An improved in-vehicle unit for E-TRACK fleet management system

By using Microcontroller and PLD Technology a new generation of system has been developed allowing reduced cost and size

EMPHASIS O.E.

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**AE abstract**

EMPHASIS OE is a young Information Technology (IT) firm, specialising in the development and integration of applications for the transportation and the distribution market sectors.

EMPHASIS activates in the following telematics applications segments of the domestic market: Fleet Management systems, Telemetry applications and WAP applications.

The firm currently employs six people and achieves annual turnover of approximately 300KEUR. Fleet management systems market accounts for the 50% of the total firm’s turnover, Telemetry applications account for 30% and WAP applications for 20%.

The firm has strong technical orientation and during the course of its operations (since 1996), has acquired significant experience in the areas of transportation management and telematics in acting as specialised service provider, developer and small-scale producer of customised applications and market specific products.

EMPHASIS competition includes firms established in the software/electronics/communication integration field. Until now fleet management activity has no significant domestic market competition while telemetry and WAP activities compete in an already mature market.

In 1996, EMPHASIS introduced E-TRACK, an innovative fleet tracking and management system providing two-way communications between vehicle and centre of operations. The in-vehicle unit of the system collects and makes available to the centre of operations data such as the geographical position of the vehicle, the condition of the freight and other operational data.

Prior to the application experiment, the firm had no experience in microelectronics design and development. The objective of the application experiment was to improve the electronics of the in-vehicle unit, which was implemented on an industrial PC board, by using Microcontroller and PLD technologies in order to reduce it’s physical dimensions, physical weight, power consumption and cost.

Microcontroller and PLD technologies were chosen because they comply with the above requirements and, in comparison with other technologies (FPGA, ASIC), allow for flexibility to specific customer requirements, make prototyping easy during design development and keep the cost low in relatively low-volume production quantities.

By taking full advantage of these technologies, EMPHASIS will be given the opportunity to become more competitive from the technological point of view, penetrate new market segments such as the small vehicle and motorcycle/scooter fleet and finally introduce E-TRACK in the large European Market.

The application experiment was completed in 11 months at a cost of approximately 52,8 KEUR.
The payback period for the application experiment is estimated to be less than 2.4 years and the return on investment within a 3.3-year period (the estimated product life) about 129%.

Following the application experiment, EMPHASIS is now capable of undertaking the incremental design of the improved product for other applications, and the manufacture of the new product.
Keywords and Signature

Transportation
Telematics
In-vehicle unit
Fleet management system
Microcontroller / PLD
G.P.S. (GEOGRAPHICAL POSITIONING SYSTEM)

Signature:
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Email: gpap@emphasisnet.gr

2. Company size

EMPHASIS OE is an independent, small, five-year-old firm, which currently employs six people and achieves annual turnover of approximately 300KEUR.

The engineering team consists of five engineers specialised in the areas of transportation management, business informatics, and software engineering and transportation telematics.

3. Company business description

EMPHASIS OE is a system integrator of applications for the transportation and the distribution market sector. It has a strong technical orientation and acts as:

- Specialised service provider.
- Software developer.
- Developer of customised applications.
- Developer and small-scale producer of market-specific products.

In 1996, the company introduced E-TRACK, an innovative fleet tracking and management system providing two-way communications between vehicle and centre of operations. The in-vehicle unit of the system collects and makes available to the centre of operations data such as the geographical position of the vehicle, the condition of the freight and other operational data.
E-TRACK is the basic system upon which EMPHASIS builds customised applications and provides specialised (transportation-specific) services. Since 1997, E-TRACK has been adopted as an IBM solution and sells in the Greek market through IBM sales channels.

4. Company Markets and Competitive Position

EMPHASIS activates in the following telematics applications market segments:

- Fleet Management systems.
- Telemetry applications.
- WAP applications (Internet applications through GSM network.)

Fleet management systems market accounts for the 50% of the total firm’s turnover, Telemetry applications account for 30% and WAP applications for 20%.

EMPHASIS provides fleet management solutions to the following types of end user customers:

- Transportation of goods (either national or international)
- Transportation of people (either public or private)
- Distribution of goods (within urban areas)
- Field services (either public or private)
- Small parcel distribution / couriers

In addition, EMPHASIS provides OEM fleet management system solutions to IBM.

