5.18. Forwarder simulation Results
- summary of the train statistics;
- number of ITUs managed;
- number of trains served;
- average residence time of the ITUs in the terminal;
- percentage of direct transfers;
- queue distribution on rail tracks or buffers;
- road gate waiting time;
- area occupation.

Selecting the forwarder option, a dialog box shows a list with the forwarders defined in the intermodal environment and the user must select one forwarder. Figure 5.18 shows the results for the forwarder 1 associated to the Verona terminal. The results given by the simulation are the following:

- number of ITUs managed;
- total kilometres travelled by the trucks;
- total hours travelled by the trucks;
- number of non-productive journeys.

A similar procedure can show the results for the corridor simulation process. The results table gives a summary of the origin-destination time for each ITU (figure 5.19).
5.2 The intermodal transport planner

A prototype system TELETRUCK [6] [7] for planning, optimising, and monitoring of road haulage has been developed at DFKI. The underlying approach is based on multi-agent technology. The physical objects of the transport domain (trucks with drivers, trailers, and load spaces) are modelled by active software processes (intelligent agents), which are able to plan on the basis of their resources and means provided by the corresponding physical objects. They are embedded in a common environment (a multi-agent system) — potentially distributed in a network of several computers which could be located at different transport departments — reflecting the communication and interaction of the agents.

For the PLATFORM simulator the approach needed a couple of extensions for combined rail–road haulage (figure 5.20). New agents with intermodal planning and execution competencies had to be integrated. They are equipped with smooth access to the resources of the two transport means. The different mode operators (road and rail agencies) are modelled as agents, which are responsible both for the intermodal and for the intramodal co-ordination of the transports. These agents are capable of planning and supervising the execution of plans and, in principle, they are able to migrate through the telecommunication network from one mode operator’s server to the other’s. Thus the accompaniment of the transport flow by the data flow is modelled, both during the planning and the monitoring phases.

![Figure 5.20. The intermodal transport chain as a road–rail–road combination](image)

In order to use the output of the intermodal planner, the schedules for delivery and pick-up at the terminals, as input for the simulation of the road and rail corridor some extension had become necessary. Road network simulation is essentially based on the planned road haulage — for the prototypical implementation at hand. That means the scheduled time windows for pick-up and delivery of ITUs control the road simulation directly. ITUs are picked up at customers and carried to the terminal as scheduled — usually we take the beginning of the time window, which results in average driving times for the planned routes according to the electronic maps underlying the TELETRUCK system.

5.2.1 A multi-agent system for the intermodal transport chain

The conceptual basis for the development of the model for the intermodal transport chain is shown in figure 5.21. Each transport service is represented by a software agent. The lower part of the figure represents the physical world; its
A multi-agent model is shown in the upper part of the figure, labelled Agent World. Each transport operator is represented in the agent world as an agent. Each of them has the task and ability to manage its local resources and the knowledge about these, which is indicated by the contents of the clouds over each agent’s head. The intermodal transport order needs to be planned and negotiated as well and then executed in co-operation.

The forwarding agents, at the beginning and at the end of the chain are instances of the TELETRUCK system, designed as a standalone agent-based forwarding system and able to manage the processes of forwarders. Each TELETRUCK agent stands for a well-structured society of agents, specialising in road transport. Each physical component of a forwarding agency is represented as an agent. Further on, a virtual agent is introduced, which has no physical equivalent and is equipped with planning and execution abilities required for road-based transport.

The terminal agents represent the commercial departments of intermodal terminals and are able to manage the business processes of terminal operators: each terminal agent is able to process booking requests and manage a reservation system for freight trains. Such a system is comparable to reservation systems for passenger transport. Booking and reservation systems, even though less common in today’s freight traffic, will in future provide essential support for the smooth management of fast loading devices within intermodal terminals such as the Automated Loading System, the Krupp Fast Handling Device, or the Daimler KombiLifter [8]. As such fast handling devices will mature from their currently prototypic status into products, which will be more common in intermodal terminals of the future, precise management of terminal flows and operations through booking systems will be required.

As in the TELETRUCK agent society, a virtual agent is introduced without a physical equivalent in the real world. This agent is associated with the intermodal transport order and supply it with special planning and execution capabilities for intermodal transport processes.

Figure 5.21. The physical transport chain and its representative software agents
5.2.2 The TELETRUCK system: a road haulier multi-agent system

The TELETRUCK system models the business processes of transportation companies, in particular the allocation of transportation requests to means of transportation. A shipping company disposes of a fixed number of transportation components like drivers, trucks, trailers, containers, swap-bodies. These units may differ in many ways: trucks can be classified, for example, as pure tractors, those with fixed loading space or those that can carry containers. The type and size of the loading space of the containers constrains the type of cargo that can be transported. Human drivers too differ in their supplied working time and the type of cargo they may transport depending such on issues as special training or certain licenses, e.g. for dangerous goods. These resources must be managed in such a way that the transportation tasks at hand can be executed with minimal cost.

The multi-agent approach used in TELETRUCK partitions the overall scheduling problem into handy sub-problems. Each vehicle’s plan is represented separately and can easily be adapted to dynamic changes. A co-ordinated market mechanism is used to realise a global optimisation of the overall solution.

The TELETRUCK agent society has been implemented as a holonic agent system. A holonic agent or holon is an agent that is composed of sub-agents working together in order to pursue a common goal. The users or the other members of the agent society can interact with a holon as if it were a single agent. This permits modelling of several levels of abstraction in a convenient way.

In a holon one agent is distinguished as the head of the holon. The head co-ordinates the resource allocation within the holon and controls the communication with the rest of the agent society. The head can be equipped with the ability to plan for the sub-agents.

The TELETRUCK system comprises holons of several types. For each transportation device of the forwarding company as well as for each of its drivers there is an agent which manages the resources of the device or the driver. These agents have their own plans, goals, and communication facilities in order to provide their resources for the transportation plans according to their role in the society.

![Diagram of holons for road-based transport](image)

**Figure 5.22.** Composition of holons for road-based transport
They can merge together with a Plan and Execute Unit (PnEU) and form a holon which represents a complete vehicle which is actually capable of executing transportation tasks. For example such a vehicle holon may consist of a PnEU, a driver, a truck, and an ITU (figure 5.22).

The PnEU is the head of the vehicle holon, represents it to the outside agent world, and is authorised to reconfigure it. A PnEU plans the vehicle’s routes, loading stops and driving time, and is therefore equipped with planning, co-ordination, and communication abilities, but does not have its own resources. Each transportation holon is headed by such a PnEU. Additionally, there is always one idle PnEU with an empty plan that co-ordinates the formation of a new holon from idle components if needed.

The vehicle holons are internal sub-holons of a super-holon which represents the entire transportation company. This holon that subsumes the complete agent society is headed by a company agent. The company agent announces and distributes the incoming orders, gives the acceptance of the tenders, controls global optimisation, co-ordinates the execution, and channels all communication of the system with the user, i.e. the dispatch officer. Hence, the company agent represents the society to the user — and to partner companies to be represented also by such company agents [9], or here, in the intermodal framework, the company agent represents the company to the terminal agents in the transport chain. The company agent also co-ordinates the internal co-operation and interaction among the PnEUs.

For the formation and co-ordination of a holon, an extension of the contract net protocol [10] has been chosen. It allows not only assigning a task to a single vehicle, but — in case of a large amount of cargo that cannot be hauled with one truck — to split the task into sub-tasks and assign them to several vehicles [11]. A co-ordinated market mechanism, the Simulated Trading procedure [12] is used to optimise the vehicles’ plans iteratively. In the multi-staged simulated trading procedure the truck agents submit offers to sell and buy tasks to the company agent which matches them such that the global solution improves. In analogy to simulated annealing mechanisms the company agent accepts a worsening of the solution in early stages in order to leave local optima in the solution space. Nevertheless, optima that are left are saved. This decentralised approach is well suited for this complex setting since local information is sufficient for globally efficient resource and task distribution. The model has been implemented and tested in co-operation with a haulage company [7].

5.2.3 Extensions of the TELETRUCK road-based transport planning system to intermodal planning and execution

For the extension of the TELETRUCK approach to intermodal transport, the intermodal terminals have been modelled in a similar way: each terminal is represented by an agent, which stands for a holonic agent society of terminal service agents. However, a fine-grained agentification of resources in terms of modelling components of trains such as wagons or engines as autonomous agents
is currently not required for terminal services. Thus, the holonic terminal agent society consists of the terminal agent, acting as the head, the booking agent, managing the booking requests for the trains handled in the terminal, and the locomotive agents, which represent the whole trains. The booking agent comprises the heart of the terminal services for the negotiation and planning of intermodal transport orders.

Currently, the combination of train is fixed, due to the time-tabled nature of this transport mode. Therefore, in contrast to the fine-grained TeleTRUCK approach, the means of transport here is represented by only one agent. The formation of rail holons, for modelling the committed transport plans and the agents in transit is managed by the booking agent. It is much simpler than the compilation of the road-based holons, because railway is a time-tabled transport mode. The booking agent has a timetable, where departures and destinations as well as the length and compositions of the trains are noted. With this information the booking agent processes booking requests using a constraint solver and distributes the ITUs onto the trains according to their transport time requirements. Figure 5.23 shows the process of holon compilation for the rail-based transport.

Inter-connecting the two transport modes in the agent world, and thus allowing for intermodal transport orders, requires more sophisticated planning competencies and execution processes. Such intermodal planning competencies are usually managed as a hands-on-process either by the client requesting the order himself or by the expeditors of transport operators, e.g. terminals, providing pre- and end-haulage for rail-based transports. Knowledge and competence of intermodal transport planning are clustered and concentrated for each transport operator, by encapsulating these into a new intelligent agent. This agent is integrated in the respective holonic agent societies which allow it smooth access to resources of the respective transport agency.

