# FINAL REPORT FOR PUBLICATION

# PRECISE IT

Contract N°
IN-97-SC.2198

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Prepared for:
**EUROPEAN COMMISSION DG TREN**

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Project Duration: **01-01-1998 to 31-03-2000**

Date: **29/05/00**

Document N: D8104346

**PROJECT FUNDED BY THE EUROPEAN COMMISSION UNDER THE TRANSPORT RTD PROGRAMME OF THE 4th FRAMEWORK PROGRAMME**

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# 1. SCOPE

This documents summarises the activities performed during the development of the PRECISE IT Project (Contract N° IN-97-SC.2198) within the IV° Framework – TRANSPORT Program.

# 2. PARTNERSHIP

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**CALZONI** is one of the leading European concerns for engineering and construction in the fields of energy, defence, environment and aerospace components. The basic knowledge is in the field of mechanics and electronics, characterised by specific design and development to meet particular customer requirements.
Team of engineers, technicians and skilled personnel are committed to the study, design, manufacture, inspection and installation of the various products relying on the most advanced information systems.
For many years now CALZONI has been committed to the research and development of control systems based on the most advanced HW and SW technologies, in particular for naval applications, where it has developed a sound knowledge of positioning technologies (electronic beacons, GPS, etc.).

**METRAVIB RDS**, as a 28 years old specialist in vibration and acoustic, participates to several international programmes. In the context of the PRECISE IT Project, mainly the

experience in the field of airborne acoustic detection and location systems may be underlined. The company has been developing such devices for defence applications for more than 5 years, in particular for anti-snipers use, where METRAVIB RDS is considered offering to the world wide market the best product.
METRAVIB RDS has already several commercial references, including French army (systems used in Bosnia these past 4 years), and foreign countries as well, including Italy and Australia.
A (growing) team of presently 8 engineers is totally devoted to this range of product, covering the scientific aspects (signal processing), technological aspects (processing unit, arrays,...), and experimental side as well (on site implementation and tests).

**Rohde & Schwarz** is an internationally active company in the fields of radiocommunications and test and measurement equipment. For more than 60 years the company group has been developing, producing and marketing a wide range of electronic products and has subsidiaries and representatives in over 70 countries around the world. Rohde & Schwarz is one of the leading European suppliers of professional radio systems for use in stationary and mobile ground stations, e.g. on ships, in aeroplanes, used by embassies, authorities and armed forces. Rohde & Schwarz employs as a subcontractor Position Management Systems, which provides products and services to improve the performance of intermodal terminals. PMS is an independent consulting organisation and software development enterprise with experience in the field of DGPS applications. R&S and PMS are headquartered in Munich and Hamburg, Germany.

**LSCT** is one of the Maritime Terminal Containers in the Contship Group (the other is Medcenter Container Terminal) and is dedicated to transport in the maritime environment. The company started its activity in 1987 and today ins one of the highest technology Maritime terminal of the Mediterranean area.

**CEMAT**'s mission is to promote, organise and sell domestic and international rail-road combined transport of semi-trailers, swap bodies and lorries. In 1996, CEMAT carried out 182.000 national and 210.000 international transports.
For the fulfilment of its mission, CEMAT manages a network of 39 terminals located nation-wide that managed, in 1996, more than one million crane handling.
CEMAT has contributed to some research projects concerning combined transport:

- Feasibility study for the pilot project "Germany-Italy-Greece
- COMBICOM Project
- IQ-Intermodal quality (under way)

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# 3. EXECUTIVE SUMMARY

PRECISE IT intends to contribute to the optimisation of intermodal terminal operations, addressing those operational problems that can be put in relation to the position of ITUs and/or vehicles on the terminal.

The optimisation of the activities associated with intermodal terminal operations and the consequent reduction of operative costs are vital issues for increasing the competitiveness of intermodal transport of freight.

In many intermodal terminals additional costs, time delays and quality deficiencies are often due to the wrong positioning of ITUs and to the inefficient management of personnel and vehicles dedicated to the moving of ITUs.

The project intends to address those problems that can be put in relation to the position of ITUs and/or vehicles on the terminal. Indeed, one of the prerequisite conditions for improving the overall efficiency of the terminal operations is to have, in an automatic way, the real-time error-free information about the position of all stocked ITUs and moving vehicles inside the terminal.

# 4. OBJECTIVES OF THE PROJECT

Based on already existing and addressed technologies, the main objectives is to set-up and test a demonstration system for the automatic location of ITUs and vehicles inside intermodal terminal areas, in particular for maritime container terminals. For doing that, several technologies – GPS, acoustic, laser, RF/ID tags – will be investigated for their use in this particular field.

# 5. MEANS USED TO ACHIEVE THE OBJECTIVES

In order to achieve the objectives, the following sequence of activities have been executed:

- analysis of terminals and technologies
- design of the system and its components
- development
- testing
- conclusions

The analysis of both maritime and inland terminals was performed by the terminal operators (LSCT and CEMAT) that are partners in the project by means of internal personnel interview and on the basis of other European terminal operator experience and by CALZONI taking in consideration other EC projects dealing with intermodal transport.

The applicable technologies were analysed by R&S and METRAVIB on the basis of their experiences.

The design of the system and its components has been done using already existing and assessed technologies.

Each partner developed its HW and SW solution and performed the necessary factory tests.

The test of the system has been done at LSCT facilities, setting-up the vehicles and the test area inside the terminal.

All the partners have been involved in the definition of the guidelines for European terminal operators and in the evaluation of the costs.

# 6. SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE PROJECT

The project description is structured in three main chapters:

- system requirements;
- overall design;
- results of field tests.

## 6.1 SYSTEM REQUIREMENTS

The system requirements have been analysed in terms of:

- maritime terminal requirements;
- inland terminal requirements;
- sensors requirements

### 6.1.1 Maritime Terminal Requirements

The first step performed was the analysis of terminal's characteristics in order to be able to develop a system which could meet the real needs terminal operators have.
This goal was achieved in two different ways: on one hand the terminal operators have done internal analysis and personnel's interview to point out the features an automatic positioning system has to have and to underline the structure and the operational processes the terminal has. On the other hand, the project took into consideration other EC projects dealing with intermodal transport.
Two areas in Europe can be considered: the Mediterranean sea and the North Europe. In the Mediterranean there are approximately 35 maritime terminals, while in North Europe we have approximately 10 maritime terminals. La Spezia is a natural port protected from winds near by mountains; it is located in the north Thirrenian sea halfway between Genoa and Leghorn. About 5000 containers are parked every day in our Terminal.

#### *6.1.1.1 Terminal container description*

A container terminal can be define as a store where incoming containers, waiting to leave for their final destinations, can be parked. Container cycle of life in the terminal could be described as follow: arrival by boat, train or truck, park in terminal, delivery through boat, train or truck.

#### *6.1.1.2 Container description*

Two different classes of container can be currently managed, their difference essentially being the dimensions: These two container classes have different typologies and their use depends on the sort of commodity that must be handled or on the dimensions and types of load (for example: reefer, ventilated, open top … ). All different types of containers can be moved in the same way.

#### *6.1.1.3 Parking area description*

In a container terminal different parking areas are defined, where the incoming containers are temporarily parked (stacked one on the other), waiting for being shipped or carried on by truck. Any terminal has its particular parking areas, due to the terminal extension, environmental constraints, operational needs and so on. In LCST terminal such areas are defined by the types of equipment that operate in the interested zone, in the distinctive case have been identified the following zones:

- reach stacker areas
- RTG areas
- RMG areas

Each area has been identified by a two alphanumeric character name. Each zone is divided into a network drawn on the ground that borders the positions in which the containers must be parked (ground-slot); the design of this network change according to the equipment type that operates in the area. Each zone can be assimilated to a matrix in which each ground-slot has an unique identification. Matrix lines are, in this case, denominated 'row' and the columns 'bay'; in both cases the values are three alphanumeric characters.

Each ground-slot is therefore identifiable from the following values:

- parking name (i.e. CA, R1 …)
- row number (i.e. 132)
- bay number (i.e. 033)

Considering that the two container classes are one the double of the other in length, to use the areas in a flexible way, it has been decided to adopt the following operational procedures: the park grid has been numbered so that there will only be odds bay numbers. In this way each ground-slot will be at 20' containers measure. The 40' containers will be parked in two contiguous ground-slot (two 20' positions) and the container position will be the lacking bay (e.g. the position of a 40' that is in bay 157 and bay 159 will be the 158). In order to maximise the areas usage many containers can be stacked in each ground-slot. The number of levels (tier) in each ground-slot depends essentially on the equipment that operates in the zone:

- reach stacker area: 7 tier
- RMG area: 5 tier
- RTG area: 4 tier

The tier value is a two alphanumeric progressive characters (even only) from '02' to '14'; the container on the ground will be tier '02', the one immediately above tier '04' and so on to tier '14'.

Concluding, to identify the container position (slot) in the terminal, the following details are necessary:

- parking name | |
- bay number | ground-slot |
- row number | | slot
- tier | |

#### 6.1.1.4 *Maritime Terminal Equipment*

Containers can be handled with different types of equipment, depending on operative needs. The most used equipment in the European terminals are:

- Reach stacker
- RMG (Rail mounted gantry crane)
- RTG (Rubber tyred gantry crane)
- Straddle carrier

In details:

- **Eurokai - Hamburg** moves the containers using RMGs and straddle carriers
- **MCT - MedCenter Terminal** uses straddle carriers and reach stackers
- **SCT - Salerno Container Terminal** works with RTGs and reach stackers
- **LSCT - La Spezia Container Terminal** uses RMGs, RTGs and reach stackers

Each one of the above, to move the container, has a device called spreader that hooks the container by inserting four twist into it and locking them with a 90 degrees rotation. Then it holds up the container for the lifting. The spreader has a 20' container dimension automatically extendible to lift 40' containers. The twists lock only when a container is hooked (pick-up position) and unlock when it is released in a parking area (set-down position).

#### 6.1.1.4.1 *Reach stacker.*

The reach stackers are the most flexible terminal equipment. They can be used in different zones and they have an elevated movement ability. This kind of equipment has the capability to operate also inside piles of containers. The reach stackers use, in the filling/emptying operations of a bay, the 'lifo' (last in first out) modality. A continuos exchange of information with the informative system and the possibility of gathering data about the reach stacker functionality are required for the improvement and the automation of the operational procedures. This is why most terminals both in Mediterranean and North Europe area have vehicles equipped with several sensors and with wireless terminals, which allow the driver to collect the data and to communicate with the informative system. For LSCT pilot system to be well designed some more detailed information about our vehicles are needed. LSCT terminal has currently active 15 reach stackers: 9 Kalmar, two exclusively for empty containers, and 4 Fantuzzi. All reach stackers have the wireless terminal and give the information regarding the spreader state (open/close); the new vehicles give also the following details: arm extension, raising angle, container weight and type (20' or 40'), engine operation hours and engine revs. The maximum accessible speed is 40 km/h. The type of available feeding on the reach stacker is 24V.

#### 6.1.1.4.2 *RTG*

RTGs operate on a well defined area, especially designed for this kind of vehicle. Their movement ability out of this area is very restricted. The only 'lifo' type limitation is related to the tier of container as the positioning is done from the top. Currently 3 RTGs are operative. These vehicles have installed a wireless terminal and they can have a contact device for the opening/closing of the twists. The maximum accessible speed is 132 m/min. The type of possible feeding is: 380V, 220V, 110V, 24V.

#### 6.1.1.4.3 *RMG*

This vehicle, being rail mounted, operates exclusively in designed areas. Their procedures are similar to the RTG ones. In LCST terminal RMGs are provided with a PLC controlled automation system that determines position, damages and every possible signal this equipment could get. The PC displays the real time position of the spreader; this position is useful to the operator for the positioning/search of containers in the yard. The PLC is currently interfaced with a PC that provides the consumer job orders management and the visualisation of contingent alarms; this PC is connected to the central Information System through LXE radio modem. Communication between on board PC and Information System is mainly oriented on the job orders that the central system sends to the RMG. RMG has then to reply to the system, once performed or refused the job, with an adequate message. Other information exchanged between the systems are: alarms, RMG time synchronisation with the central system, operator information requests on containers, equipment statistics (such as working hours, number of jobs performed…). Currently LSCT have 8 RMGs operative (4 Magrini and 4 Kocks). The maximum accessible speeds are, for the Magrini 120 m/min, for the Kocks 180m/min. The type of possible feeding is: 380V, 220V, 110V, 24V.

#### *6.1.1.4.4 Straddle Carrier*

Straddle carriers are equipment that operate on a well defined area, especially designed for this kind of vehicle. Their mobility is half way between reach stackers and RTGs one. The only 'lifo' type limitation is related to the tier of container as the positioning is done from the top. The type of possible feeding is 24V. LSCT does not use this kind of equipment.

### 6.1.1.5 Handling Procedures

Each terminal all over the world has its own handling procedures, so generalise them is very difficult. Otherwise, apart from some minor differences, the key operations must be the same. The container in fact has to be received, checked, moved to its parking place and then delivered. The terminal operativity is usually divided into two principal flows: import and export. We have import when the container is discharged from a ship and leaves the Terminal by truck or rail; export is, therefore, the opposite way.

### 6.1.1.6 Export flow

This flow can be divided into: arrival by truck or by rail. Every flow begins with the container arrival.

#### *6.1.1.6.1 Export flow with arrival by truck*

- Truck arrival and documents delivery to the proper office (external to the terminal)
- Documents control and input data on the information system
- Parking assignment for the container
- The information system creates a job order for the equipment that will discharge the truck
- Truck arrival at the gate
- Technical inspection (seal and damages check of the container) with data input on the information system
- Job sending from the information system to the equipment that will park the container (according to the assigned park)
- Truck arrival at the parking zone
- The proper vehicle after having selected the job to perform, hooks the container (closing twist) freeing the truck that, finished the operation, leaves to the exit.
- Container moving in the set parking position
- The equipment parks the container (opening twist) and gives job confirmation (in case the sit-down position is different from the predisposed one, the operator will input the new position in the information system)
- At embarkation, new job order for the vehicle

- The equipment selects the job, hooks the container, puts it on the truck that will bring it underdeck; the operator opens the twists and confirms the job performance
- The equipment underdeck (unloading) takes the container from the truck and puts it on board.

#### 6.1.1.6.2 *Export flow with receipt by rail*

This flow is different form the above one only for the first 9 points:

- Train arrival in the Terminal
- Containers assignment positions in the terminal on the information system
- Technical inspection
- Job order preparation and dispatch to the equipment
- Job Equipment acknowledgement
- Containers picking by reach stacker or RMG
- Possible internal truck positioning
- Container transportation to the planned parking area

### 6.1.1.7 *Import flow*

This flow can be divided into truck arrival or rail arrival as well.

#### 6.1.1.7.1 *Import flow with arrival by truck*

- Container arrival by ship
- Data input on information system and position assignment
- The unloading crane puts the container on an internal truck that takes it to the parking position
- Job order making for the equipment that will unload the truck
- Truck arrival at parking position
- Container discharged and parked in the prearranged area; input of the related data on the information system
- Collection truck arrival at the proper office, documents check and data input on the information system. This will create a job for an equipment
- The truck goes to the gate and the job is sent to the equipment that will load the container
- Truck arrival to the parking area
- The equipment loads the truck and inputs the operation on the information system
- Truck leaves the terminal through the gate

#### 6.1.1.7.2 *Import flow with arrival by train.*

The first six points are identical to the above ones, the others are modified as follow:

- The rail reload from the proper office plans the wagons composition
- Wagons arrival in the terminal
- Jobs are sent to the equipment that will move the containers
- Containers are picked-up from parking position and the related data are input on the information system by a wireless modem
- Possible positioning on truck
- Containers transport to reloading track
- Container positioning on planned wagon
- Train leaves the Terminal

### *6.1.1.8 Information and Communication Systems*

In the latest years Information and communication systems have became more and more important inside maritime terminals. They are effectively used both for the optimisation of ship and yard planning and for having interactions between crane drivers and management operators. Such a system needs a wireless communication system and a computer for data storage and for the planning program to run. The existing informative system in LSCT is composed by different type of hosts that have functions correlate between them:

1. IBM AS/400- system that prevalently attends to the management of all the containers data and register each modification effected on the data.
2. Digital Alpha- it attends to the gate and RMG automation.

Currently each reach stacker and RTG vehicle have installed a wireless terminal that interact with the AS/400 host through a Network Controller. These equipment does not work with the job order but this feature is expected to be available with a new system that will be installed on an NT host and that will be interfaced with the AS/400. The job order management on the RMG is currently managed from the Alpha system that prepares, sends and receives messages from the RMG. The final information system will be organized as follows:

- the reference database will be however managed from AS/400. It will interface with a Windows NT host in which will be installed a ship, yard and rail planning system; this host will manage the equipment and the operations in real time (parking, job orders…).
- NT will be interfaced with AS/400 through a standard communication protocol. The NT will have also an interface with the Network Controller LXE/ Tecklogic and will manage all the wireless operations.

The system shall have well defined the parking areas and all the equipment that will operate there (including trucks); to each area will be designated some dedicated equipment that will receive and perform the jobs to them designated. The subsystem that takes care of the job management will take information from the IBM database and from the varied subsystems that composes it and will create job order according to the containers to be parked and to the areas assigned equipment; consequently this subsystem will create some works queues that will be sent to the interested equipment. Each equipment driver will choose the job to perform and, once finished it, will confirm the position (in the case that it has effectively parked the container in the job's set-down position) or will type the different parking position where he has set-down the container. The system is supplied with a monitor that will provide, not graphically, some Terminal equipment information in real time (last set-down, inactivity time, number of movements done in a shift…). It will be predisposed, to obtain real positions from DGPS system through the serial port of the wireless terminal installed on the equipment.

### *6.1.1.9 Positioning Necessities and Relevant Effects*

Currently the container positioning problems are due to the fact that it does not exist any kind of automation that provides a precise container parking position, but this is all done by the operator. This means that we may find typing errors in containers number and parking position, parking omission and therefore container loss into the terminal. There is the necessity of limiting the human contribution for the parking operation, in order to let the system find out the exact sit-down and pick-up points while the operator should only confirm the shown figures. In order to have some figures of the savings due to the positioning system, terminal operations suitable to be addressed by such a system have been analysed. The positioning problems faced are mainly in the RTG and reach stackers areas. Reach stackers, due to their movements, their small size and to the fact they can slip into piles of containers, should be the most difficult vehicles to locate. Moreover in LSCT terminal reach stacker areas are the ones that more likely, for operative needs, change the layout. In these areas of the yard containers are parked also in piles fifth tier high (seventh tier for empties). In LSCT Terminal about 100 containers per month happens to have bad position or without parking position, needing 10-15 minutes per container to found them. Considering 2900 movement per day, with an automatic positioning system, supposing to have about 5-10 seconds save for any movement, a total savings of about 4-8 hours per day can be foreseen.

## 6.1.2 Inland Terminal Requirements

### *6.1.2.1 Characteristics of inland terminals*

At first we need to identify some relevant aspects characterising the rail road combined transport inland terminals (which diversify from port terminals specialised in container traffic). In short:

- they handle continental traffic;
- they handle several different loading units, such as:
    - swap bodies;
    - semi trailers;
    - land containers;
    - maritime containers;

this is a “complexity” compared with the terminal specialised in “container only”:

- they do not handle storage but stop over.

The need of stocking areas are, in this way, much limited;

- they are characterised by a fast loading units round trip;
- they must be consistent with the relevant technical characteristics of trains (length).

Another relevant element is the starting situation of the infrastructure (terminal).
Shortly, two “pure typologies” can be envisaged:

- re-use of the existing railway terminals for the rail road combined transport;
- new terminals, built “ad hoc”.

### *6.1.2.2 Structural characteristics of terminal for rail road combined transport (RRCT)*

Five relevant aspects have to be considered

- quantity;
- dimensional characteristics;
- layout;
- automation level.

#### 6.1.2.2.1 *Quantity*

Data referred to Italian reality are below listed. There are 76 inland terminals, 24 of which are specialised in containers.

| REGION | CONTAINERS | COMBINED & CONTAINERS | TOTAL |
|---|---|---|---|
| **PIEDMONT** | 6 | 8 | 14 |
| **LOMBARDY** | 4 | 10 | 14 |
| **VENETO** | 2 | 5 | 7 |
| **TRENTINO A. ADIGE** | - | 1 | 1 |
| **EMILIA ROMAGNA** | 3 | 8 | 11 |
| **LIGURIA** | 2 | - | 2 |
| **FRIULI V. GIULIA** | - | 1 | 1 |
| **TUSCANY** | 6 | - | 6 |
| **LAZIO** | - | 4 | 4 |
| **MARCHE/UMBRIA/ABRUZZO** | 1 | 2 | 3 |
| **CAMPANIA** | - | 2 | 2 |
| **PUGLIA** | - | 2 | 2 |
| **CALABRIA** | - | 1 | 1 |
| **SICILY** | - | 6 | 6 |
| **SARDINIA** | - | 2 | 2 |
| **TOTAL** | 24 | 52 | 76 |

**(source: National Transport Count - 1997 operating system)**

**Table 1 - Inland Terminals – Italy**

In the following table are listed the data referred to European reality (please note that some terminals are port terminals).

| COUNTRY | No. OF TERMINALS |
|---|---|
| AUSTRIA | 7 |
| BELGIUM | 4 |
| DENMARK | 1 |
| FINLAND | 2 |
| FRANCE | 33 |
| GERMANY | 80 |
| GREAT BRITAIN | 11 |
| PORTUGAL | 2 |
| SPAIN | 9 |
| SWEDEN | 9 |
| SWITZERLAND | 8 |
| THE NETHERLANDS | 5 |

**Table 2 - European Terminals**

#### 6.1.2.2.2 *Dimensional characteristics*

Dimensional characteristics of inland terminals may be assessed either with regard to the traffic performed or to their infrastructural composition.

*DIMENSIONAL CHARACTERISTICS ON TRAFFIC BASIS:*

- ***Large Terminals***: Total traffic movements exceeding 50,000 loading units
- ***Medium-Size Terminals***. Total traffic movements between 20 and 50,000 loading units
- ***Small Terminals***, Total traffic movements of less than 20,000 loading units

*DIMENSIONAL CHARACTERISTICS ON TECHNICAL COMPOSITION BASIS::*

**Containers Terminals**

- LARGE: with large storage capacity (c>3000 TEU)
- MEDIUM: with medium storage capacity (1000<c<3000 TEU)
- SMALL: with small storage capacity (c≤1000 TEU)

**Combined Transport Terminals**

- LARGE: with track numbers greater or equal to 6
- MEDIUM: with track numbers from 3 to 5
- SMALL: with track numbers below or equal to 2

#### 6.1.2.2.3 *Location characteristics and horizontal coverage level*

Regarding the locating characteristics, we have two different situations:

| | |
|---|---|
| reuse of pre-existing facilities | generally located in heavily urbanised urban environment |
| new facilities | inside goods centres or freight villages or in limited urbanised areas |

For what concerns the presence of stop over areas that might represent a constraint to GPS, situations differ mainly in the terminal traffic typology.

| | |
|---|---|
| terminals specialised in combined transport | “limited” height constraints |
| terminals specialised in containers | similar constraints to those of port container terminals |

#### 6.1.2.2.4 *Layout*

he terminal layout results from the adapting of a pre-existing structure or from a new one. With broad generalisation::

***“adaptation” of pre-existing facilities***

The layout for single terminals differs according to:

- ♦ specific location factors
- ♦ area geometry
- ♦ length and configuration of existing tracks
- ♦ system of access and circulation

**New facilities**

The lay-out is governed by:

- ♦ tracks number and length
- ♦ infrastructural composition (ratio of track meters/yard sq. meters)

#### 6.1.2.2.5 *Automation Level*

The automation level analysis of the terminal used for rail road combined transport can be developed - inside this project - on quality basis only. A punctual research - including direct contacts with terminals - differs from the scope defined for the research and from the identified time and budget constraints. The terminal's dimension (either as area occupied or as traffic volume) is the key variable conditioning the automation level. As can be observed only for "large terminals" it is possible to suppose as automation area the flow management inside the terminal.

#### *6.1.2.3 Terminal operations cycle for rail road combined transport*

The terminal operation cycle for the rail road combined transport can be divided in two:

- loading units cycle
- train cycle

For each of them we show the relevant activities:

- **loading unit cycle**
  gate operations
  transfer along the track
  wagon loading
  ......

- **train cycle**
  entry
  loading/unloading
  inspection
  terminal exit
  .......

#### *6.1.2.4 Type of operational equipment present*

The operational equipment used in the terminals for the rail road combined transport is related to:

the type of handling;
the type of loading unit to handle.

For what concerns the handling, we may have:

vertical handling.
In this case the loading unit is translated from road vehicle to railway wagon using a mechanical equipment which lifts it from the ground;

horizontal handling.
In this case the loading unit is translated from road vehicle to railway wagon without moving from the ground and without mechanical equipment;

The loading unit to handle represent a relevant variable in case of horizontal handling (while is unimportant for vertical handling).

#### *6.1.2.5 Loading Unit Type*

Dimensioning of the loading units used for the rail road combined transport is coded by C.E.N. (COMITATO EUROPEO DI NORMAZIONE - EUROPEAN COMMITTEE OF RULES).

#### *6.1.2.6 Location requirements*

The analysis of the localisation requirements of the operational equipment and of the loading units inside the terminal for the rail road combined transport is articulated in the following points:

- identification of localisation requirements (Systems typologies);
- identification of the critical variables which must be considered for the various localisation requirements;
- evaluation of the satisfaction level of the critical variables as regards to localisation requirements.

### *6.1.2.6.1 Locating requirements identification (Systems typologies)*

We can identify four possible locating requirements:

- for identification of operational equipment inside the terminal and for information purposes (System 1);
- for identification of operational equipment inside the terminal for operating activity management purposes (System 2);
- for the location of the road vehicles inside the terminal (System 3);
- for the location of the loading units inside the terminal (System 4)

### *6.1.2.6.2 Critical variables identification*

Ten relevant variables were identified:

- expected performances: operational problems addressed by the system;
- expected savings: improvements in the terminal's operation which are due to the system;
- position accuracy: level of accuracy the measure needs;
- acquisition frequency: how often the Load Unit position has to be calculated (for example only at the moment of the twist lock openings/closes);
- data transmission frequency: how often the mobile unit has to send its data to the information server (for statistics purposes this action could be done once a day);
- robustness: the physical stresses the unit has to support;
- constraints on the system's layout: constraints which are due to the terminal environment (dimensions, cables, ...);
- vehicles: vehicles which have to be localised.
- Interactions with the drivers: changes in driver's operation which are due to the system;
- interactions with the management system: modality of the interactions between our system and the terminal information system.

## 6.1.3 Sensors requirements

### *6.1.3.1 Acoustic*

#### *6.1.3.1.1 System design criteria*

The acoustic location system design is based on the following desired requirements:

- location precision of 1 meter
- position measurement to take a few seconds maximum
- data interface (RS232) to central terminal management unit

The system principle of operation is based on existing METRAVIB RDS algorithms developed for impulsive sound detection and location (light arms / artillery fires). These algorithms allow to compute, using the signal received by a 4 microphones array , the direction of the sound and, when several such arrays are used, the absolute location of the sound source. These algorithms are to be tailored to the specific conditions and requirements of vehicle location within a container terminal. Therefore the following matters have to be addressed:

- terminal background noise evaluation (level, frequency …)
- acoustic source specification (type, power, frequency, proposed location …)
- acoustic location performances simulations and algorithms adaptation
- system architecture : number of sensors, separation
- system input/output requirements (radio transmission availability, power supply availability)
- price considerations

#### *6.1.3.1.2 Terminal background noise assessment*

Normal terminal activity induces a background noise that has to be taken into account for the system design in order to optimise the acoustic source and processing parameters and deduce the detection and location performances. A measurement campaign has been conducted to measure :

- the noise level at some distance from the carrier
- carrier engine noise
- obstacle mask effects (container rows)

#### *6.1.3.1.3 Acoustic source specification*

Since we have control over the acoustic source (which is not the case for the standard implementation of the algorithms in case of firing detection) we can take this opportunity to optimise the system performances and to take into account the operational requirements. Eventhough the container terminal is a noisy environment, it is desired that the acoustic location system does not increase the acoustic nuisances. This requires to use either a low or high source frequency because of human hear sensitivity. The requirement of having an omni-directional source makes it necessary to preferably select a lower frequency source. The use of a lower frequency also reduces the masking effect of obstacles. However the minimum usable frequency is limited by the following considerations:

- the lower the frequency, the more difficult to emit high acoustic power

- with lower frequencies system response time will be longer (required signal duration proportional to the inverse of the frequency)
- frequency coding is more difficult since the number of available frequencies is reduced due to the minimum required frequency separation (limited bandwidth)

This first analysis leads to choose the emitted frequencies around 300 Hz. The attainable emitted power, as measured from existing sources, is about 120 dB. The source emission characteristics must fulfil the following requirements :

- be long enough to permit a precise determination of the time of arrival that will be used to determine the source position
- be coded in such a way that the source can be identified (using time and/or frequency coding)
- total emitted signal duration must be compatible with the system location update rate
- signal repetition must be compatible with the system layout to avoid position ambiguity

#### 6.1.3.1.4 *Acoustic location performances simulations and algorithms adaptation*

System performances are evaluated by studying separately:

- the location performances for a given timing precision
- the emitted signal definition required to achieve the required timing precision

##### 6.1.3.1.4.1 *The location precision performances*

First of all the different existing algorithms must be evaluated in order to select the one best adapted to our problem. To summarise there are two types of algorithms already available at METRAVIB RDS :

- the ones that process several microphones making a collocated array in order to deduce the direction of arrival of sound (far field assumption). Using the intersection of the directions determined by different arrays gives the source location (goniometric method)
- the ones that process distributed microphones and determine directly the source position under a near field assumption

METRAVIB RDS experience on these two kinds of algorithms shots location allows to evaluate the possible performances using both types of processing : with the first method, for acceptable array sizes, the direction precision in the horizontal plane is limited to about +/- 2 to 3 degrees which corresponds to about 5 % of the range, whereas near field algorithms (second method) can achieve less than 2 % errors in the horizontal plane under good sensor relative repartition configurations. Therefore the distributed sensor approach seems to be more powerful than the goniometric one. A more detailed simulation, dedicated to our present application, of this method has been conducted in order to assess the location performances in the horizontal and in the vertical plane. A description of the method and detailed results are shown in appendix A. As a summary of the results, with a timing precision of 1.5 ms (see the following paragraph for how to achieve this) on the measurement of the sound flight time between the carrier and 4 points located on masts (height of about 25 meters and distributed on a square of 200 meters sides), X and Y errors are within about +/- 0.5 meters and Z within about +/- 2 meters.