The related industrial sector is 3550 – Other Transport Equipment

The domestic market has a potential size (all types of vehicles) of 51000 units which is analysed as it follows:

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Units</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy trucks</td>
<td>12000</td>
<td>23.5</td>
</tr>
<tr>
<td>Light trucks</td>
<td>10000</td>
<td>19.6</td>
</tr>
<tr>
<td>Buses</td>
<td>7000</td>
<td>13.7</td>
</tr>
<tr>
<td>Small automobiles (cars)</td>
<td>18000</td>
<td>35.3</td>
</tr>
<tr>
<td>Motorcycle/scooter</td>
<td>4000</td>
<td>7.9</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>51000</td>
<td></td>
</tr>
</tbody>
</table>

Within all the above market segments, few installations of fleet management systems where observed before the introduction of E-TRACK in the domestic market on 1996. Since then however, the market has evolved rapidly, primarily in the transportation and distribution business sectors.
EMPHASIS performed 35 in-vehicle unit installations on 1997, 40 and 50 on 1998 and 1999 respectively and expects more than 80 on 2000. During 2001 and thereafter an annual growth of 30% is expected.

Sales growth is calculated on basis of the following factors:

- Increased product competitiveness
- Introduction of the product in new market segments
- Increased overall market awareness for fleet management system applications
- Geographical expansion of sales in the European market (non domestic)

In the domestic market, E-TRACK holds 100% of the Greek market share. It is the only commercially available fleet management system produced in Greece and in comparison with other systems produced in Europe, it enjoys a competitive advantage due to the extensive customization work that is required for the integration of the system to the client’s-specific business processes.

Recently however, two firms (Wackenhut Telematics and Skye Hellas) have introduced similar solutions to the domestic market. Until now, we don’t have any market figures.

Currently, E-Track is being utilized by organizations operating in the transportation and distribution business sectors and with the new design of the in-vehicle unit proposed with this Application Experiment, the firm intends to expand to the field service and courier market sectors.

The production cost of the new in-vehicle unit amounts for 467 EUR. The street price for the total solution per vehicle amounts for 1300 EUR, but the final price depends on various options as well as customization requested by the customer.

In the international market, there are several companies providing fleet management solutions. Here follows a list of competitors in the European and the United States markets.

GEC-Marconi (UK) produces the startrack system.
Euteltracs (France)
Simac (Netherlands)
Navstar Systems (UK)
Geopro (Germany)
Domeisen Engineering (Switzerland)
Terrafix (UK)
Securicor datatrak (UK)
De Lorme (USA)
CSL (UK)
Geotrack (France)
Cardy (Germany)
Skye (Germany) produces the skyefleet system

According to the information available, the competitors are mainly using PCB or Microcontroller technologies (depending on the volume of production) for the implementation of their in-vehicle units, since these two technologies are the most
feasible from the technical and economic point of view. Exact information on pricing and market shares is not available, since each installation is very much client specific.

Introduction of a fleet management system to a vehicle fleet operating company requires considerable integration work related to customer specific requirements, available data communication network facilities and available maps for the geographical area and nature of the application. In this respect, main criteria for the comparison of E-TRACK with the offerings available in the European market are:

a. System flexibility and adaptation to customer current and future requirements
b. Overall system cost (in-vehicle units, data communication network, base station software, maps, integration costs)
c. Overall system operating cost (equipment maintenance, software maintenance, map maintenance, data transmission costs through GSM network)
d. System limitations (suitability of the proposed electronic units, geographical areas supported, data communication technologies adopted)

In the domestic market, the most important strength of E-TRACK is the customization ability according to the specific client requirements.

Outside the Greek market, E-Track has not market share. The firm’s plans for introduction of E-TRACK in the European market will be assisted by the proposed new design, as the last one will strengthen company's position against criteria a, b and d.

5. Product to be Improved

The E-TRACK system architecture is defined by the following subsystems:

- In-vehicle unit
- Base station software (Management console)
- Communication network

The in-vehicle unit of the system collects and makes available to the centre of operations data such as the geographical position and speed of the vehicle, the condition of the freight (e.g. temperature) and other operational data depending on the particular requirements of the client.

The base station software collects and processes at the centre of operations the data sent from the in-vehicle units of the fleet. It provides the administrator’s console interface (management console) and connects to the company’s management (logistics) information systems.

The communication network provides the link between the base station software and the in-vehicle units of the fleet. The GSM network (circuit data connection) is being used.