Figure 5.23. Composition of the rail holon performed by the booking agent
In the road-based TELETRUCK approach, the PnEU represents the road trains during planning and execution time. For intermodal transports, an Intermodal Plan and Execute Unit (IPnEU) is introduced. Like the PnEU, it is equipped with planning and communication skills and there will always reside an idle IPnEU with an empty plan ready to start the processing of an intermodal order. Unlike the PnEU, it is not the head of a vehicle holon; it is just associated with an intermodal order, which may consist of one or several ITUs. If the order contains more than one ITU, it may be split over several trains or road trains: still only one IPnEU is planning and supervising the transport execution. The IPnEU plans and negotiates the intermodal transport of the ITUs it represents and then monitors the execution of the plan by migrating on the software side, while the ITUs are in transit. This implies on the one hand that the IPnEU has smooth access to the transport operators for the negotiation and planning of an order. On the other hand, it is a mobile agent, which accompanies its cargo in the agent world, while the goods are shipped in the physical world. Figure 5.24 illustrates this: the intelligent agent on the top is the IPnEU during the planning and negotiation phase; the walking agent is the vehicle holon which results from the planning and is active during the execution and monitoring phase. The puzzle in the body of the walker indicates the holonic agent society. The black piece stands for the IPnEU’s participation in it. The two phases are modelled differently, though it is possible to mix them freely and thus provide for emergency replanning during execution or due to newly incoming orders, their dynamic insertion into consisting plans.

The announcement of an order triggers the inactive IPnEUs (the active IPnEUs are by definition busy with either planning or executing an order) to enter the planning and negotiating phase. The planning phase itself is divided into a negotiation phase with preliminary commitments to the services requested (road based transport, rail based transport and terminal services) and a final commitment phase, where the information gained during the negotiation will be used in order to place bookings on trains and provide pre- and end-run by trucks. The preliminary commitments are level commitments, which serve two purposes: reserve resources during planning and negotiation and provide a decision and planning basis for service providers within the intermodal transport chain.

![Figure 5.24. The IPnEU planning and migrating](image-url)
The details of the negotiation and planning phase are shown in the diagram of figure 5.25. The partners in this phase are customers and transport service providers.

The customer at the origin sends an order to the forwarder of his choice. He may announce the order to several transport operators in order to receive and select the most competitive offer.

The forwarder recognises that the order requires an intermodal transport and activates an IPnEU agent to provide for intermodal planning. The IPnEU splits the order into three parts: the rail-based main run order which constrains the road-based initial and final run orders. The main run order is passed to the booking agent of one or more terminals, who then engage in main run planning. The result of this activity, the main run plan, is communicated back to the IPnEU. If the IPnEU has contacted several terminals, it sends one of them a preliminary commitment and adjusts the initial and final run orders to the chosen main run plan (latest arrival time at the origin terminal gate, earliest pick up time at the destination terminal). Other main run plans are rejected. Planning of the initial and final run can be done concurrently. In the protocol this is indicated by dashed arrows. Initial and final run planning involves the usual TELETRUCK planning and scheduling activity, which results in a holon for every road train.

Figure 5.25. An intermodal planning and negotiation protocol
With the information on the whole transport, the IPnEU can then tell the forwarder which are the times relevant for the customer, that is pick up time/interval at the customer’s site and delivery time/interval at the final destination. The intermodal planning and negotiation protocol is an application-specific extension and nesting of several classical contract net protocols [10].

The protocol described here is a prototypic reference example. It is not the only way an intermodal transport, and thus an IPnEU, is activated. Each service in the transport chain is provided with the ability to accept intermodal transport orders. That means, the customer at the origin may also contact the intermodal terminal which he may want to use directly, or the forwarder at the main run destination. The IPnEU therefore gives the respective carriage (pre-, main, or end-) to the service provider that invoked it. In contrast to the other negotiations, there is no competition of service providers along this carriage.

The protocol presented here has a very static structure. The time-tabled railway transport constrains the remainder of the intermodal transport and therefore leads to the protocol structure as it is: the time-tabled, less flexible carriage needs to be planned (and booked) first. The more flexible road transport can be scheduled according to the needs imposed by the rail terminal. This idea can be easily transferred to combining other modes of transport, such as airborne or waterborne with road. Like in combined road-rail transport chains, there is a smooth combination of a less flexible, time-tabled mode and a more flexible, namely road based transport mode.

Within the protocol a preliminary commitment is used, which depends on the acceptance of the intermodal plan by the customer. If the customer does not agree to the plan, the terminal and forwarders get retract messages. Otherwise, after a certain delay (e.g. 60 minutes) the transport operator can either use the reserved resource differently or charge the cost of the transport to the client, or even both. This serves both sides: service providers reserve their resources for the client and do not lose much time or money, if an order is then retracted. Clients have a certain planning security within the negotiation process and enough time to find out about cheaper means of transport.

The negotiation and planning phase generates an intermodal transport plan. Such a plan is a composition of plans for the different transport runs. The intermodal plan is composed of two road-based transport plans and one rail-based plan. The road-based plans realise the TeleTruck approach, that is, for each road train, a software representative, namely a holonic structure is generated. Each structure is dominated by a PnEU. The IPnEU is participating in each of these holonic structures. This is possible, because an agent can be part of several holons at a time.

The rail-based plans result in the formation of the trains. Since the IPnEU is associated with all the ITUs belonging to an order, it accompanies each of them by participating in the respective rail holon. Figure 5.26 illustrates the holonic structures, representing the co-operative transport plans.
Similar to the TELETRUCK implementation, whenever the system plans a road-based transport, the agents representing the involved physical components form a vehicle holon that is headed by a PnEU. If an ITU that is part of an intermodal transportation order is transported, not only the agent that represents that ITU but also the IPnEU that represents the transportation order are incorporated in the vehicle holon. Precisely, the ITU agent and its IPnEU form a holon that is headed by the IPnEU and that represents the ITU.

For the rail-based transport, the train that transports several ITUs can be viewed as a holonic structure that consists of the ITUs, the wagons, and the engine. We do not model the wagons explicitly but represent the whole train by the locomotive agent. The train holon is composed of the IPnEU agents that represent the intermodal orders, the agents representing the ITUs in transit, and the locomotive agent which is the head of the train holon.

As a consequence of the domain’s structure, holons overlap. The agents form holons at the time of planning and can be members in several holons. The ITU agents are part of the holon that represents the intermodal order, they belong to two vehicle holons for pre- and end-run, and to a train holon for the main run. The IPnEU agents exhibit even stronger omnipresence: they participate in the vehicle holons for pre- and end-run of each ITU in the order and they are part of the train holons that carry at least one of the respective ITUs. This agent society is represented in figure 5.26. The picture shows on both sides road-based vehicle holons that consist of a PnEU, a driver agent, a truck agent, and a conjunction of ITU and IPnEU agent. In the middle there is a rail-based train holon that contains the locomotive agent, both ITUs and the IPnEU. The IPnEU is part of all holons involved and supervises the whole transportation chain.

Figure 5.26. A holonic intermodal transport chain with two road holons in pre- and end-run
In the PLATFORM scenario a physical agent, such as an ITU agent, may be part of several holons. In contrast to the IPnEU, which has to be active in all holonic structures along the intermodal transport chain in a concurrent manner, agents representing physical objects like an ITU, may be active only in the sequence of the transports along the chain. By activity in a holon, the planning actions and commitments are not included, but the movement of the cargo in the physical world is regarded as the activity of agents in a holon during this transport execution. Through this restriction, a flexible dynamic planning and negotiation process is modelled and a realistic mapping of the physical transport into the agent world.

The ITU agents are stationary on the location of their physical counterpart and they migrate if their counterparts move from one haulier to another. Nevertheless, for planning purposes, the ITU agents can communicate with agents on foreign hosts via the IPnEU which is present at several locations during the time of planning.

Since the IPnEU is associated with an order, which may consist of several ITUs, it needs to be present at three software sites and therefore clones itself during planning time. Since not all ITUs belonging to an order may reach the terminal at the same time, cloning guarantees that the IPnEU is part in all holons in transit.

Figure 5.27. Execution protocol of an intermodal order (flow of messages and control)
While the planning phase can be compactly described with the protocol illustrated in figure 5.25, the execution requires some more elaborated methods and competencies. The execution itself can also be described in a protocol-like diagram, where messages about the result of the execution are communicated (figure 5.27). Within this figure the grey arrows indicate the transport control or supervision by the IPnEU.

The IPnEU splits the order at hand into a main leg to be on train and an initial and final leg to be executed by trucks. The intervals are based on estimated duration of the different legs. For the main leg it consults the booking agents, while for the initial and final legs the according road network area brokers are contacted (figure 5.28).

When the booking agent and the road network area brokers reply the booking for the main leg and the plans for the initial and final leg, respectively, the IPnEU has to integrate the three plans into the intermodal transport plan for the order at hand. If the integration fails new rounds with modified time windows take place.

For the region around a terminal a road area network broker agent is responsible for the organisation of the initial or final leg, respectively. This agent is implemented as an autonomous copy of a TELETRUCK system, but without subagents representing the transport units. It knows about the forwarders in the region and can contact their forwarding agent, in order to announce the transport task to them asking for their bids for that task (figure 5.29). Modified negotiation and communication facilities therefore had to replace the original ones, which were normally used for the distribution of orders to the transport subagents.