##### 6.1.3.1.4.2 *Signal definition*

The signal definition must be such as to allow a +/- 1.5 ms timing precision in order to achieve the expected location performances. The signal definition must as well take into consideration the other constraints of the system requirements.

###### 6.1.3.1.4.2.1 Signal frequency repetition

Since we can control the emitted signal, we can increase the signal to noise ratio by averaging the timing measurements. This feature is very interesting to fight against the background noise that can be found within the terminal. In order to avoid ambiguity in the location determination, the signal repetition period must be greater than Dmax/c where Dmax is the maximum distance to be measured and c is the sound speed. For a square configuration we can round up Dmax to 2*D where D is the size of the side of the square.

###### 6.1.3.1.4.2.2 Signal structure

The signal structure to be repeated must be optimised in order to:

- achieve a good timing precision
- allow source identification (several emitters will be on the site and must be identified)

The initial general structure proposed for the signal is made of N individual time gates used for code. Each time gate is used to emit about 10 periods burst at the nominal frequency. Using frequency coding alone has shown to be inefficient if we want to keep a reduced bandwidth as well as reduced signal duration. Simulations using 10 bits codes (each code 30 ms long) with a repetition rate of 600 ms averaged 10 times have shown to give a timing precision better than 1 ms under realistic background noise conditions and for transmitter/receiver distances of over 100 meters. The decoding of the transmitter code has also been tested successfully when only one code is present simultaneously in the signal. When several signals are present, the huge variability of their respective strength due to propagation effects (distance, obstacles), makes it difficult to decode the weakest one. The simulations have therefore shown that the system requires a more sophisticated coding in order to extract the correct timing information when two signals are superimposed with a high contrast in amplitude. Such signal characteristics can be obtained with signals that exhibit a very low interrelation. These signal can be achieved with a frequency sweep technique used in underwater acoustics. The signal is swept between two frequencies (a few times 10 Hz around 300 Hz is sufficient) while applying a specific signal envelope. The performances of this new type of signal have been evaluated : it has been shown that emitter code recognition was feasible within the full range of the emitter location.

##### *6.1.3.1.4.3 The location range performances*

Using the signal structure defined in the previous paragraph, simulations have been carried out to evaluate the minimum signal to noise ratio needed to achieve the required system performances. The background noise used for this evaluation comes from the experimental data gathered at LSCT container terminal. Two types of data are available :

- background noise in the terminal at a distance from any carrier
- directly on a carrier close to the engine exhaust with engine running high

The results show that, for the first noise environment conditions, the defined signal allows to achieve ranges over one hundred meter. However, in the second case, the range is extremely variable since the noise level is very un-stationnary (engine, carrier reverse alarm …). In such a pessimistic case, the range can be reduced down to 10 meters, which is not acceptable. Eventhough the latter configuration is very pessimistic since no optimisation has been made on the receiver location on the carrier and the engine was running high, we must at this stage consider that if the receiver is placed on the carrier, we might be facing situations with too poor performances. Of course on a case by case basis, depending on the type of carrier, this solution could still be used since it appears to be more economically efficient. The preferred solution is then to have the acoustic source carried by the carrier and the receivers at a fixed positions away from noise sources. In such a case the range is no more a limitation and the distance between sensors is defined by the required location precision that is 100 meters or so.

###### *6.1.3.1.4.4 Environmental effects compensation*

Since the carrier position measurement is deduced from the implicit knowledge of the sound speed, wind and temperature effects must be accounted for. The variation of sound speed with temperature is well known and can be corrected with a simple temperature sensor (a 1°C precision is sufficient to achieve 0,3 % precision on sound speed). The effect of wind is more complex since :

- wind is turbulent
- wind measurement is more complex than temperature (it is a vector)

We must keep in mind here that a 1% on speed of sound correspond to about 3m/s. Therefore we do not need to have a very precise knowledge of the wind to be able to reach a precision of less than 1%. To measure the wind speed without external dedicated sensors two methods using acoustic measurements could be implemented :

- use extra acoustic sensors with known positions: the speeds are then deduced from the measured flight times
- perform measurement of the carrier position with more sensors to allow for the added unknowns due to the wind and temperature to be determined.

##### *6.1.3.1.5 System architecture*

The system will be made of two types of stations : the fixed stations and the mobile stations. One type of station must be emitting the signal and the other ones listening. The fixed stations can be fitted on the ground and whenever possible on light masts. This second solution corresponds to a better configuration for sound propagation. The separation between two fixed stations will be typically 100 meters. Field experiment will be required to determine the maximum separation. A 1000m x 500 m terminal with 10 carriers therefore requires roughly :

- 66 fixed stations
- 10 mobile stations

The fixed to mobile stations ratio is therefore about 7.

Let us first concentrate on a single vehicle configuration. The vehicle location will be determined by one mobile receiving station in the case of several fixed emitting stations or by several fixed receiving station and only one emitting mobile station. In any case the fixed stations must be synchronised precisely. This can be achieved either in using a GPS receiver on each fixed unit or in using synchronisation by radio means. The GPS solution, if not optimised for an industrial system because it leads to higher costs, has the advantage of avoiding any interference on the site with existing radio equipment as well as not requiring a permit if high emitted power is required. However the radio solution has the advantage of allowing extra control over the system : for example it can be used to trig the emitters only when necessary and therefore reduce the system nuisance in the case of fixed emitters. Using a radio trigger reduces the amount of unknown to solve in order to determine the position: the radio trigger gives precisely the absolute time of the emission. The fixed receiver versus mobile receiver solutions have both drawbacks and advantages:

- mobile receiver solution:

  Cost effective since fewer receivers are used (emitters are cheaper than receivers). Moreover the position result is available at the mobile side and can be directly input into the terminal management network using the existing link to the carrier. From a signal to noise ratio this solution is the worst since the receiver is installed on the carrier that generates high noise levels. We have seen that this problem can lead in extreme cases to unacceptable range limitation.
- mobile emitter solution:

  The carrier will emit the signal only when needed. This configuration has however some shortcomings:
  - the results from several receivers must be combined to achieve a position measurement. The position measurement must therefore be made at a central computer that has to be linked to each of the receivers. Then the location acknowledgement and the actual position, if required, must be transmitted to the carrier. The burden on the computer network is therefore increased. To limit the burden on the network, the central computer could be a computer installed on the carrier.
  - the overall system cost is higher:
    - more receivers are used,
    - a receiver network is needed
    - location computation must be performed by a central computer.

Even if the second solution is not as cost effective as the first one, we choose at this stage to select it as the preferred solution since the other one has shown to be potentially weak under severe noise condition. However the hardware will be designed to make it possible if required during the field experiments, to evaluate the first scenario.

###### *6.1.3.1.5.1 System hardware design*

The emitters do not require an important processing power (we do not take into account the central processing task that is performed by a dedicated computer) therefore they are designed using a micro-controller board. When a signal emission is requested (radio trig in case of fixed emitters or manual trig in case of mobile emitters), the signal is read from memory and written to digital converter using a fixed frequency clock. The same signal is repeated several times. In case the trig was manual a radio top is sent in order to give a time reference for the receivers. The receivers require more computing power since a sliding interrelation is computed using the different emitters signatures. For an industrialised system a cost effective structure would include a micro-controller board to handle input/output through the RS232 and a DSP board to compute in real time the interrelations. Ultimately if the communication task is not too complex a single DSP board could be used to handle all the tasks. However for the prototype stage we will keep a PC structure that can simultaneously handle the input/output and the signal processing. The receiving module will therefore be composed of a PC computer (ruggedized PC 104 type) with an analogue-to-digital converter board and a specific microphone pre-amplifying and filtering board. A radio module will be incorporated to either trig the emitters or receive a trig from them.

###### *6.1.3.1.5.2 Network requirements*

We describe here the requirements corresponding to the most demanding configuration, that is the configuration with the fixed receivers. Let us describe the way the measurement are performed under this configuration :

- a carrier loads/unloads a container
- a measurement request is issued by a manual trig of the mobile emitter installed on the carrier
- the mobile emitter sends a radio top and several acoustic pulses with the code corresponding to the carrier
- the receivers receive the radio trig and start processing the acoustic signal to look for the carriers signature.
- The time of flight is computed as the difference between the radio top and the time of arrival of the acoustic signal
- A message is sent to the RS232 serial link. The messages originating from all the fixed receivers must be gathered using a radio link (not supplied) into a central computer
- The central computer derives from all the messages from all the receivers the carrier position
- The carrier position can be sent back to the carrier through the radio communication network if necessary. If the central computer is on the carrier this last step is removed

#### 6.1.3.1.6 *Conclusion*

On the basis of numerical simulations together with acoustic measurements on site, the feasibility of the acoustic locator has been demonstrated. The main characteristics of the draft specifications of such a system are :

- frequency band : 300 - 600 Hz
- repetition rate : 600 ms to 1s
- signal duration : 100 to 400 ms
- acoustic level of the transmitters : ≈ 120 dB
- distance between fixed stations : ≈ 100 meters
- accuracy: < ± 1 m in the horizontal plane
  ± 2 m in the vertical direction
- response time : ≤ 3 s

Up to now, the safest solution seems to be the use fixed receivers and transmitters onboard vehicles. However, as the opposite solution would lead to significant gains on cost and complexity, complementary investigations will be conducted to optimise the system in order to make this latter feasible. Anyway, the hardware of the demonstrator will be developed (in parallel) to be compliant with both options.

### 6.1.3.2 *DGPS, GPS and other sensors*

#### 6.1.3.2.1 *GPS*

The satellite based Global Positioning System (GPS) allows highly accurate positioning around the world. GPS has 21 operational satellites and three spare satellites in six orbits at an altitude of 20.000 km. The system was developed and installed by the US Departement of Defense (DoD). Each satellite transmits on two L-band frequencies (L1/L2), which are modulated with a Pseudo-Noise-Code (PNC) divided into:

- SPS (Standard Positioning Service) or C/A Code (Coarse Acquisition)
- PPS (Precise Positioning Service) or P Code

Although the GPS system is intended primarily for military applications, the DoD has released the C/A code for civil use. As the data of this code are artificially degraded the maximum accuracy level is about 100 m. This is normally sufficient, for many users. In the field of container location, however, the accuracy has to be increased by the aim of DGPS technology.

### *6.1.3.2.1.1 Differential GPS System (DGPS)*

In order to achieve the required accuracy, GPS has to be operated in a differential mode. However this improvement is at the expenses of more complex hardware and software. The Differential GPS System (DGPS) includes four main components:

- Reference Station
- Mobile User
- Data Link and
- Monitoring and Control Station.

The coordinates of the fixed GPS receiver of the Reference Station has to be precisely known, so the difference between the real and the measured position can be calculated and the correction vector determined. This position error will normally be transmitted via a data link to the mobile user for his own correction. The management of the data link as well as the position indication of all mobile users on a digital map or the position data management will be performed in the central monitoring and control station.

### *6.1.3.2.1.2 DGPS Correction Process*

The DGPS systems can be roughly divided into three categories:

- DGPS with RTCM 104 correction (position accuracy 3...10 m)
- DGPS with raw data correction (position accuracy 0,5...2 m)
- DGPS with RTK correction (position accuracy 0,01...0,5 m)

The method of position correction is mainly based on the measurement of the pseudo ranges of all received satellites.

*RTCM 104 correction*

The RTCM104 format is specially developed by the Radio Technical Commission for Maritime Services, Committee No. 104. A number of different messages have been defined in the Data Message and Format area, with different levels of finality. Some message types have been fixed, others are available for future definition. It was attempted to accomodate the widest possible user community, including marine, land-based and airborne users. The already wide-spread standard service, using message type 1 to 3, allows accuracy of 3 to 10 meters.

*Raw data correction*

A highly precise position determination requires an extensive correction of all measurement errors of the satellite raw data. These errors result from:

- ephemeral data
- satellite clocks
- model of the ionosphere
- troposphere data
- carrier phase shifts and
- reception of different satellites and their number.

By the correlation of all these data from the reference receiver and the mobile receivers the down-grading of the GPS system by S/A can largely be eliminated. The accuracy of the position as well as the height above SL (sea level) of such DGPS systems are therefore in the range of 0,5 to 2 meters.

*RTK corrections*

Real Time Kinematic (RTK) corrections are mainly used in the field of geodetic survey. GPS-receivers for this application provide simultaneously code and carrier phase measurements on both frequencies (L1/L2). In order to provide centimetre accuracy the integer ambiguities introduced by using that phase observable must be resolved. The RTK technique therefore is suitable for static or slow motion applications with positioning accuracy of few centimetres to 0,5 meter. Post-processing accuracy are even in the mm-range.

#### *6.1.3.2.2 Laser*

The laser technology has become widely used thanks to the availability and large scale production of laser diodes (CD ROM, range finders …). Many patents have been applied for in this field in the recent years. There is no doubt that this technology has reached today a mature stage with several companies proposing products ranging from hand held laser range finders to 3D laser imaging systems. Some of these products, especially the hand held range finders, include an electronic compass allowing a complete bearing and distance measurement. It is common to find today range finders with range and precision compatible with the terminal management requirements. It the range finders are better adapted to high range (several km) and medium precision (a few meters), some laser telemetry system exist with a more reduced range (a few hundred meters) but a better resolution. However, in any case, to be used for our application these devices must be adapted in order to :

- automatically follow the reflectors
- include processing from several laser measurements or complementary compass measurements to determine an absolute position.

The consequence of these considerations is that the range finder has to be mounted on moving parts that automatically follow the target. The use of such devices has several shortcomings :

- any moving device that has to operate continuously in the outside has a reduced mean time between failure
- it induces an important overhead on the total system cost due to
    - the mechanical hardware
    - the control electronics
- it is not adapted to the problem of vehicles that go in and out of the measurement system : the requirement to detect a new vehicle that comes within the measurement range of the laser system adds a lot of complexity to the design : there is a need to locate new reflectors which can be done by one of the following means :
    - scanning with laser on a 360 degrees azimuth to detect reflectors. This solution increases the system complexity and has the potential problem of detecting wrong reflectors (glass, metal plates …), plus a relatively slow scanning rate (mechanical limitation).
    - starting with a known position and performing continuous position measurement in order to always know the available reflectors positions (this requires a map of all the reflectors positions). If the system looses its position (rain, fog, dirty reflector …), it must be reinitialised. This solution therefore requires an external position measurement device such as a GPS in order to initialise the laser position measurements.

Besides the laser technology has its own limitations :

- cannot work in the presence of obstacles (container, moving vehicles …)
- has limited performances under rain and fog.

As a summary the laser distance measurement is well adapted to hand held measurements. In the case of following an object within a predefined area (a moving crane for example) this technology can still be used but with added complexity. Some systems have been developed to operate in a wide area requiring to use different reflectors depending on the position within the area, that have confirmed the poor reliability and high cost of this type of solutions.

As a conclusion the laser technology is not adapted to the specific problem of locating vehicles (carrier) that can go in and out of the detection area and that can be masked by objects such as other vehicles or containers. In that sense it can be considered as being more like a GPS system than complementary to GPS.

#### *6.1.3.2.3 Radar*

Radar systems are one of the most important equipment for marine and air traffic control. The distance between the radar antenna and the target is related to half the travel time of the reflected electro-magnetic pulse. The principle of primary radar is based on the so called primary energy, reflected on metallic objects and received, displayed and evaluated at the radar and control site. In most cases primary radar today is combined with secondary radar. For this type of radar system the target (vehicle, aircraft and so on) needs a transponder, which receives the interrogation pulse and transmits this pulse after a fixed delay time on another frequency back to the radar station. In the field of medium to long range control, both radar systems have accuracy of only 50 to 100 meters. Primary radars for ground movement control at airfields however have excellent resolutions. With such equipment cars and aircraft can be clearly identified. Trials are also taken with high resolution primary radar in container terminal areas, in projects funded by the EC. It was shown however, that the identification of single containers is not sufficient. There were also a significant influence by reflected signals and line of sight problems.

#### *6.1.3.2.4 Tags*

The electronic Tag was developed as a passive component for identifying and location of goods to be followed with precision. Tags are working like a transponder, in which a unique identification number is encoded. Tag Readers can detect these devices remotely at distances up to 6 meters. Tag systems are based on a proven radio-frequency technology, operating on the 2400 to 2500 MHz band. This band is adopted as the European standard in the transportation industry for vehicles and container identification systems. Vehicles, driving at normal speed, are remotely and automatically detected and identified at all strategic points where reading stations are installed. To supply energy to the transponder an alternating magnetic field is radiated by the vehicle‘s antenna frame. As soon as the energy level is sufficient the transponder transmits its programmed code back to the vehicle. The antenna frame, which can vary in size depending on the application is both, a transmitting and receiving antenna. The antenna system detects field line fraction in x, y and z directions. A fourth receiving antenna (option) enables error compensation for chaining reading distances. In addition to the identification of container lots it is possible to carry out curve steering for very large vehicles, e.g. in order to achieve speed adjustment of the two sides of the vehicle in the course of the curve.

The interpreter determines the transponder code. By referencing all four received voltages the distances in x and y directions is calculated from the transponder to the centre point of the antenna, which compensates the transponder influence. These distances may be output on various optional interfaces (e.g. RS232). Crossing a zero line triggers the output of a positioning impulse.

#### *6.1.3.2.5 Odometer*

If an odometer and a gyro measuring the heading of a vehicle are perfectly calibrated and the initial geographic position and heading of the vehicle are known, then the position and heading can be determined in the future. However, angular errors are accumulated with time due to bias and scale factor errors. The odometer scale factor cannot be calibrated to better than a fraction of a percent and changes slowly with time and tire pressure and vehicle speed. During a long drive the measured position will increasingly diverge from the actual position. Despite this, the estimate of the vehicle position is continuos and bounded by the equations of motion of the vehicle. Speed sensors are available on the following physical principles:

- heel revolution counter
- ultrasonic Doppler effect
- radar
- optical correlator.

#### *6.1.3.2.6 Inertial*

Inertial navigation is accomplished by integrating the output of a set of sensors to compute position, velocity and attitude. The sensors used are gyros and accelerometers. Gyros measure angular rate with respect to inertial space and accelerometer measure linear acceleration, again with respect to an inertial frame. The accelerations are integrated twice to a position in the three-dimensional space. Complexities arise due to the various co-ordinates encountered, sensor errors and noise in the system. All earth fixed measurements are related to a North-Earth-Down (NED) right handed co-ordinate system. For the vehicle to be monitored the longitudinal axis is normally labelled as x and the cross axis as y. The z-axis is down to complete a right-handed co-ordinate system. This co-ordinate frame (xyz) moves with the vehicle and is fixed in the body. In general this frame is rotated with respect to the NED. As soon as the attitude of the vehicle is known the accelerations $\underline{a}_{\underline{body}}$ measured by the sensors in the body fixed co-ordinate system can be transformed in the NED-system $\underline{a}_{\underline{NED}}$. The integration is performed within a model of the vehicle, the so called Kalman-Filter. As an input either accelerometer or odometer can be used. The transformation matrix from the NED to the xyz-body-axes are given by:

$$EULER = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{pmatrix} \cdot \begin{pmatrix} \cos\Theta & 0 & -\sin\Theta \\ 0 & 1 & 0 \\ \sin\Theta & 0 & \cos\Theta \end{pmatrix} \cdot \begin{pmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

where:

$\Phi$ roll
$\Theta$ pitch
$\Psi$ azimuth

The accelerometer output can now be rotated from the body fixed system into the NED-system:

$a_{NED} = EULER^{-1} \bullet a_{body}$

The schematic structure of a locating system combining GPS as a primary sensor with an inertial system as a secondary sensor is presented in the following drawing.

#### 6.1.3.2.7 *Valuation of sensors*

The preceding listing gives an overview of existing sensors and their field of operation. In the following table the different kind of measuring results are figured.

| **Sensor** | **Position Determination** | **Single Positioning** | **Track** | **Acceleration** | **Speed** |
|---|---|---|---|---|---|
| GPS | X | | X | | |
| LASER | | X | | | |
| RADAR | X | | | | |
| TAGS | | X | X | | |
| ODOMETER | | | | | X |
| INERTIAL | | | | X | |

Concerning the requirements of container location operations the most advantage sensors are GPS and Tags. These two types are therefore the basis of the PRECISE project and will be analysed in detail in the next sections.

### *6.1.3.3 Container Location System by means of GPS*

The interest in vehicle positioning systems is to confirm the drop-off position of the container and permit optimisation of the machine’s travel path. While various systems have been tried, GPS now appears to be a cost-effective solution. DGPS is typically accurate to within 0,5...1 meter, enough to locate the container within the appropriate slot in the computer yard plan. Positioning systems can also provide continuous tracking of the mobile unit in real-time, but if this results in messages being continually transmitted to the host computer, still more processing and data capacity will be required.

#### *6.1.3.3.1.1 System overview*

Pinpoint positioning systems consist of a reference station and the positioning equipment in the mobile carriers. DGPS utilizes the fact, that all GPS locations determined within a 100 km range feature about the same deviation. A reference station inside this area, whose exact position is known, generates correction data for all mobile users. The received satellite raw data relating to the reference and the mobile stations must be compared with each other. Each GPS positioning instrument in the reference station and the mobile stations (e.g. Straddle Carriers) therefore are assigned a GPS receiver and a telemetry antenna. The telemetry antenna serves for transmitting data from the reference to the mobile stations. The mobile units are equipped with a correction processor for calculating their high precise position. The location data including longitude and latitude can be converted into customised storage area co-ordinates. In addition these data plus the weight, stacking level and size of the container upon arrival at the terminal are transmitted on request to the management centre via a radio data link. The administration collects the data from all mobile stations and co-ordinates all actions to be taken. For the rough operational conditions, the system has to meet stringent environmental requirements as regards immunity to vibration and shock, temperature and other climatic influences.

#### *6.1.3.3.1.2 Container Location System COLOS*

The container positions are determined by the mobile stations (e.g. Straddle Carriers), which transmit the corresponding location to the administration, whenever a container is stored or picked-up in the terminal. The reference station basically consists of a GPS antenna, whose precise position is known, a top-quality GPS receiver and a telemetry transmitter. The data required for position correction are transmitted to the mobile stations via the telemetry link at a rate of 9600 Baud. For GPS location the mobile stations are also fitted with a GPS antenna and a top-quality GPS receiver. The correction data from the reference station is collected by a telemetry receiver. The correction processor compares it to the station own GPS position data and calculates the high precise position of the mobile unit. Switchover to a coupling sensor network in areas of shadowing effects (where no GPS reception is possible) is made in the following navigation processor. This navigation processor also enters the standardised position data into a customer-specific co-ordinate system (e.g. WGS 84 into x and y) The location management system converts the analogue data such as weight, storage height and length into a serial telegram and combines these data with the location string to a customised data format. The complete identification data telegram of the container will be interrogated and transmitted to the administration via a separate radio data link. An RS232 interface ensures connection to this radio data link system and transfers the data in ASCII format.

### *6.1.3.3.1.3 Container Management System CMS*

A further step has been taken in the development of the Container Location System CMS. In comparison to the COLOS system the CMS allows the location of containers in ports with the aid of satellite navigation plus additional management functions, e.g. location management or monitoring of operational procedures for the purpose of optimisation. Due to standardised interfaces, GPS receivers (also combined GPS-GLONASS receivers) of different accuracy classes can be used depending on the positioning accuracy required. Hardware and software are of modular design, allowing the following system configurations:

- Basic configuration:
  Differential satellite navigation (DGPS, also DGLONASS) with position output in geographic co-ordinates (longitude, latitude) or in customer-specific xy-coordinates
- Enhanced configuration:
  - Decentralised location management
  - Dead-reckoning sensors
  - Additional software for diagnostics and monitoring of operational procedures.

#### 6.1.3.3.1.3.1 Reference station

The standard reference station consists of a satellite navigation receiver and a telemetry transmitter, which transmits the correction data once per second to all mobile users. The positioning accuracy depends on the type of satellite navigation receiver used as well as on the type of correction data and the correction algorithms. A reflection-free installation of the antenna of the reference station and a subsequent position filtering in the CPU of the mobile station is required to achieve an accuracy of better than 1 meter in dynamic operation.

*Satellite Navigation Receiver*

For high-accuracy location systems with optimum satellite availability a combined GPS-GLONASS receiver with the following features should be used:

- GPS channels
- GLONASS channels
- Corrections acc. RTCM104, Version 2.1
- Real-time positioning accuracy < 1 m

*Telemetry transceiver*

Several trials in container terminal areas have shown, that a significant reduction of multipath reflections can be reached by using the VHF-band for correction data transmission. The typical specification of a data transceiver module is as follows:

- Data rate 9600 kbit/s
- Modulation mode GMSK
- Transmitter power 0,5 W
- Error detection through checksum.

#### 6.1.3.3.1.3.2 Mobile station

The mobile station comprises a satellite navigation receiver, a telemetry receiver and a CPU with a Multi-IO card. Together with a DC/DC converter all these modules are accommodated in a wall-mountable case. External units such as a container weight sensor and a driver's display can be connected. Moreover, interfaces are provided for the radio data terminal built into the carrier vehicle and for the vehicle's own sensors. The correction data sent by the reference station are received by the telemetry receiver of the mobile station and taken via an RS232 interface to the satellite navigation receiver. With the aid of the correction data the satellite navigation receiver corrects its position and outputs it in WGS84 co-ordinates (longitude, latitude and altitude) to the CPU. To increase the positioning accuracy, the position data are filtered in the CPU and, depending on the implemented software, customer-specific xy-coordinates or the container position (position, row, field) is sent to the data output The Multi-IO card connected to the CPU has digital inputs (24 V) for evaluating the following signals from the vehicle's sensors:

- spreader contact (twist lock) open/closed
  (this signal can be used as a trigger signal for the transfer of the location result upon drop-off or pick-up the container)
- spreader width 20 or 40 feet (container size)
- storage level (1, 2, 3 or 4) of the container (height)

A current interface (4...20 mA) for determination of the container weight is available. The collected data (container position in xy-coordinates or location number, storage level, container size and container weight) are output to the radio data terminal, which normally is already installed as standard equipment in the carriers.

*Indicator and Driver's Display*

For simple confirmation by the driver that the required location has been reached, there is a floating contact to which e.g. a lamp can be connected. The lamp indicates to the driver that the correct location has been reached. For this function a decentralised location management is required An alphanumeric display can be connected for display of:

  - current position (in co-ordinates or container location)
  - container location to be approached, if sent by the operator centre via the radio data terminal

– status and error messages of mobile station.

###### *6.1.3.3.1.4 System software*

For the optimal and cost effective operation of the container location system different software packages are required. These are:

- Status and diagnostic software
- Decentralised location management
- Site surveying
- Facilities management system.

*Status and Diagnostic Software*

For error diagnostics in the mobile station and in the reference station a software is required, which allows evaluation of the data output by the satellite navigation receiver in ASCII format with the aid of a terminal program. For the operator's centre a software should be suitable for the evaluation and the display of error and status messages of the mobile stations and the reference station.

*Decentralised Location Management*

A map of the terminal is stored in the CPU of the mobile station. Any changes in the container location plan of the terminal therefore has to be sent as a radio message from the central station to the vehicles. The basic location plan of the terminal is described by:

- all relevant corner points of the terminal
- distance of all rows from the defined corner points
- designation of storage sites, blocks, rows and columns.

The overall layout of a terminal can be produced with the aid of a PC-based CAD tool (e.g. running under Windows 3.11 or Windows 95). In advance a complete survey of the area is required for this purpose. With the decentralised location management it is possible that instead of the position (longitude and latitude or customer-specific xy-co-ordinates) the container storage location is directly output to the radio data terminal upon depositing the container. On the optional driver's display the current container location can also be indicated instead of the co-ordinates. Moreover it can be signalled whether the container storage location approached agrees with the nominal location, provided that the nominal location has been transmitted via the radio data terminal. Another advantage is that the position data measured in the mobile station can be compared with the location allocation. In this way, inaccurately measured positions can be corrected (map matching). Changes to the storage location file require an update in each mobile station. This should preferably be made via radio data transmission. Correct updating is monitored by the operator's centre. It should be borne in mind that during the data transmission some mobile stations may be out of operation, so that an update of these mobile stations has to be made subsequently. The operator centre keeps an acknowledgement list. For vehicles which have not acknowledged the update, the data will be transferred once more.

*Site Surveying*

If a laptop rather than the driver's display is connected to the mobile station, the latter can be used for surveying the container storage sites. This is done interactively by a special software in the laptop. The measurement is referred to the corner points of the blocks. The vehicle drives to the respective point, the user enters the data of such point (block number and other associated parameters) and the mobile station outputs the filtered position data. The measured data are stored in the laptop and can be transferred to the CAD tool mentioned above.

*Facilities Management System*
The vehicle's position can be transmitted upon drop-off or pick-up of the containers as well as cyclically. All vehicles and their current state (loaded/empty, moving/waiting ... ) can be shown up-to-date on a digital map of the terminal. In the map all operating facilities of the system are indicated, such as: cranes, rails and gates. The terminal characteristics are projected and modified with the aid of the CAD tool mentioned above. Data exchange with other Windows applications is possible via a software interface, allowing for instance statistical evaluation with EXCEL. In this way statistical data can be collected on the utilisation of the resources (moves per storage layer, average time per move, min./max. distance covered) as well as on bottlenecks in the goods flow (e.g. waiting loaded for crane, waiting empty at gate ...) of a terminal. These data allow conclusions to be made as to the optimum utilisation of the resources.

###### 6.1.3.3.1.4.1 Error detection

Mobile station and reference station have a large number of self-test functions for reliable detection of failures. LED indicators on the front panels of the mobile and reference station equipment indicate whether valid data are supplied by the satellite navigation receiver, telemetry data are received or transmitted and whether the external and internal supply voltages are available. A status message is output by the reference stations via an RS232 interface in case of failure of the correction data output by the satellite navigation receiver. The data telegram sent by the mobile station to the radio data terminal contains the following error messages:

- Failure of satellite navigation receiver
- Failure of valid position data (e.g. due to insufficient number of satellites or antenna faults)
- Failure of correction data reception
- Failure of analogue sensors.

These faults can also be displayed on the driver's display. Instead of the driver's display, a laptop with test software for diagnostics (see above) can be connected. This software allows evaluation of the data output by the satellite navigation receiver in ASCII format with the aid of a terminal program.

##### *6.1.3.3.1.5 System availability*

Today the MTBF of state of the art equipment and technical components is 30,000 hours. High availability is ensured by the rugged design of the equipment as well as by the logistics concept. According to this concept, an on-site repair involves the complete replacement of a mobile station or reference station and takes approximately 15 minutes. Repairs at module level then can be carried out in special workshops.

###### 6.1.3.3.1.5.1 Redundancy configuration of reference station

To ensure the required high system availability, a redundant configuration is recommended for the reference station, i.e. a master and a standby reference station, operating in hot standby mode. The GPS antenna sites of which must be accurately determined in WGS84 co-ordinates. Each of these two reference stations comprises a satellite navigation receiver, a telemetry transceiver and a comparator with modem. Together with a 230 V power supply these modules are accommodated in a 19-inch case.

*Functional Description*

In the master reference station the correction data produced by the satellite navigation receiver are transferred via the comparator to the telemetry transceiver from where they are sent once per second in the broadcast mode to all mobile stations. The correction data are also received by the telemetry transceiver of the standby reference station and sent back via the modem to the master reference station. The comparator of the master reference station performs an integrity monitoring of the correction data. In the case of a failure, the standby station will take over and transmit the correction data. The comparator contains a processor which is able to send status messages to the operator's centre via an RS232 interface. A four-wire line is required for connecting the modems of the two reference stations.

###### 6.1.3.3.1.5.2 Dead reckoning sensors

A dead reckoning sensor system should be used to enable location also at sites, where short interruptions in the satellite reception caused by shadowing effects may occur. To avoid modifications of the vehicle, as would for instance be required in the case of wheel-mounted speed sensors, a solution using two acceleration sensors mounted perpendicular to each other along the vehicle axis and additionally supported by a gyro sensor has to be chosen. The sensors are all accommodated in a black box, which can easily be mounted in the vehicle together with the mobile station. The electrical connection is done via an RS232 interface.

#### *6.1.3.3.2 Automatic Equipment Identification*

Automatic Equipment Identification (AEI) is the ideal tool for short range data transmission in the transportation industry. Based on a proven Radio Frequency (RF) technology, their superior combination of capabilities speed, range, accuracy, reliability and flexibility allow for fast and accurate data exchange with moving vehicles with outstanding performances. The AIE system is specifically designed and adapted to automatic vehicle access control, car park and fleet management applications. AEI provides the first true hands-free system, allowing for a wide range of integrated and flexible solutions. Vehicles are authorised or denied access, without having to manually insert or present an access card.

##### *6.1.3.3.2.1 Principle of operation*

Vehicles equipped with an identification tag (in which is encoded a unique identification signal) are detected when driving by the reader stations located at entrance and exit gates. The code supported by the signal, is immediately transmitted to a processing unit which analyses it, then accepts or refuses access to the vehicle. The identification code can contain information such as the vehicle number, the container number as defined in the ISO 10374 standard, or any information programmed by the user. The code can include up to 10 or 20 ASCII characters (64 or 128 bits) of memory, depending on the type of tags used.

*Reader station*

The reader is composed of four main modules:

- the transmitting/receiving antenna
- the RF source
- the logic board and
- a power supply

It is contained in a single compact enclosure which can interface directly to existing systems. The whole system is maintenance-free. In order to detect the transponder, the reading station transmits a modulated signal within the same frequency band. The tag reflects back the signal to the reading station, through a technique called "modulated backscatter". The reflected signal supports the identification code, which is then processed by the reading station. The vehicles being recognised at normal driving speed putting an end to time-consuming queues and delays at check points. It therefore enables to improve the throughput of vehicle flows, increases the speed of authorisation and control operations and minimises the need for human intervention.

*Identification Tag*

Two different types of identification Tags are typically used:

- AEI-Tags for fleet management
- Transportation Tags

Tags are RF field disturbance devices used in harsh environmental conditions. Each Tag encodes an identification number or data message on the signal broadcast from a reader system and reflects it back to the antenna for decoding by the system. Transportation Tags in addition are multi-frequency, battery-powered devices used in applications requiring long range operation (working range up to 70 m at 900 MHz). They can store up to 20 alphanumeric characters (120 data bits), which may be programmed at the factory or by a field programmer.

### *6.1.3.3.2.2 AEI devices in Positioning Systems*

Identification systems can be used for guiding and/or positioning vehicles. This usage makes it possible for the computer to determine its position within a system by means of a coded transponder signal. So called one dimensional transponders are mainly used for:

- Stock keeping
- Determination of vehicles
- Material handling control
- Identification of containers and boxes
- Proximity protection of track guided vehicles
- Position finding for public transportation.

#### 6.1.3.3.2.2.1 Functional description

When a vehicle passes a transponder the receiver determines from the strength of the signal the defined displacement of the transponder in relation to the antenna position. The computer recognises its instantaneous direction of travel in direction x and crosswise in direction y. The corresponding reader then calculates the code and the transponder‘s position in relation to vehicle‘s direction of travel and transfers it as serial data information to the output. Each time the co-ordinate axis is crossed in the direction of movement a potential floating positioning pulse which lasts a second is output. Since the transponders are not programmable, code conversion must be done. The lower 16 transponder bits of the code will be searched for in a 2000 line table If a match is found, the corresponding 24-bit number will be output. This table may be read out, changes saved to disk, or reloaded again using appropriate software. Furthermore, the syntax and timing of the reader‘s periodic serial data output is constantly monitored, i.e. even without transponder the reader delivers a constant output. The mobile unit consists of:

- combined antenna to send (heater) and a coil to receive
- decoder (interpreter)
- power supply.

Tags are buried in the earth at defined spots along that way the vehicle shall follow. Whenever the antenna crosses a transponder it is energised by means of an energy field of the antenna. As soon the energy supply is sufficient in the transponder it starts attenuation the magnetic field. Periodically and according to its code. This attenuation reflects to the antenna and generates amplitude modulation (AM) in its transmitter. The receiver then filters the useful signal from the AM and outputs it to the interpreter (LF-signal). Depending on the strength of the signal returned to the antenna, the interpreter is able to determine at which defined distance from the reading antenna the transponder is located. Following the crossing of the transponder and the decoding of the transmitted data the interpreter outputs the transponder code via a serial line. Additionally two digital signals are provided:

- Midpoint crossover
- Data valid.

For guiding function the system is a combination of two single and slightly modified transponder systems.

###### 6.1.3.3.2.2.2 Guiding Systems

Incremental encoders (or steering potentiometer) enable to alter the course as desired. Due to a previously entered descent (T107 + incremental value) it is therefore possible to turn on the new track. The vehicle corrects itself again at the next transponder (T436). The distances between the transponders are to be determined according to the conditions. The transponder T107 enables to determine the deviation from the intended track (10 mm). Now the board computer would be able to determine the new course in order to reach the virtual track as quickly as possible at T108/109. The second antenna frame controls the synchronous operation in the same way. Incremental encoders enable to position the crane at arbitrary places between the transponders e.g. at a container position. The distance between the transponders are to be determined according to the spot conditions. The typical system accuracy is as follows:

| | |
|---|---|
| Resolution: | 3 mm |
| Repetition accuracy: | +/- 6 mm |
| Central positioning: | +/- 5 mm within 125 mm from antenna centre at nominal reading height to +/- 20 mm;<br>additional +/- 6 mm error margin for every 50 mm that the reading height is altered. |

*Inductive guided vehicles*

It is possible to use transponders as switch-transponder for very large vehicles, that are guided by inductive wires, for switching from one frequency loop to another. When approaching the switch-transponder (T001) the vehicle is informed via radio or inductive transmission to change to loop 3, it is possible to create variable transportation courses.

*Curve steering*

In addition to the identification of container lots it is possible to carry out curve steering for very large vehicles like Gantry Cranes, e.g. in order to achieve speed adjustment of the two sides of the vehicle in the course of the curve.

*Collision avoidance for automatic guided vehicles*

An anti-collision system for driverless vehicles enables in conjunction with a locating system the management of traffic at intersections. To avoid collisions the vehicles use a common radio data link. The intersection is divided in different sectors. Each vehicle puts information of the current position on the radio bus.

The locating system passes a message each time the vehicle enters or leaves area 1 or 2. From this event an unambiguous surrogate can be derived to manage the entire traffic. A typical application of such a traffic management system is a tag reader system that acquires the code of ground-transponders and transmits the position information. The functions are:

- Wireless, bi-directional data transmission between the vehicles
- Safe data protocol
- Combination of a radio- and a tag based locating system
- Efficient collision avoidance system for intersections.

#### *6.1.3.3.3 Comparison of Tags and GPS sensors*

The description of Tags and GPS sensors has shown, that both systems are qualified to fulfil the requirements of vehicle and container location at terminal areas. Nevertheless both systems have different advantages as well as some disadvantages.

| Sensor | Advantages | Disadvantages |
|---|---|---|
| **Tags** | - Simple and low-priced modules<br>- High accurate positioning<br>- AEI = Automatic Equipment Identification<br>- No significant environmental influence on temperature, rain vibration, pollution | - Single positioning only<br>- Fixed track<br>- Costly installation (infrastructure)<br>- Required minimum distance of nearby installed tags (> 8m)<br>- TAGS must not be covered by metallic plates |
| **GPS** | - Cost effective sensors<br>- Output of position, direction, time, status<br>- Tracking<br>- High location accuracy by DGPS operation<br>- No significant environmental influence on temperature, rain vibration, pollution | - Reduced location in areas with shadowing effects (hangars, cranes, bridges, buildings)<br>- Sensitive against multipath effects |

One of the main requirements for the PRECISE project is the location of containers inside an terminal area with different container transport vehicles, as:

- RTGs
- RMGs
- Straddle Carriers
- Reach Stackers
- Prime Movers.

An overall system should be suitable for any kind of operational and technical requirements. The system also should be capable to work under difficult environmental conditions. Special attentions has to be given to:

- fog and heavy rain
- pollution
- shadowing effects
- temperature and
- vibration.

Further aspects are cost effective solutions and a short maintenance time for a high reliability of the system. The following table gives a summary and a comparison of the pros and cons of Tags and GPS.

### *6.1.3.3.4 Requirements of GPS systems for intermodal terminal*

The comparison of Tags and GPS has shown, that GPS is the most flexible and cost effective sensor. The high flexibility of GPS however can be reduced by environmental conditions. While an unrestricted line of sight is required for a good and undisturbed reception of the satellite signals, there are several environmental conditions, where this cannot be guaranteed, like:

- high buildings and hangars
- „tunnel effect“ inside high container stacks
- ship walls
- shadowing effects by RTGs and RMGs (in case of operating Straddle Carriers or Reach Stackers)
- multi-path reflections (in case of low antenna height)
- radio interference.

#### *6.1.3.3.4.1 Increase of GPS availability*

While an average of 6...10 GPS satellites are visible all over the sky in the latitudes of Europe, a minimum of 3 satellites are required for two-dimensional location.
In case of shadowing effects, however, parts of the sky can be covered by buildings, ship walls and the like. In this case the number of visible satellites can be significantly reduced. This applies especially to satellites with low altitudes respectively elevation angles. This problem can be partly solved by using not only the GPS system but also the Russian counterpart the GLONASS system. Both systems have the same qualities, but the GLONASS system is still not fully available. Nevertheless in difficult environments more satellites are visible to fulfil the requirements of a minimum satellite number. Combined GPS/GLONASS receivers are available on the market at the same prices as high precision GPS receivers.

#### *6.1.3.3.4.2 6.2 Multi-path reduction*

In terminal areas a high risk of multi-path propagation is given by the metallic environment of containers, ships and cranes. Big influences of the location accuracy will have reflections near the antenna, when a strong reflected signal will interfere with the direct path and cause severe phase shifts. Partly remedial measures can be taken by using choke rings, suppose that signals will be reflected on the metallic parts of the transport vehicle from beneath the antenna. Choke rings are flat concentrically metallic cylinders at the bottom of the GPS antenna, which decrease the multi-path influence by reducing the vertical antenna diagram at lower elevation angles.

#### *6.1.3.3.4.3 Dead reckoning sensors*

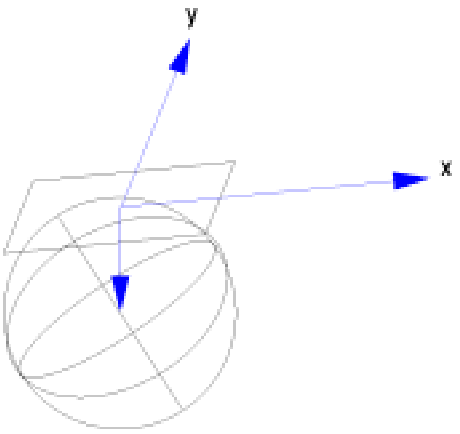
Satellite antennas installed at the top of Straddle Carriers, RTGs or RMGs normally have an unrestricted view to the satellites due to the height of the vehicles. Reach Stacker however are operating between container stacks and beneath RTGs, RMGs and near high ship walls. The view to several satellites therefore is very often restricted, also when using combined GPS/GLONASS receivers. In cases like these only dead reckoning sensors will help to solve the problem. The commonly used dead reckoning sensors are a combination of a gyro and one or more odometers. Based on the high centre of gravity and the heavy weight of loaded container stacking vehicles, tests have shown, that the slip of tires in curved tracks or during acceleration will lead to significant errors already after short distances. Acceleration sensors (see Inertial) however are not influenced by any slip but dependent on the temperature stability of their characteristics. In addition to the use of high quality sensors a compensation can be done by using an additional temperature sensor. As a high location accuracy requires to determine the centre of the container, it can easily be done with Straddle Carriers, RTGs and RMGs by installing the satellite antenna directly above the centre of the container hoisting frame Reach Stackers however carry the container with an extendable lifting arm equipped with a revolving hoisting frame. By measuring the centre of the Reach Stacker an ambiguous correction has to bee carried out to determine the container position. During the PRECISE project this problem has to be solved by testing different solutions, like antenna position, combination of different sensors or inclusion of the vehicle own signals (e.g. length of lifting arm).

#### *6.1.3.3.5 <u>Multi sensor system</u>*

The application of a container location system comprises of basic location modules with integrated sensors as well as location and management packages. The more complex the system is the more sophisticated the processing of the software tasks are. While the priority of the mobile software is the calculation of high precise location results, the central software is managing the movement of goods and container positions.

##### *6.1.3.3.5.1 Conversion from WGS84 to area co-ordinates*

A NED co-ordinate system is used with the z co-ordinate through the centre of the earth. The measurements from the GPS sensor in WGS84 are transformed into the NED-co-ordinate system by the following equations:



$$X = \left(\frac{A_{WGS}}{\sqrt{(1 - E1_{WGS} \cdot \sin^2(\vartheta))}} + H\right) \cdot \cos(\vartheta) \cdot \cos(\rho)$$

$$Y = \left(\frac{A_{WGS}}{\sqrt{(1 - E1_{WGS} \cdot \sin^2(\vartheta))}} + H\right) \cdot \cos(\vartheta) \cdot \sin(\rho)$$

$$Z = \frac{A_{WGS} \cdot (1 - E1_{WGS})}{\sqrt{(1 - E1_{WGS} \cdot \sin^2(\vartheta))}} + H) \cdot \sin(\vartheta)$$

with

$A_{WGS}$= 6378137,0 diameter of the earth (big)
$E1_{WGS}$= 6694,3800 l $10^{-6}$ 1. numerical excenter
(Longitude ρ , Latitude ϑ , Height H)

### *6.1.3.3.5.2 Relation of container position co-ordinates*

All container positions inside of a terminal are normally related to a reference point as an origin of a Cartesian Co-ordinate System (e.g. x and y with measures in meters). The determination of the container position can be done in two different ways:

- conversion of the measured WGS84 co-ordinates in Cartesian Co-ordinates (in meters) for each single position
- comparison of measured WGS84 co-ordinates and position co-ordinates by a stored table.

While a stored table is not very flexible, because it needs a continuous update of new and changed positions in all mobile units, an online conversion of co-ordinates requires a more efficient processor, which however is quite easy to realise and as a standard module on the market.

### *6.1.3.3.5.3 Terminal layout*

If the yard layout is stored in the location processor on board of the mobile vehicles, alterations in the yard layout can be updated in the location processor by broadcast messages from the central management centre via data radio. The information of the yard layout contains:

- all relevant corner points of the yard
- the distances of all rows from defined corners
- names of areas, blocks, rows and columns.

The complete and precise terminal layout can be configured with an CAD-Tool on a PC. The information interchange to already existing planning and administration tools is also possible by ASCII-files which can be modified by simple editors. Thus the operator of the terminal can modify and reconfigure the layout by himself at any time. The configuration file will be converted, broadcasted by the data radio and downloaded into the locating processor of the mobile system. This will take a few moments and afterwards all vehicles will operate on the basis of the new layout at the same time. The system performance depends on the accuracy of the position detector. Increased safety of correct identification is achieved by further post-processing of the DGPS-information computed by the locating processor. This is performed within several steps:

*Additional Filter*

After an event caused by the spreader or on manual request not a single position fix from the GPS receiver but a set of positions during the whole time of a standstill is filtered by a weighted time correlator

*Position-Matching with the terminal layout*

The map of the whole container terminal is kept in non volatile memory of the locating processor. After a position fix a map matching of the filtered value with the terminal layout is performed. Positions within a rectangle of 75% of a container footprint are set to certain. Positions outside the 75% area but within the storage place are set to uncertain. If no slot can be identified the message „no slot available“ will be sent to the terminal information centre.

*Classification*

The final result is compared with the dispatch order and classified according to the list in the box to the right.

#### 6.1.3.3.5.4 *Integration of additional sensors*

For the identification and the data management additional sensors may be connected to the CPU and/or navigation processor of the mobile units of a container location system. The analogue signals of:

- container height (stacking level 1, 2, 3...)
- container width (20 ft, 40 ft)
- twist lock (on for pick-up, off for drop-off)
- container weight (depending on the maximum load of the vehicle)

are converted into ASCII data and added to the location telegram.

With dead reckoning sensors two processes are running in parallel. The position is determined by satellite location, while the position is also calculated from the measures of the dead reckoning system. As long as valid data are available from the satellite receiver the dead reckoning system is synchronised continuously. If the satellite location fails, e.g. in case of shadowing effects, the dead reckoning system takes over the location until valid satellite data are available again. A smooth transition has to be realised, so that the user of the location system should not have notice of this process, except by an LED indication or a „BITE-Flag“ in the location telegram. An identical method has to be developed, if required, for the integration of external sensor systems for the location of Reach Stackers.

#### 6.1.3.3.6 *Cost statement*

Today the market for GPS receivers covers low cost modules for 200 EUROS or less as well as high precision RTK (Real Time Kinematic) receivers for some 10...15K Euros. The rough environmental conditions (e.g. temperature, vibrations) for container location systems will require receiver modules with MIL-technology. Based also on the operational requirements like Time-To-First-Fix (TTFF), re-acquisition time and dynamic performance the GPS receivers will be settled at the higher end of the pricing scale. The same statement is valid for the additional modules like power-supply, processor, display or the optional dead reckoning sensors.

#### 6.1.3.3.7 *Conclusion*

No doubt GPS/DGPS systems offer the user considerable benefits, including eradication of lost boxes and optimisation of both carrier movements and yard stacking. Practice has already shown, that such a location system based on GPS has enabled terminal operators (e.g. HHLA) already to enhance its capacity by some 10 to 15 %, mainly due to the fact by using now the third tier in certain circumstances and replacing the manual yard planning system, which has to be updated daily. Reach Stackers, meanwhile, pose a considerable challenge to GPS and additional sensors. They are inherently more mobile than cranes and straddle carriers, but also relatively small and easily „hidden“ by container stacks. The precise location of these vehicle are therefore an important step for the optimisation of intermodal terminal operations.

### 6.1.3.4 ***Sensors requirements: conclusion***

Being both maritime and inland terminal operators inside the project partnership, an accurate analysis of these two types of terminals was carried out.

A preliminary analysis cost/effective in conjunction with their particular characteristics (namely the terminal size, the operational procedures and the level of automation) has shown that an automatic localisation system is more interesting for maritime terminals than for inland terminals. This consideration suggests to set-up a demonstration system in a maritime terminal.

The analysis performed underlined the necessity that a localisation system could have these features:

- precise localisation of the containers put-down in the yard. The system has to avoid misplacements that cost time and money to the operators.
- automation of the procedures dealing with load/unload process. This feature will reduce time consumption and will eliminate human errors.
- optimisation of the terminal operations. This is not really a primary objective but it is however an important secondary feature.

Considering the technical aspects, the relevant requirements are:

- measure precision within 1 meter
- not many changes in the terminal layout
- resistant to the environmental constraints
- independence from the informative system of the terminal.

A general set of requirements for the set-up and testing of the system and the criteria against which the performances of the demonstration system are shown in the following table:

***System #1:*** automatically gives to the operator the ITUs position (the human operator has only a supervising function to confirm the data).
***System #2:*** the same as ***System #1*** and in addition monitors the movements of all the vehicles running inside the terminal.
***System #3:*** only gives the positions of all the vehicles running inside the terminal.

- **Legenda:**

PR = Performance Requirement TR = Technical Requirement
IR = Interaction Requirement C = Costs Requirement

- **Row explanation:**

*Expected performances*: operational problems addressed by the system.

*Expected savings*: improvements in the terminal operations that are due to the system.

*Position accuracy:* level of accuracy the measure needs.

*Acquisition frequency*: how often the Load Unit position has to be calculated (for example only at the moment of the twist lock openings/closes).

*Data transmission frequency*: how often the mobile unit has to send its data to the Information server (for statistics purposes this action could be done once a day).

*Availability*: measure availability with the accuracy above stated.

*Robustness*: the physical stresses the unit has to support.

*Constraints on the system's layout:* constraints which are due to the terminal environment (dimensions, cables, ...).

*Vehicles*: vehicles which have to be localized.

*Interactions with the drivers*: changes in drivers' operations that are due to the systems.

*Interactions with the management system*: modality of the interactions between our system and the terminal information system.

**Table 3 - Requirements**

| | | *SYSTEM #1* | *SYSTEM #2* | *SYSTEM #3* |
|---|---|---|---|---|
| **PR1** | *Expected Performances* | • Load Unit' localization<br>• data for statistical purposes<br>• interaction with the informative system in order to manage the terminal operations | in addition to System #1<br>• vehicles localization | • vehicles localization<br>• data for statistical purposes |
| **PR2** | *Expected savings* | • avoid wrong Load Unit' positioning (15-20 h/month)<br>• automation of the terminal operations<br>• optimization of the terminal traffic | in addition to System #1<br>• optimize route planning | • optimization of the terminal traffic<br>• optimize route planning |
| **TR1** | *Position accuracy* | • Load Unit (1 meter RMS) | • Load Unit<br>• vehicles | • vehicles |
| **TR2** | *Acquisition frequency* | • opening/close the twist lock | • every 5-10 sec<br>• op/cl twist lock | • every 5-10 sec |
| **TR3** | *Data Transmission frequency* | • opening/close the twist lock<br>• once a modification (for translation table)<br>• once a day (for statistical purposes) | The same as System #1 | • once a day |
| **TR4** | *Availability* | • always | • always | • when requested |
| **TR5** | *Robustness* | external / internal unit:<br>• water resistant (IP67)<br>• vibrations and shocks<br>• temperature (-20 : +60) | The same as System #1 | The same as System #1 |
| **TR6** | *Constraints of the system layout* | • limited dimensions<br>• no obstacles on the ground | The same as System #1 | The same as System #1 |
| **TR7** | *Vehicles* | • Cranes and reach-stackers only (no prime movers) | • All the vehicles present into the terminal area | • All the vehicles present into the terminal area |
| **IR1** | *Interactions with the drivers* | • the driver has only to confirm data which come from the system | The same as System #1 | • no changes in driver's operations |
| **IR2** | *Interactions with the management system* | • the system must be interfaced with the informative system<br>• the two systems work together to optimize the terminal operation | The same as System #1 | • none |
| **C1** | *Expected Costs* | • Return of investment in few years (2-3)<br>• low maintenance cost | The same as System #1 | • Low cost |

## 6.1.4 System requirements: overview

### *6.1.4.1 Acoustic technology*

#### *6.1.4.1.1 Acoustic source*

One of the main issues concerning Acoustic technology is the characteristics of the acoustic source, in terms of:

- dimensions of the transducer
- frequency, which may have a negative impact on terminal's noise level
- power of emission, for the same reason above

#### *6.1.4.1.2 Fixed stations*

The need for a certain number of fixed stations to cover the terminal area poses another challenge, in terms of installation costs and robustness of the overall system. Here again the issue has to be addressed in co-operation with LSCT. It would be advisable to use structure already existing on the terminal area (like light poles), though this may not be possible for contingent reasons. The installation costs of the fixed stations will have to be analysed.

##### 6.1.4.1.3 Time synchronisation

In order for the acoustic system to function properly, the acoustic transmitters and receivers must be synchronised. The presence of a radio trigger may represent a possible cause of trouble for terminal operators, as this may require additional authorisations from national authorities. Apart from this administrative aspect, the time synchronisation represents a technical issue which must be carefully addressed.

#### 6.1.4.2 GPS technology

##### 6.1.4.2.1 Shadow effects

As mentioned in several parts of Deliverable 1, the main draw-back of GPS systems is the degradation of the position accuracy in case of low satellite visibility. This is particularly true for Reach Stackers which, moreover, are the most flexible vehicles on the terminal. One of the project's goals is precisely to try and find a solution for this specific vehicle. Therefore, most of the efforts will be put on this goal. One issue to be addressed regards for example the position of the GPS antenna which can be:

- on top of the Reach Stacker's arm
- on the body of the Reach Stacker

Whereas the first solution appears to be the best choice for the determination of the position of ITUs, it poses some delicate technical challenges (robustness and cable's installation being the main). The detailed analysis of Reach Stacker's structure, in co-operation with LSCT, will allow to identify the optimum solution.

##### 6.1.4.2.2 Dead reckoning system

Dead reckoning systems are used as a back-up to GPS for those situations where the satellite visibility is lost for a short period of time. Several sensors can be incorporated to form such a system. A careful evaluation of casts/performance ratio must be carried out in order to set up an effective unit at a cost that can be accepted by the market. Extensive tests will be needed on La Spezia Container Terminal during the site validation in order to clearly identify the situations which allow for the dead reckoning system to effectively back-up the GPS. It should be noted that a dead reckoning unit could be beneficial also for the acoustic location system, in case of some adverse environmental conditions which could cause a degradation in the position information supplied by the acoustic sensors.

#### 6.1.4.3 Additional sensors

Both Acoustic and GPS technology supply a position information which matches the accuracy requirement only on the horizontal (x, y) plane. The position of a container is however defined by 3 co-ordinates: x, y and z, where z is the stacking level (1, 2, 3, …). For the identification and the data management additional sensors are therefore needed, at least for the mentioned z co-ordinate. Other analogue information which may be useful to the terminal operations procedures are:

- container width (20 ft, 40 ft)
- twist lock (on for pick-up, off for drop-off)
- container weight (depending on the maximum load of the vehicle)

These are normally available thanks to sensors which are already present on board of the vehicles. The information supplied by these sensors can be gathered together with the position information and relayed, via the data radio link, to the terminal operator's information system.

### *6.1.4.4 Conclusion: matching of technologies performances with system requirements*

The focus is put on the two technical requirements rated as most important by terminal operators, and precisely:

1. TR1: position accuracy
2. TR4: availability

as in fact these are the two requirements that, if they are not met, the location systems can be hardly considered to be of some use to terminal operations.

#### *6.1.4.4.1 TR1: Position accuracy*

##### *6.1.4.4.1.1 Acoustic technology*

The acoustic technology is expected to match the required position accuracy for even the most demanding system i.e. System #1. This is at least what METRAVIB's simulations have shown. This performance will clearly need to be demonstrated on the field, during the demonstration system testing.

##### *6.1.4.4.1.2 GPS technology*

GPS in the configuration of Differential GPS allows for a position accuracy of 1m or better, therefore again matching the required position accuracy for System #1, at least with a good satellite visibility.

##### *6.1.4.4.1.3 Combination of Acoustic and GPS technologies*

In good conditions described above, as either mentioned technology matches the position accuracy requirement there is *a priori* no need to consider to combine them together for the sole purpose of TR1.

#### *6.1.4.4.2 TR2: Availability*

##### *6.1.4.4.2.1 Acoustic technology*

The degradation in the position measurement in case of adverse situations, which will need to be identified during the demonstration system testing, still needs to be evaluated.

##### *6.1.4.4.2.2 GPS technology*

In case of a poor satellite visibility, the position accuracy may be degraded to such extent as to cause the system to be practically unavailable. In these conditions, it is therefore necessary to rely on a back-up system which function is to supply a position information with the required accuracy. Awell designed dead-reckoning system allows for sufficient accuracy when short interruptions in the satellite reception occur. For longer interruptions however the dead-reckoning system cannot guarantee the said precision.

##### *6.1.4.4.2.3 Combination of Acoustic and GPS technologies*

In the last condition mentioned above, from the technical point of view it may be interesting to evaluate a location system combining Acoustic and GPS sensors, which will possibly be considered for the pilot installation. However, the preliminary data on the costs of such systems, as anticipated by MVIB and R&S, suggest that the cost/benefit ratio of a system combining both technologies will need to be evaluated with great care.

*The activities performed have confirmed what was foreseen in the Technical Annex to the CEC Contract, and precisely that, given the terminal requirements set forth by terminal operators Acoustic and GPS are the most interesting technologies to consider for the set up of ITUs location systems. Both seem equally applicable in most environmental conditions, whereas they also have draw-backs in adverse conditions. The demonstration system which will be set up in La Spezia Container Terminal will identify these adverse conditions, and allow to define the best configuration which will allow to match all terminal requirements.*

## 6.2 OVERALL SYSTEM DESIGN

The system design have been analysed in terms of:

- GPS network
- acoustic network
- data transmission network
- Position Information Server

### 6.2.1 Overall system architecture

The general architecture of the system is the following (see Figure 1):

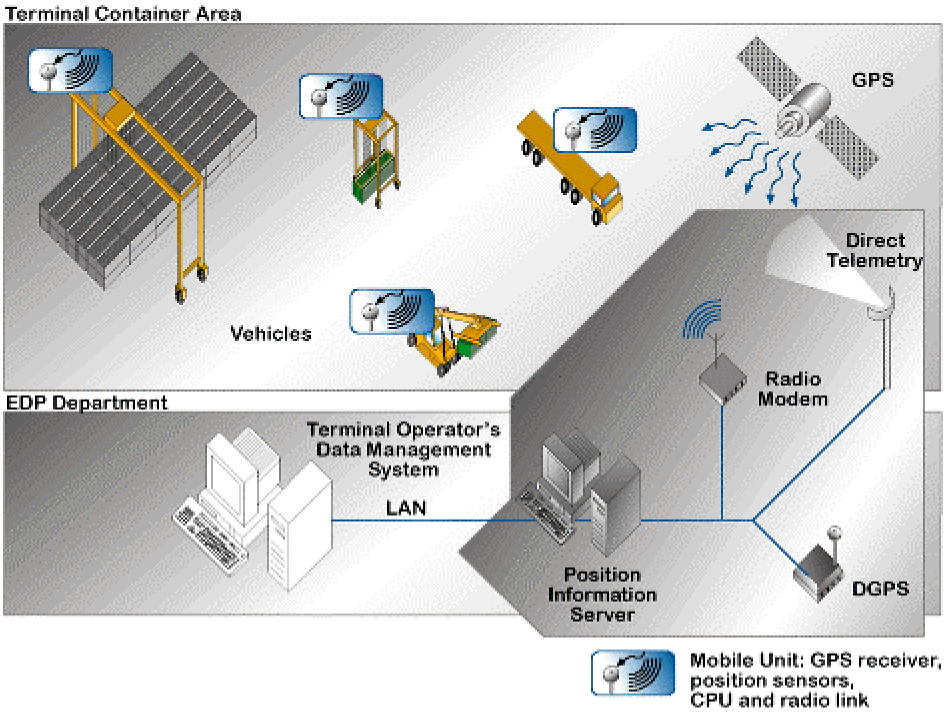


Figure 1:Overall System architecture

- A set of sensors dedicated to determining the location of vehicles which have the capability to move ITUs inside the terminal area (in this case only one reach stacker and one RTG will be considered).
- A mobile control unit installed on each vehicle (made of a set of electronic boards and dedicated software for local data processing an input/output management) interfaced with the vehicle and the location sensors, which collects all information from the various sensors, puts it in a standard form and makes this information available for transmission.
- A data transmission network which connects the mobile units and the Position Information Server.

- The Position Information Server which is the control and monitoring system that manages all position information, interfaced on one side with the Terminal Data Management System through a standard interface, on the other side with the data transmission network and therefore with the mobile units.

As said, in the pilot installation two different systems will be tested separately :

- An acoustic system based on a set of fixed transmitters disseminated on the test terminal area and a receiver on board of each vehicle. When a vehicle needs to know its position, it sends a radio pulse to the acoustic transmitters that will emit a signal that will be elaborated by the receiver in order to determine the position.
- A DGPS system based on GPS and the reference station in conjunction with a dead reckoning system based on inertial sensors. The fusion of the data from both sensors is supported by a Kalman filter that represents the dynamic behaviour of the vehicle.

Therefore two different mobile units have been developed: one by METRAVIB (acoustic system) and the other by R&S (DGPS system). In order to minimise the impact on the vehicles and to save money and time we tried to use the same physical interfaces for both systems. For the data transmission network design only the available standard market solutions have been considered. Also for the Position Information Server, only standard market technologies have been evaluated both for hardware and software solutions.
The final architecture for the demonstration system is the following:

- Two mobile units for both the system under test, one for each vehicle (RTG and Reach Stacker) will be installed onboard. The mobile units will be interfaced with the position sensors (Acoustic or DGPS+dead reckoning) and the available vehicle’s signals to evaluate the vehicle’s position.

- The mobile units will be interfaced via a serial line RS232 with the radio modems onboard a vehicles in order to transmit the position data

- The position data transmitted will be received by the RFUs connected to a Network Controller interfaced with the Position Information Server.

- The Position Information Server will receive the position data, will manage them and transmit the “pick” and “place” events to the Terminal Operator’s Data Management System that will display the park positions and the ITUs movements in the test area.

## 6.2.2 GPS network

Based on the analysis of the different types of location technology, a DGPS system with dead reckoning sensors was selected as one of the most advantageous solution for the location of containers inside an intermodal terminal. The required modules for the mobile units and the reference station were selected and the interfaces between the vehicles and the control and management system were specified. Details were given in the following report. During a technical meeting installation problems were discussed and clarified. The report will close with some test results of the development of the dead reckoning system, which will be the back-up system of the DGPS in case of shadowing effects. The aim of this document is the definition of the hardware and software of the DGPS system and the interfaces between the Mobile Units (MU) and the Position Information Server (PIS).

### 6.2.2.1 *Technical data of selected modules*

#### *6.2.2.1.1 System overview*

The DGPS Location System includes a Reference Station and two Mobile Units. The system is working with correction data based on the RTCM 104, Version 2.1, format. All modules were selected especially in consideration of the environmental operational conditions, e.g. temperature and vibration.

*Reference Station*
The Reference Station is composed by a GPS/GLONASS receiver, a telemetry transmitter for the correction data and a AC/DC power supply. For future applications the Reference Station can be equipped with a control processor for main/standby operation.

*Mobile Unit*
The more complex part of the system is the Mobile Unit. The correction data transmitted by the reference station are received by the telemetry receiver and sent via an RS232 interface to the GPS/GLONASS receiver. With the aid of the correction data the satellite navigation receiver corrects its position and outputs it in WGS84 co-ordinates (longitude, latitude and altitude) to the CPU. To increase the positioning accuracy, the position data are filtered in the CPU and, depending on the implemented software, customer-specific xy co-ordinates are sent to the output. The multi-IO card connected to the CPU has digital inputs (24 V) for evaluating the following signals from the vehicle's sensors:

- twist lock on/off (closed/open) (this signal is used as a trigger signal for transfer of the positioning result upon drop off or pick up the container)
- spreader width 20 or 40 feet (container size)

Two current interfaces (4 to 20 mA) are provided for the determination of the container height by measuring the length and the angle of the hoist arm of the Reach Stacker. The storage level of the RTG is depending on the number of rotations of the cable drum (500 pulses/spin). In this case the container level will be determined by an ultrasonic device, which will measure the distance between the top of the container and the sensor platform (near the cable drum). For the dead reckoning sensors the following analogue inputs with a 0...5 V and 2...3 V range are available:

- Rotating Rate X
- Rotating Rate Y
- Rotating Rate Z

- Slope X
- Slope Y
- Temperature

A DC/DC power supply converts the supply voltage of the vehicle to the required voltage range of the Mobile Unit.

#### *6.2.2.1.2 GPS/GLONASS receiver*

The selected satellite receiver is the GG24 from Ashtech. By using GPS and GLONASS, one of the primary advantages is the increased satellite coverage. With 48 satellites from the combined constellations, there are twice as many satellites available for position computation, which is extremely beneficial in obstructed operating environments. The specifications of the GG24 receiver are:

*Real-Time Position Accuracy*

| GPS + GLONASS | CEP (50%) | 2dRMS (95%) |
|---|---|---|
| Autonomous | 7 m | 16 m |
| Differential | 35 cm | 75 cm |

*Standard Features*

- 12 Channels L1 GPS code & carrier
- 12 Channels L1 GLONASS code & carrier
- 30-seconds warm start
- 40-seconds cold start
- 2 second re-acquisition time
- Receiver Autonomous Integrity (RAIM)
- Standard NMEA-0183 output

*Navigation Board*

- Differential Remote RTCM V2.1
- Message Types 1,2,3,6,9,16 and 31,32,34,37 (from future V2.2)
- 5 Hz position update rate
- 20 g tracking capability

*Reference Station*

- Differential GPS Reference Station RTCM V2.1
- Message Types 1,2,3,6,9,16 and 31,32,34,37 (from future V2.2)
- 1PPS timing signal
- 2 Hz position & raw data update rate
- Raw data output

*Communications*

2 bi-directional RS232 Serial Ports

*Physical & Environmental*

| | |
|---|---|
| Operating Temperature | - 30° C to + 70° C |
| Sustained Acceleration | 20 g |
| Power Consumption | 2,5 W |
| Speed | 1000 knots |
| Altitude | 60.000 ft |

### *6.2.2.1.3 Processor board*

The processor board of the Mobile Unit will execute the following main tasks:

- position determination by dead reckoning sensors
- conversion of WGS84 into customer-specific xy-coordinates
- interfacing with the radio data terminal

A special adapter card is performing the A/D-conversion of all analogue signals of the dead reckoning and the vehicle sensors. The selected Single Board Computer is a high performance, fully IBM AT compatible, PC/AT board. It includes the following features:

- Microprocessor with internal CPU clock running at 100 MHz
- Internal Cache Memory
- Support of 16-bit standard ISA bus
- 4 MB DRAM
- 2 MB Flash Disk onboard
- Watchdog timer
- Multi-function connector for external connection of keyboard, speaker, reset button and hard disk
- Parallel printer port
- Two serial ports

A Serial Expansion Card offers full architecture, hardware and software compatibility with the PC Bus and provides two further serial ports with internal 16-byte FIFO buffers and one bi-directional parallel port. The Multifunction Data Acquisition Module provides a versatile I/O subsystem for embedded applications. It handles 8 single-ended inputs (TTL I/O) referenced to analogue ground. Additionally 4 digital inputs and 4 digital outputs are available. The maximum possible A/D conversion rate is 100.000 samples per second using DMA.

*Physical & Environmental*

| | |
|---|---|
| Operating Temperature | - 25° C to + 70° C |
| Power Supply | + 5, ± 12 VDC |
| Power Consumption | 7 W |

### *6.2.2.1.4 Telemetry*

The radio data modules are single board devices in Eurocard format, which are primarily developed for the distribution of correction data from a reference station to mobile stations in a DGPS system. In the transmission mode any characters will be accepted via the data interface by the module. The maximum telegram length is 2000 characters. The telegram transmission will start with a preamble and a synchronisation word and will be closed with a checksum. If the field strength of the RF signal is sufficient, the controller will switch the data module into the reception mode. After verification of the telegram with its correct checksum the data will be available at the data interface. Should the telegram and the checksum be incorrect, the receiver will remain quiet and no data can be read out. All internal frequencies are generated by a PLL-synthesiser. The synthesiser initialisation starts by switching power on.

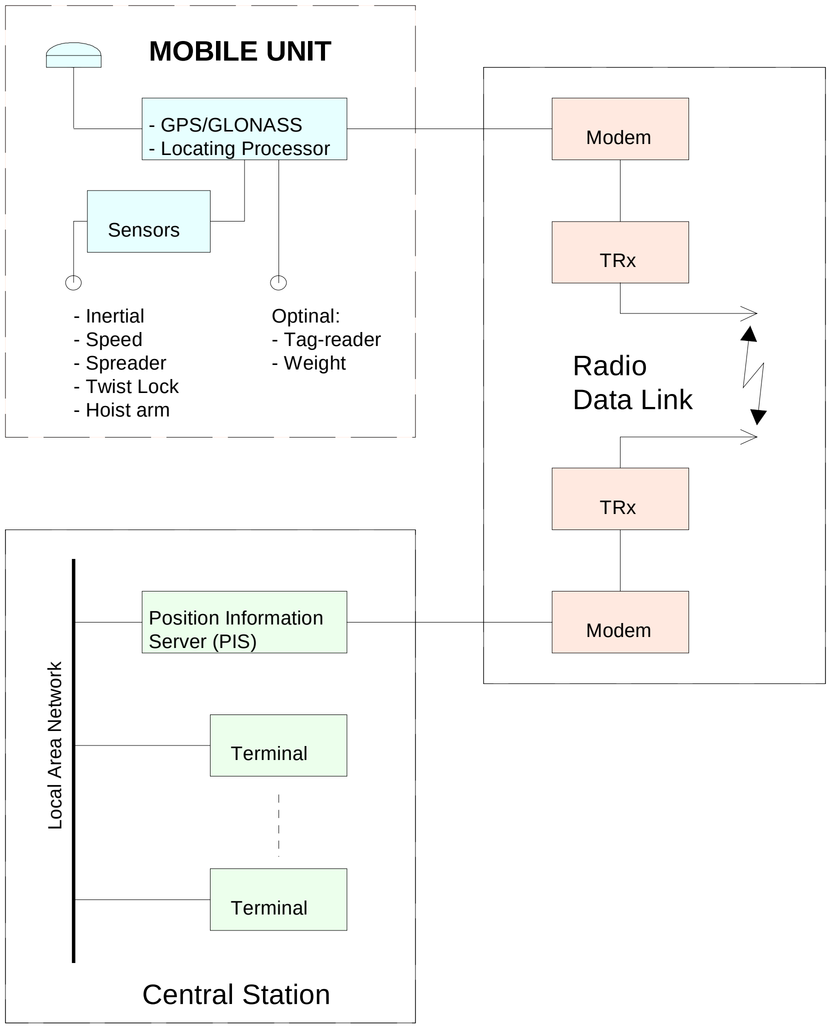
*Technical Data*

| | |
|---|---|
| – Frequency range | 170 MHz in accordance with FTZ Regulation 17 TR 2014 |
| – Frequency adjustment | Ex works (EPROM) |
| – Frequency bandwidth | 20 kHz |
| – Operation mode | Simplex (half duplex) |

| | |
|---|---|
| – TX-RX switching time | < 50 ms |
| – Supply voltage | 12 VDC ± 10% |
| – Input current | Transmit: 450 mA, Receive: 130 mA |
| – Transmission power | 0.5 W PEP |
| – Sensivity | 0.5 µV / 12 dB SINAD |
| – Modulation | GMSK |
| – Data rate | 9.6 kbps |
| – Data interface | RS232C, 2.4, 4.8 or 9.6 kbps |
| – RF connector | SMC male |
| – Vibration | in accordance with MIL-STD-810 land mobile |
| – Shock | 10 g, 11 ms half sinus |
| – Operating temperature | -30 °C to +70 °C |

### *6.2.2.2 Specification of data telegrams*

The data exchange between the vehicles and the Position Information Server (PIS) in the Central Station will be done via radio data terminals. It will be assumed, that radio modems are available for the adaptation of the RS232 output of the Mobile Unit (MU) to the radio data equipment.



*Software*
To simplify the message handling by the PIS, a uniform data format for GPS and the Acoustic System is agreed. For the communication protocol: MU is the master and PIS is the slave.

*Hardware*
Serial interface 4800,8,1,N with hardware handshake (RTS, CTS)

### 6.2.2.2.1 *Data telegram MU-PIS*

The data telegram including the container position is available at the MU output, when the Twist Lock signal is „on“ or „off“. The data transmission will be done in accordance with NMEA-183.

Protocol Data Unit (PDU) from the vehicle to the central PIS:
$XXXX<Destination>, XXX<Source>, XX<Vehicle ident>, <Message-no>, <Message-type>, <Message>, <CRC>, CRLF
X = fixed position, element of defined values

| **Item in PDU** | XX | **Meaning** | **Value S** | **Length in Character R** |
|---|---|---|---|---|
| XXXX <Destination> | | | PPIS1 | |
| | P | Free NMEA-Telegram | | 1 |
| | PIS | Position Information Server | | 3 |
| | Destination | Ident | 1 | 1 |
| XXX <Source> | GPS | GPS | | 3 |
| | Source | Ident | 1 | 1 |
| XX <Vehicle-id> | RS | Reach Stacker | | 2 |
| | GC | Gantry Crane | | |
| | SC | Seaside Crane | | |
| | PM | Prime Mover | | |
| | VC | Van Carrier | | |
| | Vehicle-id | Ident | | 2 |
| <Message-no> | | | 1-9999 | 4 |
| <Message-type> | | Down-Load | D | 1 |
| | | Up-Load | U | |
| | | Information | I | |
| | | Alarm | A | |
| | | Status | S | |
| | | Take (Pick) | T | |
| | | Put (Place) | P | |
| <Message> | | | | |
| | X | Position x in mm | | 8 |
| | Y | Position y in mm | | 8 |
| | Z | Position z in mm | | 6 |
| | Area | Area Identification | 1-99 | 2 |
| | Size | Size of container | | 1 |
| | | 20´ | 1 | |
| | | 40´ | 2 | |
| | Date | YYYY.MM.DD | | 8 |
| | Time | HH.MM.SS | | 6 |
| | Quality | Position quality | 1-9 | 1 |
| CRC | | Cyclic Redundancy Check (ASCII) | | 2 |

| | | | | |
|---|---|---|---|---|
| CRLF | | Carriage Return<br>Line Feed | 0x0D<br>0x0A | 2 |

**Table 4: Data telegram MU-PIS**

#### 6.2.2.2.2 *Data telegram PIS-MU*

The validity of the container position can be verified from the MU by a comparison of the requested position from the PIS and the real vehicle location.

Protocol Data Unit (PDU) from the central PIS to the vehicle:
$XXXX<Destination>, XXX<Source>, <Message-no>, <Message-type>,
<Error code>, <CRC>, CRLF
X = fixed position, element of defined values

| **Item in PDU** | XX | **Meaning** | | **Length in Character** |
|---|---|---|---|---|
| XXXX <Destination> | | | | |
| | P | free NMEA-Telegram | | 1 |
| | GPS | GPS | | 3 |
| | Destination | Ident | | 1 |
| XXX <Source> | | | | |
| | PIS | Position Information Server | | 3 |
| | Source | Ident | | 1 |
| <Message-no> | | | | 4 |
| <Message-type> | | Ack<br>Nack | | 1 |
| <Error code> | | No error<br>Error type | | 1 |
| CRC | | Cyclic Redundancy Check (ASCII) | | 2 |
| CRLF | | Carriage Return<br>Line Feed | | 2 |

**Table 5: Data telegram PIS-MU**

### 6.2.2.3 *Installation details of mobile units and sensors*

Two test field for the location trials has been selected. It is required that the container positions have to be determined in a X/Y co-ordinate system with the reference antenna as the origin of co-ordinates. Therefore the reference point and the corners of the test field have to be exactly measured in advance. The origin of the calculated X/Y co-ordinates will be the same for both GPS and Acoustic systems so as to allow a direct comparison of localisation results. The conversion from X,Y,Z co-ordinates into container positions will be done by the PIS in the central station.

#### 6.2.2.3.1 *Installation of reference station*

Under consideration of installation and maintenance aspects it was decided to install the reference station inside the technical building. The antenna mast should be fixed at the easterly side of the roof (towards the test field) and the antenna height should increase the TV camera. A cable length of 20 m seemed to be sufficient. For the transmission of the correction data a radio licence from the Italian PTT is required. The preferred frequency range is 140...170 MHz.

#### *6.2.2.3.2 Installation of mobile units*

Only two mobile systems will be installed, one on a RTG and one on a Reach Stacker. In both cases the GPS antenna needs to be always in a horizontal position. The most preferably solution for the Reach Stacker installation will be a strong and stable mast of about 1...1,5 m fixed at the spreader near the centre of the container. This antenna mast can be used also for the installation of the microphones from Metravib. The housing of the mobile DGPS system and the sensor box can be easily installed in the driver cabin with some screws. Behind the driver cabin of the Kalmar Reach Stacker there is a shaft with free visibility to the ground. Here the ultrasonic speed sensor can be installed. The antenna cable has to be fixed along the cable channel aside of the hoist arm. The installation of the GPS system on the top of the RTG cabin will not cause any significant problems. The power supply at the Reach Stacker and the RTG will be 24 VDC. Following electrical signals are available on board of the Reach Stacker and the RTG:

- Twist Lock (0/24 VDC)
- Spreader Size (0/24 VDC)
- Hoist arm length (0...24 mA)*
- Hoist arm angle (0...24 mA)*

* = Reach Stacker only

- Encoder with 500 pulses/spin**

** = RTG only

### *6.2.2.4 Test results of dead reckoning sensors*

A number of tests of the dead reckoning sensors are already carried out. The measurements have presented the expected good results. Figure 2is showing a slow motion test drive, only by using acceleration sensors, gyros and a speed sensor. The important result is, that the beginning of the test circle ends at the same position as at the end of the test.

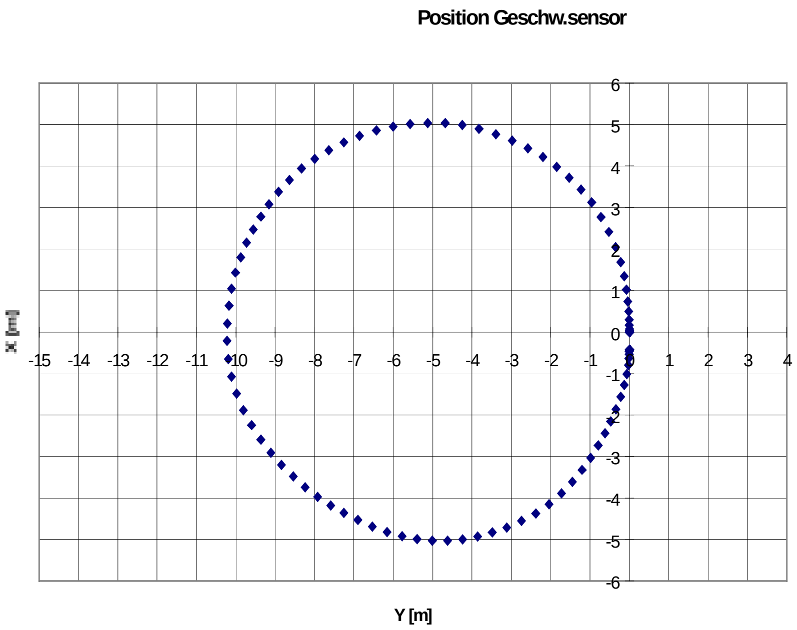


**Figure 2: Position determination by dead reckoning sensors**

The following figure is showing another test with a car. The maximum speed during acceleration on the straight leg was about 50 km/h. During the first lap of this test the complete system, including DGPS and dead reckoning sensors, was in operation. After the first lap the DGPS system was switched off and the remaining track was determined only by the dead reckoning sensors.

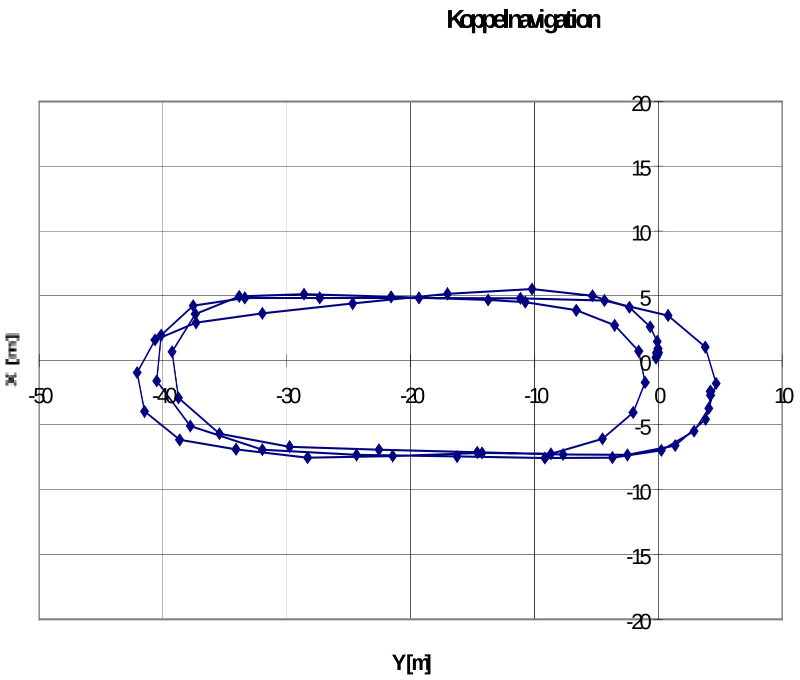


**Figure 3: System test with GPS and dead reckoning sensors**

Depending on the artificially degraded position accuracy, the signal strength (noise) and the correction data, the calculated GPS track underlies strong fluctuations. The result of this test therefore shows, that the adjustment of the Kalman-Filtering and the interaction of the different sensors (DGPS and dead reckoning) have to be slightly optimised. The problem is the transition phase between the GPS track and the dead reckoning sensors.

## 6.2.3 Acoustic network

### 6.2.3.1 *Interface between the mobile control and the location sensors onboard vehicle*

The vehicle position shall be calculated for each manipulation of a container (catch/deposit of a container). To avoid mistakes due to the operator, an interface will be provided between the mobile control (standard trigger signal for each catching / deposit of a container) and the acoustic processing unit embedded in the vehicle. The trigger signal is assumed to have the following format :

- +V when the twist is locked (V is a voltage value to be specified by LSCT);
- 0 when the twist is unlocked.

Each detection of transition between 0 and +V (positive slope) or +V and 0 (negative slope) will start the computation of vehicle position, and a message will be issued to the Position Information Server (see following sections).

### 6.2.3.2 *Interface between the Position Information Server and fixed sensors*

Due to the configuration that has been selected for the Acoustic Positioning System (mobile receiver), no dedicated interface between the PIS and the fixed sensors is required. Fixed sensors are indeed constituted of simple acoustic transmitters (acoustic signal generator, amplifiers and speakers) triggered by a RF signal (transmitted by the control unit embedded in the mobile acoustic receiver).

### 6.2.3.3 *Interface between the mobile processing unit and the position information server*

The interface between the processing unit embedded in the vehicle and the Position Information Server will be provided via a serial link (RF modem). The data transmission will be done in accordance with NMEA-183. The structure of the messages that will be sent by the Acoustic Positioning system is summarised in Table 4.

Each message sent the Acoustic Positioning System shall be acknowledge by the Position Information Server. For this purpose, an acknowledgement is sent by the PIS to the APS, using a format similar to the previously described in table 5.

### 6.2.3.4 *Hardware & Software considerations*

#### 6.2.3.4.1 *Mobile Acoustic Processing Unit*

The hardware of the mobile acoustic processing unit will be constituted by a PC104 computer with the following characteristics

- overall dimensions : 13 cm (width) × 15 cm (depth) × 13 cm (height)
- power supply : between 9 V DC and 30 V DC
- Pentium class processor (CMM686GX) at 233 MHz with 32 MB DRAM
- add-on board for A/D conversion (12 bits / 500 kHz)
- 2 serial link (RS232)

In addition to this processing unit, a RF transmitter will be used to trigger acoustic transmission. The choice of this module is not yet definitive. The acoustic receiver will be composed of a microphone equipped with a preamplifier (power supply compatible with 24V available inside both reach stacker and gauntry crane).

#### *6.2.3.4.2* *Fixed transmitters*

Each fixed transmitter will be composed of

- a RF receiver (trigger)
- a signal generator (transmitted signal stored in a PROM)
- a high power amplifier
- 2 to 4 transducers (depending on the frequency band that will be chosen)

The power supply of each transmitter will be 220 V AC.

#### *6.2.3.5 Complementary work on Acoustic System Design*

First, the mobile receiver configuration, where acoustic transmitters are located at fixed positions around the terminal area. This is the simpler configuration and hence the most cost effective solution, since it requires the smallest number of receivers (that are the most expensive components of the system). Another advantage comes from the fact that transmission of «Acoustic Position» of the vehicles to the PIS is considerably simplified compare to the second configuration.

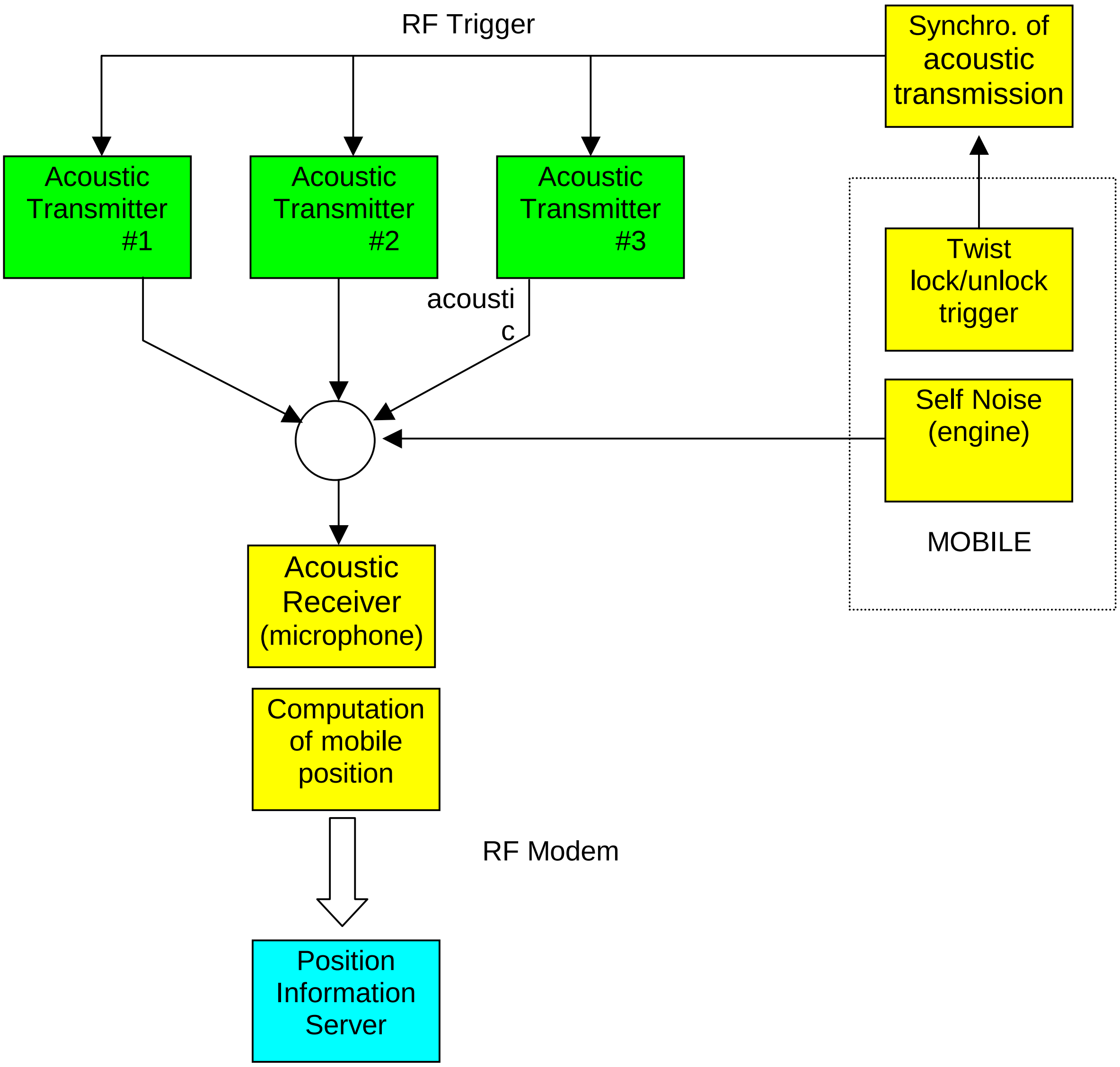


**Figure 3: Mobile receiver configuration**

However, this solution presents a severe drawback due to the potentially low signal to noise ratio on the acoustic receiver side for vehicles powered by thermal engines, since the engine self noise may drastically corrupt the reception of acoustic signals from the transmitters. On the contrary, the mobile transmitter configuration is less sensitive to mobile engine noise corruption (since the noise is considerably attenuated at the receiver side, due to the propagation attenuation). However this configuration is more complex because each individual signal measured at fixed receiver positions is to be transmitted to the Position Information Server where the calculation of mobile position is achieved. This complexity has an important impact on the overall cost of the system especially if large terminal area are to be equipped, because the number of fixed acoustic receiver has to be drastically increased.

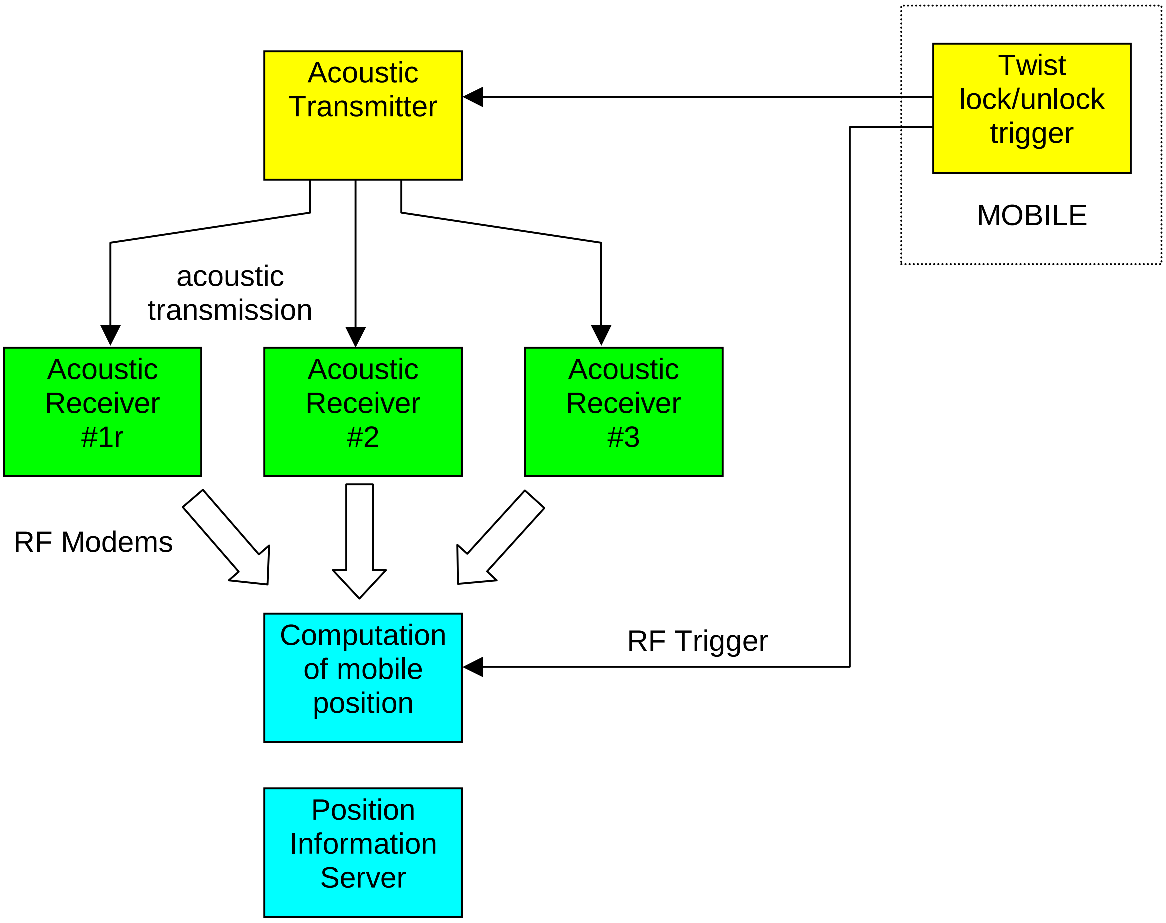


**Figure 4 : mobile transmitter configuration**

*6.2.3.5.1* *New measurement of engine noise on a reach stacker*

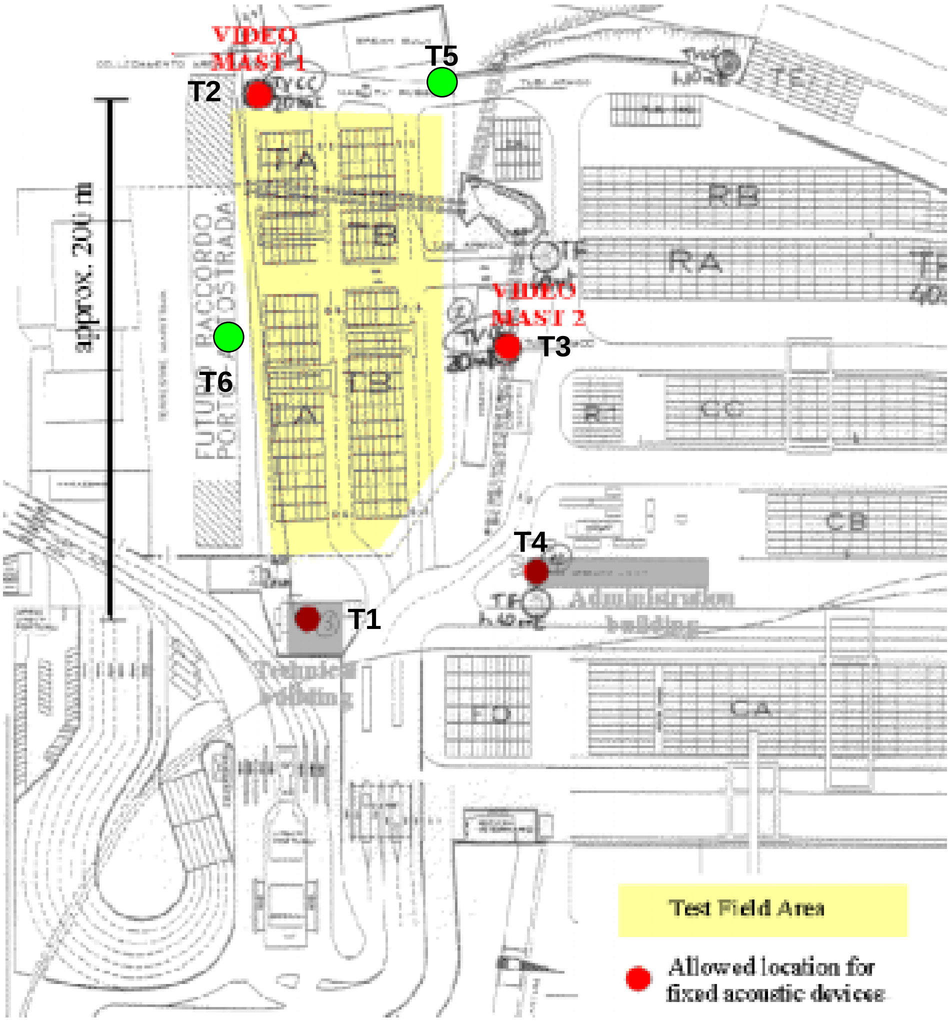
The preferred solution is therefore the mobile receiver configuration. However, to check the performances of the system, care must be taken to accurately evaluate the influence of acoustic signal pollution by vehicle self noise. For this purpose, new acoustic measurements were performed by METRAVIB with the help of LSCT at the end of the meeting held in La Spezia on 3/03/99. A microphone was fixed at the top of a FANTUZZI reach stacker and the acoustic noise was recorded during typical operating conditions (rapid displacement, catching/deposit of a container,…) for approximately 10 minutes.

### 6.2.3.5.2 *Simulation of Acoustic Positioning System*

During the meeting held at LSCT on 3/03/99, the test site area was defined as the TA-TB zones. In addition, four locations for the installation of fixed acoustic transmitters were provided by LSCT

- Transmitters T2 and T3 will be installed on the top of a TV mast, at an approximate altitude of 20 m.
- Position T1 is the top of a technical building (approximately 10..12 m height), close the main gate.
- An additional location (T4) has been proposed by LSCT for acoustic transmitter and corresponds to the top of the administrative building.
- Two additional transmitter location were also considered during the simulation (T5 & T6). They correspond to acoustic transmitters positioned on the floor (altitude *z*=0).

To evaluate the positioning performances, 43 predefined container locations were considered during the simulations, chosen so as to be representative of the whole test area.



### 6.2.3.5.3 *Simulation of Acoustic Positioning System*

Simulations were conducted using the transmitted chirps (hyperbolic frequency modulations with a Gaussian envelope). Each fixed acoustic transmitter uses a dedicated signal, tailored to minimise cross-correlation with the other transmitters as well as to maximise signal to noise ratio at the output of the matched filters on the receiver side. The parameters that have been varied during the simulations are summarised in the table below:

| **Parameter** | | **min. value** | **max. value** |
|---|---|---|---|
| Number of fixed transmitters | | 3 | 5 |
| Reach stacker noise | | min RPM | max RPM |
| Transmitted signal | Frequency bandwidth | 360 Hz | 1500 Hz |
| | Duration | 50 ms | 1 s |

The transmitted sound pressure level was fixed to a level of 120 dB at 1m. As to the influence of the noise emitted by reach stacker engine on acoustic positioning, It can be stated that an accuracy of approx. 0.3 m is achieved when reach stacker engine is running at minimum RPM. At maximum RPM, the positioning accuracy is about 0.8 m. Large positioning error occurs when the reach stacker is close to the “corners” of the terminal area, since the attenuation of acoustic waves that travels from bottom transmitters is very high. Notice that for the future (full scale) implementation of the system, the number of fixed transmitters will be widely increased and this will overcome this problem. Frequency bandwidth of the transmitted signal has to be increased to improve localisation accuracy. This results is not surprising since increasing the frequency bandwidth of the acoustic signal increases the signal to noise ratio (engine noise from stacker being essentially a low frequency noise). Increasing the duration of transmitted signal is also favourable, but the improvement in localisation accuracy is less sensitive. Moreover, the use of 5 transmitters (T1 to T5) is less accurate that the use of 4 transmitters (T1, T2, T3, T6**)**. It will thus be required, for the evaluation of the acoustic positioning system on the test site, to locate a transmitter at position T6. When reach stacker engine is running at maximum RPM, the best results of acoustic positioning have been found for the following configuration:

- 4 transmitters located at positions T1, T2, T3 and T6
- transmitted signals between 500 Hz and 1500 Hz with a duration of 1s.

Required accuracy of 0.5 m is not achieved for all the possible vehicle locations within the test site, since almost 6 (of 43) estimated positions are deviating of more than 0.8 m from the exact location.

1. Two solutions may be envisaged to improve the results. The first solution is to increase the number of transmitters (from 4 to 6) to provide a refined meshing of the test area. This is however difficult to achieve within the frame of PRECISE IT project since it would require to install additional mast where the transmitters can be fixed on.
2. The second solution consist in using a high frequency chirp for acoustic transmission in order to reduce the influence of stacker engine noise on the measurements. The problems that can be anticipated are twofold :
    - on the one hand, propagation losses at high frequency will be drastically increased, and a compromise has to be found between a sufficient attenuation of stacker generated noise and a reasonable level of the acoustic chirp at the receiver side. A potential solution could be to use a transmitted chirp with a frequency band around 6 kHz.
    - on the other hand (and this is potentially the most critical point), the masking effect due to the containers surrounding the vehicle may corrupt the estimation of position (due to multiple reflections). Experiments and

simulations are conducted at METRAVIB to investigate this potential problem.

### 6.2.4 Data transmission network

Here is described the design of the data transmission network that connects the mobile control units onboard a vehicles to the position information server. Only available standard market technologies will be considered.

### *6.2.4.1 Design Criteria*

*6.2.4.1.1 Overview*

For an automatic localisation system in terminal containers the major aspect one must take into account in designing the radio network is the data transmission rate.
The data transmission rate depends on:

- the terminal management procedures (data flow inside the terminal)
- the number of vehicles to be localised
- type of automatic location system referring to the table of requirements in Deliverable 1

The radio network can be designed for different transmission frequency depending on several aspects ( terminal layout, data transmission rate, wiring, maintenance, costs ...).
The frequency bands usually available are :

| | |
|---|---|
| 400 - 500 MHz | optimised Narrow Band for transmission rate till 9600 Baud (Bit per second) |
| 900 - 930 MHz | optimised Spread Spectrum for transmission rate till 64 K Baud |
| 2.4 GHz | Spread Spectrum for transmission rate till 2 M Baud |

Increasing the frequency you increase the data transmission rate but you increase also the number of the fixed station required to cover the area and then the costs of the network. In principle we can consider two approaches:

- the selection of integrated networks commonly used in data warehousing radio-frequency application
- the design of the network based on standard elementary components (radio transmitter/receiver, modem, antennas ...)

The first solution offers an easier setting-up of the system because of the standard interfaces provided with the most commonly terminal management systems even if the cost is relatively high. In the second solution the cost of the elementary components is significantly lower than the first but the set-up of the system seems to be more complicated either in hardware (assembling of various manufacturers' components) or in software (management of the transmitters/receivers stations) and also the interface with the terminal management system has to be developed. Analysing advantages and disadvantages of both solution an integrated network seems to be the best for these kind of systems.

*Integrated Networks*

The commonly integrated networks available on the market for data warehousing radio frequency application is composed by two main parts: the fixed and the mobile part.
The fixed part is composed by:

- a number of Radio Frequency Units (RFU) placed in fixed positions. The RFUs receive/send the data from/to the mobile components and are connected via fiber optics or other wiring systems to a Network Controller.
- one or more Network Controller connected with the RFU and interfaced with the information system. The network controller receives all the messages from the RFUs and send them to the correct user. and vice versa it receives the data from the information system and send them to the right RFU.

The mobile part is composed by:

- Radio terminals on board a vehicles
- Hand-held terminals for the operators
- Radio modems connected with other device.

The RFUs are placed inside the terminal in order to cover all the working areas. The number of RFU needed is evaluated after a campaign of measurements usually done by the vendor of the network. Several standard interfaces with the data management system are provided either in hardware (Ethernet TCP/IP, Token ring, serial ..) or in software ( the most commonly protocols are available).

### *6.2.4.2 The test site solution*

In LSCT an integrated radio is already installed network, The frequency transmission is in the Narrow Band so the maximum transmission rate is 9600 Baud. Considering the data flow through the network inside the terminal during normal operation, the transmission rate is compatible with the **acquisition frequency** and **data transmission frequency** requirements defined in table 3 for all the localisation systems. For the localisation systems test two additional radio modems will be installed: one on a RTG and one on a Reach Stacker. These radio modems will be interfaced with the mobile units and the transmitted data will be received by the already existing RFUs and then sent to the Position Information Server via the network controller.

## 6.2.5 Position Information Server

### *6.2.5.1 PIS Requirements*

The Position Information Server (PIS) is a control and monitoring system, which handles the information about the container positions in the harbour area. The knowledge of the container position and of their movements inside the harbour area allows to optimise the storing of containers in the terminal and to reduce the routes of conveying means. The container position is detected by the mobile units via:

- a DGPS system,
- an acoustic system.

A GPS satellite system is installed on the mobile units. This system allows the detection of the position with a 100 meters accuracy. A DGPS system is used in order to increase the precision. The DGPS method is implemented via a 'reference station' installed in the terminal, which detects a reference position for the mobile units and generates a correction signal for them. The mobile units receive a signal from the GPS satellites system and the correction signal from the 'reference station' and, processing them, they compute their position with a precision of less then one meter. The DGPS system equipped with other sensors as accelerometers, speed sensors and gyros to make up for the lack of the satellite reception The DGPS system on the mobile unite is connected by

RS232 to modem radio. This modem radio transmits the position data to the mini-controller radiobase station, which is connected to the PIS by LAN. The acoustic system, alternative to the DGPS, is implemented installing some ultra-sonic emitters in the harbour area and equipping the mobile units with a receiver. When the vehicle executes a “pick” o “place” a radio pulse comes transmitted to the ultra-sonic emitters. So, the ultra-sonic emitters send the acoustic signal. This signal is received by vehicle to determine its position.

The acoustic system on the mobile unite is connected by RS232 to modem radio. This modem radio transmits the position data to the mini-controller radiobase station, which is connected to the PIS by LAN network.

The PIS system has to:

- receive the containers 'pick' and 'place' positions through the mini-controller, which collects the messages from the mobile units; the position is expressed in X,Y,Z where the origin (0,0,0) is the “reference station” position;
- convert the received 'pick' and 'place' positions into grid co-ordinates (row, bay, tier) on the basis of the terminal map;
- control the correctness of the 'pick' and 'place' operations and of the related positions;
- coupling the 'pick' operation to the 'place' operation executed by the same mobile mean;
- send the 'pick' and 'place' events to the central information system (AS400); each event will be structured with the following information: date, time, grid co-ordinates, identification number of the mobile mean that conveyed the container;
- keep a local information concerning the anomalous 'pick' and 'place' events.

#### *6.2.5.1.1 Development and target environment*

The PIS system is composed by two application process:

- a background application process, called “PIS_Elab_Link” which provides to operative tasks (“Pick” or “place” event messages detection, working out, determination of a “pick” or “place” event on a container and transmission of the relating message to the central informative system);
- a foreground process, called “PIS_HMI”, which effectuates the interface with “human-machine”
-

Both the operative processes are conceived to operate on the same target machine equipped with an operative system Windows NT 4.0. The background operative process is structured as a “Windows NT service”, a program working while the operative system is active and no user is logged on. In this way the operative system opens “PIS_Elab_Link” starting up the computer. This operative system is elaborated in Visual C++6.0. The foreground operative process, called “PIS_HIM”, is elaborated in Visual Basic 6.0, to realise and to care of interface program.

### ***6.2.5.2 System Interfaces***

#### *6.2.5.2.1 Interface with mobile units (DGPS)*

PIS receives the 'pick' and 'place' positions from the DGPS or the Acoustic system via the mini-controller radio-base station by TELNET connection on Ethernet network. In this connection, the DGPS/Acoustic system is communication master and PIS is communication slave. The message received by PIS has the following structure:

| Item | XX | Meaning | Value | Length in char |
|---|---|---|---|---|
| XXXX<Destination> | | | PPIS1 | |
| | P | | | 1 |
| | PIS | Position Information Server | | 3 |
| | Destination | Ident | 1 | 1 |
| XXX<Source> | GPS<br>MVB | DGPS<br>Acoustic | | 3 |
| | Source | Ident | 1 | 1 |
| XX<Vehicle-id> | RS<br>GC<br>SC<br>PM<br>VC | Reach Stacker<br>Gantry Crame<br>Seaside Crane<br>Prime Mover<br>Van Carrier | | 2 |
| | Vehicle-id | Ident | | 2 |
| <Message-no> | | | 1-9999 | 4 |
| <Message-type> | | Down-Load<br>Up-Load<br>Information<br>Alarm<br>Status<br>Take<br>Put | D<br>U<br>I<br>A<br>S<br>T<br>P | 1 |
| <Message> | | | | |
| | X | Position x in mm | | 8 |
| | Y | Position y in mm | | 8 |
| | Z | Position z in mm | | 6 |
| | Area | Area Identification | | 2 |
| | Size | Size of container<br>20’<br>40’ | <br>1<br>2 | 1 |
| | Date | YYYY.MM.DD | | 8 |
| | Time | HH.MM.SS | | 6 |
| | Quality | Position Quality | | 1 |
| | | | | |
| CRC | | Cyclic Redundancy Check(ASCII) | | 2 |
| CRLF | | Carriage return<br>Line feed | 0x0D<br>0x0A | 2 |

**Table 6– Structure of the PIS received message**

An average of 200 messages per hour will be transmitted. PIS answers with a message has the structure described in table 7. The DGPS/Acoustic system repeats three transmissions if no received the answer message containing “ACK”.

| Item | XX | Meaning | Value | Length in char |
|---|---|---|---|---|
| XXXX<Destination> | | | | |
| | P | | | 1 |
| | GPS<br>MVB | GPS<br>Acoustic | | 3 |
| | Destination | Ident | | 1 |
| XXX<Source> | | | | |
| | PIS | Position Information Server | | 3 |
| | Source | Ident | | 1 |
| <Message-no> | | | 1-9999 | 4 |
| <Message Type> | | Ack<br>Nack | A<br>N | 1 |

| | | | | |
|---|---|---|---|---|
| <Error code> | | No error<br>Error type 1<br>Error type 2<br>Error type 3<br>Error type 4 | 0<br>1<br>2<br>3<br>4 | 1 |
| CRC | | Cyclic Redundancy Check (ASCII) | | 2 |
| CRLF | | Carriage return<br>Line feed | 0x0D<br>0x0A | 2 |

**Table 7 – Structure of the PIS answer message**

#### *6.2.5.2.2 Interface with host (AS/400)*

The PIS system is connected to the central information system (AS400) via a LAN network. PIS sends the 'pick' and 'place' information received from the mobile units. The communication is done via a TCP/IP socket connection on an Ethernet network. In this connection the PIS is the communication master and AS400 is the communication slave. The “pick” and “pace” information are send from the PIS to the central information system (AS400) by a following message:

| Item | XX | Meaning | Value | Length in char |
|---|---|---|---|---|
| XXXX<Destination> | | | PAS4 | |
| | P | | | 1 |
| | AS4 | AS400 | | 3 |
| | Destination | Ident | 1 | 1 |
| XXX<Source> | PIS | Position Information Server | | 3 |
| | Source | Ident | 1 | 1 |
| XX<Vehicle-id> | RS | Reach Stacker | | 2 |
| | GC | Gantry Crane | | |
| | SC | Seaside Crane | | |
| | PM | Prime Mover | | |
| | VC | Van Carrier | | |
| | Vehicle-id | Ident | | 2 |
| <Message-no> | | | 1-9999 | 4 |
| <Message-type> | | Event | E | 1 |
| | | Information | I | |
| | | Alarm | A | |
| | | Status | S | |
| <Message> | | | | |
| | Date Take | YYYY.MM.DD | | 8 |
| | TimeTake | HH.MM.SS | | 6 |
| | Row Take | | | 3 |
| | Bay Take | | | 3 |
| | Tier Take | | | 1 |
| | Area Take | Area Identification | | 2 |
| | Quality Take | Position Quality | | 1 |
| | SPARE | | | 2 |
| | Date Put | YYYY.MM.DD | | 8 |
| | Time Put | HH.MM.SS | | 6 |
| | Row Put | | | 3 |
| | Bay Put | | | 3 |
| | Tier Put | | | 1 |
| | Area Put | Area Identification | | 2 |
| | Quality Put | Position Quality | | 1 |
| | SPARE | | | 2 |
| | Size | Size of Container 20' or 40' | 1<br>2 | 1 |
| | SPARE | | | 4 |
| CRC | | Cyclic Redundancy Check (ASCII) | | 2 |
| CRLF | | Carriage return | 0x0D | 2 |
| | | Line feed | 0x0A | |

**Table 8 – Structure of the message sends by PIS**

AS400 answers to the PIS with a message has the structure described in table 9.
The PIS repeats three transmissions if no received the answer message containing “ACK”.

| Item | XX | Meaning | Value | Length in char |
|---|---|---|---|---|
| XXXX<Destination> | | | | |
| | P | | | 1 |
| | PIS | Position Information Server | | 3 |
| | Destination | Ident | | 1 |
| XXX<Source> | | | | |
| | AS4 | AS400 | | 3 |
| | Source | Ident | | 1 |
| <Message-no> | | | 1-9999 | 4 |
| <Message Type> | | Ack | A | 1 |
| | | Nack | N | |
| <Error code> | | No error | 0 | 1 |
| | | Error type 1 | 1 | |

| | | | | |
|---|---|---|---|---|
| | | Error type 2<br>Error type 3<br>Error type 4 | 2<br>3<br>4 | |
| CRC | | Cyclic Redundancy Check (ASCII) | | 2 |
| CRLF | | Carriage return<br>Line feed | 0x0D<br>0x0A | 2 |

**Table 9 – Structure of the AS400 answer message**

### 6.2.5.3 *Functional specification*

#### 6.2.5.3.1 *Introduction*

The PIS system handles the following functions:

- data acquisition;
- grid position computation;
- pick and place coupling;
- host connection;
- HMI for system configuration and management;
- System tracing functions for software debug

#### 6.2.5.3.2 *Data acquisition*

The function “data acquisition” takes care of:

- collecting the container position data at the moment of the “pick” or “place” event from the DGPS on board of the mobile unit and from the acoustic system;
- check the data collected by the two sources in order to check if there are anomalies in the container position detection;
- sending to the “grid position computation” the function data about the container position and the time when this position was measured.

The function 1.1 executes the data acquisition of the “pick” or “place” events coming from the mobile units equipped with the DGPS system and sends the data to the function 1.3. The “pick” or “place” data coming from the mobile units include:

- an identifier of the operation (“pick” or “place”);
- the time when the operation occurred;
- the container position at the moment of the operation;
- the identifier of the mobile unit which executed the “pick” or “place” operation;

The function 1.2 executes the data acquisition of the ‘pick’ or ‘place’ events of a container coming from the acoustic system and it sends the data to the function 1.3. The ‘pick’ and ‘place’ data coming from the acoustic system include:

- the identifier of “pick” and “place” operation;
- the time when operation occurred;
- the container position at the moment of the operation;
- the identifier of the mobile unit which executed the ‘pick’ or ‘place’ operation.

The function 1.3 compares the data acquired from the two measuring systems. Furthermore a correlation strategy among the two system acquisition of the same event is foreseen in this document but it will not be implemented because of the two system which are alternative. In this way, the PIS couldn’t receive the information about the same event from both the acoustic system and the DGPS. This strategy provides that for each operation acquired by the mobile units equipped with the DGPS the function searches for the corresponding operation acquired by the acoustic system. The operations correspondence is evaluated on the following criterion:

- the “pick” or “place” operation has, of course, to be executed by the same mobile unit;
- the information about the event detected by the DGPS and by the acoustic system are received before the next operation of the mobile unit.

The following pseudo-code describes the comparison procedure.

```
procedure: comparison between the data collected by the DGPS system and the
acoustic one;
      if a message about a “pick” or “place” event was collected by the DPGS
         system or by the acoustic system
         then
      if a corresponding operation is detected via the acoustic system
          then
                  if DGPS sent valid data
                          then the container position co-ordinates
                               detected via DGPS are sent to function 2
                               (“grid position computation”)
                          else the co-ordinates detected via acoustic
                               system are sent to function 2 (“grid
                               position computation”)
                  endif
          endif
         else
          if a message about the following event is received on the same mobile
             unit
               then
                  If a message of an event detected by DGPS with valid
                     position data or of an event detected by the acoustic
                     system
                          then
                               co-ordinates detected via acoustic system
                               are sent to function 2 (“grid position
                               computation”)
                          else
                               an acquisition error is detected and
                               stored in the “anomalies log”
                  endif
      endif
   endif
end procedure
```

### 6.2.5.3.3 Grid position computation

The function "grid position computation" deals with:

- converting the container position co-ordinates gathered by the "data acquisition" function into grid co-ordinates referred to the terminal map;

- evaluating the reliability of the 'pick' and 'place' positions, checking that they are not more than one meter far away from the centre of the terminal cell where the container was positioned or picked up;
- sending the position data expressed in terms of grid co-ordinates and the operation time to the "pick and place coupling" function.

#### 6.2.5.3.4 *Pick and place coupling*

The "pick and place coupling" function takes care of:

- coupling the 'pick' operation to the 'place' operation executed by the same mobile mean;
- checking if a 'place' operation occurs after a τ interval starting from the time of the associated 'pick' operation;
- checking if a 'place' event occurs without a preceding 'pick' operation on the same mobile mean;
- checking if the 'pick' and 'place' operations occurred in the same position by the same mobile mean;
- checking if a 'place' operation occurs for a mobile mean without a minimum elapsed time after the 'pick' operation;
- storing all the above situations and the uncoupled 'pick' and 'place' operations on the "anomalies log";
- sending to the "host connection" function: the mobile mean position in grid co-ordinates and the time data related to the coupled 'pick' and 'place' operations.

#### 6.2.5.3.5 *Host connection*

The "host connection" function deals with:

- opening a TCP/IP socket between the PIS system and the AS400;
- transmitting a message with the data of the event of 'pick' and 'place' of a container;
- storing all the communication anomalies on the "anomalies log".

#### 6.2.5.3.6 *HMI for system configuration and management*

The " HMI for system configuration and management " function provides the following operations:

- harbour terminal map configuration;
- configuration of all necessary time-outs;
- execution of system start and stop operation;
- execution of back-up and restore operations;
- print-out of the "anomalies log".

The terminal are has a rectangular form and contiguous cells compose the grid; the configuration of the map occurs inserting the following information in the special request form of the HMI:

- area identifier;
- x, y co-ordinates of the terminal vertex up on the left;
- x, y co-ordinates of the terminal vertex down on the right;
- wideness x of a cell of the terminal grid;
- wideness y of a cell of the terminal grid.

The time to configure are:

- maximum time (in sec.) before which the place event has to be received after the pick event on the same mobile unit;

- minimum time (in sec.) passing after a place event before which the pick event has not to occur on the same mobile unit ;
- maximum time of presence (in min.) of the message containing the information on pick and place on the same container, before it is transmitted to AS400.

The configuration of this times is possible inserting the values in the special request form in HMI. The controls to execute the data backup and restore of the systems are in HMI with reference to:

- the configuration of the terminal area map;
- the configuration of the parameter time of the system;
- the anomalies log.

The information about the occurred anomalies is stored in the “anomalies log”. HMI visualises the “anomalies log” on the ground of the day in which the anomalies occurred. The visualisation of the anomalies of a selected day is possible inserting the correspondent date in a special form. It is possible to know the description of the kind of anomaly and the report of time and date.

#### *6.2.5.3.7 System tracing functions for software debug*

The "system tracing functions for software debug" function allows to:

- execute a tracing of the messages exchanged among the functions;
- storing on a file of the messages received by the mini-controller;
- storing on a file of the messages transmitted from AS400.

The files containing the messages received from mini-controller and transmitted to AS400 are created daily and they are called:

- “mess_in_AAAAMMGG” containing messages received from minicontroller;
- “mess_out_AAAAMMGG” containing messages transmitted to AS400.

A special form, when the “tracing” is operative, provides to the visualisation of the data structure exchanged among the functions. This visualisation allows working out the exchanging of the messages among the functions, from the minicontroller reception to the sending to AS400.

### *6.2.5.4 Software architetture*

#### *6.2.5.4.1 Overview*

The PIS' software architecture consists of two processes:

- Elab_Link ($P_1$)
- HIM ($P_2$)

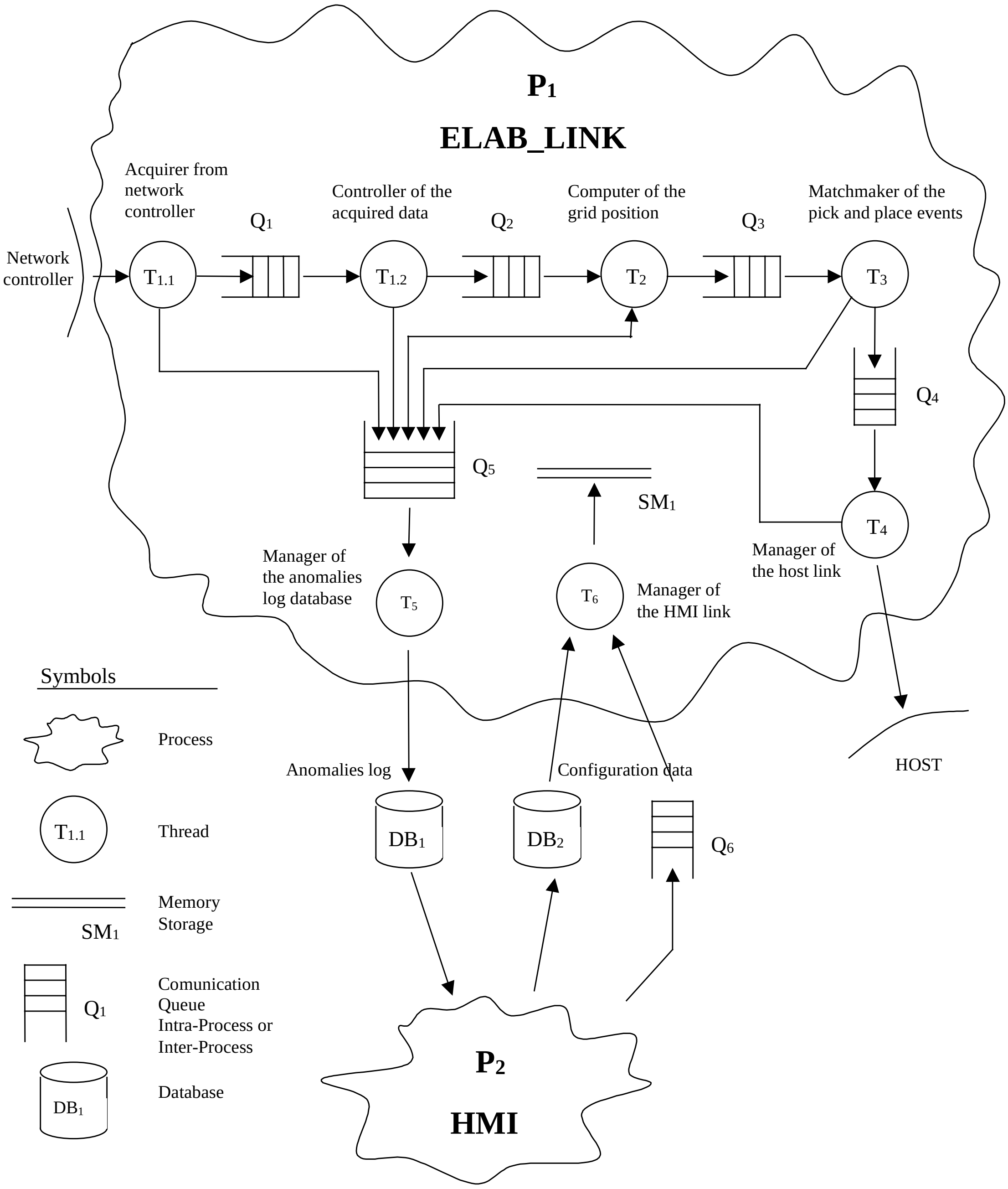


**Figure 5 – PIS system map**

The $P_1$ "Elab_Link" process works in background and deals with the following PIS operative tasks:

- reception of the event of “pick” and “place” messages in the containers executed by the mobile means and transmitted by the acoustic systems and DGPS;
- conversion of the “pick” and “place” position received in grid co-ordinates referred to the terminal map;
- coupling of the “pick” event with the “place” event executed by the same mobile mean on a container;
- sending of the information message about the “pick” and “place” event executed by the same mobile unit on a container to central informative system AS400.

Concurrent threads to accomplish its tasks simultaneously compose the Elab_Link process. The data exchange between the threads is realised by intra-process communication queue.
The $T_{1.1}$ thread “Acquirer from mini controller” acquires the messages transmitted by the mini controller relating to the collecting of a “pick” or “place” event by the DGPS or acoustic system.
The $T_{1.2}$ “Controller of the acquired data” checks the acquisition data of the “pick” or “place” event of a container executed by the two systems on the ground of the 1.3 function.
The $T_{1.1}$ and $T_{1.2}$ threads accomplish the data acquisition function.
The $T_2$ “Computer of the grid position” converts the position co-ordinates of the container acquired by the previous thread in grid co-ordinates referred to the terminal map on the ground of the function 2 “grid position computation”.
The $T_3$ thread “Matchmaker of the pick and place events” couples the “pick” event and the “place” event executed by the same mobile mean with reference to the “pick and place coupling” function 3.
The $T_4$ thread “Manager of the host link” transmits the message containing the information about the “pick” and “place” events to the central informative system AS400 with reference to the “host connection” function.
The $T_5$ thread “Manager of anomalies log database” picks up the anomalies collected by the different threads of the $P_1$ Elab_Link process and inserts the anomalies in the $DB_1$ “Anomalies Log” database.
The $T_6$ thread “Manager of the HMI link” writes in the memory area $SM_1$ of the $P_1$ process, the configuration data formulated by the $P_2$ HMI process and contained in the $DB_2$ “Configuration data” database. Every thread of this process can enter in the memory area $SM_1$. The $P_2$ process asks for updating the configuration data by the communication inter-process $Q_6$ queue.
The $P_2$ “HMI” process manages the interface window of the application and the working of “HMI for system configuration and management”. This process executes the system “start and stop”, creating and destroying the $P_1$ process; it configures the map of the harbour terminal area and the parameter time of the system; it inserts these configuration data in the $DB_2$ “Configuration Data” database and by the communication inter-process $Q_6$ queue ask for updating the configured data to P1 process. The $P_2$ process executes the backup and restore operations of databases containing the configuration data, the “anomalies log” and the “anomalies log” visualisation.

#### 6.2.5.4.2 *Inter-process communication*

The communication between $P_1$ process and $P_2$ process is realised by:

- $DB_1$ “Anomalies log” database which contains information about the kind of anomalies and the exact time in which the anomalies occurred.
- $DB_2$ “Configuration data” database is composed by two schedules; one containing the configuration data of the terminal area map and the other containing the values of the time of the system to parameter
- The communication inter-process Q6 queue, which contains the request of $P_2$ process to $P_1$ process to update the configuration data.

Thread $T_5$ fills $DB_1$ database inserting the information about the anomalies found by the thread in $P_1$ process.
$P_2$ process accedes to $P_1$ process in order to accomplish the “log of anomalies” visualisation request executed by the operator. $P_2$ process fills $DB_2$ database inserting the configuration data formulated by the operator relating to the terminal area map and to the time of the system to parameter.
The $T_5$ thread of $P_1$ process accedes to $DB_2$ database in order to update the variables of the common memory area $SM_1$ containing the data to configure by the operator which are used by the thread $T_1$ of $P_1$ process. The communication queue is filled by $P_2$ process and emptied by $P_1$ process.

#### 6.2.5.4.3 *Intra-process communication*

The communication queues $Q_i$, effectuate the data exchange between the $T_i$ threads of $P_1$ process.
The $Q_1$ communication queue is used for the data exchanging between $T_{1.1}$ thread, that acquires messages, transmitted by DGPS and by the acoustic system and $T_{1.2}$ thread that checks data of the same “pick” and “place” event on a container acquired by both the system.
The $T_{1.1}$ thread inserts data of the messages acquired at the bottom of the $Q_1$ queue, stopping, during this step, the access to the queue for the other thread.
The $T_{1.2}$ thread accedes to $Q_1$ queue in order to read the data of existing message, to check the validity of data and to remove them. The $T_{1.2}$ thread blocks the access to the queue for the other thread, that use the queue only during the step in which the thread $T_{1.1}$ ask for the number of the existing messages in the queue and for the removal
The $Q_2$ communication queue is used for the data exchange between $T_1$ and $T_2$ threads; $T_2$ thread works out the position in grid co-ordinates.
The $T_{1.2}$ thread inserts data at the bottom of $Q_2$ queue blocking during this step the access to the queue for the other thread.
The $T_2$ thread accedes to $Q_2$ queue in order to read the existing data picking them up from the head and blocking, during this step, the access to the queue for the other thread.
The $Q_3$ communication queue is used for the data exchange between $T_2$ thread and $T_3$ thread which couples the “pick” and “place” events executed from the same mobile mean on a container.
The $T_2$ thread inserts data at the bottom of $Q_3$ queue blocking during this step the access to the queue for the other thread.

The $T_3$ thread accedes to $Q_3$ queue in order to read the existing data picking them up from the head and blocking, during this step, the access to the queue for the other thread.

The communication queue $Q_4$ is used for the data exchange between $T_3$ and $T_4$ which the link with the host.

The $T_3$ thread inserts data at the bottom of $Q_4$ queue blocking during this step the access to the queue for the other thread.

The $T_4$ thread accedes to $Q_4$ queue in order to read the existing data picking them up from the head and blocking, during this step, the access to the queue for the other thread.

The communication queue $Q_5$ is used for the data exchange between $T_{1.1}$, $T_{1.2}$, $T_2$, $T_3$ and $T_4$ which collect the anomalies and $T_5$ thread which takes out the anomalies from the queue and inserts them in the $DB_1$ “Anomalies log” database.

The $T_{1.1}$, $T_{1.2}$, $T_2$, $T_3$, $T_4$ insert the data of anomalies collected at the bottom of $Q_5$ queue blocking, during this step, the access to the queue for the other threads.

The $T_5$ thread accedes to the $Q_5$ queue in order to read the anomalies data existing in the head of the queue blocking, during this step, the access to the queue for the other threads.

### *6.2.5.4.4 Human Machine Interface*

$P_2$ process “HMI for system configuration and management” manages the PIS system interface outwards. This interface is formed by a main form “PIS FORM” which allows to accede to further mask. In particular the user can accede to the following forms:

- “PIS configuration form” to configure the system functioning data “LAN configuration form” to configure the machines IP addresses which form the system and that are connected to the machine of the PIS
- “Anomalies view form” to visualise the anomalies of the system.
- “Archive form” to manage the backup and restore data.

The access to the previous forms is possible from PIS form by using the following buttons:

- “PIS CONFIGURATION” button, to accede to the “PIS configuration form”;
- “LAN CONFIGURATION” button, to accede to the “LAN configuration form”;
- “ANOMALIES” button, to accede to the “Anomalies view form”;
- “ARCHIVE” button, to accede to the “Archive form”.

Further buttons are on the main form and they allow to perform the following functions of the control system:

- “START AND STOP” button to start or stop the $P_1$ Elab_Link process that works in background as “Windows NT service”.
- “EXIT” button to leave the interface process of PIS

SYSTEM STATUS RUNNING

ACTIVE SYSTEM DGPS - ACUS

ACTUAL AREA CONFIGURATION DATA

| | |
|---|---|
| ID area | 1 |
| X,Y point Top Left Angle (mm) | 10000,5000 |
| X,Y point Bottom Right Angle (mm) | 510000,255000 |
| X Amplitude Grid (mm) | 3000 |
| Y Amplitude Grid (mm) | 12000 |

ACTUAL TIMES CONFIGURATION

| | |
|---|---|
| T MAX wait tx AS400 (min) | 60 |
| T MAX Place after Pick (sec) | 900 |
| T MIN after Place before Pick (sec) | 60 |

ANOMALIES STATUS SYSTEM OK

The $P_1$ Elab_Link (RUNNING or STOP) process status and the data of the current configuration system are visualized on the “PIS form”. The “PIS form” indicates: which is the system that collects the position of the operative container (DGPS or Acoustic), the setting up relating to the harbour terminal area, and the parameter time of the system. There is also a signal of the anomalies status that shows the following three situations:

- “SYSTEM OK”: showing that no anomalies occurred after the last check executed by the user.
- “WARNING”: showing that some anomalies occurred in the system:
  - ➢ error in the reception from “DGPS”
  - ➢ error in the reception from “ACUS”
  - ➢ Pick not valid
  - ➢ Place not valid
  - ➢ Pick far from the centre of the cell
  - ➢ Place far from the centre of the cell
  - ➢ Pick and Place in the same position
  - ➢ Place executed too late after the Pick
  - ➢ Pick executed too soon after the Place
  - ➢ Pick not coupled

    - Place not coupled
    - ACK problems with AS400
- “ALARM”: showing that a serious system anomaly occurred:
    - error in the socket with “Mini Controller”
    - error in the socket with AS400
    - three tx repetition executed with AS400

When the $P_2$ “HMI” process starts, it recovers from the “Configuration data $DB_2$” the configuration data used by PIS in the last execution. If the user wants to start the $P_1$ “Elab_Link” process with different configuration data, he can modify them acceding to the “PIS Configuration form”.

When the $P_2$ “HMI” process starts, it tries to connect to the “Queque_Com_HMI_Elab_Link” named pipe required for the communication between the two process created by $P_1$ “Elab_Link” process.

$P_1$ “Elab_Link” process has a server role on the named pipe and $P_2$ “HMI” process a client one.

If the $P_1$ process is operative the connection will be realised and the “SYSTEM STATUS RUNNING” indication will be visualised; the “START/STOP” button will show only the indication “STOP” as the $P_1$ process could be stopped.

If the connection is not realised the $P_1$ process is not operative and the “SYSTEM STATUS STOPPED” indication will not be visualised; the “START/STOP” will show only the “START” indication as the P1 process could be started.

$P_2$ “HMI” process communicates to $P_1$ “Elab_Link” the following messages by the communication channel realised by the named pipe:

- possible modification of configuration data. In particular, “HMI” sends one or more of the following messages:
    - “Change Time” to update the configuration of the parameter time system with the values contained in the first record of the “time table” schedule of “Configuration data” database.
    - ”Change Map” to update the configuration of the terminal area map with the values contained in the records of the “Map table” schedule of “Configuration data” database;
- the “system tracing” enabling or disabling by sending the message:
    - “Enable Tracing” to enable;
    - “Disable Tracing” to disable;
- the “clear” request of “Anomalies log” database.

The “START” or “STOP” indication is on “START/STOP” button according to the process “Elab_Link” status, therefore to the function that it can execute.

The “STOP” control asks for a confirmation, before its execution, by a special “dialog box”.

In this form it is possible to configure the working parameters of the system:

- terminal area map
- parameter time
- enabling and disabling the “System Tracing for Debug”

The records on the configuration schedule “Map Table” can be inserted or erased in $DB_2$ database by the Ins/Del buttons. The enabling and disabling of “System Tracing for debug” is executed by the “Active System Tracing” check button. The “HMI” process sends to the “Elab_Link” process the information about the updating of configuration data when the user presses “Update” button. To select the data existing in a configuration record it is enough to select this record with the mouse. The values of the selected record are visualised in the special edit box. The form dedicated to the “LAN configuration” allows to set the IP addresses of the machines composing the system. The access to this mask is enabled only if “Elab_Link” isn’t operating. The “Anomalies view form” is dedicated to the anomalies and allows to visualise anomalies occurred in the system. This form presents as default daily anomalies in schedule. The “Archive form” allows to backup and restore the configuration data. The backup transfers data of configuration databases and of anomalies on a selected support. The restore transfers data in the opposite direction. Important: these operations are available only when the process “Elab_Link” isn’t operating.

#### *6.2.5.4.5 Processes scheduling*

The scheduling of processes is made by the Windows NT operative system. The process $P_1$ “Elab_Link” is realised as “Windows NT Service” and is automatically executed at the start up of the computer with no logging on for the users. The service “Elab_Link” can be stopped and restarted by the $P_2$ “HMI” process.

## 6.3 RESULTS OF FIELD TESTS

Two systems were actually implemented in the LSCT:

1. DGPS/DGLONASS system
2. Acoustic system

### 6.3.1 The DGPS/DGLONASS System

#### *6.3.1.1 Introduction*

A DGPS/DGLONASS system including two Mobile Units (MU) and one Reference Station was developed, manufactured and tested. Special attention was given to the software development of the Mobile Units. The main task was the fine tuning of the multi tasking process, which handles the position results, the dead reckoning sensors and the data output to the Position Information Server (PIS).

#### *6.3.1.2 System Development*

Based on the system layout and the technical data, one Reference Station and two Mobile Units were developed and manufactured.

##### *6.3.1.2.1 Preparation of installation*

In parallel to the system developement and manufacturing a Technical Meeting was held in La Spezia on 5th of August to clarify all problems related to the installation.
Following details were discussed and fixed:

- Cable lengths
- Selection of connectors and sockets for the adapter cables, which can be used by all partners
- Installation of Reference Station
- Installation position of Mobile Units on board of Reach Stacker and RTG
- Installation of GPS/GLONASS and telemetry antennas
- Installation position of Ultrasonic Sensor.

##### *6.3.1.2.2 Cable measures*

The cables were manufactured according to the installation requirements. The measures are shown in the following tables.

##### *6.3.1.2.2.1 RF cables*

Table 10 is showing the measures of the RF cables.

| RF-Connector | *Type of* cable | Cable length | Function | RF-Connector |
|---|---|---|---|---|
| *N* | RG214 | 20 m* | Refer.-Station | TNC |
| *N* | RG214 | 18,5 m* | RTG | TNC |
| N | RG214 | 18,5 m* | Reach-Stacker | TNC |

* attenuation of RG214 is 23 dB/100m at 1000 MHz

**Table 10: RF cables**

#### *6.3.1.2.2.2 Adapter cables*

To allow easy access to the board sensors and the supply voltage, two short adapter cables (2 m length) were fixed to the board distribution point, terminated with a special (Binder)-socket for the adaptation of the Mobile Units (DGPS and Acoustic). Each Mobile Unit was connected to the adapter socket by an interconnecting cable, see figure 6.

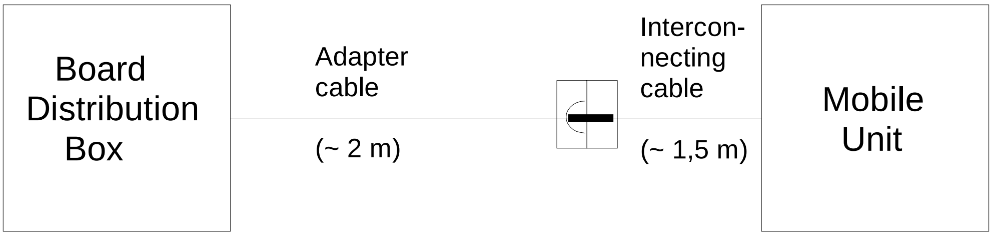


**Figure 6: Connecting Cable Layout**

#### *6.3.1.2.3 Equipment Layout*

*Housing*
The modules of the Reference Station are included in a standard 19“ case. The operation voltage is 230 VAC.
The modules and dead reckoning sensors of the Mobile Units are included in waterproof cases (protection class IP65). The operation voltage is 10....33 VDC.

*Antennas*
Both GPS/GLONASS antennas for the Reference Station and the Mobile Units are mounted on a choke ring for multipath reduction. The telemetry antennas are aerials with magnetic adhesive for easy installation.

### *6.3.1.3 System Installation*

#### *6.3.1.3.1 Reference Station*

During the first trials in August/September the Reference Station was put in operation inside the Technical Building, which is located near the test area The assigned telemetry frequency is 164,725 MHz. Before starting the trials, the reference position was measured by an averaging process (about 4400 measures). The determined position is:

44,11021827 N or 44° 06′ 36,78″ N
09,84510550 E or 09° 50′ 42,38″ E
32,5 m height.

The GPS/GLONASS antenna and the telemetry antenna were installed at the south-easterly corner of the roof on a 2...3 m high mast (see figure 3).

#### *6.3.1.3.2 Reach Stacker*

On board of the Reach Stacker the Mobile Unit and all connecting cables were not fixed for the tests. The installation of the GPS/GLONASS antenna, however, caused some more problems. As it is required to measure the center position of the container, the antenna has to be installed on a fixed support at the top end of the hoist arm To guarantee the visibility of all satellites at the sky, the horizontal alignment of the choke ring is important. An additional cardan joint therefore was installed. The antenna cable was layed in parallel along the pneumatic hoses. The cable type, RG214, was a compromise between flexibility, cable attenuation and price. For a long time installation a more ruggedized cable should be used, which will be more suitable against damaged by the continuously extension and retraction of the hoist arm. The ultarsonic sensor has been installed on a metallic plate underneath the Reach Stacker near the front wheels. An unrestricted view to the ground is an important requirement for the functioning of the speed measurement, otherwise it will be disturbed by undesired reflected sound signals on the vehicle chassis.

#### *6.3.1.3.3 RTG*

The height of the RTG allows an unrestricted view to the sky. Special measures, like dead reckoning sensors, therefore are not required. The GPS/GLONASS antenna was installed on the operation platform overhead the center of the container hoist crane. The height sensor for the tier evaluation was not available during the tests, but there was no need for the scope of the project.

### *6.3.1.4 System Tests*

*Pre-Test*

A pre-test was carried out in September to proof the basic functions of the system.
The GPS/GLONASS positioning, the DGPS/DGLONASS functions and the take-over from SATNAV to dead reckoning showed the expected good results. Caused by a software problem, however, the track of the test drive could not be stored. The sensor signals for Twist Lock, Angle of hoist arm and Length of hoise arm were not available and could not be tested. During trouble shooting a short-circuit at the terminal adapter was caused, resulting in a burned A/D board and power supply of the Mobile Unit. These problems and the repair of one Mobile Unit finally caused a delay in the final testing.

*Intermediate Test*

During the trials in October the Mobile Units on both vehicles, Reach Stacker and RTG, were installed and tested. All sensor signals on the Reach Stacker have been available and completely evaluated by the Mobile Unit. Due to a damage of the ultrasonic speed sensor the dead reckoning system has not been tested. The trials, however, have shown the problems of a stand-alone DGPS system related to multipath effects by the metallic environment and the significant position error by the loss of the telemetry signal. As the communication between the Mobile Unit and the Data Terminal did not work, it was realized, that the interface protocol has to be modified.

*Final Test*

After solving all detected problems during the preceding tests, the final field test was carried out in December. The results will be presented in the following section.

#### *6.3.1.4.1 Presentation of results*

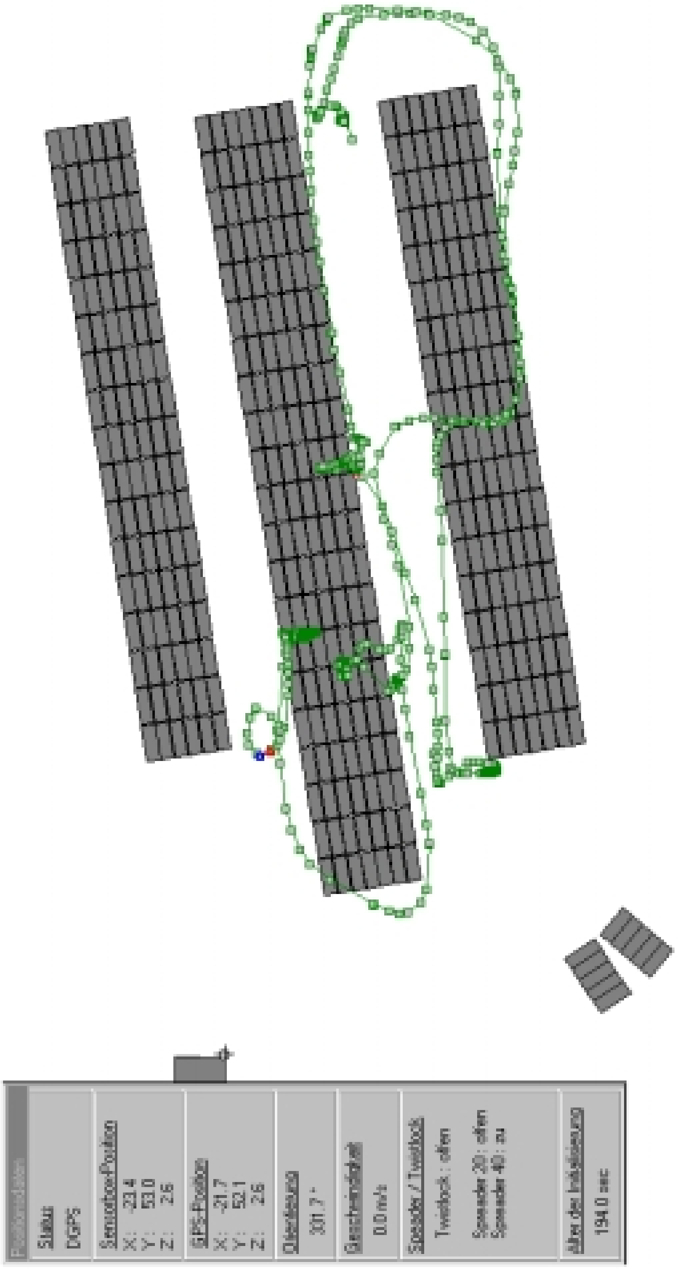
For a better presentation of the results a software tool was developed, which shows all container stacks inside the test area. This tool also allows an easy overview and position check during the test drive. In case the measured position corresponds with the error circle radius of the container center, the colour of the respective container position changes from grey to yellow. All figured container positions have the measures for 20 ft containers. 40 ft containers therefore will cover two positions. If the reception of the telemetry data fails, the measured position changes from green to red.