The AE is aiming to improve the in-vehicle unit. The in-vehicle unit handles the following functions:
- Geographical positioning
- Data logging
- Data processing
- Communication protocol

The current implementation of the in-vehicle unit is based on an industrial PC board. Its block diagram is shown in figure 5.1.

A Dead Reckoning subsystem combines Gyroscope and Odometer data with GPS data to improve position accuracy on urban areas. The unit has 3 printed circuit boards (GPS receiver board, Industrial PC board, Interface electronics and power supply board).

**Basic in-vehicle unit specifications**

- GPS receiver number of channels: 10
- Position accuracy: 100m
- Track data logging interval: 5..30 sec
- Data logging memory size: 128 Kbytes
- Digital inputs: 8
- Power supply input voltage: 7..35 V (vehicle's electrical system)
- Power consumption: 12 Watts
- Physical size: 26.5 X 8.5 X 18.0 cm (4054 cm³)
- Physical weight: 1.1 Kg

*Figure 5.1 Block diagram of the current design*
Figure 5.2 Illustration of the existing product
Reasons to innovate

Although an industrial PC board design greatly contributed to fast design and reduced time to market, some market segments are excluded because of the unit's physical size, weight and power consumption (small vehicle fleets, motorcycle/scooter fleets). The proposed new design, utilising Microcontroller / PLD technologies, addresses these issues and allows access to the market segments mentioned above.

In, addition as the volume of production increases there is an increasing need for reduction of the production costs. The new design addresses well this issue too.

The quantifiable improvements of the new design over the old one are summarised in the table below:

<table>
<thead>
<tr>
<th></th>
<th>Old</th>
<th>New</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>Industrial PC Board</td>
<td>Microcontroller / PLD</td>
<td></td>
</tr>
<tr>
<td>Physical size</td>
<td>26,5 x 8,5 x 18,0 cm (4054 cm³)</td>
<td>18 x 7 x 12 cm (1500 cm³)</td>
<td>63%</td>
</tr>
<tr>
<td>Physical weight</td>
<td>1,1 Kg</td>
<td>0,5 Kg</td>
<td>55%</td>
</tr>
<tr>
<td>Power consumption</td>
<td>12 Watts</td>
<td>4 Watts</td>
<td>67%</td>
</tr>
<tr>
<td>Production Cost</td>
<td>612.9 EUR</td>
<td>467.7 EUR</td>
<td>24%</td>
</tr>
</tbody>
</table>

The proposed new design is described in more detail in the next chapter.

6. **Product improvements**

6.1 **Target objectives**

New design objectives (by order of importance) are:

- Physical size reduction (to less than 2000 cm³)
- Power consumption reduction (to less than 5 Watts)
- Reduction in production costs
- Increased adaptability to specific user requirements
- Physical weight reduction (to less than 0,6 Kg)
- Increased reliability (if possible)

6.2 **Functional specifications**

In the new design, data logging and data processing will be undertaken by a microcontroller system while peripheral logic will be undertaken by a PLD component.
The main specifications for the microcontroller system are:

- Intel 8051 family 8 bit microcontroller
- Clock frequency: 24 MHz
- Code memory size: 24 Kbytes
- RAM size: 256 bytes
- Watchdog
- Real time clock

The PLD component implements the following peripheral logic circuits:

- Odometer debounce logic
- Digital data input multiplexer

The PLD component allows for data input multiplexing as well as for establishing relationships between different data inputs. The above function allows for development of applications with variable number of data inputs as well as variable type of alarms based on combinations of data inputs.

The vehicle track data logging memory size is 32 Kbytes (64 Kbytes in option). A serial memory is used to reduce pin-count of the microcontroller.

An external UART handles data communications. The microcontroller runs all the necessary data communication protocol software.

The block diagram of the new design is shown in figure 6.1.

![Figure 6.1 Block diagram of the new design](image-url)
6.3 Main improvements of the new design

The above design complies with the objectives set in section 6.1.

The new design eliminates the Industrial PC board. An immediate consequence is elimination of one printed circuit board and important reduction of power supply needs. Further compactness is obtained by the introduction of the PLD component in order to implement all interface logic and the reduction of power supply physical size.

The new design component count is low. The elimination of one printed circuit board lead to a reduced number of electrical connectors.

For the above reasons the new design will accomplish the following critical specifications:

a. Physical size: 1500 cm$^3$
b. Power consumption: 4 Watts
c. Physical weight: 0.5 Kg
d. Reduced production cost: The new design production cost is 76\% of the current design production cost
e. Increased reliability (with significant reduction of discrete components and number of electrical connectors)
f. Increased flexibility in data acquisition requirements, due to the use of the PLD component.