Figure 5.28. Road network simulation architecture
The forwarding agents of the local forwarders are again realised as autonomous copies of the TeleTruck system, of course with their usual subagents for the transport units and their components. In extension of the normal TeleTruck functionalities the forwarding agents had to be able to communicate and negotiate with the road network area broker. That is, the forwarding agents now have to receive the announcements of the (initial or final leg) orders that are passed over by the road network area brokers and they have to reply with a bid for that order. In order to provide the bid, they compute their potential plans for executing that order in collaboration with their transport subagents. The road network area broker selects from the offered plans the most suited one and replies it to the IPnEU, which in turn has to integrate it with the main leg plan and the second road haulage plan.

Figure 5.29. The road network area broker and its subagents

5.3 The intermodal terminal simulator

5.3.1 Overview of the simulation module

The simulation of an intermodal environment involves the simulation of a set of terminals interconnected by rail corridors.

Each terminal in the Terminal Simulation Module (TSM) is composed of the following parts (figure 5.30 and 5.31):

- a set of platforms and one storage area;
Figure 5.30. Buffer and storage areas, platforms and cranes in the terminal simulation module

Figure 5.31. A view of the process in the shunting area and at the rail gate
the shunting area, where incoming trains are queued before entering the terminal;
the rail gate, the link between the shunting area and the terminal;
the road gate, where trucks check in before being routed either to platforms, for transhipment or to the storage area for delayed transhipment;

Each PLATFORM is composed of a set of rail-tracks served by the same gantry cranes. A number of gantry cranes can serve a set of rail-tracks. In each PLATFORM there is a buffer area where are stored the ITUs which cannot be directly transhipped.

The TSM works interconnected with the ITP. The behaviour of the co-ordination between the two modules is explained below. The ITP uses the TSM as a service to request the rail leg of an intermodal transport. The ITP has to match the various legs of a transport from an origin to a destination. The ITP has access to the train timetable of the two terminals along the route and makes bookings on the trains. Finally the ITP generates the trucks which deliver and pickup the ITU at the two connected terminals.

The TSM can also work as a standalone module for two reasons.

The first is that the ITP can generate transport assignments only along the axis defined by the two interconnected terminals, along the corridor. In the real world, each terminal is connected to many other terminals and therefore only a fraction of the trucks deliver or pick up ITUs which are in transit to and from the other terminal in the corridor. For this reason, the same software modules that are used to run the TSM as a standalone module are used to generate these alien truck arrivals and departures. Once they were implemented it was straightforward to let the user simulate the TSM standalone.

The second depends on the fact that the user might be interested in a more customisable generation of truck arrivals, to test the terminal against different scenarios. The standalone mode allows this customisation down to the lowest detail.

When the TSM works as a standalone module, it is flanked by two supporting modules: the truck generator and the train generator (figure 5.32).

The train generator is a module used to schedule train arrival and departures according to the train timetable. Each terminal has a train timetable, and it must be consistent with the timetable of the interconnected terminals.

The truck generator is a module used to generate the truck arrivals in the terminal with respect to the ITU bookings on the scheduled trains. Truck generation can be automatic or manual. In the automatic case, the user must select the coefficients of a function used to distribute in time the truck arrivals for pick-up and delivery. In the manual case, the truck arrivals are inserted by hand in a database table.
5.3.2 Generating transport plans

The ITP has the task of generating a transport plan for an ITU from origin to destination, comprising two forwarding agencies, located somewhere on the road network. The ITP sees the terminal as a resource that provides one leg of an articulated trip, from an origin terminal to a destination terminal, connected via a rail corridor. The ITP can query any terminal to check whether a corridor exists between this terminal and the destination one. This information is stored in the corridors table in the database associated with the origin terminal. Once this query has been successfully executed, the ITP can book places on a train connecting the origin terminal with the destination terminal. The list of departing train is stored in the train timetable table in the terminal database. The train departure time from the origin and its expected arrival time at destination are also retrieved from this table. With this information on hand, the ITC must fill in the bookings on this train. This procedure must be repeated for all the trains that leave the terminal during the simulation horizon.

At this stage the ITC must schedule trucks which will deliver the ITU to the origin terminal from its origin on the road network and that will pick up the same ITU at the destination terminal, thus bringing it to the final destination.

5.3.3 Generating truck arrivals and departures

Once the transport plans have been generated, the ITC must generate truck arrivals for ITU delivery, filling in the incoming trucks table in the origin
terminal. This table is periodically read by the TSM and used to generate the truck arrivals in the terminal model. The origin terminal then unloads the truck and sends it back to the road network, writing the truck data in the *outgoing trucks* table.

In the meantime, the TSM is loading the train for which the ITUs were booked. When the loading process is over, the train leaves the origin terminal and is transferred to the destination terminal via the corridor.

At the same time, the ITP has generated the truck arrivals for ITU pick-up, according to the transport plan. These trucks also fill in the *incoming trucks* table, this time for the destination terminal database. The destination terminal uses this information to generate the truck arrivals in the simulator, it unloads the ITUs from the train on the trucks and registers the outgoing trucks in the proper table.

The ITP checks the *outgoing trucks* table to generate the final leg of the ITU delivery.

### 5.3.4 Synchronising the terminal and the transport planner

The two programs might be running on different machines, at different clock speed, and their local simulation time can easily diverge (figure 5.33).

The two simulators start at the same instant, and consequently also their local simulation time is the same. In principle, just after ten seconds of processing time, the simulation time in the two simulators may have considerably diverged. In the example, the simulation time in the ITP is behind the simulation time in the TSM.

In this case, when the ITP simulator generates an event (a truck arrival), the TSM sees an event with a time label of 90min, but in the meantime the simulation has already reached t = 180min.

![Figure 5.33. Simulation times](image-url)
In figure 5.34 it is graphically represented what happens if an event arrives *after* its simulation time has elapsed. The event D3 should have been executed by the TSM before events I3 and I4. If there is no possibility of backtracking the simulation, cancelling events I3 and I4 (thus applying the *time warp* simulation method), the consequence is that the two simulators will proceed at the speed of the slower of the two.

![Diagram of synchronisation problems](image)

Figure 5.34. Synchronisation problems

To solve the synchronisation problem, the two simulators exchange the simulation time at a fixed interval. This approach transforms the simulation from *discrete events* to *discrete time*, since the simulation clock advances at fixed increments.

A possible synchronisation algorithm is the following:

```plaintext
wait for duration Delta
  t_itp:= readITPLocalTime();
  while (t_ts > t_itp)
    delay(some seconds);
    t_itp:= readITPLocalTime();
  end while;
writeTSLocalTime();
// perform some simulation actions
end wait;
```

This is the piece of code that runs in the TSM main loop. A similar code will run in the ITP simulator. If the TSM local time is greater that the local time fetched from the ITP simulator, in the loop the TSM does not advance the simulation time, but wastes some CPU (delay(some seconds)) and then checks again if the ITP time has increased. When the TSM time has been reached by the ITP, the TSM simulator logs its current time and proceeds with the simulation.

5.4 The project evaluation

5.4.1 Cost-Benefit Analyses in PLATFORM

In CBA, costs and benefits (effects) of with-project scenarios are systematically presented in a balance sheet. Costs are compared with benefits and the choice of
the best solution descends from the value of some or all of the following indicators with respect to the do-nothing scenario:

- Internal Rate of Return (IRR);
- Net Present Value (NPV);
- Benefits-to-Costs Ratio (BCR);
- Pay-Back Period (PBP).

In conducting a CBA the following steps must be taken:

- definition of the do-nothing and with-project scenarios;
- identification and evaluation of costs and benefits;
- choice of the evaluation criteria;
- discounting and balance;
- sensitivity analysis;
- decision.

The do-nothing scenario is the base situation to which every comparison is always referred. Once it is drafted, results can be gathered from real-world observations (both inputs and outputs of the simulator), if available, either running the simulator, using as inputs the data of the current situation and considering the simulation outputs as measurements. In any case, it is useful to run the simulator and to compare simulation outputs and measured data in order to calibrate the simulator in a feedback process.

The with-project scenarios describe the terminal and in general the transport chain once different policies and/or technologies are adopted to improve the productivity of the transport chain focused on the terminal enhancement. These scenarios will be compared with the base scenario: results will be gathered running the simulator, simply considering outputs as measurements.

The identification of costs and benefits, and the related evaluation, must be conducted specifically for each different category of commercial actors. Even if the main goal of minimising costs is the same for all of them, different items must be considered in each analysis in relation with the specificity of the service supplied by the actors.

Costs and benefits in the appraisal will vary according to the possibility of obtaining the necessary input data and among schemes (for example, criteria which are relevant to national schemes may not be relevant to international ones). The following impacts are indicated as mandatory in the EURET studies [43]:

- construction costs;\(^2\)

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\(^2\) Labour, raw materials and logistic, equipment, delays to traffic during the construction, land and property acquisition including compensation, measures to reduce negative impacts.
...transport costs;  
...travel time savings;  
...safety savings;  
...local environment;  
...revenues.

Relevant costs and benefits in the PLATFORM evaluation for terminal operators, forwarders and rail operators will be analysed later on.

Since many transport investments have potentially long lives, the decision to make such investments rests inherently on long-term forecasts of traffic. Costs and benefits should be evaluated taking into account the useful life of the investment and the related forecast traffic. Year by year the number of ITUs managed in the terminal changes in the different scenarios, which must be updated with the forecast growth. Observed trends in traffic growth can be used for forecasts in the do-nothing scenario, while the modal shift induced by the alternative scenarios of development can be forecast in relation to the overall transport price reduction that the projected enhancements allow.