#### *6.3.1.4.2 Reach Stacker test results*

For the alignment of the container positions, all corner points of the container stacks were measured using the DGPS/DGLONASS system. The building with the Reference Station is in the lower left side of the figures, marked with a star for the antenna position. Figure 7 shows a first trial with excellent positioning characteristics, also in specific small lanes. The circular path, the drive over the same route and the drive into positions with a container in the lower level between stacks four level high are showing the reproducible results of the DGPS/DGLONASS sytem.

*Remark:* The right container stack is divided into two smaller stacks. Hence there is a small lane in the middle of this stack.

Figure 8 is the cut enlargement of figure 7. It shows the manoeuvring of the Reach Stacker in front of a 40 ft container position. After driving into the stack, the hoist arm were let down nearly to the ground. The surrounding containers were stacked four levels high and the view to the sky was restricted. In that position the dead reckoning took over to calculate the vehicle position.



Positionsdaten

Status
DGPS

Sensorbox-Position
X: -21.4
Y: 53.0
Z: 2.6

GPS-Position
X: -21.7
Y: 52.1
Z: 2.6

Orientierung
301.7 °

Geschwindigkeit
0.0 m/s

Spreader / Twistlock
Twistlock : offen
Spreader 20 : offen
Spreader 40 : zu

Alter der Initialisierung
194.0 sec

Figure 7: Test drive at the LSCT test area

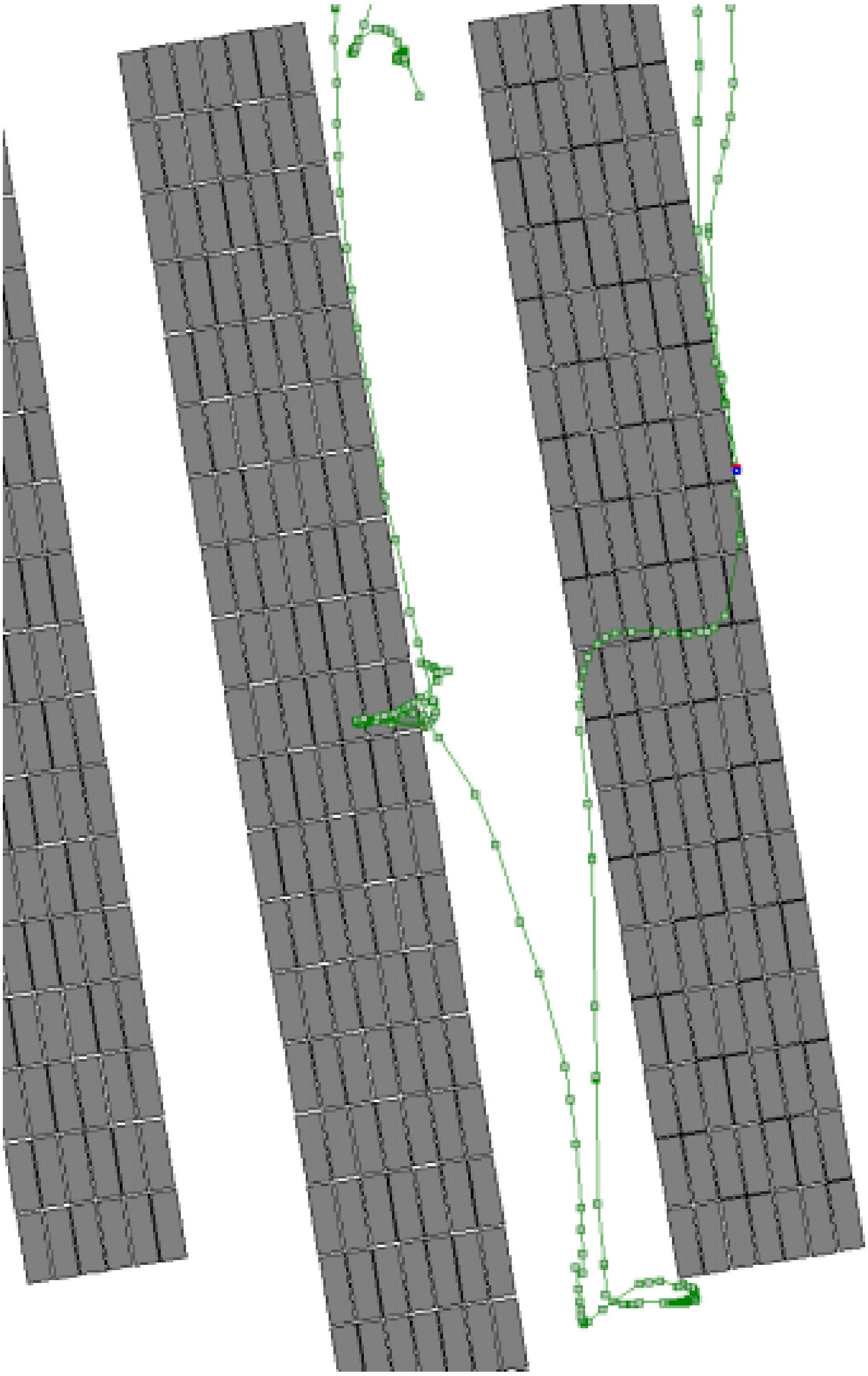


Figure 8: Cut enlargement of the trial shown in figure 7

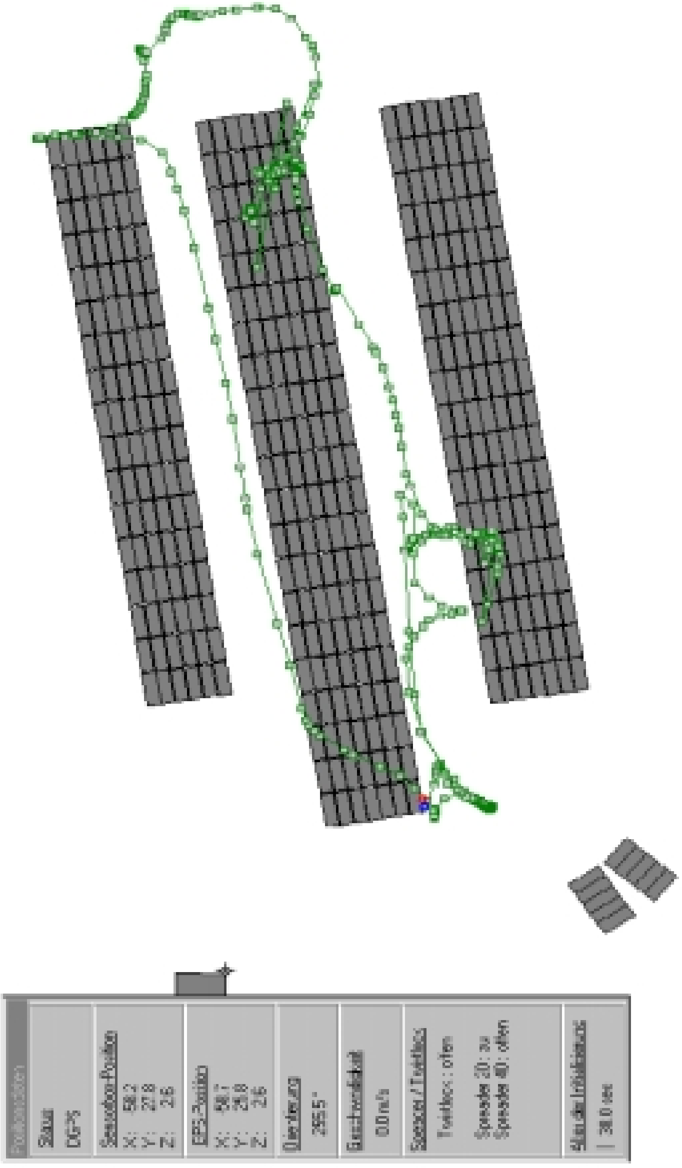
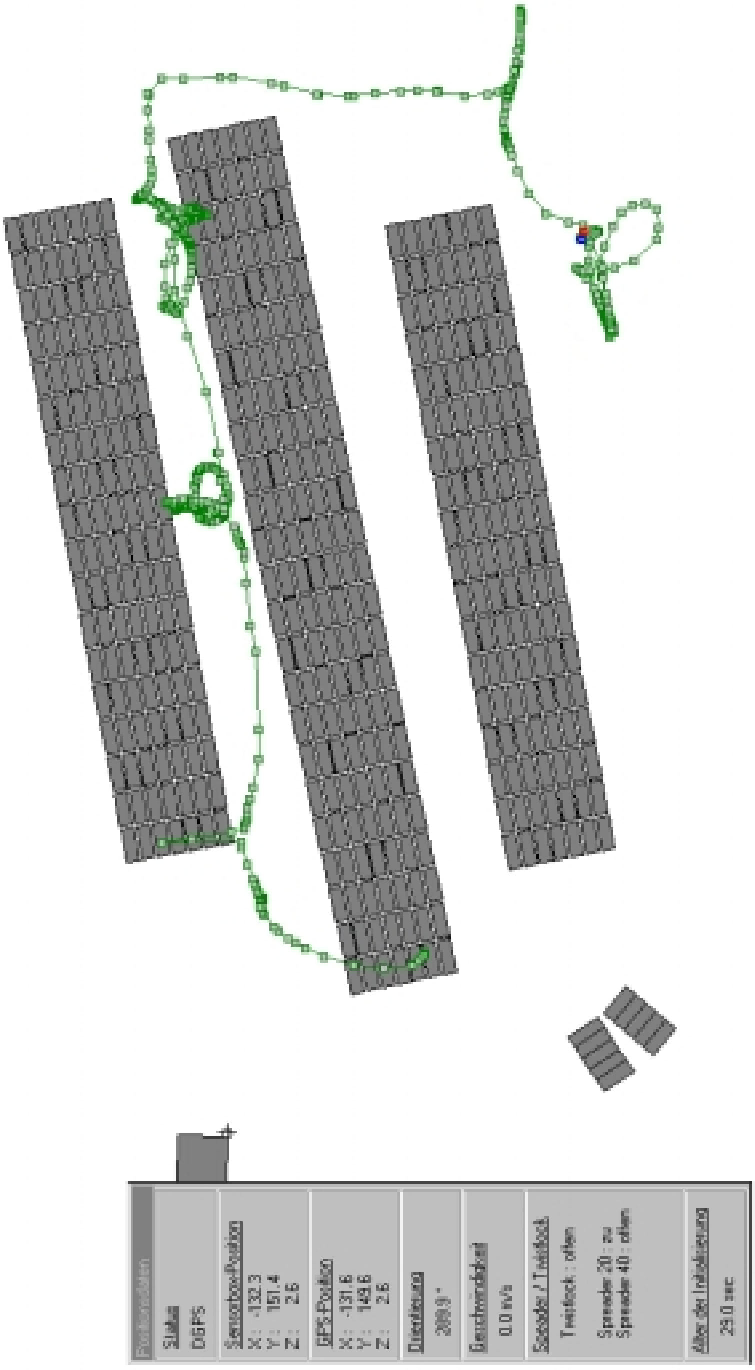


Figure 9: Test drive at the LSCT test area with disturbed positioning



Positionsdaten

Status
DGPS

Sensorbox-Position
X : -132.3
Y : 151.4
Z : 2.6

GPS-Position
X : -131.6
Y : 149.6
Z : 2.6

Drehung
269.9 °

Geschwindigkeit
0.0 m/s

Spreader / Twistlock
Twistlock : offen
Spreader 20 : zu
Spreader 40 : offen

Alter der Initialisierung
29.0 sec

**Figure 10: Test drive inside and outside of the LSCT test area**

During the trials, showing in figure 9, some disturbances occured, while the Reach Stacker entered the stacks at different positions. The reason was a drop out of the telemetry data reception. The DGPS/DGLONASS system therefore switched over to uncorrected positioning in the GPS/GLONASS mode only with less accuracy. Another trial is shown in figure 10. Inside and outside of the test area the results are excellent. Figure 11 again is a cut enlargement of the circle path between the left and the middle stack. After the first approach of a container position, the Reach Stacker was driven a circle and approached the position again. This test showed the ability of the reproduction of the position recognition of the system.

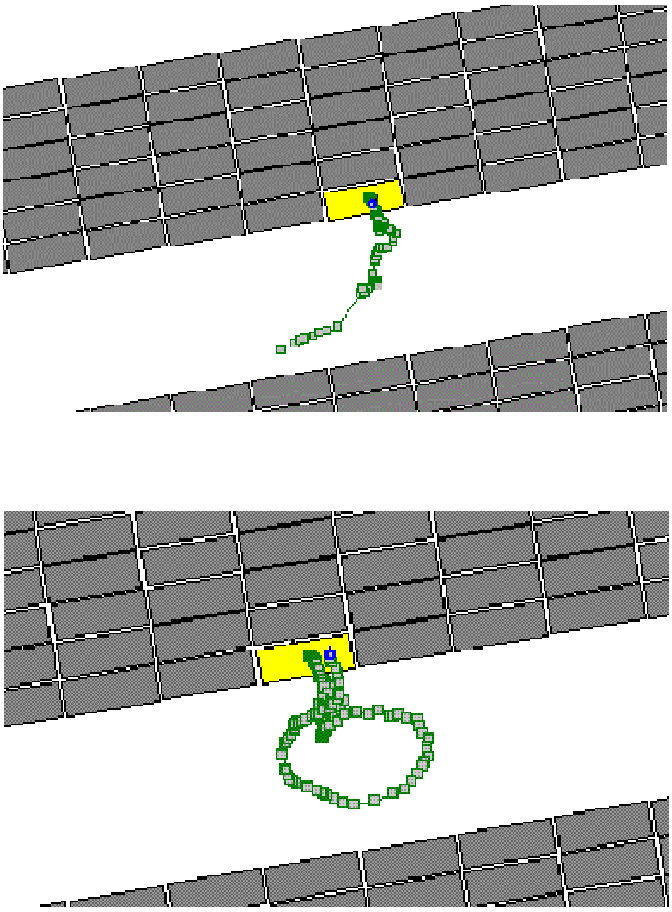
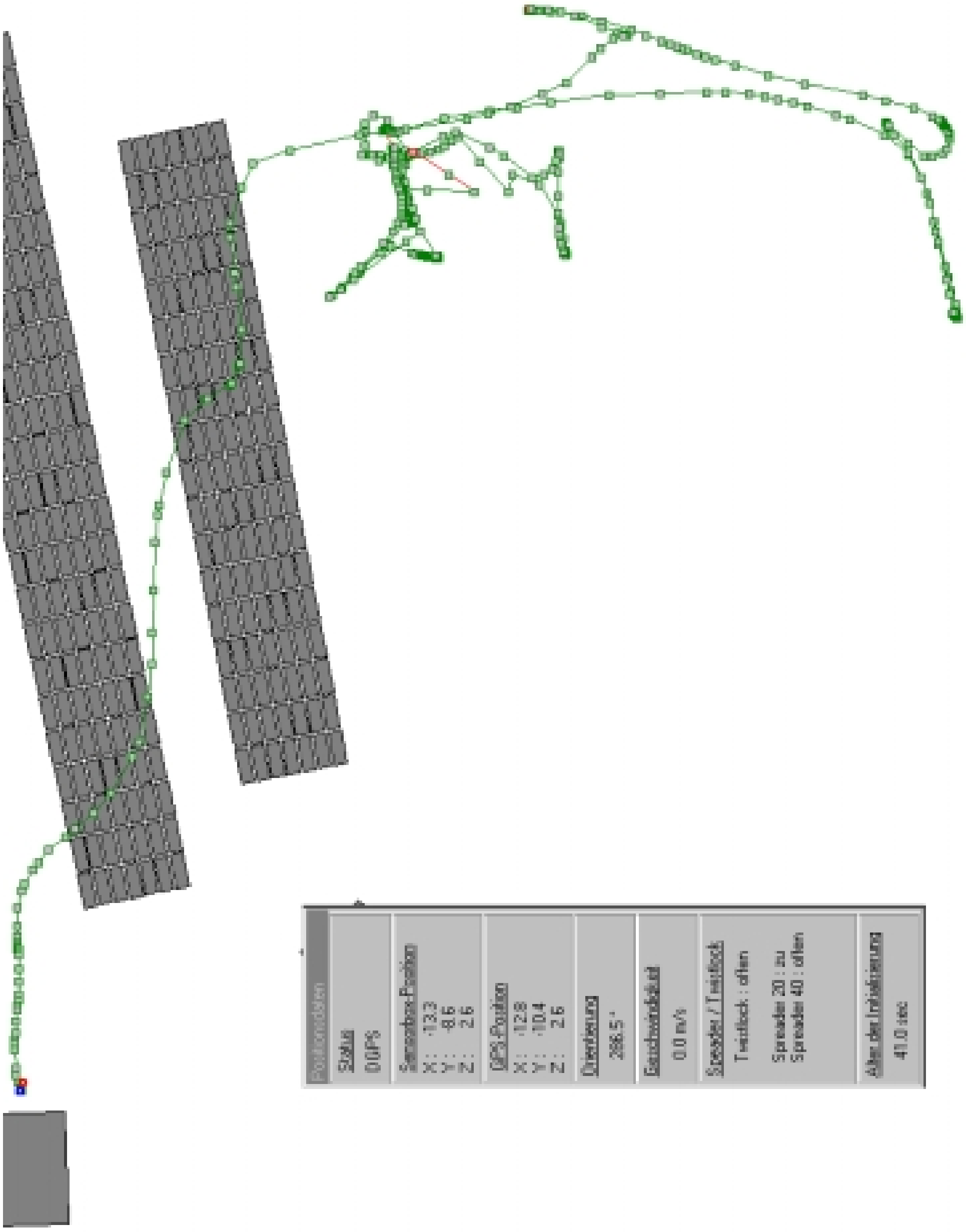


**Figure 11: reproduction of position recognition**



Positionsdaten
Status
DGPS
Sensorbox-Position
X : -13.3
Y : -8.6
Z : 2.6
GPS-Position
X : -12.8
Y : -10.4
Z : 2.6
Orientierung
288.5 °
Geschwindigkeit
0.0 m/s
Spreader / Twistlock
Twistlock : offen
Spreader 20 : zu
Spreader 40 : offen
Alter der Initialisierung
41.0 sec

Figure 12: Test drive outside the LSCT test area

The search for container positions outside the test area is shown in figure 12. In nearly all cases the container positions were surrounded by a four level high stack and the hoist arm lowered to the ground. The switch over from DGPS/DGLONASS positioning to dead reckoning and vice versa cannot be noticed.

#### *6.3.1.4.3 RTG test results*

Because of the exposed antenna position of the RTG, the visibility of the sky was unrestricted and without any multipath reflections. Therefore only a few position measurements were carried out. The results were as expected, the position of the container center could be identified with high precision and no position fluctuation was detected. As already stated in para 3.2 dead reckoning sensors for this application therefore are not required. As the antenna height of the RTG is fixed, an additional height sensor for the container level is required. This sensor was not available, but for the scope of the project, there was no need to install one.

#### *6.3.1.4.4 Connection to the PIS*

The data outputs of the Mobile Units were connected to the new data terminals installed in the vehicles. According to the agreed data telegram, each time the Twist Lock was activated, all informations were transmitted to the Position Information Server (PIS) and indicated on the central processor display.

### ***6.3.1.5 GPS field tests conclusion***

The field tests at the LSCT test area with the DGPS/DGLONASS system have shown the expected results. The system at the Reach Stacker was excellent working all over the stacking area, including the take over from DGPS/DGLONASS to the dead reckoning sensors. The position of the antenna at the top end of the hoist arm was well proved and feasible for installation without any exceptional expenses. The RTG system required no special attention, because of the multipath free surrounding and the unrestricted visibility of the sky.

## 6.3.2 The Acoustic System

The objective of the measurements was to determine the feasibility of using an acoustic system to accurately estimate the position of a mobile (with a precision of approximately half a meter) on a container terminal.

### *6.3.2.1 Overall view*

*6.3.2.1.1 <u>Description of the equipment</u>*

The equipment developed by METRAVIB is composed of :

(i) Four fixed acoustic transmitters, equipped with a Radio Frequency (RF) receiver (used to trigger acoustic transmission), a waveform generation module (including different predefined waveform for each transmitters, stored in a PROM), a power amplifier and a set of loudspeakers (2 loudspeakers for low frequency range, and 4 loudspeakers for the high frequency range). The approximate weight of each transmitter is 40 kg, and the power is supplied via 220 V AC.

(ii) Two Mobiles Processing Units (MPU) for the equipment of 2 vehicles (typically, a RTG and a reach stacker). Each MPU includes :

- An RF transmitters, to trigger acoustic transmission on the fixed transmitters
- A microphone for the reception of acoustic signal
- A data acquisition and processing unit, based on a PC104 architecture, that can be connected to a RF modem for position transmission to the Position Information Server (PIS).

*6.3.2.1.2 <u>Deployment of the acoustic system onboard vehicle</u>*

The acoustic sensor (composed of a microphone and pre-amplifier electronic board) is located on the top of the arm. The constraint on sensor environment are not as severe as for GPS, since it can be located at almost any location on the vehicle.

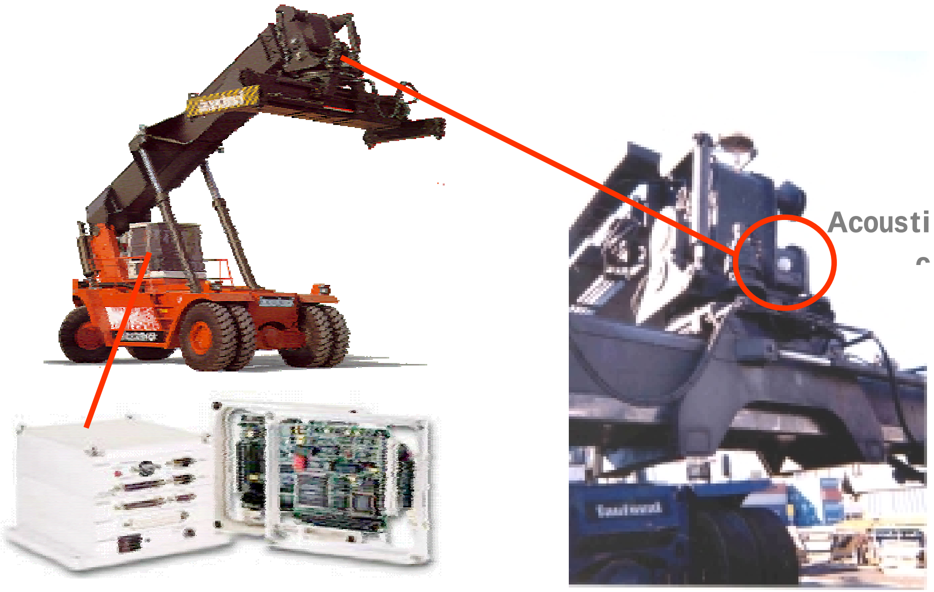


**Figure 13 : deployement of acoustic system onboard a reach stacker**

#### 6.3.2.1.3 *Presentation of the tests performed on acoustic system*

The performance evaluation of the system was performed in 3 steps:

(i) Preliminary trials conducted on the test site (LSCT). As reported in the next section, a lot of problems were encountered during this test and the system evaluation was very partial (hence the need for the two other tests).

(ii) Factory tests performed at METRAVIB after the repair of the acoustic system, damaged at the issue of preliminary tests. The objective was to check the validity of position estimation in a simplified configuration (free filed propagation, smaller test area). In addition, some improvement of the acoustic processing were evaluated.

(iii) Validation tests conducted at LSCT on a Reach Stacker.

### 6.3.2.2 *Preliminary tests on site*

#### 6.3.2.2.1 *Test description*

The tests were conducted from the 4th of October to the 8th of October 1999 et La Spezia Container Terminal (LSCT). The deployment of the system is shown on the figure 1 below

**Figure 14: deployement of fixed transmitters on the test site during the preliminary tests**

The test site corresponds to the area filled in yellow on the LSCT map (container stacks TA & TB). The first transmitter (reference) is located on the roof of the maintenance building (at approximately 10 meters in height), 2 transmitters are located on the top of TV mast (20 m height) and the last transmitter is fixed on the roof of a neighbouring building (close to the town centre of La Spezia).

#### *6.3.2.2.2 Problems encountered*

A lot of problems were encountered during these preliminary trials, as listed below :

1. ***Wrong estimation of transmitter position*** : the precise measurement of transmitter positions is required for the acoustic system to estimate mobile position. To measure transmitter positions, the DGPS system from R&S was used at the beginning of the tests. Unfortunately, the system was not fully operational at this date and a large error (tens of meters) was encountered in the estimate of transmitters positions.
2. ***Malfunction of RF trigger*** : due to high transmission losses in the connection cables used for RF trigger boards (embedded in both the mobile unit and the fixed acoustic transmitters), it was almost impossible to achieve a simultaneous acoustic transmissions on the four transmitters.
3. ***Noise annoyance*** : due to both the bad placement of one transmitter and to the use of audible acoustic frequencies for the design of the acoustic system, some people living in the buildings close to the terminal complain for the noise soon after the beginning of the test. The high level of transmitted signal (120 dB ref. 20 µ Pa at 1kHz) together with the proximity of the acoustic transmitter n°4 to the city centre was responsible for this annoyance. The transmitter n°4 was therefore shut down for the end of the test to limit noise annoyance and no more complain were recorded.
4. ***Partial destruction of data acquisition boards*** : due to over voltage on some inputs of the mobile system (the origin of which has been elucidated and corrected later), both mobile systems have been partially damaged by the end of the test.

Despite the problems encountered, some preliminary information was collected during the tests. In particular, it has been noticed that the influence of multipath effects (mainly due to the reflection of acoustic waves on the container stacks) could drastically limit the performances of acoustic localisation. Bias in position estimates indeed arise when the amplitude of the direct path signal is lower than that of the reflected echo, since an error occurs in the measure of the time of flight between transmitter and receiver (on the vehicle). Improvement of acoustic processing has been provided after the preliminary trials to enhance the rejection of spurious echoes and make the processing of position estimation more robust.

### *6.3.2.3 Factory tests at Metravib*

#### *6.3.2.3.1 Test description*

After the preliminary trials, the system was repaired at METRAVIB. In particular, cable connections for RF trigger transmission were modified (use of cables with low attenuation in the RF range) and digital I/O channels were redistributed on the acquisition board (use of non destructed channels). In addition, the processing SW was upgraded to reduce multipath influence on position estimation. Some factory tests were performed on a test area close to METRAVIB to check the behaviour of the system. Figure 15 below depicts the configuration used for the tests.

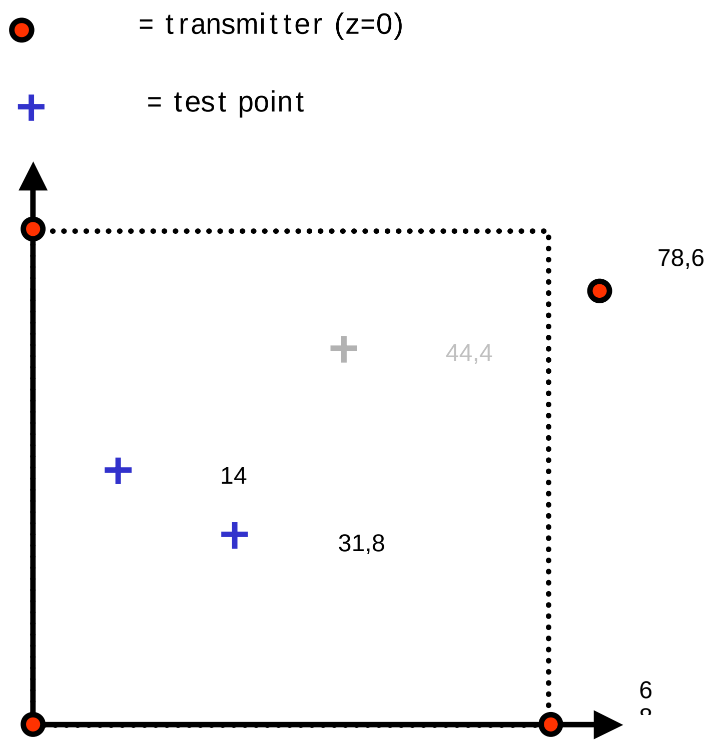


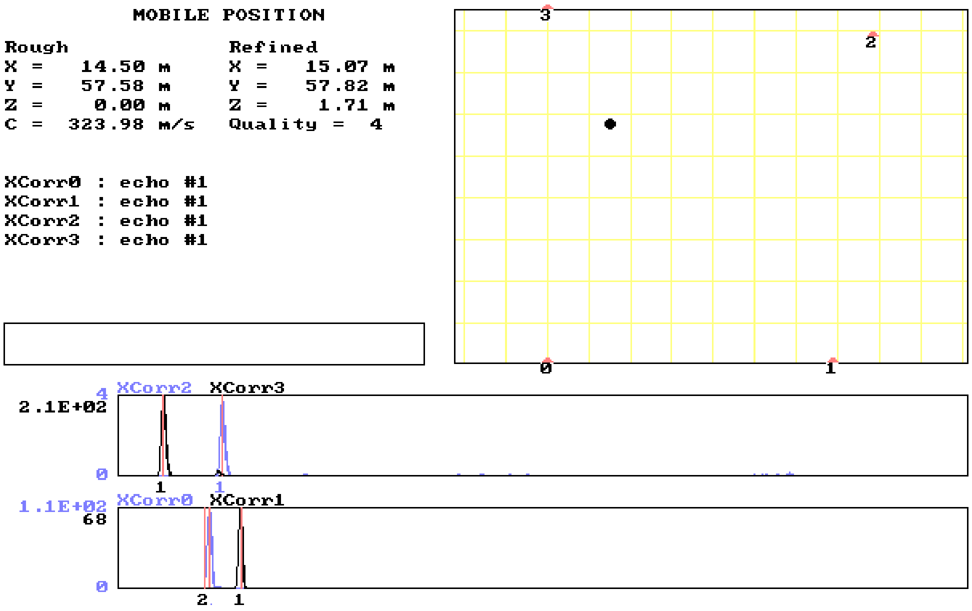
**Figure 15 : configuration for the factory tests at METRAVIB**

The transmitters were lying on the ground and positioned as shown on fig. 15. Exact transmitter positions were measured using theodolite (angle measurement) and laser telemetry (range measurement). The corresponding precision on position is approximately ±1 m. Three reference points were also accurately positioned on the site (but only 2 points were used to test the system). Since the chosen area is flat and non constructed, no multipath effect were observed during the tests (the objective was to test the system in the best favourable conditions, not to reproduce the real situation on site).

#### *6.3.2.3.2 Results*

Figure 16 shows a copy of a typical screen output from the acoustic localisation system. Signals shown on the bottom of the figure are the results of coherent processing of the microphone output. Since no multipath effects are present, each of these signals exhibit a maximum amplitude for a time delay corresponding to the time of flight between transmission form each acoustic transmitters and reception on the microphone.

In addition to the 3-D position, an estimate of sound velocity *c* is also provided by the system. Although the values for this parameter are close to the theoretical one (*c* = 344 m/s at 1kHz for a relative humidity of 50%), the observed deviation may be explained by the error on exact transmitter position, which in turns induce some bias on sound velocity estimates.



```
MOBILE POSITION

Rough                    Refined
X =   14.50 m            X =   15.07 m
Y =   57.58 m            Y =   57.82 m
Z =    0.00 m            Z =    1.71 m
C =  323.98 m/s          Quality =  4

XCorr0 : echo #1
XCorr1 : echo #1
XCorr2 : echo #1
XCorr3 : echo #1
```

**Figure 16: screen copy of acoustic system display during measurement at first test point.**

Tables 15 & 16 summarise the results for position estimation when the microphone is successively located at test point 1 and test point 2. Position in X and Y direction are quite well estimated (the error is less than 1.5 m, which is the order of magnitude of the accuracy on transmitter positions). The estimation of altitude z is much less precise since all the transmitters are positioned at the same altitude (z=0).

| | X (m) | Y (m) | Z (m) | C (m/s) |
|---|---|---|---|---|
| *Real* | ***14.0*** | ***58.1*** | ***0.5*** | |
| *Estimated* | 15.07 | 57.82 | 1.71 | 323.98 |
| | 14.88 | 57.82 | 0.04 | 323.98 |
| | 14.86 | 57.82 | -0.88 | 316.28 |
| | 14.75 | 56.86 | -0.99 | 280.70 |

**Table 15 : measurement results on the first test point**

5.3.2.1.1.1.

| | X (m) | Y (m) | Z (m) | C (m/s) |
|---|---|---|---|---|
| *Real* | *31.8* | *31.8* | *0.5* | |
| Estimated | 32.00 | 30.58 | -0.88 | 326.18 |
| | 31.24 | 31.36 | 0.03 | 302.70 |
| | 31.94 | 30.61 | 1.49 | 324.72 |

**Table 16 : measurement results on the second test point**

### *6.3.2.4 Tests on site*

The validation tests were performed on LSCT site on 2nd & 3rd of March 2000. Due to both the limited time of these tests and the destruction of the acquisition board of one of the systems, only a reach stacker was equipped for acoustic positioning (RTG has not been considered during this test since it corresponds to a more favourable situation). Upon precise specification, the deployment of fixed transmitters was slightly changed from the preliminary tests in order to limit noise annoyance and to improve the acoustic coverage of the test site (transmitters has to be closer to the TA & TB areas). The picture on figure 17 below shows the new positions of transmitters. The first transmitter is still located on the roof of the maintenance building (close to the DGPS reference antenna), a second transmitter is located on the roof of the administration building, the third one is fixed on a light mast (z = 17 m) and the last one is still located on top of a TV mast (z = 20 m).

**Figure 17 : deployment of fixed transmitters for the validation tests.**

The positions of both transmitters and test points disseminated over the site were measured using a high precision DGPS system (using a large number of averages for each measurement to limit noise influence).

#### 6.3.2.4.1 *Test description*

For the evaluation of system performances, the reach stacker was moved at some predefined positions as shown on the measurement grid on figure 18 below.

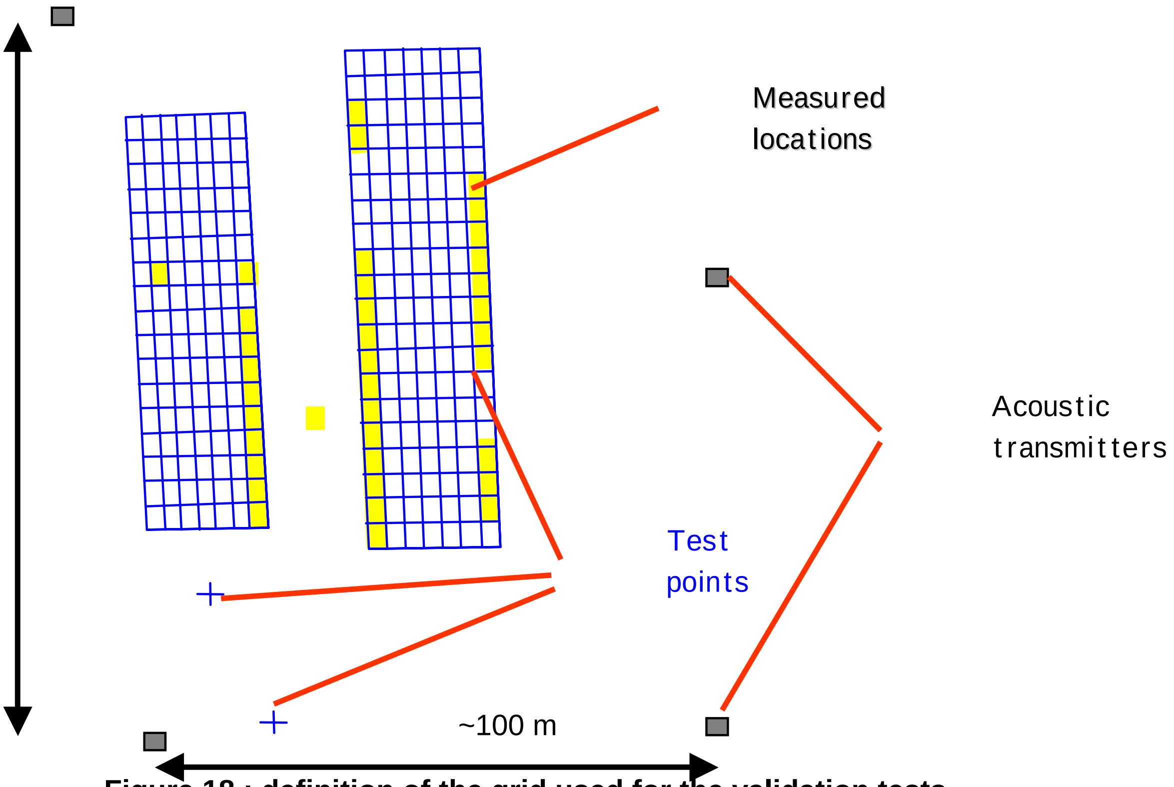


**Figure 18 : definition of the grid used for the validation tests**

Measurement were performed for both

- A fixed position of the reach stacker with variable orientation of the arm, so as to evaluate the influence of sensor altitude on the performance of acoustic positioning
- A variable position for the reach stacker at maximum arm length (i.e. maximum altitude for the acoustic sensor).

In addition, the positions estimated at test points were compared to the exact positions measured using DGPS.

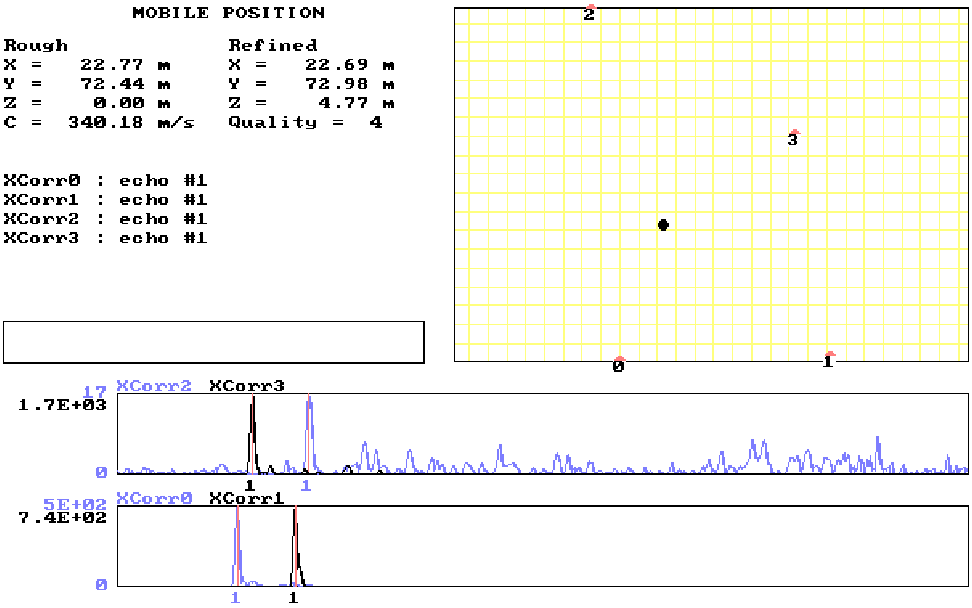
#### 6.3.2.4.2 *Results*

##### 6.3.2.4.2.1 *Fixed mobile position – variable altitude of the acoustic sensor*

Figures 19 & 20 show the output of acoustic signal processing for the same position of reach stacker but for various altitude of the acoustic sensor, and table 3 summarises the results obtained for various arm length.

When the maximum arm length and arm angle are used (fig. 19), no noticeable reflected echoes are observed on the measured signal and the estimated position of the mobile is correct (the error is less than 1 m in both X and Y directions).

Unfortunately, when the arm is in horizontal position (fig. 20), the signal peaks corresponding to the direct propagation path cannot be discriminated from the reflections on the surrounding container stacks and estimates of mobile positions exhibit large errors. It should be noted that, in this case, the estimated value for the sound velocity provide a good indication of estimation confidence. Large deviations from the theoretical value of 344 m/s indeed indicates bad accuracy in the estimated position (as shown on the 2 last lines in table 3, for instance).

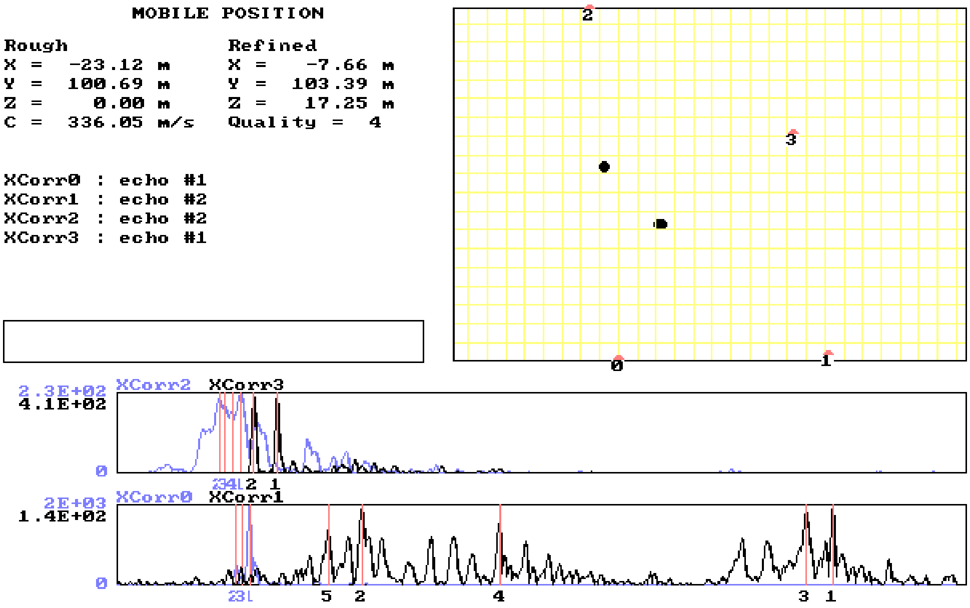


```
              MOBILE POSITION

Rough                    Refined
X =    22.77 m           X =    22.69 m
Y =    72.44 m           Y =    72.98 m
Z =     0.00 m           Z =     4.77 m
C =   340.18 m/s         Quality =  4

XCorr0  :  echo  #1
XCorr1  :  echo  #1
XCorr2  :  echo  #1
XCorr3  :  echo  #1
```

**Figure 19: results of acoustic localisation for the maximum altitude of acoustic sensor (maximum arm length and maximum angle). No noticeable multipath effect is observed.**



```
              MOBILE POSITION
Rough                 Refined
X =   -23.12 m        X =    -7.66 m
Y =   100.69 m        Y =   103.39 m
Z =     0.00 m        Z =    17.25 m
C =   336.05 m/s      Quality =  4

XCorr0  :  echo  #1
XCorr1  :  echo  #2
XCorr2  :  echo  #2
XCorr3  :  echo  #1
```

**Figure 20: results of acoustic localisation for the minimum altitude of acoustic sensor (arm in horizontal position). Received signals are polluted by multipath effects (large number of peaks in the received signals due to multiple reflections).**

| *X (m)* | *Y (m)* | *Z (m)* | *C (m/s)* | *Harm length* |
|---|---|---|---|---|
| 22.69 | 72.98 | 4.77 | 340.18 | Maximum |
| 22.81 | 73.21 | 6.30 | 340.71 | |
| 23.12 | 72.55 | -3.95 | 339.43 | |
| 21.57 | 73.21 | 2.61 | 341.46 | ¾ |
| 21.47 | 73.06 | 4.80 | 340.42 | ½ |
| -7.66 | 103.39 | 17.25 | 336.05 | Minimum |
| 8.76 | 73.04 | -13.75 | 340.95 | Horizontal harm |
| -12.31 | 66.06 | -36.15 | 487.07 | |
| -121.33 | 117.16 | 26.02 | 102.36 | |

**Table 17: results of position estimation at a fixed mobile position and for various altitude of the acoustic sensor.**

The main conclusion of the measurement performed for fixed stacker positions and variable arm length and orientations is that the acoustic sensor should be located as a reasonable altitude for the estimation to be correctly performed. In particular, this means that no accurate positioning can be provided when the microphone is close to a container stack. For this reason, the remaining part of the evaluation was performed using the maximum altitude for the microphone (maximum arm length and orientation).

#### *6.3.2.4.2.2 Measurement at test points*

Tables 18 & 19 summarise the measurement results at the test points P2 and P3. When compared to DGPS, results are very accurate (error less than 1.3 m in X direction and 2 m in Y direction) It should be noted that these errors originate from either

1. the error in DGPS measurement that is probably less than 0.5 m,

2. the error in reach stacker positioning : the order of magnitude of this error is clearly more than 0.5 m, especially if we consider measurement at test point P3 were no clear mark was provided on the ground to give the exact position of this point (and it can be seen from table 3 that measurement performed on the first and the second day of the tests differ in Y direction of about 4 m !),
3. the error due to the acoustic system itself.

A better test would have been to perform both acoustic and DGPS measurements at the same time, to allow a direct comparison of the results (this was not possible since the reach stacker was not equipped to operate both acoustic and DGPS in the same time). Another interesting observation is that the order of magnitude of the altitude is provided by the acoustic system, even if this value is not very accurate because the transmitters were almost positioned at the same altitude.

| | *X (m)* | *Y (m)* | *Z (m)* | *C (m/s)* | *Note* |
|---|---|---|---|---|---|
| GPS | ***-54.13*** | ***96.93*** | | | |
| Acoustic | -54.36 | 99.00 | 16.14 | 339.97 | Measured on 02/03/00 |
| | -55.23 | 95.24 | 7.74 | 338.30 | Measured on 03/03/00 |
| | -55.30 | 95.20 | 8.29 | 338.67 | |

**Table 18 : results of position estimation at test point P3.**

| | *X (m)* | *Y (m)* | *Z (m)* | *C (m/s)* |
|---|---|---|---|---|
| GPS | ***-9.02*** | ***38.69*** | | |
| Acoustic | -9.33 | 39.49 | 10.81 | 339.93 |
| | -9.87 | 39.29 | 10.86 | 338.94 |

**Table 19 : results of position estimation at test point P2.**

### *6.3.2.4.2.3 Results on the measurement grid*

Figure 21 shows the results of reach stacker positioning for different locations on the measurement grid. The coloured dots that have been plotted correspond to positions where estimated sound velocity is in the interval 338-342 m/s (the colour refers to the date of the measurement and is not used). Dots that have not been coloured stands for locations where the associated sound velocity is outside the range 338-342 m/s.

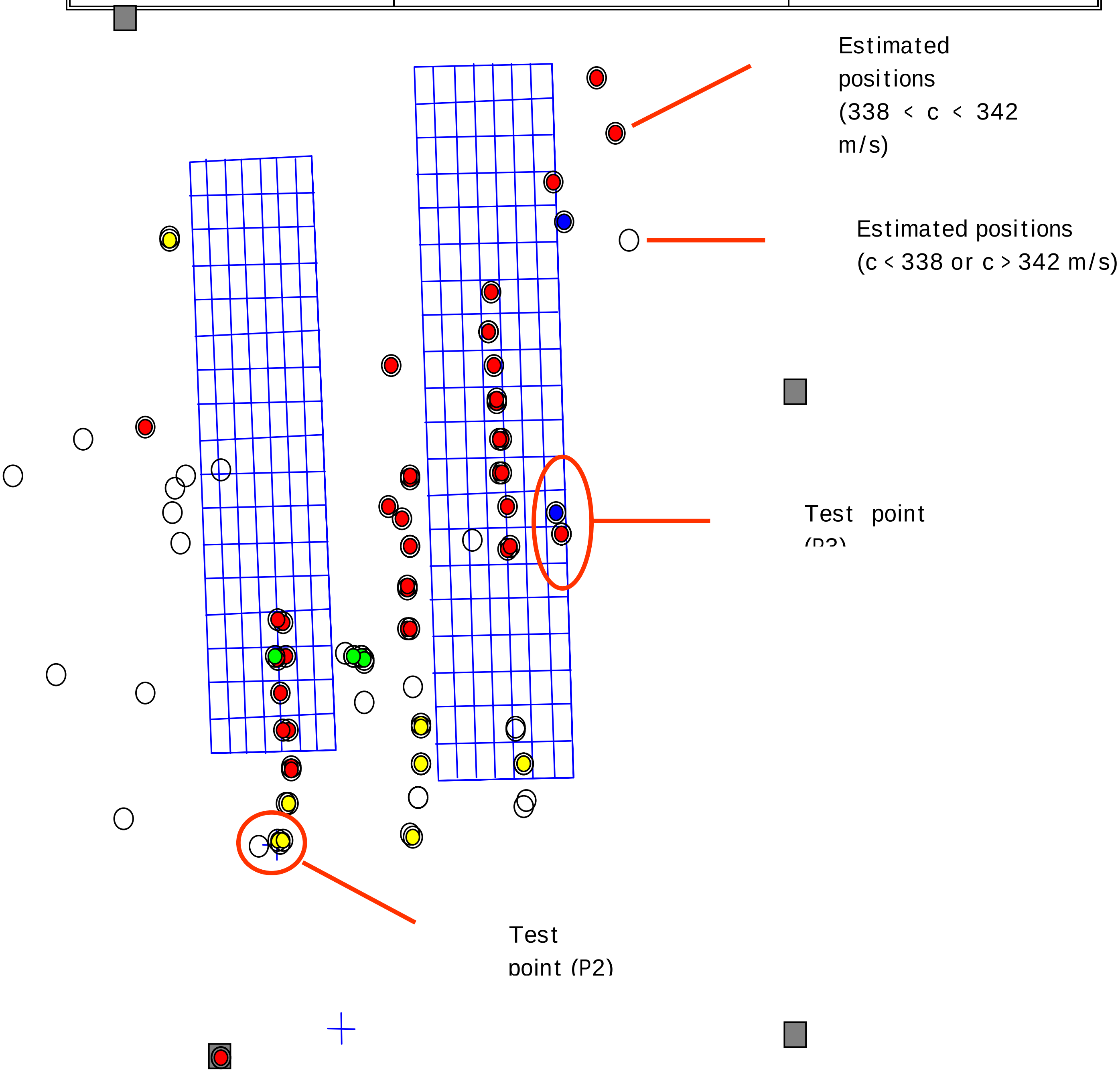


Figure 21 : results of reach stacker positioning on the measurement grid. Dots coloured in either red, yellow, green or blue correspond to estimated positions associated to a sound velocity within the interval 338-342 m/s. Non coloured dots are associated to a sound velocity outside this interval (i.e. bad confidence on the estimation result).

#### *6.3.2.4.3 Comments on the results*

It is clear from the results shown on figure 21 that estimated positions are shifted from theoretical once in both X and Y directions. This results is surprising since, when comparing the estimated position at test points, a good agreement have been found between measured and real positions. After discussion with Calzoni and LSCT, it appears that the co-ordinates of the grid that were used to draw the picture in fig. 21 have been measured during trials performed in December (using the DGPS system from Rhode & Schwartz), whereas the locations of test points were measured prior to the tests by the end of February (using a DGPS system provided by Calzoni). In the interval, the stacks of containers was moved (from approximately 2 meters ?) due to a reorganisation of the terminal. In addition, the tests were performed while the terminal was in operation, so that it is not clear whether all the container stacks shown on the theoretical grid were really present during the test. It is clear also from these results that the mobile positions close to the corner of the test area (top right locations on fig. 21) are very difficult to measure. In order to increase the range covered by the acoustic system, it would be necessary to use more transmitters spread over the test site (this problem is similar to DGPS when only a small number of satellite are observed simultaneously).

### *6.3.2.5 Conclusions*

The first conclusion of the test fields validation is that the feasibility of acoustic positioning in a real environment has been demonstrated. A prototype of acoustic positioning system has been set-up and successfully tested on site. The positioning accuracy in the X,Y plane is approximately 1 m to 2 m, which should be sufficient to determine the logical position of the container during catching/deposit operations (because the minimum size of a container is 6.2 m in length by 2.45 m in width). It should be noted however that, because the error cumulates tests errors (from both GPS measurement and approximate reach stacker positioning), the intrinsic accuracy of the Acoustic Positioning is probably better. The altitude of the container cannot be directly estimated from acoustic measurement, but this parameter can be easily computed using the signals already provided on a reach stacker (hoist arm length and angle). The main drawback of the actual system is provided by the use of audible frequency ranges for acoustic transmission. This problem can be overcome for a real implementation by using higher frequency ranges (almost non audible, as e.g. between 15 kHz to 20 kHz) instead 0.5 to 1.5 kHz for the actual system. This solution was rejected at the beginning of this project because it was though that a lower frequency range would have been more favourable for the elimination of multipath effects in a real environment. The results of the validation tests show that multiple reflections on the surrounding container stacks is still a problem in the low frequency range. The solution is to locate the acoustic receiver at the maximum allowed altitude. The picture of figure 22 shows a possible implementation : the receiver is fixed to a flexible mast with a suitable length to emerge from the container stacks. Even if the risk of destruction of the microphone due to a shock with some obstacle is limited because of the flexibility of the mast, the extreme low cost of this device (some few Euro) makes this solution realistic from a maintenance point of view.

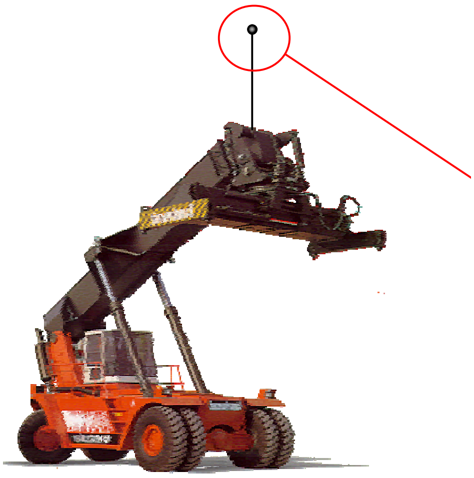


**Figure 22 : optimised position for the acoustic receiver**

Another limitation of the actual prototype comes from the need for a radio frequency trigger (remotely operated from the mobile unit using twist lock signal), which can be difficult to achieve when a large number of vehicle are to be surveyed. The solution to this problem is simply to use continuous transmission from the fixed transmitters, the only constraint in this case being to synchronise the transmitters (similar solution to that used in a GPS system), which in turn can be performed using alternative solutions to radio frequency transmissions (e.g. acoustic transmission can be synchronised using the fundamental frequency of standard 220 V power supply). Thanks to continuous transmission, it would also be possible to perform a continuous tracking of the vehicle. This tracking could be coupled to some simplified dead reckoning system (similar to that used in DGPS for example) to decrease the risk of container misplacement due to multipath effects. The implementation of an acoustic localisation system on a container terminal will require the use of a greater number of fixed transmitters, disseminated over the site. This configuration will be favourable to a better robustness of position estimation since it is probable that more than 4 transmitters will be “heard” by the acoustic receiver onboard the reach stacker. Like for GPS system, including more transmitters (satellites) in the measurement will increase the accuracy of the estimated position.

### 6.3.3 Field test conclusions

The field validation campaign for the automatic location systems has shown the need to improve the systems before they can be put on the market. This is true especially for the acoustic system that presents more problem related to the noise, the installation, the availability, but this is inevitable because it is the first application of this technologies in this specific field. On the other hand it seems that the costs for an acoustic location system are significantly less than the costs for a GPS system. While for the inland terminal it seems that automatic location systems are not cost/effective, for maritime terminal they will be necessary to increase competitiveness, efficiency etc… Some of the benefit in using automatic location system in maritime terminals are listed below:

- elimination of misplaced containers
- potential for added automation -- the positioning information can be used in many other ways, as well.

- improved control of the operation and better quality of service -- with accurate, real-time information the operator gains better control of the container yard and can offer improved service to customers
- efficiency increases in data exchange to and from the drivers
- savings in reduced yard markings quality management benefits
- more efficient and reliable operation results in lower costs
- improved information flow
- better vehicle utilisation
- better process documentation
- fewer human errors and improved safety.

# 7. CONCLUSIONS

The project has shown that the technologies selected (GPS and Acoustic) are really applicable and offer a solution for an automatic location system of ITUs inside intermodal terminals.

While the GPS technologies was already used and tested in precise location systems (with some draw-backs in adverse conditions), for the acoustic it was not so clear, at the beginning of the project, what kind of results could be reached.

The most efforts were put on find a solution for reach stackers that are the most flexible vehicles inside the terminals and often are working in critical condition for the position measurement point of view (under the cranes, between wall of containers ..).

The tests have been demonstrated the following:

- GPS integrated with a dead reckoning system gives excellent results all over the stacking area and guarantees the accuracy and availability requirement for the position measurement.
- the acoustic positioning system is feasible in the real environment even if the accuracy and availability requirements are not completely achieved.
- the use of a Position Information Server which take care of all the operations dealing with the management of position data, allows for a functional separation between the determination of the position information and the management of this information for the purpose of terminal operations (taken care by the operator’s information system).
- The joint use of GSP and acoustic systems, even if from the technical point of view is quite easy to implement, does not increase in significant manner the accuracy and the availability of the automatic location system to justify the costs.

The analysis cost/effective in conjunction with the particular characteristics of the terminals (namely the layout, the size, the operational procedures and the level of automation) has shown that an automatic localisation system is more interesting for maritime terminals than for inland terminals.

# 8. ANNEXES

In the following the list of publications related to the project:

Deliverables:
- D1: System requirements and preliminary analysis of applicable technologies (Restricted)
- D2: Overall system design criteria (Confidential)
- D4: Result of field tests (Public)
- D5: Recommendations, guidelines and cost assessment (Public)

Presentations

Clustering meeting in Brussels (1998)
European Transport Conference form 9th to 10th of November 1999 in Lille.

# 9. REFERENCES

[D1] Deliverable D1: System requirements and preliminary analysis of applicable technologies

[D2] Deliverable D2: Overall System Design Criteria

[D5 Annex 3] Deliverable D5: Recommendations, guidelines and cost assessment

[D4 Annex 1] Results of field test for the DGPS system
[D4 Annex 2] Results of field test for the Acoustic system