Critical specifications a, b and c will allow introduction of the E-TRACK fleet management system in small vehicle and motorcycle/scooter market segments. Critical parameters d and e will improve E-TRACK position to all market segments. Specification f allows for the implementation of complex data acquisition requirements while maintaining the same microcontroller software.

Figure 6.2 Illustration of the improved product
7. Technology choice rational

7.1 Why Microcontroller-PLD technologies

A. Microcontroller - PLD

The main objective of the proposed application experiment has been to improve the electronics of the in-vehicle unit of the E-TRACK system in a way that it:

- Becomes more compact and less power consuming.
- Maintains its flexibility to allow for quick customisation.
- Makes prototyping easy during design development.
- Keeps the cost low in relatively low-volume production quantities.
- Minimises inventory risks.

In this respect, we believe that the proposed mixed Microcontroller-PLD technology offers the best solution because:

- It allows for a clear design that makes the best use of both technologies. The microcontroller is being used to accomplish the various processing tasks and the PLD to implement the peripheral logic.
- It allows for a compact, yet flexible design that extends the functionality and reduces the size and the power consumption of the unit. The system has become more convenient for customisation and is ready to accept one or more extra inputs according to the demands of each specific application.
- Usage of ready-made, cost-effective, widespread available devices minimises inventory costs.
B. Microcontroller – Discrete component logic
Combination of microcontroller with discrete component logic was considered initially as an alternative. This design option was rejected for the following reasons:

- Increased unit physical size
- Increased power consumption
- Increased PCB complexity
- No possibility for customization to specific digital input/output requirements

C. Microcontroller – FPGA component
The combination of a microcontroller with an FPGA component instead of a PLD component is inappropriate because it is less cost effective and because the new design does not require the large integration scale offered by the FPGA technology.

D. FPGA component (with incorporated microcontroller)
This alternative results in a decreased physical size, however is inappropriate because of the following reasons:

- Increased design cost
- Increased technological risk

E. ASIC (Digital or Mixed Analog/Digital) technology.
The ASIC solution has also been examined but:

- It is less cost-effective in low-volume production quantities.
- It requires more prototyping, simulation and manufacturing time.
- It is poor in future modification and it has inventory risks.
- Increased application risk

For this reason, even though it provides an even higher integration level, it is not the most appropriate for the current application experiment. The relative advantages or disadvantages of each combination of technologies are summarised below:

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical size</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Physical weight</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Power consumption</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>PCB complexity</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Design cost</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Prototyping</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Customisation</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Future modification</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Low volume production cost</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Inventory risk</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Technological / application risk</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
7.2 Choice of microelectronics devices

Intel’s 8051 family and Atmel's SPLD series devices have been chosen for the implementation of the unit.

- Intel’s 8051 family 8-bit industry-standard microcontroller is widespread available, well documented and supported by numerous libraries. Several vendors propose microcontrollers that are 8051 compatible. The microcontroller system can be upgraded in terms of speed and code memory size.
- Atmel's SPLD PLD series, with densities reaching 750 gates, can be used to implement entire digital sub-systems within a single programmable device. They are also easily available and supported by a good number of tools (ABEL, CUPL, PLDesigner XL and LOG/iC), which provide a higher level of integration and reduce design cycles. SPLD devices have optionally 25uA standby current, which makes them suitable for battery powered automotive applications.

7.3 Choice of Design and Test Methods

A top down design approach has been adopted. VLSI design laboratory assisted all the design steps that are presented hereafter

- Detailed specification establishment taking into account the possibilities and the particularities of the technologies adopted. VLSI design laboratory has transferred knowledge and assisted specification establishment.

- System level design according to specifications, assisted by VLSI design laboratory.

- Concrete system component design (microcontroller hardware platform, microcontroller software, PLD component)

An industry standard microcontroller development system (including C-compiler, assembler, in-line emulator and debugger) has been used as the platform for both hardware and software development of the microcontroller system.

8051 microcontroller system software test, has been performed at the first stage using code simulator and at the second phase using logic analyser.