Discounting of costs and benefits (impacts) is needed in order to compare cash flows that occur at different times. A monetary impact that occurs during the first year of the investment life has a higher value than the same impact occurring later. In discounting it is usual to take the current year, rather than a future year, as a benchmark. In this way monetary impacts at present are worth their real value, while impacts in future years will be adjusted by calculating their present value.

The CBA basic rule for accepting a project is that its NPV, the sum of discounted cash flows during the useful life of the investment, is positive. Alternative criteria are that IRR, the interest rate which makes NPV equal to zero, is greater than the interest rate or that BCR, the ratio of benefits to costs, is greater than the unit.

on nature and landscape.

3 General operating costs, infrastructure operating costs, operating costs of transport means, infrastructure maintaining costs, standing costs of transport means.

4 Working and non-working time by vehicle category, such as cars, LCVs, HCVs, buses, etc.

5 Fatalities, serious injuries, slight injuries, damage-only accidents, environmental damage from accidents.

6 Noise, vibration, atmospheric pollution, visual intrusion, severance, planning blight, disruption during construction, land take/open spaces, landscape and townscape, effects on agriculture and nature.

7 Receipts in money terms.

8 The most advanced procedures for traffic forecasting fall into three stages. The first involves estimating the volume and location of future economic activities output and consumption, including exports and imports; analogous estimates of future population are also needed. In the second stage, the output and population data are translated into traffic, both by volume and by origin and destination. In the third stage, the traffic is distributed to the transport modes and routes.
These rules are similar, and all of them state that a project fulfils the requirement that it is more profitable than a borrowing or lending interest rate (the opportunity costs of capital). The last two criteria, however, do not give consideration to the absolute value of the NPV of a project; as a consequence they should be used with caution in comparisons of projects of different sizes and exclusive of each other: when there is no budget constraint, it is always the project with the highest NPV, used in the PLATFORM evaluation process, which must be chosen (which means the project which reaches the highest possible level of utility).

The enhancement of performances of an intermodal terminal derives from the adoption of different kind of measures. **Terminal operators** can adopt new management procedures and/or technologies, purchase new handling equipment, enlarge the terminal areas (terminal gates, rail tracks, buffer areas, storage areas).

Benefits derived from these enhancements can be measured in terms of increase in revenues, which are directly proportional to the number of ITUs handled: the PLATFORM simulator supplies this indicator as output. The ITUs must be differentiated depending on the destination, due to different transport fares.

At present storage areas are free of charge for shippers and forwarders for the time they leave the ITUs in the terminal. The possibility of making these operators pay for this parking is under evaluation. In this case revenues from parking should be considered in the CBA. The PLATFORM simulator supplies as output the average number of ITUs stored, average storage space occupied and the average storage time. The effects on the balance of operators of different levels of pricing can be investigated.

Parking pricing can have a negative impact on demand, which is influenced for the main part by transport costs. On the other side, shippers and forwarders are pushed towards a higher use of the intermodal transport by increasing the service reliability. The PLATFORM simulator measures the service reliability in terms of percentage of ITU to reschedule, overall time lost in loading/unloading operations, overall time a truck spends in the terminal (from the approach to the gate, including the queue, to when it leaves).

The benefits must be compared with the costs to be afforded to implement and maintain the terminal enhancements, some of them supplied by the simulator as outputs, other to be supplied to the simulator as inputs to be analysed:

- real estate acquisition costs (land and property acquired to realise the project);
- engineering construction costs (materials, labours and cost for alleviating environmental impacts);
- equipment costs (cranes, front lifters and trucks on internal service as well as hardware and software for management purposes);
- periodic costs (renewal and maintenance costs, highly influenced by the number of movements which damage the pavement that must be maintained);
operating and administrative costs (the simulator gives as an explicit output the costs related with the crane movements; costs of personnel must be added);

interest payments on loans (only the loans taken to found the project);

taxes (the difference in taxes due to the projects accounts here).

Also in the case of forwarders benefits can be measured in terms of increase in revenues deriving from the number of ITUs handled.

If forwarders supply also road-only services on the analysed links, the modal shift from road-only transport to intermodal transport must be taken into account. The increase in revenues deriving from a higher number of ITUs on intermodal transport can be lowered by a decrease in road-only transport. These revenues depend on the destination of freight transported.

The costs to be taken into account are:

- real estate acquisition costs (enlargement of warehouses, etc.);
- equipment costs (costs of new trucks and ITUs, etc.);
- periodical costs (renewal and maintenance costs, proportional to the number of trucks composing the fleet and to the distance covered in a year by each truck);
- operating and administrative costs (if workers are paid independently of the time they work, this is a fixed cost; otherwise, at least for trucks driver, it is proportional to the time they work);
- interest payments on loans;
- taxes.

There are several other parameters quantified by the simulator and not explicitly considered in the CBA. For example, keeping constant fleet dimension and drivers employed, the reduction of non-productive journeys means to increase the number of ITU handled and higher revenues. Therefore the minimisation of non-productive journeys is implicitly operated by the simulator: forwarders interested in evaluating whether a certain project allows a reduction of non-productive journeys can simply run the simulation and look at the outputs, without performing the CBA.

Rail operators can measure benefits in terms of increase in revenues deriving from the number of trains served by the terminal. The simulator does not state this quantity, which is an input to the simulation, in terms of train timetable. The simulator analyses the possibility of serving more trains than in the do-nothing scenario; the consequent request of new train paths by the terminal managers can be translated into additional revenues for the rail operator.
Costs and benefits to consider now are in the following list:

- real estate acquisition costs;
- engineering construction costs;
- equipment costs;
- periodical costs (renewal and maintenance costs of rails and rolling stocks, the first depending on the number of trains travelling on the corridor, the second on the number of wagon trips);
- operating and administrative costs (costs for personnel is related to the number of circulating trains);
- interest payments on loans;
- taxes.

Other indicators evaluated by the PLATFORM simulator, in which the rail operator may be interested, are related to the optimal usage of personnel and rolling stock and to the level of satisfaction of their clients. Indicators of these evaluations are reported below. The optimisation of rolling stock and personnel usage is given by the \textit{average time spent by trains in the terminal}. The level of satisfaction of clients can be expressed in terms of punctuality (\textit{average difference between actual and planned arrival/departure time}).

### 5.4.2 Multi-Criteria Analysis in PLATFORM

Authorities are concerned with the welfare of the community and therefore impacts such as pollution, energy consumption and safety are more important than net profits.

The evaluation method that can most correctly evaluate the impact of these effects is MCA. Several MCA methods have been developed and used over the years, the common characteristic among them being the opportunity to rank several possible projects. Even if all MCA are developed on a common basis, they can easily lead to different solutions. The presence of more or less objectives weights decreases the degree of freedom left to the evaluator: the freer he is to choose, the more he needs to be a sector expert.

The MCA chosen for PLATFORM is one of the simplest methods and derives directly from the so called \textit{conjunctive model}. It requires a set of measurable criteria (an indicator can be used as a criterion as well as a set of indicators variously combined) and the arbitrarily defined \textit{acceptance point} for each criterion: the project is acceptable only if the values assumed by all the indicators are higher than the respective acceptance points.

This MCA does not allow the ranking among alternatives or projects: it just makes the evaluator determine if the intervention can or cannot be implemented.
Regarding intermodal transport, authorities aim to:

- reduce external effects of road transport;
- improve safety;
- reduce energy consumption;
- reduce costs of transport.

The first three objectives are strictly dependent on the kilometres travelled by heavy vehicles on the road network; the third is also influenced by the number of movements of cranes and other equipment in the terminal; the fourth depends on the results of the CBA performed for the commercial actors of the transport chain (one for each leg of the chain).

The chosen criteria in the MCA are then three:

- the difference between the kilometres travelled in the do-nothing scenario and in the with-project scenario is not negative (in this calculation the trips the forwarders make to feed the terminals and the road-only transport trips are included);
- the difference between the number of equipment movements per ITU in the do-nothing scenario and in the with-project scenario is not negative;
- the three CBA all have a positive net present value.

This means that to perform this MCA the three CBAs must be run. If the project is implemented in only one leg of the chain the investment costs are null in the other legs but the benefits (or drawbacks) must be evaluated in any case.

5.4.2 The simulation scenarios

Depending on the preferences expressed by intermodal operators throughout Europe, the increase in the productivity of their terminals must be investigated in tandem with project scenarios to be compared with the do-nothing scenario, each containing the scenarios of the previous levels:

- present situation;
- adoption of computer-aided management;
- adoption of new transhipment equipment.

The succession of the scenarios, in the order they are reported, corresponds to increasing levels of investments: the less the operators must invest to improve the productivity of the terminal and the level of the service they offer, the more the service itself can attract new market shares to intermodality.

Present situation

The do-nothing scenario is the term of comparison for the evaluation. It is necessary to simulate it also for calibration purposes.
Some input data for the simulation of this scenario (e.g. train timetable, trucks arrival time at the road-gate) have been supplied by CEMAT for one week of operations. The terminal working parameters (e.g. operational time of the cranes, service time at the road gate) are taken from the questionnaires filled by the operators at the beginning of the project.

To simplify the set up of the database, the start and end time of the terminal operations for both the operators and the clients has been unified between 5.15 and 23.15. This 18 hours period has been subdivided into 3 shifts, each of 6 hours. The allocation of resources and the availability of the rail and road gates have been defined with respect to this partition into shifts.

The simulator uses two types of transhipment equipment: gantry cranes, to load and unload trains, and lifters, to move the ITUs to and from the storage area. In the simulation of Verona, where some rail tracks are not served by gantries, some lifters have been defined with the function of gantries, but using their proper handling capacities, to allow the ITUs transhipment.

