FUSE Application experiment 23590

Dissemination/Demonstrator document

SINGLE POINT FAILURE TOLERANT ELETTRONIC BRAKE CONTROL

AE number	**23590**
New Technology	**Electronic controls with microcontroller on PCB's**
Contact TTN	**Corep**

AE abstract

Keywords: Railways, brakes, fault tolerant, voting logic, redundant logic, criteria for subcontractor choice, training via internet

Poli Costruzione Materiali Trazione S.p.a. a more than 150 years old Italian company with about 70 employees, designs, manufactures and sells brake equipment and additional electro-mechanical parts for railway vehicles. The company in this AE has developed an electronic brake control system that it will be used to control the brake cylinder pressure of a rail vehicle, in order to ensure an anti-slide braking action.

The Company has only mechanical experience and was forced to introduce an electronic control since the train speed has been strongly increased in the recent years and an anti slide control was necessary to increase the reliability and to reduce the maintenance costs Before the AE the customer had to acquire the breaking control system separately, since POLI was note able to provide it. This was also contradicting the Reliability, Availability and Maintainability (RAM) recommendation aimed at making one company only responsible for the correct functioning of the whole system.

This caused a steep reduction of POLI profit and a forecasted market share significant decrease as Poli Costruzioni Materiale Trazione had to face competitors which were already manufacturing some kind of electronic controller.

The objective has been therefore to develop the design of electronic brake control system, and to learn the process to procure the hardware, test it for in-coming quality control, install it when on field, manage customer specific upgrades. The adopted technology makes use of microcontroller based electronic control implemented on PCB's. The choice was due to the advantage offered from this technology in terms of flexibility, programmability and difficulty to be copied. The total cost of the AE is 90 kECU and it has been completed in 13 months.

The company is now independent in dealing with the client's and final user's requirements, both at the whole system design and after-sale assistance level. The production of our electronic control results in a saving of about 33% in comparison with the purchase cost of the electronic control in the railway market. Payback period is supposed to be 2 years from the termination of the AE and return on investment (ROI) is estimated to be about 2.. ROI is calculated using the actual AE cost and the differential cumulated profit margin achieved in 4 years of investment life, thanks to the introduction of the new electronic technology.

During the AE we could realise that it is possible for us to work with electronics and that this technology can be used to improve performance of different products we already produce.

1. POLI COSTRUZIONI MATERIALE TRAZIONE Spa (previously POLI Officine Meccaniche)

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2. Company size

The company employs 70 people with 9 mechanical designers; before starting the AE no one was involved in electronics.

Company turnover in 1998 was 7 MEUR

3. Company business description

Poli Costruzione Materiali Trazione SpA was established in 1816 as a shipyard. At the end of the World War II the enterprise got into the railway field becoming a leader company for the production of precision mechanical devices. In particular we have developed disc brake equipment for rolling stock. These equipment (patented) guarantee performance, which are unequalled in the world. Poli Costruzione Materiali Trazione S.p.A. designs, manufactures and sales the following products for railway and *mass-transit* vehicles:

- Pneumatic end electro-hydraulic brake systems.
- Reduction gears.
- Axles for motor and trailer cars.
- Resilient wheels.
- Mechanical and electro-mechanical parts.

The company activities cover also the aspects of marketing and after-sales.

Before the beginning of the AE the annual turnover of our company was about 5 MECU 50% of which thanks to the disc brake equipment and relevant components (DBE&RC).

On 24 December 1997 **Poli Officine Meccaniche** merged with the company **CO.MA.TRA** and changed its denomination into **Poli Costruzione Materiale Trazione**

4. Company markets and competitive position at the start of the AE

As mentioned above the market of the company is located in the railway field. Main customers are those companies manufacturing rail vehicles, while the final users are railway and metro administrations.

An overview of the DBE&RC market share is given in the table below:

Company	Italian market share	European market share
Competitor A	25%	40%
Competitor B	25%	40%
POLI COSTRUZIONI MATERIALI TRAZIONE	50%	2%
Others	-	18%

Competitors A and B are working in the same market field but they are able to supply a more wide range of braking components including the anti-slide electronic control.

Since we are not yet able to provide our customers with the complete braking system, it is reasonable to foresee a decrease in company market share with respect to our competitors who are able to produce and market an electronically controlled braking equipment.

Our main problem before the innovation was to keep the market while maintaining a reasonable margin.

Our forecast for the braking equipment market share and profit is represented in fig.1 and fig.2, while in section 16 we describe the market analysis after the AE.

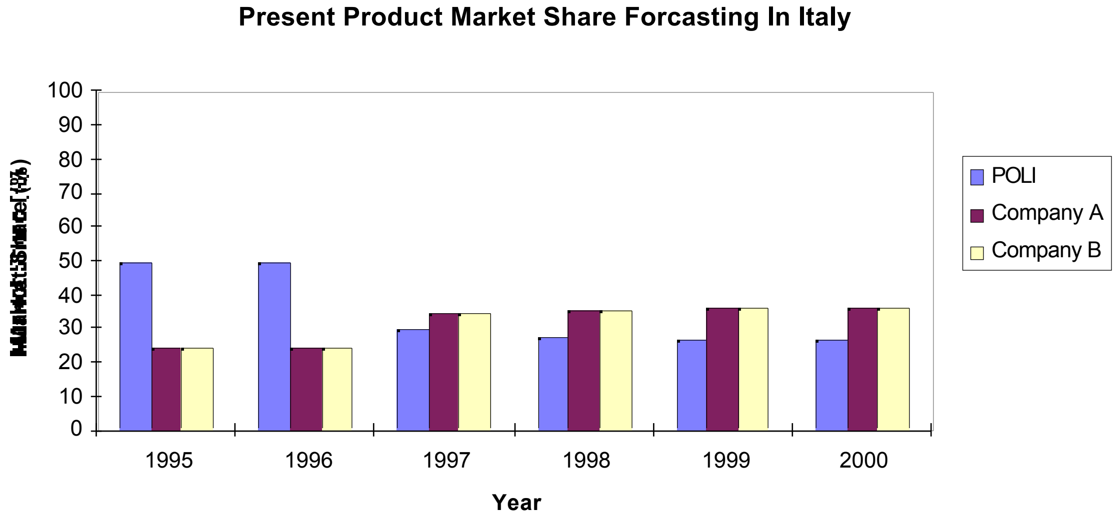


Fig 1 Product market forecasting before starting the AE

At the beginning of the AE a strong reduction of the market share for the following years was expected; thus, to keep our market share unaffected till 2000, we would have been forced force us to significantly reduce our profit by decreasing the price to the final user, as it is shown in the following diagram with a decreasing trend for both turnover and profit.

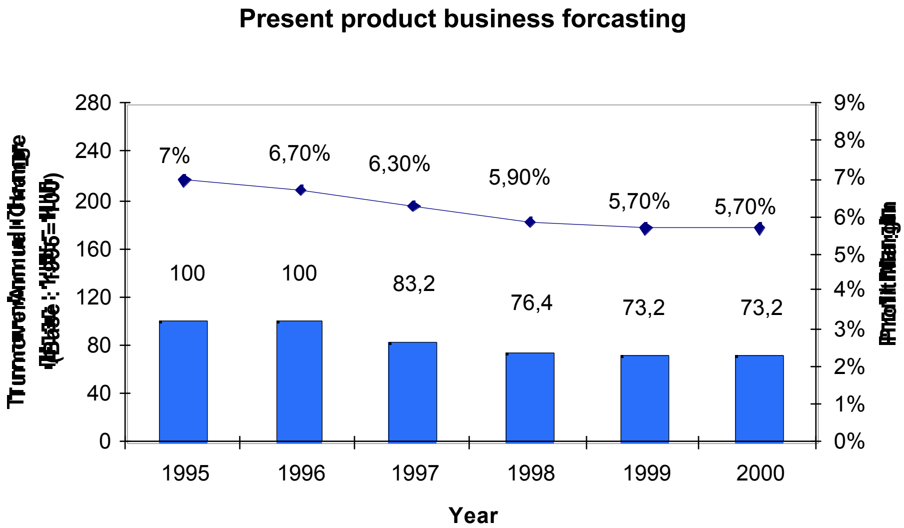


Fig 2 Product business forecasting before starting the AE

The market of breaking systems can be estimated of the order of few hundreds complete equipment for the domestic market and some thousands at European level.

Mechanical spare parts and components represent a significant share of the turnover.

The old product used very precise mechanic components where POLI had the technological edge at least in the domestic market, but for the future the emphasis would have been on the electronic control which was expected to represent more than 20% of the whole braking system cost.

It should be in any case clear that the POLI competitors were in a much stronger position at European level, since countries (France, Germany, Switzerland) anticipated the need of electronic control due to the higher speed of their rail vehicles.

As far as we know they do not use advanced electronics only microprocessors and discrete analogue and digital components, no one has a “hot redundant approach similar to the one followed by us”

Reliability with train as fast as 300 km/hour becomes a real problem since, according to the RAM specifications, should remain operational and safe even if one of the main electronic part fails.

Since we developed our own electronic control device in a quite reasonable short time, we expect to be able to easily regain the market shares lost during the last period and to increase about 10% our market share within 4 years

Furthermore the new controller exhibits added features that can greatly improve reliability while simplifying the maintenance problems. These are not available in the products of the competition and, according to first reactions we received in our preliminary contacts with our customers, we expect to bring to the market a highly competitive product.

Since now POLI has been forced to buy the electronic controller at a very high price, but with our proprietary solution we estimate to save more than 30% on the whole system. As a consequence we will be able to sell at a lower price and our customers will be impressed also from new high tech image of the company.

We plan to obtain the international UIC (Union International Chemin de fer) homologation from the Italian Railway Administration within the 1999-and this will certainly open us a wider market allowing us to increase the gross margin in the following 4 years.

We want to thank FUSE that gave us the opportunity to be introduced and get acquainted with a technology without relying on third parties or even competitors.

5. Product to be improved and its industrial sectors

The product to be improved is the brake system for rail vehicles. Each car of rail vehicle is equipped with either a pneumatic or hydraulic brake system. Recently on most cars these devices have been provided with an electronic brake control system to prevent wheels from sliding on the track.
Poli Costruzione Materiali Trazione *Spa* product line includes hydraulic and pneumatic brake for rail vehicles. Such systems may be split into the following range of parts:

- Brake Discs
- Calipers
- Brake Actuators
- Valves.

The vehicle driver operates the brakes by feeding the brake actuators (either by air or hydraulic fluid) which, through the caliper action, deliver an appropriate braking force to the brake disc fitted to the rake axles.

When the trains were slow no major anti skid control was requested. The need appeared with fast trains and became of paramount importance with the “high speed trains” which should allow for train speed higher than 200 kms/hour

The electronic control device prevents wheels from skidding or sliding by monitoring each axle speed and acting on the brake actuators by a suitable valve.
The enclosed block diagram (see Fig 3) shows the functioning of this system and interaction of the individual components.
In the same figure it is also shown how the electronic controller should be interfaced with the rest of the braking system.

We must highlight that before the AE Poli was not able to provide the anti-skid electronic control system embedded with the braking equipment and therefore we were able to offer our customer only two possible solutions both uncomfortable for them:

1. Provide ourselves the electronic anti skid control and sell it separately at an high price
2. Provide only the mechanical part, forcing the customer to buy a dedicated electronic control from a different supplier to with the related problems of the shared responsibility from more providers on the breaking system operation.

This constituted a reason for POLI customers to look for a less expensive and simpler solution to be provided by our competitors and the strong need for us to improve our braking system by introducing new electronic control features

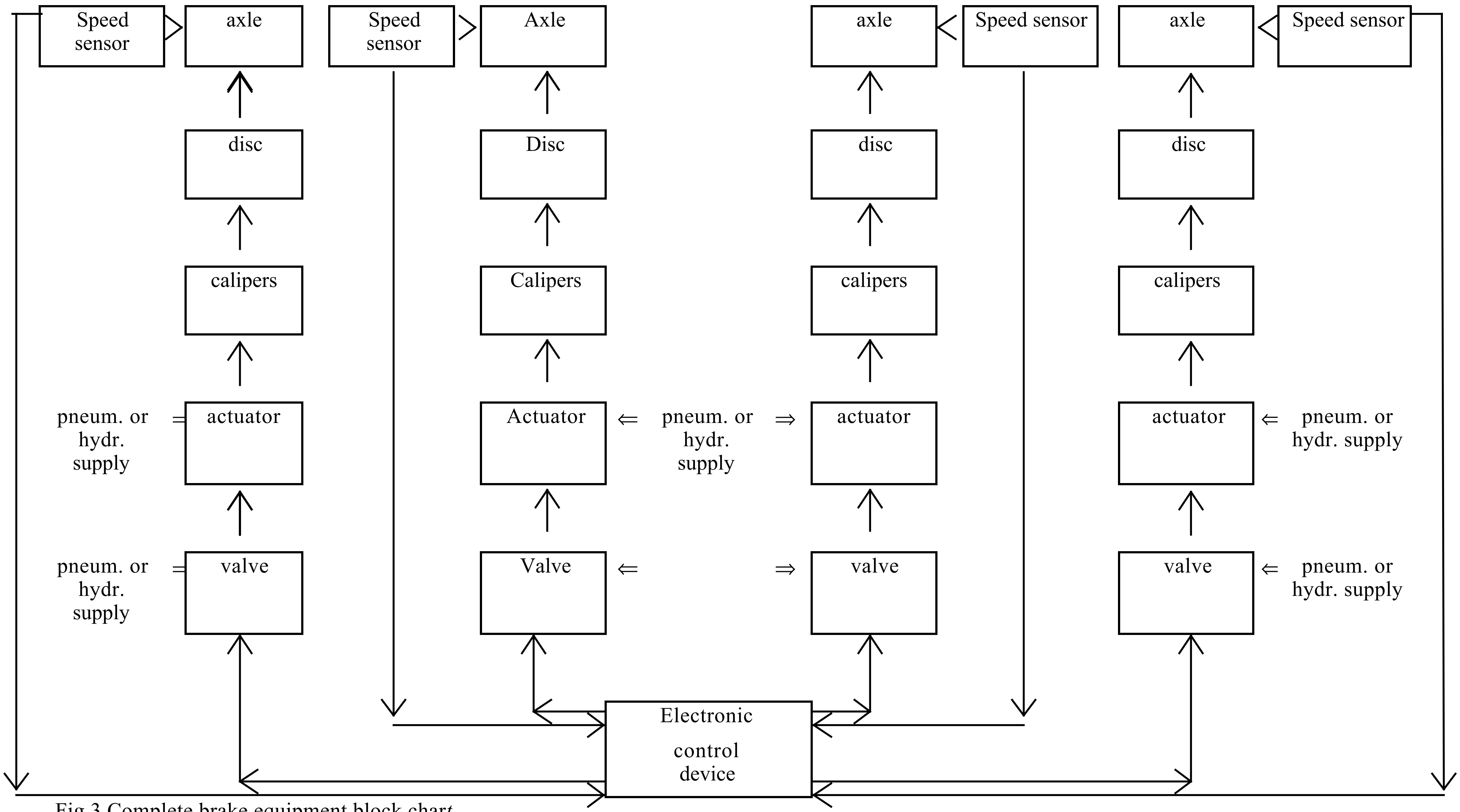


Fig 3 Complete brake equipment block chart

It is certain that the main parameter to improve with the introduction of an electronic technology is certainly the maximum allowed train speed which should be increased up to 250 km/hour.

But the introduction of electronic parts would not harm the global system reliability., which is a strength of our current product.

Reliability parameters to keep under control are

Average lifetime >15000 hours

MTBF (mean time between failure) should be such to have the control fully operational, in case of a single failure, until the next maintenance period (single point failure approach)

6. Description of the technical product improvements

The aim of *Poli Costruzione Materiali Trazione SpA* was to provide the customer with a highly reliable product, which at the same time shall remain as simple as possible with respect to its interfaces with the train operator and/or maintenance technician. We addressed these goals through a design tolerant of any single point failure in order to reduce diagnostic to the very minimum (as opposed to a more conventional approach where diagnostics needs to be much more complex).

The safety and braking requirements are specified by the specific UIC regulations, as detailed in the Fiche 541-05 OR. In particular the Fiche UIC details several tests which are to be carried out on a train, equipped with the anti-slide controller and with an additional number of sensors and data recording instrumentation, in order to obtain product certification. The outcome of these test must show that no wheel was locked, and that the specified distances to come to a halt were complied with.

As we are still discussing with the Italian Railways on when to start the test campaign, we cannot yet state whether we comply with the Fiche UIC, however it is known from the relevant literature that the braking distance requirements are usually complied with by controllers that manage to maintain the wheel’s slip rate in the range 15% to 25%. Our control algorithm it is designed just to achieve that.

The controlling concept proposed tries to achieve a very high reliability by following a “distributed hot redundancy” approach, yielding a design tolerant of any single point failure. Though this approach might seem more expensive in terms of total components count, in reality it allows significant savings in terms of software development (very simple routines for diagnostics) and a much simplified maintenance schedule. Furthermore, as an additional bonus, the total system *downtime*, due to one single point failure in the electronics, is reduced to zero.

The system remaining fully operational, no replacement of the faulty plug-in card will be needed till the time of the next scheduled maintenance. In such a circumstance the task of the maintenance technician is very simple: replace the faulty card, and ship it to *Poli Costruzioni Materiali Trazione SpA* for further investigations and repair.

The architecture of the system is described here below in figure 4, depicting the functional block diagram of the complete SPFTEB each Control Board supplies the magnetoresistive speed sensors with 1/3 of the biasing current, it squares the sinusoidal signal, and transfers it to the microcontrollers inputs by means of optocouplers

- each Control Board issues two Valve Driver Board select commands (e.g.: Control Board A issue select command PwA to power Valve Driver Board A, and command PwA' to power Valve Driver Board B)
- these commands are then majority voted by the dc/dc converter supplying each Valve Driver Board, in order to switch it ON
- each Control Board issues also 8 ON commands (represented by the arrow "Commands A" for Control Board A, "Commands B" for Control Board B, "Commands C" for Control Board C) to the 8 drivers of each Valve Driver Board
- these commands are then majority voted at the level of each of the 8 drivers contained in a Valve Driver Board

The three redundant chains of valve drivers are selected by the three control modules on a 2/3 arbitration base. If a failure is detected the redundant driver chain is activated.

In addition, in order to be able to detect failures, some status signals (not shown) are constantly monitored.

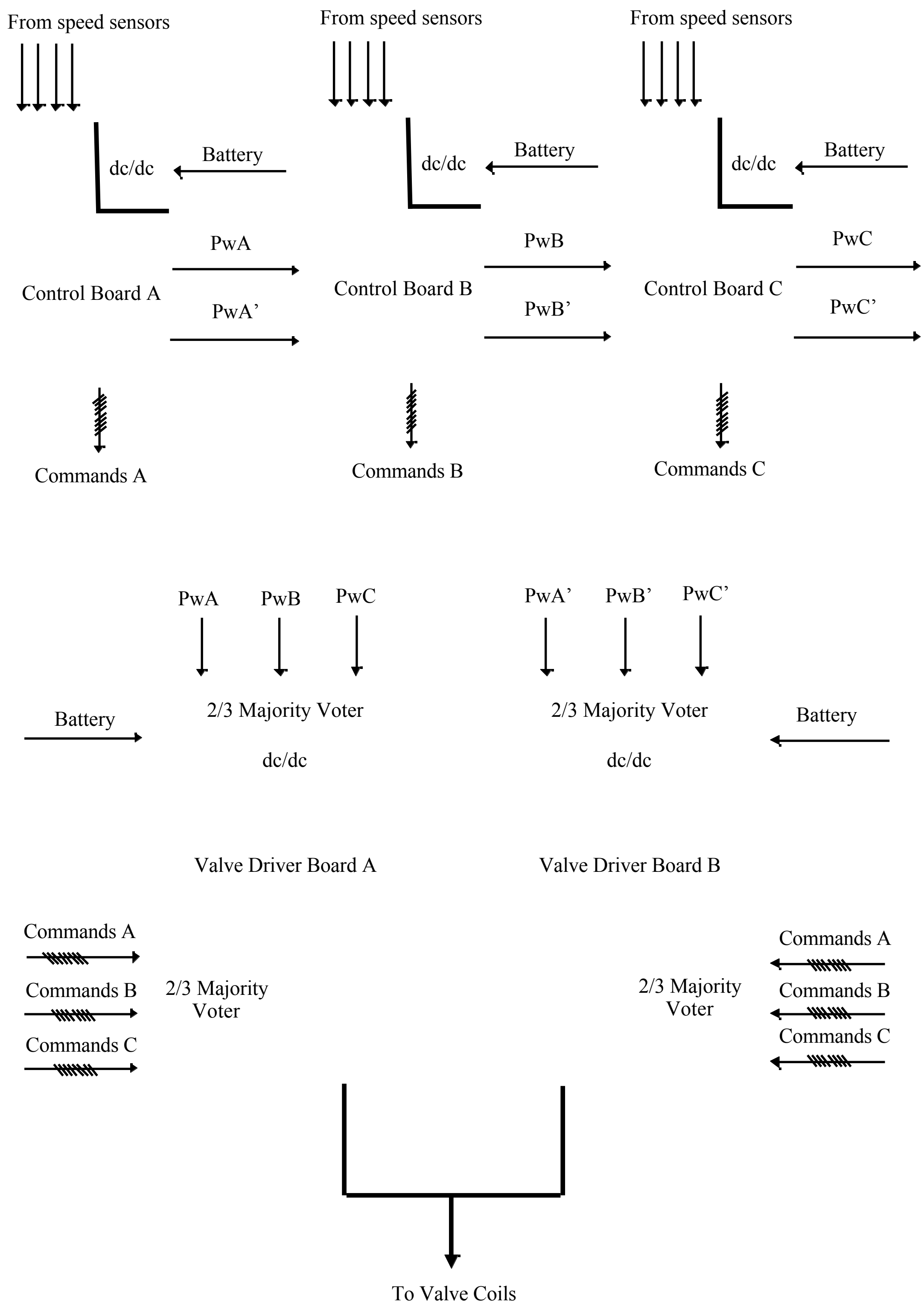

From speed sensors
dc/dc
Battery
Control Board A
PwA
PwA'
Commands A
From speed sensors
dc/dc
Battery
Control Board B
PwB
PwB'
Commands B
From speed sensors
dc/dc
Battery
Control Board C
PwC
PwC'
Commands C
PwA
PwB
PwC
Battery
2/3 Majority Voter
dc/dc
Valve Driver Board A
PwA'
PwB'
PwC'
2/3 Majority Voter
dc/dc
Battery
Valve Driver Board B
Commands A
Commands B
Commands C
2/3 Majority Voter
2/3 Majority Voter
Commands A
Commands B
Commands C
To Valve Coils

Fig 4

The main features of the newly developed cvontroller are:

- 3 identical “hot redundant” Microcontroller Boards
- 2 identical Valve Driver Boards operating according to a 2/3 arbitration criteria.
- Real time diagnostic for failureto switch from the main valve chain to the redundant one
- Single failure insensitive operation mode (failures are in any case monitored and displayed). This assures continuity of operation and strongly reduces the stop time for the maintenance of the braking equipmentValve coils are driven by constant current generators, allowing to halve power requirements with respect to the more conventional voltage driven solution.

A dedicated PSU had to be developed with larger input voltage range and at a much reduced cost than the one commercially available.

Ant-slide Control Criteria

The embedded software implements a conventional control algorithm. An example of implemented criteria follows.

Velocity Threshold Criterion

The current axle speed is compared with two dynamic (dependent on the current train speed) thresholds

- if current axle speed is larger than the larger threshold it means the axle is not sliding and no command action is decided., . Therefore the control system does not interfere with the braking command decided by the driver.
- if axle speed is between the 2 thresholds, the braking pressure should be maintained at this level as it means that the sliding rate is under control
- if axle speed is lower than the lower threshold, it means that the sliding rate is too large and the axle will probably block, hence braking effort shall be decreased

Figure 5

Fig 5 A photograph of the prototype, manufactured as outcome of the AE

The controller is composed by 5 euro-card PCBs (100*160 mm), as follows:

- 3 identical microcontroller boards, each containing a 5W galvanically isolated dc/dc converter, 1 microcontroller (8 bits RISC architecture) , 2 linear regulators, 1 quad OpAmp, 1 EEPROM, 4 quad optocouplers for isolated signal interfaces
- 2 identical valve driver boards, each containing a 200W galvanically isolated dc/dc converter, 8 majority voters, 8 switched mode current generators (1 A)

Reliability specifications

Failures rates

- discharge command to a cylinder for longer than 10 sec shall have a probability < 10^{-6} /h
- loss of effort reduction capability shall have a probability < 10^{-5} /h

Availability

The system guarantee 100% availability since it is single point failure tolerant.

Maintenance

Since the device is single point failure tolerant, no corrective maintenance is necessary before the scheduled intervals. The scheduled intervals are fixed by the customer for the train maintenance.

Technical Specifications

Operating voltage:	16.8 V DC to 36 V DC
Operating current with all outputs OFF:	150 mA (at 24 V DC)
Operating current with all outputs ON:	3.5 A (at 24 V DC)
Speed range:	2 to 250 Km/h
Weight:	2.1 Kg

7. Choices and rationale for the selected technologies, tools and methodologies

The main specifications for the innovated product concern the availability of a flexible, reliable and easy maintainable on board controller.

For a company with no experience at all with electronics the usage of a PCB solution realising an embedded system, represents the less risky solution while allowing flexibility at a minimum cost impact, with respect to partial redesign or upgrades.

In Any case we examined all the possible alternatives and our conclusions are offered in the following table:

	Advantages	Disadvantages	Reasons for discard
DSP	Architecture devoted to Signal processing	Higher cost than MCU (Micro Controller Unit) More complex and expensive simulation and debug tools	Anti slide control algorithms are not too much complex and can be easily managed with a MCU
FPGA	High speed operation more controllable critical paths	Higher cost than MCU (50% more for the less complex) No A/D conversion interface available	Algorithms do not have special speed requirements. A/D and D/A conversion are a mandatory requirement
ASIC (mixed*)	Can miniaturize and mix analogue and digital signal processing	Request very large production volumes (at least several hundred thousands) Very expensive mask costs (at least 40 MEUR) for volume production. It requests highly skilled subcontractors, very expensive design tools and a very long development time (more than 1 year) If it has to include the power part it becomes difficult to find the foundry. Very risky solution	Expected production volume is very low (few hundred per year at most) Market window is narrow The power part (electronic valve drivers) is very important for the product competiveness

For these reasons we decided to develop a multiboard system (6 boards) with the control implemented via a Microchip MCU, and the power part realised with commercially available components.

- As already explained an hot redundant approach has been selected to comply with the very severe reliability recommendations
- We had to develop our own DC/DC converters stages because after a survey of the equivalent components available on the market we could not find any with the requested performance compatible with our final target cost.

  Since the converters involve non linear power electronics with inductors and transformers, it was rather difficult to use conventional circuit simulation techniques. Simulation was used only in the linear part of the circuit using a macro model approach for controlling the stability of the feedback loops.

  To verify the behaviour of the real circuitry we extensively tested the breadboards of the DC/DC converters where we could measure very good stability margin.

  The same approach was used for the valve driver board.
- For the anti skid control a microcontroller solution was considered the most flexible one at the lowest risk. In fact we need to be able to change both the core and the thresholds of the anti skid algorithm according to the railways administration we propose our electronically controlled breaking system. With a microcontroller this can ean easily be done simply modifying the firmware without any change to the hardware and, what is more important, the results of the mchanges can be quickly demonstrated to the potential customer so increasing its feeling for our product.

During the AE we familiarised with the development flow for embedded software applications.

A PIC microcontroler was selected for three reasons:

1. Easy to use development tools
2. Low cost of the component
3. Previous experience of the subcontractor

The development followed the following flow (which is standard for experienced designers, but was completely new to the FU):

- First a detailed flow-chart was prepared
- Then the corresponding assembler code was written
- The microchip MPLAB simulator was then used for a preliminary testing of the code by stepping through each line of the program and modifying by hand the content of the relevant registers to emulate changes in the status i/O pins
- The PICMASTER In Circuit Emulator was then exploited to assess the real time performance and modify the code accordingly.
- Once the controller board was available, we checked the algorithms, the firmware ad the thresholds.
- The software was then in circuit tested and only when all the blocks were found to operate correctly, the architecture of the final boards was developed and the layout of each PCB designed accordingly.
- The prototype has been tested by simulating the sensor signals both by means of suitably controlled function generators, and by implementing a Virtual Instrument by means of the LabView™ software tool, which allowed us to use a PC in order to generate precisely controlled frequency modulated sinusoids, emulating the speed sensors output signals during accelerations and decelerations. An analysis of the corresponding output signals from the valve drivers allowed to verify the proper implementation of the control algorithm. In addition a simple test bench consisting of a DC motor driving a toothed wheel has been built to allow testing of the magnetoresistive speed sensor in a configuration similar to the actual operating conditions.

The unit has been implemented into a standard rack mountable 19” enclosure. For easy maintainability the various electronic functions have been implemented on standard plug-in eurocard modules.

The final circuit includes digital processing electronics PCBs within the same enclosure which also contains the PCBs for switching mode power conversion modules (dc/dc converters, valve driver), therefore the layout of each PCB had to minimise any interaction between the power and the signal boards. In particular the valve driver PCB contains power paths with current of several amperes being switched at a relatively high switching frequency (100 KHz typically). This is why our Subcontractor, who has experience in EMC aware design, was also responsible for the detailed PCBs layout design.

Contacts have been taken with the Italian Railways for a final test on an actual railway car.

8. Expertise and experience in microelectronics of the company and the staff allocated to the project

Poli Costruzione Materiali Trazione S.p.A. designs brake systems and components for railway installations. The company has experience in precision mechanics, thermal simulations, structural calculation, material structure, therefore it has a big expertise in railways mechanical technologies but it has no experience in electronics technologies.

Three persons have been allocated to the project. One person involved in this AE has a background experience in the programming field having acquired a two year experience in developing software for thermal analysis to be used in satellites. Other people are specialist in braking system and have no previous experience with electronic.

The following persons were allocated to project:

- Mr. Giuseppe Poli :. He has been deeply involved in the AE for the development of the embedded software and participated to the EUROPRACTICE training course.
- Mr. Gabriele Moretti : He took care of the development of the anti slide control algorithm.
- Mr. Paolo Poli : He has been involved in the development of the anti slide control algorithm and testing phase.

9. Workplan and rationale

RISK ASSESSMENT

The development of an highly reliable controller including so many parts and technologies would have represented an high risk for our company if we not found the right subcontractor, with enough technical skill. Also the tight monitoring from the TTN helped in keeping the project under control maintaining it at the planned duration.

The organisation of the AE development activities has been subdivided into several Work Packages (WP), each one ending with the delivery of the corresponding deliverables. Payments to Subcontractor were also bound to the timely delivery of the agreed deliverables.

Here below it is described the content of each WP, the respective role of First User and Subcontractor, and the WP deliverables.

WP 1: Requirements Specification for dc/dc converter and valve driver PCBs.

- Objectives: to define the electrical interface requirements for the dc/dc converter and valve driver modules.
- Tasks
  - T11: definition of the auxiliary dc/dc converter specification (FU 10, Sub 5 Person/day)
  - T12: definition of the valve driver specification (FU 10, Sub 5 person/day)
- Role of First User and Subcontractor
  - First User: define the characteristics of standard train electrical power buses.
  - Subcontractor: support to First User in the definition of power , voltage, and current levels, as well as bandwidth requirements, for the various functional modules.
- Deliverables

Task	Code	Description	Milestone
T11	D11	dc/dc Spec. document	M1
T12	D12	Valve driver Spec. document	M1

WP 2: Training and drafting of control algorithm.

- 1 Objectives: training of First User to microcontroller programming techniques.
- Tasks

- T21: article for FUSE Newsletter (FU 5, Sub 0 person/day)
- T22 attendance to professional course (FU 5, Sub 0 person/day)
- T23 collection of relevant literature on anti slide braking control, and preparation of preliminary control algorithm (FU 31, Sub 10 person/day)

- Role of First User and Subcontractor
  - First User: attendance to professional course, collection of relevant literature, drafting of preliminary control algorithm.
  - Subcontractor: assistance to drafting of control algorithm for what concern the interactions with the various hardware functions.
- Deliverables

Task	Code	Description	Milestone
T21	D21	Course material	M2
T22	D22	Preliminary algorithm flow chart	M2

WP 3: Design and breadboarding of the dc/dc converter module.

- Objectives: design, bread boarding and testing of the dc/dc converter module.
- Tasks
  - T31: detailed design and document preparation (FU 2, Sub 20 person/day)
  - T32: breadboard manufacturing and testing, test report preparation (FU 6, Sub 20 person/day)
- Role of First User and Subcontractor
  - First User: involvement in design phase to understand block diagram level functions and electrical interface properties.
  - Subcontractor: detailed design, breadboard manufacturing, breadboard testing, documents preparation.
- Deliverables

Task	Code	Description	Milestone
T31	D31	Dc/dc Detailed Design Description	M3
T32	D32	dc/dc Breadboard Test Report	M3

WP 4: Design and breadboarding of the valve driver module.

- Objectives: design, bread boarding and testing of the valve driver module.
- Tasks
  - T41: detailed design and document preparation (FU 2, Sub 20 person/day)
  - T42: breadboard manufacturing and testing, test report preparation (FU 3, Sub 20 person/day)
- Role of First User and Subcontractor
  - First User: involvement in design phase to understand block diagram level functions and electrical interface properties.
  - Subcontractor: detailed design, breadboard manufacturing, breadboard testing, documents preparation.
- Deliverables

Task	Code	Description	Milestone

T41	D41	Valve Driver Detailed Design Description	M4
T42	D42	Valve Driver Breadboard Test Report	M4

WP 5: Design and breadboarding of the control module.

- Objectives: design, breadboarding and testing of the control module.
- Tasks
  - T51: First User participation to detailed design and embedded software development (FU 30, Sub 20 person/day)
  - T52: detailed design and document preparation (FU 10, Sub 20 person/days)
  - T53: breadboard manufacturing and testing, test report preparation (FU 60, Sub 20 person/day)
- Role of First User and Subcontractor
  - First User: involvement in design phase, development of embedded software, software design description preparation.
  - Subcontractor: detailed design, breadboard manufacturing, breadboard testing, documents preparation.
- Deliverables

Task	Code	Description	Milestone
T51	D51	Software Design Description	M5
T52	D52	Control Board Detailed Design Description	M5
T53	D53	Control Board Breadboard Test Report	M5

WP 6: Final prototype manufacturing and testing.

- Objectives: design of the PCBs layouts implementing the final detailed designs, manufacturing of a sufficient number of modules for the brake control of 4 axles, assembly of the manufactured PCBs inside the 19’’ rack, testing of the complete brake control system.
- Tasks
  - T61: Drafting of PCB layouts, manufacturing of the required number of PCBs, assembly of the final prototype (FU 12, Sub 15 person/day)
  - T62: Prototype testing and preparation of the “Final Report” and “Executive Summary” (FU 24, Sub 25 person/day)
- Role of First User and Subcontractor
  - First User: active participation to the definition of the test set up, implementation of the final test.
  - Subcontractor: preparation of PCB layouts, manufacturing of the final prototype, active support to the test campaign.
- Deliverables

Task	Code	Description	Milestone

T61	D61	Delivery of Final Prototype	M6
T62	D62	Final Report	M7
T62	D63	Executive Summary	M7

Phased Work Plan

Month	1	2	3	4	5	6	7	8	9	10	11	12	13
WP1													
T11	_												
T12	_												
WP2													
T21	-												
T22	__												
T23	_	___											
WP3													
T31		___											
T32			___										
WP4													
T41				___	__								
T42					__	___							
WP5													
T51							___	___	___	___	___		
T52							___	___	__				
T53									__	___	___		
WP6													
T61												___	
T62													___

M1 M2 M2.1 M3 M4 M5
M6,M7

Variations with respect to the original Work Plan.

During the development we realised that for a proper fine tuning of the control software it would have been better to anticipate the manufacturing of the prototype. We therefore discuss the matter with our subcontractor, who agreed to accept the additional burden put on him in trying to squeeze the time originally foreseen for the preparation of the manufacturing files.

In the end it was agreed to anticipate the prototype manufacturing phase T61 so that the prototype could be ready one month earlier, whereas the end of the software development phase has been delayed by one month. Overall, the project could still progress on schedule, as the 1 month delay in the preparation of the detailed software design was compensated by the 1 month gained for the prototype manufacturing phase. Hence, at M5 delivery D61 (final prototype) replaced delivery D51, which was instead delivered at M6.

WP5													
T51							___	___	___	___	___	___	___
T52							___	___	_				
T53									_	___	___		
WP6													
T61											___	___	
T62													___

The sharing in effort between the different contractors for each workpackage is summarised in the following table

	First USER		Subcontractor	
	Planned effort [wd]	Real Effort [wd]	Planned effort [wd]	Real effort [wd]
WP1	13	20	10	10
WP2	18	46	6	10
WP3	13	8	40	40
WP4	11	5	40	40
WP5	95	90	43	60
WP6	25	26	30	40
Total	175	195	169	200

A lot of effort was spent by the first user in WP2 (training) mainly on the job since a complete new methodology had to be learn t by POLI technical staff.

The subcontractor explained the main issues of embedded systems but then the FU project leader was left with specific development task under the hot line assistance of the subcontractor

The justification for this extra work resides in the following reasons:

- The definition of the control algorithm requested a long study of the available literature and simulation data, beyond two meetings with the Italian railway administration
- The FU had to carefully study the PIC architecture and instruction set in order to be able to define, under the subcontractor's assistance, the various control routines.
- The subcontractor found more difficulties than expected during the software development phase especially concerning the hot redundancy part
- The debug phase took more time since the threshold had to be optimised for giving the best results both in set up and i stability of the control algorithm. Also the feature concerning the software robustness had to be carefully assessed together with the EMC compliance of the whole system.

It should in any case be noticed that thanks to the careful risk assessment in the TA definition phase, no delay was caused to the AE conclusion.

10. Subcontractor information

10.1 Training Subcontractor

The training for the AE was subcontracted to a European consortium funded by the UE for organising courses for the European industries addressing microelectronics design and technology main topics.

The course selection was made in the catalogue of the available courses with the help of the TTN on the base of the reported course summaries and 2 courses were chosen that were supposed to provide the First User with the fundamentals of embedded system design.

Thus on June 18 and 19 Mr. G. Poli attended the following training courses on design and debug techniques with microcontrollers technology.

- Microcontrollers – Introduction
- In Circuit Emulation (ICE) Systems

The general impression was that the first courses introductory course was well organised and the lectures introduced the subject of the advantages of designing with the new technology very effectively and from different perspectives. The second course was more practical and included hands-on experiences.

Perhaps for our application the choice to carry out the in circuit emulation using the C language was not the best. In any case we suggested the organiser to include in the catalogue summary e the information concerning the organisation of the hands-on experience and the requested basic know-how.

In such a way the attendees would no more suffer for lack of C programming knowledge, as it was the case for the First User.

10.2 Design Assistance Subcontractor (DAS)

The Design Assistance subcontractor selection was more critical. We had many choices both with academic electronic engineering departments and with private consultants and design houses.

We met three possible candidates following these criteria:

1. As we already explained, we had very tight constraints regard to reliability and operation continuity of the controller, thus a specific experience was requested in this field.
2. Moreover it was requested to design an high performance power stage for the valve drivers and a voltage regulator with high spread in the unregulated input.
3. All these abilities had to combined with a clear perception of a medium size company market goals and the capability to offer a good on job training to our inexperienced staff.

The importance of a really skilled and experienced designer should be stressed for similar kinds of applications.

The selected subcontractor showed us a block diagram of a system solution where all the problems seemed to be taken into account with a large usage of hot redundancy and arbitrage techniques.

This was due to his long experience in developing prototypes for electronic control of power actuators for industrial automation (switching converter topologies, as well as digital and analogue control techniques for spacecraft's electrical power bus regulators). In particular he has gained valuable experience in the design of reliable, single point failure tolerant, power and control electronics.

In this AE our consultant has been responsible for all the development activities and for the on job training. He also took care together with us for the choice of the PCB manufacturer and of the final system testing procedures. A more detailed description of his involvement during each WP can be found in the above WP description.

It is worth mentioning although the DAS and the project leader knew each other from a long time, a formal contract between the two parties was prepared and signed where the payments to the subcontractor where graduated according to the milestones and deliverables of the Technical Annex.. Also in the contract it was specified that the content of the delivered documents would have become property of Poli Costruzione Materiali Trazione SpA, which could then make of it any use it believed most useful to its business activities. In any case the acquaintance with the consultant allowed to establish a friendly and cooperative atmosphere that was a real key for the success of the on the job training approach.

This is also demonstrated from the fact that the DAS joint the project leader in some meetings with the most important customer of the company that is the Italian railway administration. On the other side, the DAS helped the POLI engineers to gain familiarity with the assembler language and the software development procedures by preparing dedicated exercises that were exchanged and corrected via e-mail. This proved to be a very affective procedure allowing more people of the POLI design staff to be involved in the main part of the software development and test with a significant save in timing

For a completely unaware company like ours it is very important to have a really cooperative partner since in this way the training process is simpler and more tailored to the trainees background.

The subcontractor should be open to discussion and able to take the different points of view proposing those examples that are close to the audience experience.

In this particular application he should always keep in mind the need to get a failure free and safe equipment.

He must also be en expert in EMC (Electro Magnetic Compatibility) problems, since we learnt in this AE that the electromagnetic interference c an heavily affect the safety and robustness of the equipment.

Finally if we can give an advise to other companies trying to repeat the application experiment, we would certainly suggest them to always try, during the subcontractor selection process, to assess the flexibility in accepting work plan and engineering change requests. This is very important, as starting a new development always carries a risk due to some inherently unavoidable uncertainties. A subcontractor based not far from the company is also an advantage that should not be underestimated.

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

We had been planning to design, test and produce this electronic brake control for a long time but we never started.

Our company was specialist in mechanics and we had no experience at all with electronics. The idea of developing this new product to complete our brake system appealed to every department in the company but none liked to start working in a new technological field.

We were fully aware that the market demand was changing and the company needed to quickly move toward more advanced technology, but every day work kept us stuck with those techniques we had confidence with.

We certainly needed to handle complete new design and methods and approaches like

- Suitable technology choice
- Hardware/software partitioning

- Power electronic design capability
- Redundancy and high reliability design practice
- Proprietary firmware development
- Software test and debug methods

Moreover it would have been necessary to deal with a completely new type of components and materials (the electronic one) so that also our purchase office and the production and quality departments would have to be involved in the new technology introduction.

As a justification you should remind that the need of a sophisticated electronic controller on board of trains is relatively recent as the speed, at least in Italy, significantly increased (almost 50%) only in the last 5 years and the need of one company as only responsible for the correct functioning of the whole system is very recent.

Main reasons to this resistance to change obviously resided in the technical capability and financial risk of the company to bring the project to a successful conclusion; this mainly because of the company lack of skills and experience in electronics.

This also meant that it was difficult for us to imagine how to manage an electronic development. There were indeed several design houses and consultants who could help us, but we were scared by the very narrow reliability requirements of our application.

We already knew a potential consultant who could have be hired for the development, but needed information on how to be sure of the availability on time of the prototype and in general of the way to control our subcontractor work.

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

When we heard about FUSE we really realised that we had a unique opportunity to win our psychological barriers with a low risk for the company. Therefore we got in touch with the TTN which provided assistance in organising the project. They helped us in investigating our current market situation and estimating the opportunities for profit increase that were offered by the innovated product clearly explained us all the difficulties and problems we would have to face to accomplish the experiment, and suggested that the way to become enough self-confident was on one side look for a basic training and on the other find a suitable external consultant (subcontractors) to acquire the necessary knowledge. This enabled Poli Costruzione Materiali Trazione S.p.A. to carry out the project with the help of a consultant having a long experience in the electronic field and to gain the proper know-how to produce and sell this new product.

Preparing a FUSE submission allowed us, with the help of our TTN, to understand the complete process of developing a prototype using the electronic technology and the skill and experience requested from a possible subcontractor. We also understood how the preparation of a complete work-plan where all the development phases should be clearly identified could help us to reduce the risks of unsuccess while keeping our subcontractors work under tight control.

Thanks to the experience of our consultant, who as already explained, is a specialist in the design and development of power electronics switching converter topologies as well as digital and analogue control techniques, we greatly enhanced our confidence in practising the new technology and understood the main concept of design and testing complex electronic circuits. To better exploit the training on the job that was available with our DAS, we attended a course, which provided us the basic know-how about microcontrollers and for developing the suitable software.

On suggestion of our TTN, a number of various meetings were also held with our main customer to find out whether the new product could comply with their current and future requirements. These meetings made us trustful that our design was correctly conceived. As a result of all discussions the specifications for the Application Experiment were outlined. Moreover we got interesting information about new market opportunities we didn't expect.

During the introduction of the new technology the staff charged to carry out the AE worked very hard to learn and to put into practise the new knowledge. Fortunately the company did not find any special problem during this experience and the originally planned conclusion was respected: this also thanks to the good collaboration we had with our subcontractor.

13. Knowledge and experience acquired

When we started the AE we pursued the following objectives:

1. Acquire the capability to specify a complex electronic system
2. Obtain enough skill to be able to carry out the complete test (including the electronic part) of our product in a fully independent way
3. Capacity to perform small modifications and adjustment to the software
4. Capability to handle the purchase of electronic parts and deal with the component distributors

At the end of the experiment we can say that the result as far better than we expected infact we also acquired:

- Capability to plan, organise and manage complex projects, by structuring it in suitable work phases with clearly assigned roles and responsibilities.
- New knowledge concerning electronic technologies which stimulated the company to keep and increase the acquired know-how in order to be able to less and less independent for the future technology choices
- Familiarity with electronic parts and information on assembling such parts into suitable modules.
- Capability to use and manage a sub-contractor in case future developments requires major hardware modifications.
- Capability of checking the correct functioning of the individual PCBs and the whole system.
- Failure detection of the individual PCBs and management of failure analysis.
- Ability to handle a set of development tools together with the awareness of the advantages in using an In Circuit Emulator (ICE)
- Capability to modify the software in order to adapt to the special requirements of the customer.

We believe that our project fully complies with the RAM design recommendations since it deals with the reliability requirement using high derating electronic components, and addresses the availability and easy maintanance requests using an hot redundant architecture and a single point failure approach.

14. Lessons learned

During the AE the company had a very positive experience and didn't find any particular problem. The former «psychological barrier» was overcome thanks to the training course and the constructive help of the TTN and the subcontractor. The company to learn and to put into practise the new technology did a big effort but such an effort was re-paid when we could verify the good result of the AE. This experience made us self-confident enough in this field and now we are already planning to use electronics to improve the performance of different components we currently manufacture**.**

Some points have to be remarked

- As a matter of fact our engineers had to learn first of all how to deal with the problematic of using electronic components for high reliability applications (temperature, voltage, power, etc. derating) , and secondly how to develop a suitable control software. This, according to us, already represents a big step forward for POLI and can also prelude to further innovation choices at system level (intelligent distributed sensors with Digital Signal Processing techniques
- We think that it is very important to develop a reasonable planning, estimating from the beginning the time to allocate to each single task, since this allows to be sure to comply with the forecasted time to market and to keep the subcontractors work under control
- The expertise and the attitude of the DAS are vital for the success of the project. Its skill and expertise should be the one requested for the project and should be assessed in advance, with help of unbiased experts. The assistance of our TTN was very useful to this purpose.
- A traditional training course is important to understand the terminology and to state the basic concepts, but should not be overestimated; we learnt perhaps more through the training on the job given by our subcontractor. What really makes the difference according to us is the enthusiasm of the company staff involved in the project and their will to learn new things and to practise them.

We must mention here the difficulties that we met in becoming used to a new development approach.

The designer of POLI companies had a previous experience at undergraduate course in developing software in BASIC language, and really thought assembler would have not made such difference.

Instead he realised that when an inexperienced designer has to deal with a complex software development in assembler, a systematic methodology using flow-charts, hierarchic partitioning and inclusion of program is of great help .

We understood also that using suitable development tools like simulators and emulators is essential to handle complex projects in order to easy and speed-up the hardware validation and the software debug phase.

Something we found very useful was the possibility of having a set of increasing complexity development exercises that our subcontractor prepared and sent us via mail.

In such way we were given the opportunity to check what we learnt in the attended course and on special manuals and receive an immediate correction and warning from our DAS

15. Resulting product, its industrialisation and internal replication

The outcome of the tests carried out on the final prototype confirms that the objectives we set at the beginning of the AE were successfully achieved. We were also very satisfied to verify that the approach suggested by our sub-contractor resulted in some additional advantages with respect to the product marketability:

- the product, although featuring triple redundancy, is about half the size of the one offered by our main competitors
- power consumption, when driving the electro-valves, is halved with respect to other marketed controllers
- estimated end price is very competitive

For what concerns the product industrialisation, we have decided to continue the fruitful collaboration with our consultant for anything which will have an impact on the detailed electronic design, such as customer specific add-on features, impact verification of new international standards, etc.

We plan to set up a very flexible approach to the industrialisation of the product, trying to avoid the need for personnel dedicated full time to this product. We will only allocate manpower when orders are placed by our customers, with production organised just on demand, and most manufacturing subcontracted to external suppliers.

For this main reason, we will:

- make use of an ISO 9000 certified external supplier for what concern the PCBs manufacturing
- realise an internal automated test facility for formal acceptance of the in-coming PCBs
- seek an agreement with our consultant for continuos follow-on support.

We strongly believe that for this type of product, in the industrial reality in which our company operates, extreme flexibility is mandatory. As a matter of fact sales of this type of product are very dependent on the contingent state of the national and international markets for new trains, although we also plan to enter the spare parts market as replacement of obsolescent parts.

We also have some interesting contacts for markets different from railways: the one of the Light Rail Vehicles or metros. In this market some big multinational corporation, compete for obtaining the commitment from the administrations of some important European cities, and we want to offer our new electronically controlled braking system in establishing an agreement with one of them.

In any case we estimate to be able to market the product in the year 2000 although small pre-series will be produced before for field trials (UIC tests) and evaluations from our preferred customers. Below we describe the activities we planned up to the end of year 2000.

Activity Description and costs	*06/ 98*	*07/98*	*08/98*	*09/98*	*10-11-12/98*	*08-09-10/99*	*Year 2000*
Simulation of UIC tests 7 kECU	_____						
Prototype up-dating for UIC field tests 10 kECU		_	_				
Laboratory Test to verify the compliance with the norm EN 50155 20 kECU				_____ _			
Beginning of UIC field test					_________		
End of UIC field test 85kECU						_	
Series production							______ _

REPLICATION: we had not planned at the beginning any internal replication with the newly introduced technology, but now that we began to advertise our new technology, a request came for defining a far more complex controller for the car ferries which have no centralised control unit on board.

16 Economic impact and improvement in competitive position

By the introduction of the new technology the product's business forecasting indicated in paragraph 4 has drastically changed. The market share remains constant with a slight increase whereas with the present product it was supposed to decrease up to the 23% in the year 2000. The turnover is foreseen to increase up to the 80% in the year 2000 while with the present product it was supposed to decrease up to the 27%. In order to keep the market share during the payback period, the company will reduce prices with a consequent decrease of the profit margin which the company will recover in the year 2000 with the introduction of the new product in the market.

Looking at the 1996 consolidated budget figures the trend for the current product can be estimated according to the following graph

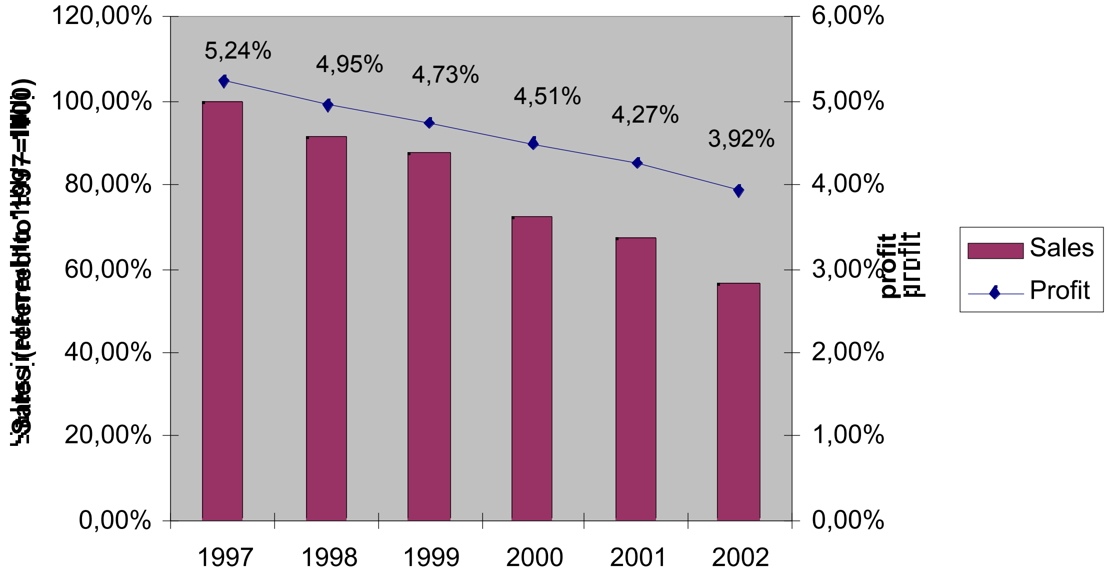


Fig. 6: Forecast for Sales and Profit with the old product

If we estimate the trend with the introduction of the new product for turnover and profit referring to the 1997 sales are shown in the next graph

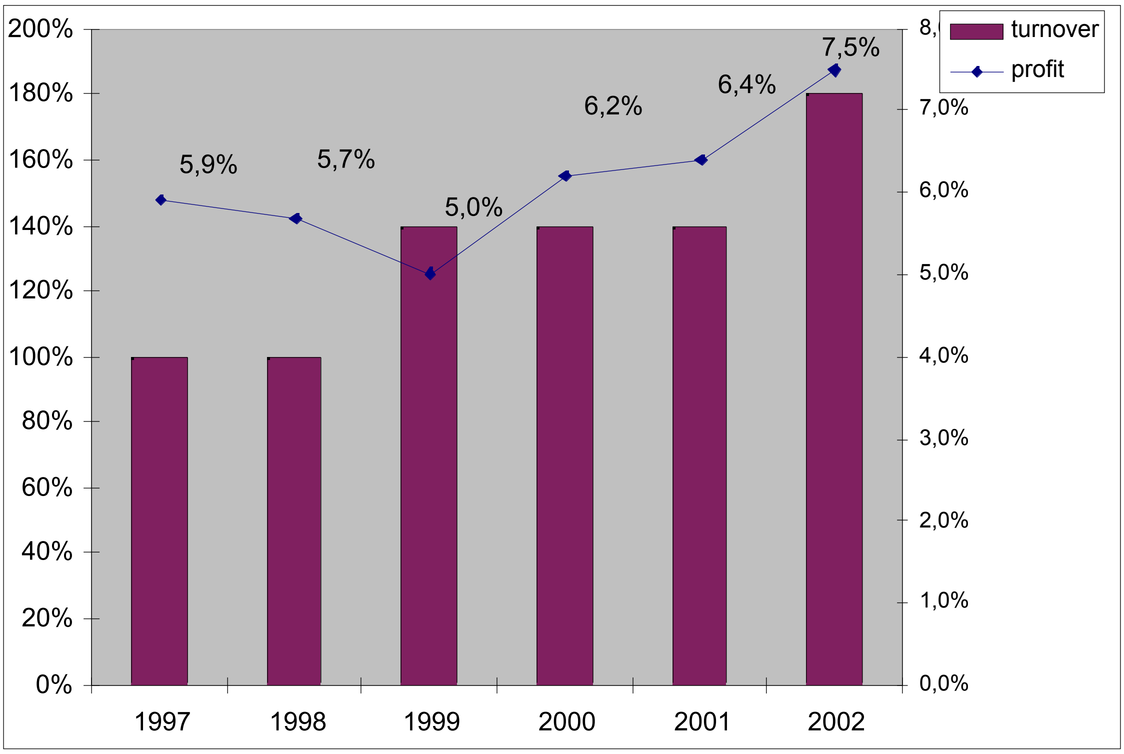


fig. 7: Consolidated 1997 Turnover and Profit and forecast for the next future (Old + New Product) [Percentage Units]

As can be seen the consolidated 1997 were better than our initial estimate due to the prices' reduction and the introduction of new mechanical technologies together with a bigger market demand are the main reasons of turnover increase during the year 1997. An important contribute was given by the better image of the company acquired after the announcement of the introduction of the new electronic technology.

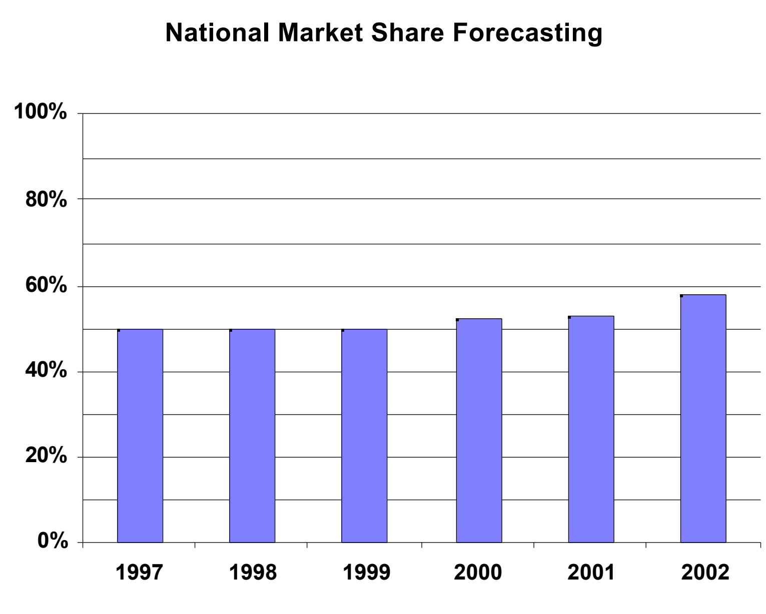
Cumulated profit increase computed from 2000 to 2002 (previous years are not considered since the profit advantage cannot attributed only to the presence of the new product) is 1,7% in the first year and 7.6% in 3 years.

Payback period results 14 months from the estimated date of introduction into the market . Return on investment (ROI) calculated using the actual AE cost and 3 years (2000-2002) cumulated profit margin due to the introduction of the new electronic technology will be 1,8 which corresponds to an average yearly rate of about 20%. In this calculation we also consider the costs for industrialisation and certification which represent the 60% of the whole expected investment (210 kECU See the previous section).

Our market share forecast is also very conservative since we mainly aimed to regain our very profitable position in the market which had been lost due to the lack of electronic technology handling capability.

We keep in mind that we are newcomers in the market of electronic breaking equipment were some multinational giants struggle since three years

Though some feedback we received from our old customers and also new potential one made us confident that in a few years we will be even able to have a light domestic market share increase (less than 10% in 3 years) as it is shown in the following graph.



17 Target audience for dissemination throughout Europe

We are now ready to spread the best practice we learnt in dealing with microelectronics and particularly

Technology management

- We can show the criteria for a reasonable technology selection comparing the different options in view of the risk, the performance and the economic targets.

- We can demonstrate the importance of a detailed workplan where effort and duration of each task are carefully estimated and checked during periodic design reviews

Subcontractor management

- We can explain on the base of our experience how to identify the requested skill and expertise
- We can also describe our contractual strategies where payments were linked to results and to the compliance with the workplan deadlines

Training and self learning

- We can tell how much important was training to us, and how despite the time you spend with the subcontractor a lot of effort for understanding, learning and practising yourself the new concepts should be taken into account.
- *Increased technical capability.* We can summarise from a completely unexperienced FU as we were, how we learnt the MCU advantages and were able at the end not only to specify a mechanic equipment involving an MCU, but also to understand the general design flow of a simple embedded system and to make modifications to the basic firmware

The target dissemination for this AE is certainly the one of the mechanic industries with poor or no experience with electronics.

These companies will gain confidence on the possibility of handling a complex electronic project where reliability and maintainability are major concern.

From this AE and with the help of the TTN they can learn how to plan manage and develop a project with complex electronic circuitry. They also will learn how to conceive new advanced solutions based on electronic technologies like software programmable device.

The advantages of microcontrollers can be as disseminated to other different industrial sectors who can be interested in improving their products introducing flexible and programmable electronic features.

Examples may include mining and extracting industry (10-14), tooling machines (28-29), chemical (24)

We think that some system solutions of cold and hot redundancy, developed in the AE, might also interest those medium size companies that operate in industrial sectors where reliability and maintenance are still a big problem. Car and avionics industries are the most significant example.

POLI will be happy to contribute to the dissemination of the AE results as it was already done in the article written for FUSE News and for the presentation given during the FUSE public information day organised by the TTN in Tortona in May 1997.