A VHDL technique has been adopted to design the PLD component. PLD design entry, processing and simulation has been performed using Atmel’s SYNARIO fully integrated, Windows based development system which provides an architecture-independent design environment offering a full spectrum design capabilities. Text, graphic, and waveform design methods can be combined. The compiler performs minimisation and logic synthesis, fits the design into one or more devices, and generates programming or configuration data. Design verification with functional and timing simulation and delay prediction for speed critical paths are available.
8. Expertise and experience in microelectronics of the company prior to the AE

EMPHASIS is IT firm specialising in the design, development and integration of applications for the transportation and distribution market sectors. The firm holds expertise in the areas of:

- Distribution and transportation management
- Business informatics
- Software engineering
- Data acquisition and Communications
- Networks and transportation telematics.
- Vehicular Electronics

The firm integrates these technologies to create products such as E-TRACK targeted to several specialised markets.

Prior to the application experiment, the company had some awareness on the deployment of microcontroller devices, but no practical experience in the design, implementation, testing and manufacture of microcontroller / PLD enabled systems.

The personnel who participated to the application experiment are the following:

- The technical manager of the firm, with expertise in networks and transportation management.
- The chief engineer, with expertise in software engineering and transportation management.
- An information technologist, with expertise in transportation telematics.

9. Workplan

The application experiment was completed in an 11-month period, in-line with the original plan. A classic workplan structure has been adopted including a specification/design/implementation/evaluation/integration product development cycle. Training to the new technologies required during the specification and design. The work was structured in the following 8 tasks:

<table>
<thead>
<tr>
<th>Task</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Technical Management</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Training</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>3 Specifications</td>
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<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Design</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5 Implementation</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>6 Evaluation</td>
<td></td>
<td></td>
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<td></td>
<td>X</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>7 Integration</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>8 Dissemination</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9.1 Planned and actual work-plan (Thick vertical lines represent Key Milestones in the Experiment)
The first user effort and subcontractor cost for the completion of each task is shown in the table that follows:

<table>
<thead>
<tr>
<th>Task</th>
<th>First User effort (Person Days)</th>
<th>Subcontractor cost (KEUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Management</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Training</td>
<td>37</td>
<td>4</td>
</tr>
<tr>
<td>Specifications</td>
<td>46</td>
<td>1</td>
</tr>
<tr>
<td>Design</td>
<td>70</td>
<td>2</td>
</tr>
<tr>
<td>Implementation</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Evaluation</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Integration</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Dissemination</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>224</strong></td>
<td><strong>7</strong></td>
</tr>
</tbody>
</table>

*Table 9.2 Planned and actual first user effort and subcontractor cost.*

The major activities conducted during the application experiment are described below:

**Task 1. Technical Management**

EMPHASIS undertook the technical management and the other administrative tasks of the project. Such tasks included setting up of the necessary environment at the company for effective technical management, preparation of time allocation schedules for persons to be involved in the project and the necessary rescheduling of other tasks they were performing in order to allow time for their involvement in the project, evaluation and report of project work.

**Task 2. Training - Technical assistance**

The VLSI design lab was responsible for the training of members of the engineering team of EMPHASIS in the use of microcontroller and PLD technologies. Knowledge transfer from the faculty and postgraduate researchers of the VLSI lab to EMPHASIS personnel was achieved through both seminar training and on the job training.

Seminar training on microcontroller and PLD design, system implementation and testing technologies was organized by the VLSI design lab and took place at its premises.

On the job training (during the specification and design phases), took place at EMPHASIS site. In addition, the VLSI design lab provided assistance to EMPHASIS in order to overcome technical difficulties whenever they occurred.

The following subjects have been covered during the training activities:

- Deployment and exploitation of the advantages of the microcontroller / PLD technology.
- Technical management in microcontroller based product developments.
Component selection, including the component trade-off decisions in designing microcontroller enabled systems.

Design, implementation, testing and manufacture of embedded microcontroller hardware systems.

Development of embedded microcontroller software.

Task 3. Specifications
EMPHASIS provided the functional specifications of the system unit in co-operation with the VLSI design lab. The overall system unit architecture and microcontroller specifications was provided by EMPHASIS whereas the specifications of the PLD by the subcontractor in co-operation with EMPHASIS. A number of minor modifications to the originally proposed system were introduced that improve its behaviour.

Task 4. Design
The functional specifications were used for the design of the system unit. EMPHASIS performed the system and the microcontroller design. EMPHASIS transformed the original embedded software (running on PC platform) to 8051-architecture software running on the microcontroller system. The VLSI design lab in co-operation with EMPHASIS performed the design of the PLD component.

Task 5. Implementation
5.1 PLD Implementation.
EMPHASIS implemented the PLD component according to the design. (Task 4)

5.2 Microcontroller Implementation.
EMPHASIS implemented the 8051 microcontroller system according to the design. (Task 4)

5.3 In-vehicle unit
EMPHASIS implemented all the electronics (including printed circuit board) of the in-vehicle unit and will integrate the PLD component with the 8051 microcontroller hardware and software.

Implementation was divided in the following stages: PCB fabrication, PCB assembly, Cabling assembly, Enclosure mechanics and Unit assembly.

An implementation of 10 in-vehicle unit has been decided since the evaluation of the in-vehicle unit required several field tests that had to be performed under several conditions.

Task 6. Evaluation and In-vehicle unit testing
EMPHASIS carried out all in-vehicle units testing. The evaluation procedure included laboratory tests and field trials. The testing phases were the following: PCB assembly test, Unit test, Software test and Field test. Embedded software test was assisted by a logic analyser.

Task 7. Integration
EMPHASIS performed the final integration of the produced in-vehicle unit with the Base Station Software and the Data communication networks of the E-TRACK system. Extensive testing was performed to ensure the proper operation of the system.
**Task 8. Dissemination of results**

EMPHASIS in co-operation with the VLSI design lab and the local TTN undertook the task of dissemination of the results.

- A final report (this document) was prepared, detailing the rational and results of the application experiment and providing information on best practice in the first use of microcontroller and PLD technologies.
- A flyer was prepared summarising the application experiment.
- The improved product was presented at Comdex and Tourism 2000 exhibitions.
- Finally, the board of the improved product will be presented at Alexandroupoli technology exhibition this year.

**10. Subcontractor Information**

The selection criteria for the subcontractor included:

- Solid applied technical expertise on microcontroller system design.
- Solid applied technical expertise on PLD system design.
- Knowledge transfer experience.
- Long term relationship with the industry.

The company identified two suitable candidates for the subcontractor role. The VLSI design laboratory of University of Patras was chosen because it complies with all the above criteria and has international reputation on both research and training activities as well as strong relationships with the industry that guarantee an efficient knowledge transfer.

The framework of the co-operation between EMPHASIS and the VLSI design lab was set up in the beginning of the application experiment jointly by the technical director of EMPHASIS and the director of the VLSI lab.

The subcontractor operated with a fixed price order for the delivery of the services described in the proposal. The subcontractor relationship throughout the application experiment was excellent and no contractual disputes arose.

More details on VLSI design laboratory experience are presented in the following paragraphs.

**RESEARCH ACTIVITY**

The areas of interest are: ASICs Design, Low-power CMOS Design, Power Estimation, Transistor and Gate Power Models, Memory Management, VLSI for Signal Processing, VLSI for Computer Arithmetic (Parallel Processors).

**TRAINING ACTIVITY**

The faculty members are teaching to both under-graduated and post-graduated students. Also, VLSI Design Lab has successfully organised a large number of courses and seminars towards the VLSI design methodology and the use of special purpose software and CAD tools.

**DEVELOPMENT ACTIVITIES**
Digital filters, a very high-speed multiplier, a special purpose LAN node based on a new communication protocol, a hand held laser distance finder, reduced power consumption processors for hearing-aid systems, ASICs for multi-I/O and control operations for Haemodialysis machine, FPGAs and PLD designs.

11. Barriers perceived by the company in the first use of the AE technology

The development and introduction to the market of a new fleet management system like E-TRACK, is a process that involves close co-operation with the customer and requires several iterative steps in the design of the system architecture before the product comes to its final form. One of the reasons for which EMPHASIS had initially adopted the PCB technology in the implementation of the E-TRACK’s in-vehicle unit was because it offered reduced time-to-market and the flexibility in redesign and configuration required at the early stages of development.

However, the firm was confronted with knowledge, financial, technical and cultural barriers as well.

EMPHASIS was aware that Microelectronics technology had advantages over PCB. The firm however, did not know how to apply this technology in the implementation of the in-vehicle unit and how to interpret its benefits in financial terms.

Microcontroller / PLD technology was known to require the investment of substantially more funds in development than PCB does. The firm, not being able to estimate the actual cost of transferring the new technology into the company, considered safer to direct its efforts to the development of software.

Perhaps, the most important barrier that prevented EMPHASIS from adopting the new technology prior to the application experiment was the technology barrier. The firm did not have the required know-how in the design, device selection, implementation, testing and manufacture of Microcontroller / PLD enabled systems.

Finally, there were cultural barriers that had to do with the mentality towards system development of software-oriented people.

12. Steps taken to overcome barriers and arrive at an improved product

By 1998, E-TRACK had been extensively tested and had matured from the architectural point of view. However, it became apparent that in order to maintain its position in the market, the in-vehicle unit had to be improved.

The firm performed an extensive search for an institution able to transfer knowledge on microelectronics technologies and the VLSI Design Lab was selected for this purpose. Following a series of meetings with the faculty and staff of the VLSI Design Lab, EMPHASIS personnel gained insight on the technical advantages in the
deployment of the Microcontroller / PLD technology in the implementation of the in-vehicle unit and on how to interpret these advantages in financial terms. This helped EMPHASIS to better understand its position in the market in relation with its competitors and revise its financial and marketing plan.

The preparation of the proposal, including the choice of technology and the optimal structuring of the work-plan was assisted jointly by the local TTN and the VLSI design so as the most efficient transfer of knowledge and successful development of the new product to be ensured.

During the implementation phase of the application experiment, the VLSI Design Lab provided EMPHASIS personnel with the theoretical background and hands-on experience required in order for the technical barriers in the development of the new product to be overcome.

During the course of the application experiment, the local TTN assisted with report auditing and supervision of the work done.

Finally, it has to be acknowledged that the VLSI design lab that has kindly set an open invitation to Emphasis personnel in order to overcome technical difficulties of any nature, whenever they occur.

13. Knowledge and experience acquired

During the application experiment EMPHASIS obtained skills and acquired knowledge in the following areas:

- Deployment and exploitation of the advantages of the microcontroller / PLD technology.
- Technical management in microcontroller based product developments.
- Component selection, including the component trade-off decisions in designing microcontroller enabled systems.
- Design, implementation, testing and manufacture of embedded microcontroller hardware systems.
- Development of embedded microcontroller software.
- Migration of software developed for x386 architecture to 8051 architecture.
- Use of support hardware and software tools.
- Financial planning in the development of microelectronics systems.

The knowledge acquired during the application experiment has added significantly to the firm’s portfolio of technological solutions and satisfied completely the objectives set.
14. Lessons Learned

The Application Experiment has revealed the following issues:

- Microcontroller / PLD systems development requires clear corporate objectives and careful financial and technical planning. Decisions made at the early stages of the development are not easily reversible later on. Prior to the start of the product development, the specification’s requirements should be clearly identified by an extensive marketing research.
- Microcontroller / PLD systems development also requires good design methodology. The specification stage is the most critical one and requires twice or three times the effort than the equivalent in PCB does. The design stage can be well assisted be use of appropriate support hardware and software tools
- Careful selection of devices is important in minimising production costs.
- Prudent craftsmanship of subcontractor’s contracts is critical in order for the quality of the final product to be ensured.

15. Resulting product, its industrialisation and internal replication

The resulted prototype in-vehicle unit is operational and compliant with the objectives described in section 6. In addition, the unit has been successfully integrated with the Base Station Software and the Data communication networks of the E-TRACK system.

The major stages to industrialise the new product involve:

**PCB fabrication**
Will be performed by a specialized subcontractor. Fabrication of a 100 unit’s lot requires a period of 2-3 weeks since the placement of the order.

**PCB assembly**
Will be performed in house by specialized personnel. Requires 2-3 weeks since the delivery of the PCBs.

**Cabling assembly**
Will be performed in house. Requires 1 week.

**Enclosure mechanics**
Will be performed by a specialized subcontractor. Requires 1 week.

**Unit assembly and testing**
Will be performed in house. Requires 1 week.
It is anticipated that the new product will be introduced to the market place within a period of two months and that the production cost per unit will be 467 EUR.

The total cost for industrialisation of the unit is around 2 KEUR.

The experience acquired by the Application Experiment in the design, implementation and testing of Microcontroller and PLD devices will be utilised in the manufacture and further improvement of the E-TRACK system and will be embedded in the design of new specialised products.

16. Economic impact and improvement in competitive position

Production cost of the in-vehicle unit (including the Dead reckoning option) is 612.9 EUR. (PCB design) The production cost for the new design is 467.7 EUR (24% reduction in the production cost). Production cost analysis of the old and the new design of the in-vehicle unit is shown on the next table.

<table>
<thead>
<tr>
<th></th>
<th>Old Design</th>
<th>New Design</th>
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</thead>
<tbody>
<tr>
<td>Dead Reckoning components</td>
<td>145.1</td>
<td>145.1</td>
</tr>
<tr>
<td>Industrial PC motherboard</td>
<td>144.1</td>
<td></td>
</tr>
<tr>
<td>Microcontroller/PLD board</td>
<td></td>
<td>96.1</td>
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<tr>
<td>Power Supply/Interface board</td>
<td>76.5</td>
<td></td>
</tr>
<tr>
<td>GPS board</td>
<td>152.9</td>
<td>152.9</td>
</tr>
<tr>
<td>Other hardware (case, connectors, etc)</td>
<td>35.3</td>
<td>26.6</td>
</tr>
<tr>
<td>Final assembly</td>
<td>32.3</td>
<td>26.4</td>
</tr>
<tr>
<td>Testing</td>
<td>26.7</td>
<td>20.6</td>
</tr>
<tr>
<td>Total</td>
<td>612.9</td>
<td>467.7</td>
</tr>
</tbody>
</table>

Added value to customer is related to the following parameters

a. Reduced physical size
b. Reduced power consumption
c. Reduced physical weight
d. Reduced cost
e. Increased reliability
f. Increased flexibility in customer requirements

During 1998 and 1999, sales of the existing system in the domestic market were 40 and 50 units respectively. During 2000, expected sales are 30 units for the existing system plus 50 units for the improved system, 80 units in total. During 2001 and thereafter an annual growth of 30% is expected. That is, 104 units for 2001, 135 units for 2002 and 176 for 2003.
Sales growth is calculated on basis of the following factors:

a. Increased product competitiveness
b. Introduction of the product in new market segments
c. Increased overall market awareness for fleet management system applications
d. Geographical expansion of sales in the European market (non domestic)

Factors a, b and d take advantage of the introduction of the new design. Furthermore, establishment of Emphasis as a player at the European fleet management market will allow penetration of E-TRACK sales in non-European markets, mainly in the Middle East.

**Projected Sales**

![Projected Sales Graph]

Emphasis turnover is estimated to increase with a 15% annual growth. The difference between this figure and the much higher sales growth is related to the decreased profit margins, due to the high competitive European market pressures.

The introduction of the new design will allow the product to be introduced in markets outside Greece. Innovation will allow Emphasis to increase market share on the large European market.

Based on the above rather conservative figures, and considering only product reduction cost and sales growth, the Return on Investment is calculated on the following table.

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</thead>
<tbody>
<tr>
<td>Projected sales</td>
<td>35</td>
<td>40</td>
<td>50</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>104</td>
<td>135</td>
<td>176</td>
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<tr>
<td>Old product</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>New product</td>
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<tr>
<td>Reduction of production cost (per unit)</td>
<td>145.2 EUR</td>
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<tr>
<td>Profits due to new design reduction of production cost</td>
<td>67518 EUR</td>
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<tr>
<td>Total investment for the project</td>
<td>52770 EUR</td>
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<tr>
<td>Return On Investment (3.3 years period - reduction of production cost) approx.</td>
<td>129%</td>
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<tr>
<td>Payback period approx.</td>
<td>2.4 years</td>
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</table>

All the above considerations are rather conservative. Considering all benefits throughout this project (Chapter 5), ROI will increase at least by 1 unit and payback period will be shortened by at least 6 months.

17. Summary of Best Practice and Target Audience for dissemination throughout Europe

The application experiment undertaken by EMPHASIS OE illustrates best practice benefits in

- The establishment of corporate objectives and in careful financial and technical planning prior to the commencement of the project development.
- The consideration of production design issues in the specifications phase, which is the most critical one.
- The usage of appropriate support hardware and software tools during the design phase.
- The prudent craftsmanship of subcontractor’s contracts.

Target audiences include companies in the transportation and distribution sectors that may benefit by replicating the results of the Application Experiment. The target audience for the dissemination of the results may include:

- Companies that intend to utilise microcontrollers to accomplish data acquisition and processing tasks.
- Companies that intend to utilise PLDs to implement logic sub-systems.

The proposed new design belongs to 3550 – Other Transport Equipment product category and will be of interest to organisations involved with the following market sectors:

- Transportation
- Distribution
- Courier
- Field Services
- Electronics Systems
- Data Communications