In order to serve the trucks coming early on Monday to pick up their ITUs, some train arrivals and handling have been simulated on the Saturday before. This procedure allowed for the definition of an initial state of the terminal buffer and storage areas.

Since the composition of the trains was not made available, the most obvious choice has been made: each ITU has been attributed to the first train arriving or leaving the terminal, depending on the truck arrival time respectively for pick up or delivery.

Also the attribution of the trains to the tracks was not available. For the simulation the trains have been attributed to the platforms and the tracks depending on the terminals served, which means that trains with the same origin/destination have been simulated as served on the tracks belonging to the same platform.

Finally, due to lack of data, it has been imposed that the trucks operate only one type of operation in the terminal, pick up or delivery, which is very close to the real behaviour.

Given the above hypotheses, the simulation of the system has given a good approximation of the reality.

The time spent in queue at the road gate varies between the observed minimum technical time of 8 minutes and a maximum of 54 minutes. It can be observed (figure 5.34) that the difference between two different peaks is approximately 12 hours, to underline the morning peak period at about 9.00 and the evening period at 20.00. The peak flows are higher at the end of the week.
Figure 5.34. Time spent at the road gate during the simulation

Figure 5.35. Distribution of the time spent at the road gate
The average time spent in queue at the road gate to enter the terminal is about 15 minutes, which means 7 percent less than the observed average time (16 minutes). The minimum technical time of 8 minutes is reached in 30% of the cases. The average time of 16 minutes is not overcome in 70 percent of the cases, while 90 percent of the trucks spend less than half an hour.

After having entered the terminal, the trucks spend an average time of 22 minutes for the internal movement and the transhipment of the ITUs. The equipment operates an average of 1.7 movements per ITU, which means that about 30 percent of the ITUs are directly moved from the train to the truck or vice versa.

The residence time of the ITUs in the terminal is very close to the real one. The overall average residence time amounts to 13 hours and in 90 percent of the cases this time is lower than 48 hours. For the ITUs delivered by train, the average residence time is 17 hours, in 90 percent of the cases it is lower than 43 hours, while the maximum simulated amounts to 75 hours. The average residence time of the ITUs delivered by truck is 10 hours, in 90 percent of the cases the residence time is lower than 24 hours and the simulated maximum is 60 hours.

![Figure 5.36. Buffer areas occupancy level](image)
Each train, considering that on each platform more trains are handled in parallel, occupies in the average the track about 4 hours for the loading or the unloading operations.

Finally the buffer areas along the rail tracks are used on average for 31 percent of their capacity (figure 5.36). The storage area remains substantially unused.

These results show that the Terminal Simulation model can be judged a valid representation of the Quadrante Europa Terminal for our evaluation purposes.

Adoption of computer-aided management

At present intermodal terminals are generally managed without the help of computer applications and information technologies: the terminal management depends greatly on the policies adopted, peculiar to each terminal, which are applied manually by the managers on the basis of their experience.

Forwarder companies and intermodal terminals are not co-ordinated at all and the the ITU trips are planned manually.

The adoption of computer-aided management can lead to lower service times of almost all the procedures adopted in a terminal, from the planing of ITU trips to the positioning of ITUs on the yard to the road and rail gate management.

The PLATFORM simulator allows the definition of the times required by each operation as input data. These times will be reasonably varied until the maximum capacity of the terminal is reached (full capacity of storage and buffer areas and/or transhipment equipment and/or rail tracks as they are at present).

To foresee the effects of optimised intermodal planning PLATFORM developed an intermodal planning simulator reproducing the computer-aided planning of ITU trips. Unfortunately, during the compilation of data for the evaluation report, we encountered unforeseen problems with the Intermodal Transport Planner and the Road Network simulator; the software that works very well with the test data we developed during the project (including concurrent simulation of road and rail network throughout three subsequent days with 25 intermodal orders planned) runs into memory problems when invoked with the data compiled for the evaluation because the number of intermodal orders is much higher than in the test-scenarios.

The effect of such computer-aided planning have, therefore, been investigated extrapolating from tests performed with small databases (23, 25 and 45 orders) the optimised arrival/departure distributions of trucks respect the train timetable and the decreasing percentage of non-productive road journey.

The extrapolation was made possible since the Terminal Simulator, besides interacting on-line with the ITP to accept planned truck arrivals at the road gate, allows the insertion of off-line planned truck arrivals by accessing a database.
table. Thus, the results of the ITP, produced on a small set of orders, have been extrapolated and used to manually generate a table of planned truck arrivals, which have been fed into the Terminal simulator.

Two parameters, then, characterise such a scenario:

- **automated road gate**, in which the effects of a 50 percent decrease in the time taken at the road gate has been added, as a consequence of a full automation of the gate operations;

- **traffic planning**, in which the effects of traffic planning have been added, as a consequence of the adoption of integrated telecommunication technologies among the forwarding agencies, the trucks and the terminal.\(^9\)

This scenario is fully evaluated from the economic and socio-economic points of view.

**Adoption of new transhipment equipment**

If this first-level simulation will determine bottlenecks in the operations of the transhipment equipment, the analysis will consider a higher number of cranes and lifters and/or innovative equipment with lower service times for transhipment in order to reach the maximum capacity of the terminal (full capacity of storage and buffer areas and/or rail tracks as they are at present).

The decision of the increase in the physical dimensions of the terminal (higher number of tracks, wider storage areas, etc.) automatically implies an increase in capacity. This is the most expensive typology of intervention and, consequently, is the **ultima ratio** for the terminal operators. The PLATFORM environment permits analysis of the implementation of such improvements, which however will be not analysed during the project evaluation phase.

The third scenario is represented in the PLATFORM project by the adoption of faster transhipment equipment. In the simulations the fast transhipment is obtained increasing the hourly performance of cranes and lifters.

The only new parameter with respect to the previous scenario is:

- **fast transhipment**, in which the performances of the cranes and lifters used in the terminal has been increased by 20 percent;

A full evaluation of this scenario has not been performed, although the tools realised allow it having the right input data, because none of the investigated fast transhipment technologies are yet on the market; no installation or maintenance costs are available either.

\(^9\) The simulation consisted in applying constant trucks arrivals at each train with respect to the train departure/arrival time.
The functionality of the fast transhipment has been shown in terms of performances of the terminal (see section 5.4.3, below).
5.4.3 Evaluation assessment

The PLATFORM project produced a simulation environment and an evaluation methodology. The methodology supplies a tool for evaluating the economic profitability (CBAs) and the social benefits (MCA) of an investment for the enhancement of the intermodal terminals. The main indicators to perform the CBAs and the MCA are supplied by the runs of the simulation environment. The simulation environment, however, also supplies other important results to assist understanding of the functioning of the overall system. The data elaborated by the simulator (queues at the terminal gates, ITUs in the storage and buffer areas, loading/unloading times and flows, terminal state, time required to serve a truck from arrival to departure), represented in the form of time graphs and distributions, should facilitate decision making for traffic management.

Comparison among simulated scenarios

Three different configurations have been simulated and compared with the present state (table 5.1):

- fast transhipment, in which the capacity of the cranes and lifters used in the terminal has been increased by 20 percent;
- automated road gate, in which the effects of a 50 percent decrease in the time taken at the road gate has been added, as a consequence of a full automation of the gate operations;
- traffic planning, in which the effects of traffic planning have been added, as a consequence of the adoption of integrated telecommunication technologies among the forwarding agencies, the trucks and the terminal.

The adoption of only new transhipment equipment has no influence on the characteristics of the entering truck flow. However, it affects the overall duration of the permanence of the trucks in the terminal: the operations internal to the infrastructure require in the average 16 minutes. Considering queue at the road gate and internal operations as a whole, the reduction in time amounts to 17 percent of the present state.

The adoption of telematics for the road gate can provide an additional advantage to the forwarders. It has been simulated, by halving the minimum technical time at the road gate in parallel with the adoption of faster transhipment technologies, a lowering of the time needed to enter the terminal to 6 minutes, while the time spent internally to the terminal is again about 16 minutes. The overall decrease in time, 37 percent, is greater.

The appropriate organisation of the trucks flow can lower the time spent by the trucks in delivering/picking up the ITUs by 46 percent. This decrease is less than expected, but it must be considered that the number of productive journeys has increased. The share of this kind of journey increases from less than 10 percent in
the present state to more than 20 percent in the traffic planning scenario. If the train timetable is adapted to better fit the truck service, this share can increase further.

In the fast transhipment scenario, the share of direct transhipments drops to 20 percent, in this way increasing the number of movements of cranes and lifters. The same result is given by the simulation of the automated road gate scenario. The absence of co-ordination between trucks and terminal increase the resources consumption.

this problem is overcome in the traffic planning scenario: the share of direct transhipments increases to 70 percent, while the crane movements per ITU decrease drastically to 1.3.

The fast transhipment scenario and the automated road gate scenario show a residence time of the ITUs in the terminal somewhat less than in the present case, but the difference is negligible. The very significant change occurs in the traffic planning scenario, in which the average residence time is almost 70 percent lower, due to the higher number of rendezvous between trucks and trains.

As a consequence the average occupancy of the buffer areas has a slight increase from 31 in the present state to 32 percent in the fast transhipment and automated road gate scenarios. The traffic planning scenario shows a decrease in the average occupancy to 12 percent. The maximum occupancy rate rises from about 80 to 100 percent.

The storage area too presents a different use in the final scenario: while in the present state and in the first two scenarios it is substantially unused, an average occupancy of 40 percent and a maximum of 90 percent is simulated in the final scenario.

In the average the storage spaces available in the terminal are used at a lower level, but with peak periods when they are used almost at capacity.

In the present state, each train occupies the track for loading or unloading purposes about 3.8 hours, considering that more trains are handled in parallel. In the fast transhipment and in the automated road gate scenarios this time decreases to 3.5 hours, which is about 10 percent lower. In the traffic planning scenario the decrease amounts to 30 percent, since the average time needed to load or unload a train decreases to 2.7 hours.

These results demonstrate that the use of new transhipment technologies and telematics for the management of the road gate cannot modify substantially the situation of the terminal without the aid of telecommunication technologies for the management of the road traffic.
Table 5.1. Comparison of simulation scenarios

<table>
<thead>
<tr>
<th></th>
<th>Present state</th>
<th>Fast transhipment</th>
<th>Automated road gate</th>
<th>Traffic planning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trucks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average time at the road gate (min)</td>
<td>15</td>
<td>15</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Average time in the terminal (min)</td>
<td>22</td>
<td>16</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td><strong>Cranes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average movements per ITU</td>
<td>1.7</td>
<td>1.8</td>
<td>1.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Direct transhipments (percent)</td>
<td>27</td>
<td>19</td>
<td>19</td>
<td>69</td>
</tr>
<tr>
<td><strong>ITUs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average residence time in the terminal (h)</td>
<td>12.6</td>
<td>12.4</td>
<td>12.3</td>
<td>4.0</td>
</tr>
<tr>
<td><strong>Buffer areas</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average occupancy rate (percent)</td>
<td>31</td>
<td>32</td>
<td>32</td>
<td>12</td>
</tr>
<tr>
<td>Maximum occupancy rate (percent)</td>
<td>78</td>
<td>79</td>
<td>79</td>
<td>100</td>
</tr>
<tr>
<td><strong>Storage areas</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average occupancy rate (percent)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>38</td>
</tr>
<tr>
<td>Maximum occupancy rate (percent)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td><strong>Trains</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average loading or unloading time (h)</td>
<td>3.8</td>
<td>3.5</td>
<td>3.5</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Evaluation of “computer-aided management” scenario

The PLATFORM simulation environment can be used by four different actors since it reproduces the entire intermodal chain: terminal managers, railways operators, forwarding companies and authorities. For this reason the PLATFORM evaluation methodology (see section 5.4.1 for more) is not oriented to one decision-maker but considers the point of view of the four actors. The needs of the first three, commercial actors, are analysed with cost-benefit analysis; the authorities point of view is analysed with a multicriteria analysis (conjunctive method).
In this section the results of the application of this evaluation methodology to the computer-aided management scenario are given.

A CBA has six steps:

- definition of the do-nothing and with project scenarios;
- identification and evaluation of costs and benefits;
- choice of the evaluation criteria,
- discounting and balance;
- sensitivity analysis;
- decision.

In a CBA the with-project situation must be compared with the do-nothing situation at the same time; projects requiring big investments (and thus a long payback period) need forecasting of the market trends, both natural and those induced by the project. The scenario evaluated here has low investment costs and a short application time. The do-nothing and the with-project scenarios are both analysed with the present market situation, without forecasting changes.

Precise quantification of the investment and maintenance costs of a computer-aided management system has not been performed because a detailed technical specification of the system was necessary and this is not the scope of PLATFORM project. Furthermore, with respect to the other terminal, road and rail equipment a computer system has a negligible cost. The benefits induced are represented by expense reduction, such as those related to crane movements (energy consumption, maintenance costs, personnel time, asphalt consumption), and future possible modal shift from road-only transport induced by the increased level of service provided.

The evaluation criteria adopted in PLATFORM is the Net Present Value as stated in the methodology definition.

The analysis period is one year (or less), so no discounting of costs and revenues is necessary. The adoption of such a system is practically free and produces the main benefit of reducing the crane operations number and service time, the direct transhipment increases to 69% and the number of movement per ITU managed decreases to 1.3 (see fourth column of table 4.1) from 1.7.

The sensitivity analysis has to be performed to ensure that even changing some of the assumptions the investment continues to be profitable. In this case, since no discount rate has been considered and no forecasting has been made, the sensitivity analysis is unnecessary.

The evaluation of this scenario is therefore extremely positive for terminal managers. The NPV is directly obtained by the reduced personnel, maintenance and operational costs. Future expectations are also possible since adopting such a system the terminal, even with the same transhipment equipment, has a higher
capacity and better performances.

The cost-benefit analysis from the railway operator’s point of view is even easier. No investments at all are required and no direct benefits are visible. The NPV for rail operators is zero.

A traffic growth that without efforts of any kind will produce benefits for railways can be expected.

Even if the NPV must be positive to make a scenario acceptable to an evaluator, in this particular case no decision making is required to railways, and no disbenefits at all are foreseeable. The rail operator have not to decide if adopt or not the system but can be sure that if the other actors will decide in that sense he will have a return.

This evaluation demonstrated that forwarders are the actors that would have the highest benefits adopting such a system.

Most forwarders’ operational costs are directly dependent on the number of kilometres travelled. At the moment nearly half of the trips are non-productive; the adoption of such a system will reduce the number of non-productive journeys to one third.

Furthermore the time lost in the terminal for loading/unloading is decreased from 22 to 14 minutes per ITU, with a gain also in terms of time.

The NPV is in this case given by the reduction of operational costs, and it is positive.

The multicriteria method chosen for evaluating the authorities’ point of view on the simulated scenario is the conjunctive method.

MCA produces a yes or no answer to whether a project is to be approved or not.

To be approved a scenario must give positive answers to five criteria:

- non-negative NPV in terminals CBA;
- non-negative NPV in railways CBA;
- non-negative NPV in forwarders CBA;
- overall reduction of the kilometres travelled on the road;
- overall reduction of number of crane movements, which means lower energy consumption and higher safety.

As already seen, the three CBAs have non-negative NPV; the kilometres travelled

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10 These figure is extrapolated from simulation performed on test databases since memory problems made impossible to adopt the ITP on this scenario
on the road by trucks operating the road leg of the intermodal chain decreased and considering a possible modal shift even the road-only can have a reduction of kilometres travelled; the number of crane movements is reduced of around 25%.

All the criteria give positive answer, then the scenario can be positively evaluated.
6 CONCLUSIONS AND RECOMMENDATIONS

The PLATFORM project addresses task 3.2/7, “Terminal control”, of the ITC work programme, 3rd Call for Proposals of the Transport Research Programme, Directorate General VII of the European Union. The project has implemented a simulation environment for the assessment of impacts produced by the adoption of different technologies and management policies to enhance freight intermodal terminal performances.

PLATFORM’s main objective was to implement a more cost-effective way to manage freight-traffic flows through the enhancement of terminal management and the integration of existing telematic systems.

The PLATFORM approach addresses rail–road terminals for rail–road transfer based on a computerised control and management system. A smooth organisation for pre-haulage and end-haulage, as well as the completely computerised management of terminal services, has been demonstrated through computer simulation of the transport flow (modelling input and output streams of both rail and road) and the terminal services. The system for the management of integrated rail–road transport has been developed and tested in selected demo terminals on a corridor available to Consortium member.

The approach has been divided into three main phases:

- analyse operators’ requirements and produce guidelines for the implementation of the PLATFORM integrated simulation environment;
- design and implement the integrated simulation environment;
- validate the integrated simulation environment on the basis of data gathered from a real test terminal, and define a standard methodology for the evaluation of the simulation results.

The first phase investigated the needs of rail–road terminal operators and users through a set of interviews and questionnaires. It highlighted the minimum requirements of an intermodal terminal of the future and designed guidelines for the implementation of simulation environment and evaluation methodology. To sum up, a computer-controlled freight terminal should have the following features:

- fast loading/unloading devices;
- computer-aided positioning of the terminal equipment to optimise transfers and on-board devices for receiving transfer instructions;
intelligent gate procedures and automated guidance of trucks to reserved loading places;
computer-based booking and dispatch systems for the reservation of transport capacity and for the allocation of loading time and position;
telematic systems for terminal-to-truck and truck-to-terminal communication, which allow for automated booking and cancelling;
electronic devices to automatically locate and register the ITU position in the yard (hand-held PCs used by crane operators and terminal managers);
computer-aided yard allocation policies, conditioned by the availability of information on the ITU positions in the yard.

The second phase designed and implemented the simulation environment.

The PLATFORM simulation environment consists of two subsystems which simulate the transport of each ITU in an intermodal corridor: the intermodal transport planner (ITP), which operates the planning of the whole intermodal transport task (ITT) for an ITU, and the intermodal transport simulator (ITS), which operates the execution of the ITT for each ITU, including internal terminal operations.

The ITP consists of three elements:

- the intermodal planning and execution units (IPnEUs);
- the forwarding agents;
- the booking agent.

The IPnEUs plan the whole ITT, splitting it into its three legs. They contact the specialised agents for planning and booking of these legs. Since PLATFORM deals with time-tabled railway transport, the IPnEU first tries to find the most suitable train for the rail based transport leg. This then constrains the more flexible road based pre- and end haulage.

The booking agent performs the planning and booking of the ITU journey by train. This agent is asked for free capacity on the time-tabled trains. It applies a constraint solver in order to check which bookings are possible. The booking agent chooses the best solution and makes the reservation.

The forwarding agents handle the planning and booking of the ITU journey by truck: these agents are responsible for the planning of delivery to and pick-up from terminals. Each forwarder is modelled through a forwarding agent. At each terminal a road network area broker agent co-ordinates the planning of the forwarding agents of the area around the terminal. All these agents are realised by instances of the TELETRUCK system.

Each IPnEU is associated with an intermodal transport order. After planning and scheduling activities are finished it supervises the simulated transport execution.
The ITS is also composed of three elements:

- the road simulation module (RSM);
- the terminal simulation module (TSM);
- the corridor simulation module (CSM).

The RSM simulates the trip legs provided by forwarders, i.e. the transport of the ITU by truck. According to the schedules for delivery and pick-up of the ITUs at the two terminals, the flow of trucks between each terminal and the customers at its local region is simulated.

The TSM simulates loading and unloading of ITUs between trucks and trains as well as storing of ITUs in the intermodal terminal. Equipment, platforms, yard areas and gate procedures are simulated in order to demonstrate the functionality of the terminal and potential for improvement. The TSM can work independently of the RSM since it is provided with a Truck Arrival Generation Module (which enables the Terminal Simulation user to select the characteristics of the truck arrival distribution).

The CSM simulates the flow of trains between terminals. According to the timetables, flow of trains from and to the terminals is simulated focusing especially the train flow within the chosen corridor.

A graphical user interface (GUI) allows for customising the simulation, for selecting the important parameters, views and maps, and for inspection of the input and output data of the simulation.

The third phase validated the simulation environment on the test site of Verona Quadrante Europa intermodal terminal; it realised and applied an evaluation methodology to the scenarios simulated and demonstrated the need for a computer aided management of the intermodal transport chain.

The validation was performed simulating a working week of the Verona terminal and comparing the results with the data measured. It was shown that the simulation environment is able to reproduce accurately the terminal operations and performances.

An evaluation methodology was developed ad hoc since the PLATFORM simulation environment, reproducing the entire intermodal chain, can be used by four different actors: terminal managers, railways operators, forwarding companies and authorities. For this reason the PLATFORM evaluation methodology is not oriented to one decision-maker but considers the point of view of the four actors. The needs of the first three, commercial actors, are analysed with cost-benefit analysis; the authorities point of view is analysed with a multicriteria analysis (conjunctive method).

Three scenarios where simulated and evaluated:

- present situation;
It was shown that the adoption of faster transhipment devices is not useful if it is not supported by the adoption of computer-aided management and that the adoption of such systems is cost-effective for every actor in the chain.

The CBAs and MCA highlighted a high convenience for every actor involved in the chain in adopting computer-aided management. The only foreseen limitation to the effectiveness of such a policy, albeit not negligible, is the necessity of the adoption of devices by every single forwarder and every terminal to make the system working.

It emerges clearly that the path to follow for the improvement of the intermodal transport passes through the adoption of computer-aided management to realise really integrated “computer-controlled freight platforms”.

PLATFORM itself represents a first step in this direction since the tools developed can be used as off-line instruments by the low and medium level management to analyse and evaluate different policies.

The entire PLATFORM environment can help the high level management and the decision makers of the intermodal transport chain to evaluate high-level policies aimed at improving the intermodal transport.

PLATFORM is already working as an off-line tool but it will soon be possible to develop on that base a terminal-oriented on-line tool able to choose the optimal management policy in every situation, to drive the operations and to communicate with the trucks arriving to pick-up or deliver ITUs.
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GLOSSARY

This glossary lists the principal terms used in the intermodal transport world and in the PLATFORM project. The definitions, where available, have been gathered from the terminology on intermodal transport approved by the Ministers of Transport of the European Community. Specific terms used in this deliverable have been added for the sake of clarity.

Accompanied transport  Transport of complete road vehicles through another mode of transport (for example by ferry or by train) accompanied by the driver.

Adaptive memory programming  A meta-heuristic approach to optimisation problems. The term can be viewed as a general term classifying approaches to optimisation which use a sub-optimal initial solution and refine this given more computing time.

AEI  Automatic Equipment Identification

Air container  A container conforming to standards laid down for air transportation.

Ant system  A programming paradigm inspired by real ant colonies. The system finds shortest paths by using an analogy to the pheromone trails real ants leave as they move towards a food source.

Articulated vehicle  A motor vehicle coupled to a semi-trailer.

ATT  Automatic Tracking and Tracing systems to make digitised data available on computers without human processing. Automatic identification is a component of tracking technologies, which are an important part of many advanced communications and information technologies being used to improve the efficiency in freight transportation.
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
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<tbody>
<tr>
<td>AVL</td>
<td>Automatic Vehicle Location systems to monitor movement of vehicles. Two-way communication system establishes a bi-directional communication between the operator and the drivers to very long distances.</td>
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<tr>
<td>Booking Agent (BA)</td>
<td>Software system which organises booking in an intermodal terminal.</td>
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<tr>
<td>Combined transport</td>
<td>Rail–road intermodal transport of swap bodies, semi-trailers and complete vehicles.</td>
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<td>Container transport</td>
<td>Intermodal transport of containers.</td>
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<tr>
<td>Container</td>
<td>A special box to carry freight, strengthened and stackable and allowing horizontal or vertical transfer.</td>
</tr>
<tr>
<td>Corner fittings</td>
<td>Standard fixing points of ITUs on the carrying vessel or vehicle.</td>
</tr>
<tr>
<td>CPCF</td>
<td>Container-On-Flat-Car.</td>
</tr>
<tr>
<td>CVISN</td>
<td>Commercial Vehicle Systems and Networks.</td>
</tr>
<tr>
<td>Direct transfer</td>
<td>Transhipment of an ITU directly from/to the truck, without storage in the yard.</td>
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<tr>
<td>Double stack wagon</td>
<td>A rail wagon designed for the transport of containers stacked on two levels.</td>
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<tr>
<td>Dynamic order scheduling</td>
<td>Scheduling on-line of orders, that is viewing the scheduling process as an open ended process.</td>
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<tr>
<td>EDI</td>
<td>Electronic Data Interface systems for the electronic exchange of transport documents, orders, etc., in a standardised form between road hauliers, clients and receivers.</td>
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<td>EDIFACT</td>
<td>Electronic Data Interchange for Administration Commerce and Transport.</td>
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<td>EDRM2</td>
<td>European Digital Road Map 2.</td>
</tr>
<tr>
<td>Feeder</td>
<td>Ships/trains used to serve feeder terminals from a hub terminal served by mother ships/trains.</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>FFM</td>
<td>Freight and Fleet Management.</td>
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<tr>
<td>FIFO</td>
<td>First-In–First-Out.</td>
</tr>
<tr>
<td>Final Leg (FL[D</td>
<td>O</td>
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<tr>
<td>FM</td>
<td>Fleet and Resource Management, that is, all activities directly related to the operational management of the fleet, which are mainly concerns of the fleet operator.</td>
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<tr>
<td>Forwarding Agent (FA)</td>
<td>Software system representing the forwarding company for the negotiation of intermodal transports with clients and of transportation services with terminal operators.</td>
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<tr>
<td>Freeport</td>
<td>Zone where freight can be stored without payment of relevant duties and taxes until leaving the zone.</td>
</tr>
<tr>
<td>Freight village</td>
<td>A single large site which includes a terminal, other technical and administrative facilities associated with combined transport (agents, shippers, customs, etc.) and accommodation for companies engaged in combined transport.</td>
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<tr>
<td>Front handler</td>
<td>Tractor vehicle with front lifting equipment for stacking and moving ITUs.</td>
</tr>
<tr>
<td>Gantry crane</td>
<td>An overhead crane comprising a horizontal gantry mounted on legs which are either fixed, run in fixed tracks (gantry cranes, portainers) or on rubber tyres (transtainers) with relatively limited manoeuvre in one plan. Such cranes normally straddle a rail–road or ship–shore interchange. Rubber-tyred gantries are more mobile than gantry cranes and are used for stacking and moving containers, usually in rows, in storage areas.</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
</tbody>
</table>
GSM  Global Systems for Mobile Telecommunications

HGMC  Hazardous Goods Monitoring and Control, that is, monitoring of dangerous goods and oversize or overview transports which needs special attention.

High cube container  Container for standard ISO length and width but with extra height (2.90m instead of 2.44m). This applies for the time being only to 40' containers.

Hub  Central point for the collection, sorting and distribution of freight for a particular region or area.

ID  Identification (code).


Initial Leg (IL[D|O|P])  Initial Leg (Destination|Order|Plan). The first part of an intermodal transport. Usually this is the transportation of the ITU from the origin to the initial leg destination, which is an intermodal terminal, by truck. The initial leg is described by the intermodal transport operator in the initial leg order, which comprises all the data needed to determine the initial leg plan.

Intermodal transport (ITT)  Movement of freight in one and the same intermodal transport unit which uses successively several modes of transport without handling of the freight themselves in changing modes. It is composed of three legs: the initial leg from origin to the first terminal by truck, the main leg between two terminals by train, ship or air, the final leg from the final terminal to destination by truck.

Intermodal transport equipment  Transport equipment to be used in intermodal transport.

Intermodal transport unit (ITU)  Containers, swap bodies and semi-trailers suitable for intermodal transport.

ISO  International Standards Organisation.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT</td>
<td>Intermodal Terminal</td>
</tr>
<tr>
<td>ITCP</td>
<td>Integrated Transport Communication Platform</td>
</tr>
<tr>
<td>ITIGG</td>
<td>International Transport Implementation Guidelines Group</td>
</tr>
<tr>
<td>Jib (classic) crane</td>
<td>Conventional lifting crane where the load is suspended by a cable from a jib</td>
</tr>
<tr>
<td>JIT</td>
<td>Just-In-Time</td>
</tr>
<tr>
<td>Land container</td>
<td>Standardised container according to the International Railways Union norms (UIC), for an optimal use mainly in rail–road combined transport.</td>
</tr>
<tr>
<td>LFM</td>
<td>Logistic and Freight Management, that is activities related to the logistic chain from the supplier to the receiver of freight with the associated information and transaction flow. These activities are mainly freight owner concerns.</td>
</tr>
<tr>
<td>Lift on-Lift off (LO-LO)</td>
<td>Loading and unloading of ITUs using lifting equipment.</td>
</tr>
<tr>
<td>Lighter-Aboard-Ship (LASH)</td>
<td>A ship-borne system in which the barges are loaded inland, linked together and pushed down an inland waterway to a point that can be reached by a ship, where the barges are lifted onto the mother ship with the use of gantry cranes (variants: FLASH, SPLASH).</td>
</tr>
<tr>
<td>LMS</td>
<td>Logistic Management System</td>
</tr>
<tr>
<td>Loading track</td>
<td>Track on which freight are loaded, unloaded, transhipped from wagons onto the PLATFORM or road vehicle.</td>
</tr>
<tr>
<td>Loading unit (LU)</td>
<td>Container or swap body</td>
</tr>
<tr>
<td>Low loader wagon</td>
<td>A rail wagon with a low loading PLATFORM specially built to carry intermodal transport equipment.</td>
</tr>
</tbody>
</table>
Main Leg (ML[D|O|P])

Main Leg (Destination|Order|Plan). The main part of an intermodal transport. Usually this is the transportation of the ITU from the first intermodal terminal origin to the main leg destination, which is the final intermodal terminal, by train. The main leg is described by the intermodal transport operator in the main leg order, which comprises all the data needed to determine the main leg plan.

Maritime container

A container conforming to standards that enable it to be used in a cellular ship. Most maritime containers conform to International Standards Organisation (ISO) standards.

MDC

Mobile Data Communications.

MEM

Macro and Code Message.

Meta-heuristics

A general term to describe incremental search techniques such as simulated annealing, genetic algorithms, taboo search and the like. These techniques are also known as Neighbourhood Search Techniques.

MGOS

Modular Grid Overlay System.

Multimodal transport

Carriage of freight by at least two different modes of transport.

Neighbourhood Search Technique

See meta-heuristics.

Operations Research (OR)

Field of science concerned with optimising processes, such as production chains, queues and others.

Overpanamax

Ship with dimensions greater than 295m length, 32.25m beam overall, 13.50m draught.

Pallet

A raised platform, normally made of wood, to facilitate the lifting and stacking of goods. Pallets are of standard dimensions: 1000mm x 1200mm (ISO) and 800mm x 1200mm (CEN).

Panamax

Ship with dimensions that allow it to pass through the Panama Canal: 295m maximum length, 32.25m maximum beam overall, 13.50m maximum draught.
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piggyback transport</td>
<td>Transport of complete road vehicles on low-floor throughout wagons.</td>
</tr>
<tr>
<td>Pocket wagon</td>
<td>A rail wagon with recessed pockets to accept the road wheels of semi-trailers, and sometimes a swap body.</td>
</tr>
<tr>
<td>Rail loading gauge</td>
<td>The profile above the rail tracks through which a rail vehicle must pass. It is limited by the size of tunnels, bridges, etc., and the proximity of buildings, platforms and equipment.</td>
</tr>
<tr>
<td></td>
<td>A gauge: total height wagon + ITU 3.85m above the rail and 1.28m on either side of the track axle (UIC).</td>
</tr>
<tr>
<td></td>
<td>B gauge: total height wagon + ITU 4.08m above the rail and 1.28m on either side of the track axle (UIC).</td>
</tr>
<tr>
<td></td>
<td>B+ gauge: total height wagon + ITU 4.18m above the rail and 1.36m on either side of the track axle.</td>
</tr>
<tr>
<td></td>
<td>C gauge: total height wagon + ITU 4.65m above the rail and 1.45m on either side of the track axle (UIC).</td>
</tr>
<tr>
<td>Rail–road bimodal semi-trailer</td>
<td>A road semi-trailer to which rail bogies can be added for transport by rail and form a block train.</td>
</tr>
<tr>
<td>Reach stacker</td>
<td>Tractor vehicle with front lifting equipment for stacking and moving containers or swap bodies.</td>
</tr>
<tr>
<td>R-EDI</td>
<td>Rate EDI Network.</td>
</tr>
<tr>
<td>Road train</td>
<td>A motor vehicle coupled to a trailer.</td>
</tr>
<tr>
<td>ROADSHOW®</td>
<td>Commercial scheduling system.</td>
</tr>
<tr>
<td>Roll on-Roll off (RO-RO)</td>
<td>The facility for a road vehicle to be driven on and off a ship or, as in the case of rolling road, a train.</td>
</tr>
<tr>
<td>Rolling road</td>
<td>Intermodal transport where the major part of the European journey is by rail, inland waterways or sea and any initial and/or final leg is carried out by road are as short as possible.</td>
</tr>
<tr>
<td>Term</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>RO-RO ramp</td>
<td>A flat or inclined ramp, usually adjustable, which enables road vehicles to</td>
</tr>
<tr>
<td></td>
<td>be driven on or off a ship or a rail wagon.</td>
</tr>
<tr>
<td>Semi-trailer</td>
<td>Any vehicle intended to be coupled to a motor vehicle in such a way that</td>
</tr>
<tr>
<td></td>
<td>part of it rests on the motor vehicle and a substantial part of its weight</td>
</tr>
<tr>
<td></td>
<td>and of the weight of its load is borne by the motor vehicle. These may</td>
</tr>
<tr>
<td></td>
<td>have to be specially adapted to be used in combined transport.</td>
</tr>
<tr>
<td>Simulated trading</td>
<td>Decentralised optimisation method.</td>
</tr>
<tr>
<td>SL&amp;D</td>
<td>Simultaneous Load and Discharge.</td>
</tr>
<tr>
<td>Spreader</td>
<td>The mechanism connecting the lifting cables on a crane or gantry to a</td>
</tr>
<tr>
<td></td>
<td>container. A spreader has four adjustable fixing points designed to</td>
</tr>
<tr>
<td></td>
<td>connect with the upper twistlock corners on, usually, 20’ or 40’</td>
</tr>
<tr>
<td></td>
<td>containers.</td>
</tr>
<tr>
<td>Stacking</td>
<td>Stacking ITUs one over another.</td>
</tr>
<tr>
<td>Straddle carrier</td>
<td>A fully mobile overhead lifting vehicle for moving containers.</td>
</tr>
<tr>
<td>Stuffing/Stripping</td>
<td>Loading and unloading of cargo into or from an ITU.</td>
</tr>
<tr>
<td>Super high cube container</td>
<td>Container of extra standard ISO length, width and height. These dimensions</td>
</tr>
<tr>
<td></td>
<td>may fluctuate, reaching lengths of 45’ (13.72m), 48’ (14.64m) or 53’</td>
</tr>
<tr>
<td></td>
<td>(16.10m).</td>
</tr>
<tr>
<td>Swap body</td>
<td>Freight carrying unit not strong enough to be stackable, except in some</td>
</tr>
<tr>
<td></td>
<td>cases when empty or top-lifted. Used only in rail–road movements.</td>
</tr>
<tr>
<td>Taboo Search</td>
<td>A neighbourhood search technique. Starting from an initial (possibly not</td>
</tr>
<tr>
<td></td>
<td>optimal) solution of an optimisation problem, a taboo search algorithm</td>
</tr>
<tr>
<td></td>
<td>may find an optimal solution by marking already explored and not good</td>
</tr>
<tr>
<td></td>
<td>solutions as taboo.</td>
</tr>
<tr>
<td>Tare</td>
<td>Weight of ITU or vehicle without cargo.</td>
</tr>
</tbody>
</table>
TeleTruck | Pre-commercial system simulating road hauliers.
Terminal Agent (TA) | Software system representing the terminal operator for the management of the activities in the terminal.
Terminal | A place where a modal change takes place.
TOFC | Trailer-On-Flat-Car.
Track gauge | The distance between the internal side of rails on a railway line. It is generally 1435mm.
Trailer | Any non-powered vehicle intended to be coupled to a motor vehicle, excluding semi-trailers.
TRAMPAS | Pre-commercial system for the support of dispatch officers with partial intelligent agents.
Triptech International® | Commercial scheduling system.
Twenty-foot Equiv. Unit (TEU) | A standard unit (6.10m length) for counting containers of various lengths and for describing the capacities of container ships and terminals.
Twistlock | Standard fixing pieces for securing ITUs to the carrying vessel or vehicle.
Unaccompanied transport | Transport of road vehicles or part vehicles through an other mode of transport (for example by ferry or by train) not accompanied by the driver.
Unit load | Pallets and prepacked units to be put into an ITU. Cargo packed or grouped into discrete units which usually conform to pallet dimensions.
VM | Individual Vehicle/cargo Management, which is mainly concern of vehicle supervisors and drivers. This activity list may not pertain to the management of all types of fleets.
WAN | Wide Area Network.
ANNEXES

A.1 List of publications, conferences, presentations and if applicable patents from the project

A.1.1 DFKI

Talks during 1998:

- Klaus Fischer: *Holonic Fleet Scheduling with TELETRUCK*. AIP Conference of the American Institute of Physics, Liege, Belgium.
- Hans-Jürgen Bürcrert: *Holonic Multi-Agent Systems for Inter-company Planning of Intermodal Transport Chains*. Forum AI – Applications in Logistics, German National Conference on Artificial Intelligence, Bremen, Germany.

Talks during 1999:

- Petra Funk: *A Multi-Agent Perspective on Intermodal Transport Chains*. Logistics Management Conference, Bremen, Germany.

Publications during 1998:

Publication during 1999:


A.1.2 IDSIA

Talks during 1998:


Talks during 1999:


Publication during 1998:


Publication during 1999: