From mould making to product engineering,
the path of a cluster

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Portuguese mould industry was a pioneering one in the introduction of new technologies and new processes and business models of industrial manufacturing in Portugal. During the last fifty years this industry has been an entry point for new advanced industrial technologies. Simultaneously it has developed a cluster structure based on a regional territorial logic. The sector has known important changes along these fifty years path, but its sustainability is a tribute to its capacity of managing innovation.

1. **An industry specialised in high precision and high complexity**

   The first Congress of the (Portuguese) Mould Industry was held in Marinha Grande during January 1983 (1). At the time the mould industry was already more than twenty five years old. In the turbulent scenario of Portugal during the last years of the 70s, the mould industry knew an increasing national relevance as an growing “oasis” of advanced technology industry exporting high quality technical moulds without social unrest, although based mainly in a region (Marinha Grande) with a rich legacy of labour movements and voting left in elections.

   The 1983 and 1985 Congresses have been very important events that showed the capacity and the strength of the mould industry. These events were held in Marinha Grande (then with very different access facilities than nowdays) and attracted important political and business leaders in times of residual revolutionary turbulence (after the 25th April 1974 revolution and before Portugal adhesion to the EEC). The events provided an opportunity for reinforcing the internal cohesion and the visibility of the sector.

   An entrepreneur and mould maker said in the Congress (Neto, 1983):

   “Unfortunately in the Portuguese industrial landscape there are not many industries like this, proud of using an advanced technology, proud of an high quality internationally recognised as one of the best in the world and proud of a market with
more than seventy different countries. A national technology that does not cost foreign currency to the country. Exporting more than 90% of the production. An added value around 60 to 85%. Dedicated and disciplined workers. Even with a State that does not incentive us, but worse, it often makes our life more difficult with every kind of difficulties”

Twenty years later a United States International Trade Comission report lists the strong points of the Portuguese mould making industry:

- short time deliveries
- advanced technology
- competitive price
- high quality and service level
- high precision and high complexity specialization

The report was requested by the Congress under the pressure of far east countries over the American tool and die industries (USICT, 2002). The report also emphasises that Portuguese mould makers are equipped with top quality equipments and that most of the companies do use last generation technologies and they are ISO 9001 and 9002 certified.

Portugal is a small country but emerged as one of the world leading producers of moulds for plastics injection: “a small industry almost exclusively for export” (USITC, 2002).

USA is the largest and most advanced buyer of moulds. USITC (2002) report includes a deep analysis of the countries most relevant to the USA market. Portugal is considered along Canada, Mexico, Japan, China, Hong Kong, Taiwan and Germany. Portugal is the only European Union country considered after Germany. This is a tribute to the Portuguese mould making companies and its innovation capacity. May be it is not the only case in Portugal, but it is one of the most successful.

From the origins and development of the industry we can identify some key points:
• an exporting industry with a non significant native market, what questions the idea that without a national market “to pull” it is not feasible to develop an high competitive and advanced industrial sector at the world level. The question should be when that is feasible and when it is not.
• a technology based industry that was born without engineers and that for an initial period time did not have engineering trained workers, but that later has been successful to integrate engineers in the operations, what emphasizes how important the non formal knowledge (tacit knowledge, according to Michael Polanyi (1966) epistemology) can be in the initial phase of an high tech industry;
• a location outside the main urban and industrial centers has not been a problem for an export activity targeting the world most sophisticated markets, what shows the importance

This essay looks for the origins and development path of the Portuguese mould making industry. We try to identify the main directions of change in the evolution of the process and product technologies.

2. The origins: behind glass and plastics

Glass and plastics were seen as potentielly competing materials, mainly for homeware and container products, when the Portuguese moulds for plastic sector begun to emerge, before II World War. Altough later the growth would be driven by export markets, it was the demand for plastic products and associated moulds that made Aires Roque aware of the potential of mould making for plastics. Aires Roque was then the owner of the most important metalshop specialized in moulds for glass products.

Synthetic plastics boomed during the 30s and 40s of XXth century (figure 1). The first factories moulding plastics were then established in Portugal. Its number grew
very much after the II World War (figure 2). Of course, these factories needed products and moulds.

The conformation methods for the available plastic materials (baquelite was then very popular) were very similar to those for glass (blow, compression, ...). Most of the products were also very similar. So mould technology for glass products has been a natural platform for the production of moulds for plastics.

Aires Roque & Irmão (Aires Roque and brother) was then the most important company producing moulds for glass, with operations in Marinha Grande and Oliveira de Azemeis, then the two main locations for the glass industries. It is no surprise that this company has been the first producer of moulds for plastics (2). One of his first clients of compression moulds for plastics (perhaps the first one) has been Nobre & Silva, one of the first plastic products producer in Portugal (3) then with a factory located around Leiria (4). In 1946 Anibal Henriques Abrantes, half brother and partner of Aires Roque, acquired the control of the company and tried to develop the moulds for plastics business, using the same mechanical technologies available for mould making for glass products: fillers, lathes and drills. Informal on the job learning by trial created the necessary knowledge.

The company had 50 people in 1946. But in 1953 the company had doubled the number of workers and changed to a new site (figure 3). Meanwhile the company name had been changed to Anibal H. Abrantes (AHA from now on). The brand new building was considered a modern and luxurious one in the industry, including canteen and showers, consequence of a human resources policy based on the valorization of people.

Assembling work was especially important. Precision was then incipient. The quality of the moulded part depended largely on the “art” of mould making learned on the job by trainees during several years (a practice still used by the industry).

During the second half of the 40s there is a boom of plastic moulding companies around Leiria, a city very close to the location of the first generation of mould makers (figure 4).
Figure 5 shows the entries in the mould making sector until the 70s. Entries are divided into three groups:

- one group of two companies based on the mould for glass business and technologies (AHA and Edilasio Carreira da Silva, the “root companies” of the sector)
- another group of sixteen companies with origins in the first group of two companies, and
- a third group of three companies based on northern Portugal and not related with the first two groups.

All these companies were founders of the industry in Portugal (6).

First generation of mould making companies have been “spillovers” by professionals with entrepreneurship, who learned the trade in the “root companies”. The knowledge of these “root companies” have been built up upon the knowledge of mould making for glass. During the first years the difference between mould making for plastics and mould making for glass was not clear. The specificity of mould making for plastics only begins to appear in the second half of the 50s.

At least 21 companies appeared in less than fifteen years, 13 of them around Leiria and Marinha Grande. More than half of these companies are direct spillovers from the “root companies” based in Marinha Grande. In the Oliveira de Azemeis and Porto areas the origin of companies were more independent – although one of the most important companies located there during that period of time (Moldoplaste) had origin in AHA, one of the “root companies” from Marinha Grande.

Between 1945 and 1970 ten new companies were born from AHA, two new companies from Edilasio Carreira da Silva and two new companies had origins in Moldemega, which was itself a spillover from AHA.

There are other origins also. Ernest São Simão, a company based in Porto, and near as old as AHA, begun operations in 1947 as a die shop for Jewellery. During the 50s it begun producing moulds for injection of plastic buttons demanded by national companies supplying the textile and garments sector. Soaresmoldes, a company
based in Oliveira de Azemeis, begun in 1962 producing special machines and dies for stamping. The company entered the moulds for plastics business later in the 60s near by chance, answering the requests from a new swedish client.

Cefamol, the association of mould makers, was founded during 1969. It was the first signal of a strong associative spirit among mould companies (Beltrão 2001).

3. An exporting oriented and dynamic path

Figure 6 shows the evolution of the exports value, from a long time series based on data from Cefamol. Figure 7 shows the data in a logarithimic scale. Exports represent around 90% of production, so the evolution of exports describes reasonably well the path of the industry production (at least from middle 60s). The sector has known an explosive growth during the last three decades of the XX century.

Growth has been strong for several decades and the initial dependency from the USA market was strongly reduced later. Exports for USA market peaked 60 to 70% of the total exports during the 70s (and returned shortly to that level between 1983 and 84), but later growth of esports or the european markets has been stronger. USA exports represent now around 15% (11% during 2000, a value too low) (figure 8). Meanwhile the european market became the dominant one for exports from portugueses mouldmakers (figure 9).

Growth (per year) has been higher than 20% during more than half of the last fifty years, a very high performance. Figure 10 showa growth rates for total exports value and also for exports only to USA. Data consolidated for 5-year periods shows the same path (figura 11).

First phase of the industry has been dominated by small moulds for toys and homewares. But that changed very much along the time period (figure 12). Moulds for toys were still important during the 80s, but nowadays they are residual.
Meanwhile automotive industry become the most important client during last decade and now represents around 30%.

Moulds for home appliances parts have been very important during the first half of the 90s, mas its importance decreased later.

Previous analysis shows that the sector grew very much, but also changed very much. It has been a supplier of the frontier markets of each decade and has showed a consistent capacity to produce more and more complex moulds for more and more demanding plastic parts. The path of the sector has followed the path of the moulding plastics, with a permanent update of the design and production capabilities and equipment with the new technologies available. This evolution is discussed in the next sections.

4. The initial competitive advantage: the “portuguese / AHA” mould making model

The industry was born for the internal national market and to answer the demand from the emerging plastic moulding industry in Portugal.

Let’s review the “modus operandis” of Anibal Abrantes. In the very closed portuguese society and economy in the after War II years ant the beginning of the 50s, Anibal Abrantes enjoyed long trips by car in Europe and combined the travelling with the searching for “novelties”. During his regular trips he visited the new retail shops (new “department stores” like Printemps in Paris, for instance) and bought new products in plastics (typically toys and homewares). Back in Portugal he would visit the moulding companies offering a ful package of “copy / imitation of the novelty plus the mould to produce the parts”. Sometimes he would produce the mould even before he had a client.
Anibal Abrantes business model was not yet the “mould maker” model based on a certain product specification made by the client, but his role was as a diffusion agent of product innovations from the european market to the portuguese market.

The industry was born “national” and not oriented for export. Leonor Sepas (2000) talks about mould companies as “born export”. That would be true later for new entries, from the 70s. The first operator, AHA or Edilasio Carreira da Silva, were “born national” and it was the national market that allowed them the first substantial profits – what can explain the focus of Anibal Abrantes in this initial business model. Figure 13 shows Anibal Abrantes with one of his plastic dolls, one of popular toys for which he supplied the moulds to portuguese moulding companies.

It was by chance that during the 50s (around 1953 or 1954) Anibal Abrantes met the man that would discover the export opportunity and make a business around it. He met Tony Jongenelen in a plastic moulding company in Northern Portugal. Tony Jongenelen was a dutch jew working for a swiss company selling mechanical “music engines” for toys. He was in Portugal looking for customers. From that meeting, by chance, a partnership was borne. And that partnership would have a very unusual impact: it would create an export oriented industry from an emerging business oriented to the national market.

Tony Jongelenen was an interesting man with a troubled personal and business history. During the War he played jazz in the nightclubs of occupied Paris while working for the resistance (8). After the War he decided to stay in Europe, while his jew friends went to the USA and became involved in the emerging business of plastic toys and musical instruments (9).

Having met Anibal Abrantes he recognised the business opportunity and he suggested to Anibal Abrantes an exclusive contract for exporting moulds for plastics. Of course Anibal Abrantes was delighted with the deal (10). It may be interesting to note that Anibal Abrantes does not seem to have tried to contact the european plastic moulding factories during his travels, but he concentrated his commercial efforts in the national market (11). The partnership would last more than a decade. During
that period of time AHA would emerge has an export oriented mould maker with through Tony Jongenelen agency.

But Tony had an health problem during the 60s and Anibal Abrantes order book dried and begun to feel economic problems. Tony first refused but later accepted to give his contacts in USA to someone in AHA in order to visit them and to find new ordres. But he choose himself the emissary, and his first mission was a success – and opened the export world opportunities to the company itself (12). Not a long time after the visit the partnership was in trouble and the friendship between the two men destroyed (13).

Tony Jongenelen wit and sense of business opportunity and his network of contacts in the american jewish community helped to discover the mine. But that does not explains why the mine was a gold one.

A cheap labour was not the gold of the mine. It was something much more important: a scalable mould manufacturing process with short delivery time – something critical and in very high demand in those booming first years of plastics by injection. And the delivered moulds worked and they were also inexpensive. Mas it was the available manufacturing capacity and short delivery times that were critical and in very short supply worldwide.

Cheap labour was then available in other european countries, may be with more favorable “a priori” conditions to export to the plastics USA market than Portugal. But it did not happen there. In Spain it would take more than twenty years to have a similar and significant activity. And Italy had then a much more developed industrial activity, but an export oriented mould making sector did not develop as in Portugal.

Up to then moulds for injection of plastics were manufactured by traditional toolmakers in USA and Germany. Delivery time was a long one: production was dependent of a small number of very specialised toolmakers, with a long experience and versatility, but also “prima donnas” who kept their skills very closed. Mouls were produced by each toolmaker team in a sequential mode typical of the craft shopfloor organization. It took more than a decade to train these toolmakers, usually
from the tool and die shops or from the precision instruments sector (“fine mechanics”). They were expensive people and they used to operate in small shops or manufacturing cells in a one at a time mould job. Production capacity was small and limited for the soaring demand after World War II. The sequential production cycle in the traditional shop environment also implied a long manufacturing time and escalating delivery times for orders in the pipeline.

And there was an additional problem: short supply of mouldmaking capacity also made production of multi parts plastic products (demanding several moulds to inject different parts to assemble) difficult to launch and more expensive. Time to market escalated. Additional fitting problems were created if different mould shops were producing different moulds.

Portugal, and AHA in particular, had no tradition of toolmakers, neither an watch industry or even a craft of precision instruments. And the tool and die industry was then small and underdeveloped, in a country without tradition of automobile or industrial equipments industries creating a significant demand for their skills.

AHA begun mould making using the same techniques and skills used to produce moulds for glass. First moulds for plastics were similar to moulds for glass products – sometimes they were even simpler (see figures 15 and 16).

In the absence of traditional toolmakers, Aires Roque & Irmão, and later AHA, hired first, lathe operators, and later milling machinists, and tried to distribute the mould manufacturing operations by different specialized work units, partially in parallel and partially sequential: a typical division of work by functional specialization (taylorism based, although without a volume based production line).

They were not aware, but they were discovering a different mould making process, with three important innovations: no need for traditional toolmakers (like those in USA and Germany), shorter manufacturing time and larger and scalable production capacity. This has been critical to offer an easily scalable capacity for the USA market were a soaring demand for moulds during the boom of injected plastic
products during the 60s (and later 50s) had trouble to find available capacity for mould making.

Labour was inexpensive, so the mould price was also cheap. Later AHA would discover he was too cheap and would regret (and partially correct) it.

In the early 50s AHA had around 50 workers. This was a significant number for a mould shop, even by international standards (mould shops with more than thirty people were rare). In middle 60s, when the partnership between Anibal Abrantes and Tony Jongalenem came to an end, AHA had hundreds of workers – a very unusual dimension worldwide. But his main competitive advantage was that AHA could supply several moulds simultaneously for the same client with a short delivery time and a very attractive price.

New companies entering the market (largely based in people trained in AHA) would adopt the same manufacturing layout and strategy, based on an industrial system (against the craft system of traditional German and American toolmakers). Specialized teams in different mould manufacturing processes and steps were developed and quality control techniques were of course required. Shopfloor management complexity increased but it allowed larger capacities and shorter delivery times.

Functional specialization also made training easier and knowledge transmission more efficient, without the corporative barrier of the traditional “toolmaker” and profiting from a local job market with an easy offer (15).

This has been the competitive advantage of AHA, and later the competitive advantage of the Portuguese mould making industry. Meanwhile the Portuguese industry became one of the most important world suppliers and its position has been sustainable.
5. Product and technology paths

5.1. Communication and knowledge support

Formal mould design was not a practice during the first years, neither detailed specification drawings, either for the part or for the mould. In some cases there could exist a paper draft of the part to be injected or of the mould. Mould details were often defined looking to a model of the part (see figure 23). At the end, the part injected could be more or less similar to the intended one. Part details were often changed along the cavidade and bucha conformation and sometimes they were the consequences of “accidents” during manufacturing. The few available drafts were prepared in craft paper, without provision for copies.

Knowledge was largely tacit and non formal, usually not recorded or documented, and embedded in the organizational routines and the skills of the individuals (borrowing the evolucionist concepts from Nelson and Winter (1982), which proved very useful as a theoretical framework to understand the path of this industry).

Mould drawings and mould design became popular years later, as key tools for the part and mould specifications. Mould drawings also became the support to record the acquired knowledge and solutions to mould design and manufacturing problems provided by the shop experience in the business. Drawings would become the key component of the communication and control system along the life cycle of the mould.

Drawings were graphics based, not text or digital, and an autonomous information subsystem was developed, largely independent of the management information system. This graphics information subsystem was paper based and centered around the technical drawings maintenance and archive functions. Information flows were based on the circulation of copies of the drawings – what meant copies could be easily done at a reasonable cost. Only nowadays is integration between the information subsystem based on geometric models and the current management information system being achieved in mould making.
Heliographic copying process made drawings copies easily available at a reasonable cost through the adoption of drafting paper as the physical support for drawings. Drawings became the central pivot of the organizations technical subsystem and made the bridge between inside and outside the mould making firm for information and knowledge sharing.

Decades ago, availability of text copying facilities have had a critical importance for the organization of the control procedures and the development of the information systems for management – a key ingredient of the “scientific management” (Yates, 1989). Something similar happened in the mould making industry, but now based on the drawings related to the part and mould: copying facilities made them central to the operation of the firms and the basis for communication and control.

Heliographic copying process was of course well known in engineering practices for a long time, but only during the last years of the 50s did AHA begun to use it currently, simultaneously with the adoption of engineering or technical drafting standards based on the current and well developed practices of mechanical engineering.

Drawings for mould design and part specification became mandatory during the 60s while respect for the specifications became critical (figure 24). Copies of the final releases of the drawings were organized in a technical dossier – at customers request the practice became a standard. These drawings were needed for maintenance purposes and easy changes in the future. During the 70s moulds complexity increased very much and “engineering” practices were standard in the drawing rooms. At the end of 70s the engineering culture and practices were dominating the initial crafts culture, including the standardization of the mould drawings based on the current american standards. Drawings became the unifying communicaton device for geometries between all the stakeholders in the mould life cycle and allowed for the easy adoption of subcontracting. The local supply chain becomes more structured with shops specialized around some of the operations or special equipments.
Part specification also changed. From the initial mould conformation based on the visual inspection of a specimen of the part to be moulded (remember the initial AHA business model), the part became specified by a photo or a drawing send by the customer - the part was dematerialized, and a physical model was needed to visualize and “to feel” the future real part, as interpreted from the drawing or from the image.

The physical model, usually a wood one, allowed an easy check of the part geometry and an easy alignment of the manufacturing routine with the experience from the previous phase. A new job, the modeller, was born. When part specification by a part drawing became current, the physical model also allowed for the correction of drawing errors by the client designer – something very usual. During the 80s the (physical) modeller begins to loose importance as long as the digital modelling facilities (CAD) become widespread.

Portuguese mould makers have been early adopters of new communications technologies driven by the need of fast communication of drawings between the foreign customers and the local firms. The mould industry was the first intensive user of telecopy among small and medium companies, yet during the 70s, mainly for exchange of drawings for budgeting.

CAD adoption changed the communication supports. Mould industry has been one of the first to exchange drawings through magnetic tapes, during late 70s and early 80s, often using IGES metaformat. During the 90s the digital exchange of geometries become routine.

Yet during the 90s the internet opened new opportunities for data exchange and communication. Geographic distributed “round the clock” cooperative work in mould design became feasible (Menezes, Soares e Rocha, 2002).

Easy exchange of CAD geometric models become a cornerstone for the progressive adoption of simultaneous engineering practices by the industry, from middle of the 80s (Neto, 1989). Cooperative design of the functional and technical aspects of the plastic part allowed a further integration of the industry in the international supply chain – and represented a partial return to the original business model of AHA.
(product plus mould), but now around new product and not around copies or imitations of third parties products.

The physical models from the 70s become prototypes during the 90s, built by fast digital prototyping technologies, directly from the CAD digital part model. Once again the portuguese mold making companies were worldwide early adopters of the technology. A national fast prototyping network was developed from 1997, driven by the industry efforts (Araujo e Soares, 2002).

5.2 Technology

Table 1 summarizes the most important mould technologies for each one of the decades during the second half of the XX century.

Tables 2 and 3 do refer to the dominant type of moulds, to the moulding plastic materials, to the types of mould products and to the moulds specifications.

Figures 17 and 18 show the evolution of the parts from the collection of AHA moulds produced during the last decades and it shows the increasing complexity of the final plastic parts. From small and medium size parts to bigger parts, higher complexity was due to the increasingly non linear shape of surfaces simultaneously with an higher accuracy and precision, from parts to be glue bounded (typically “hobby kits” during the 60s) to parts to be assembled by fitting or by welding.

The various “waves” of technologies are reported in Table 1. Figures 19 to 21 show typical moulds from the 60s and 70s. During the 60s mechanical and hydraulic copying and milling (figures 22 and 23), ponteadoras and rectificadoras (plane, interiors or cylindrics), dominate the machining technologies. Heat treatment become important and would be an important activity in AHA (17).

Non electronic numerical controlled machines (NC) appeared in the portuguese mould shops during the 70s. GSP machines, programmable furar machines, has been important during the 70s, when the industry searched to find how to reduce delivery times and to increase accuracy. Meanwhile CAM machines appeared.
Wire and penetração electroerosion had an important impact in the industry during the 70s and 80s, when tridimensional measuring machines opened new horizons for dimensional control.

The 80s have been dominated by the introduction of CAM and CAD, which was a dominant discussion theme during the three first Congres of the Mould Industry, hold in Marinha Grande. This issue has been discussed in another paper (Beira e Menezes, 2003). Productivity issues around machining drove the adoption of CAM, but adoption of CAD was driven by communication issues: clients would send soon magnetic tapes with computer files instead of paper drawings (19).

AutoCAD diffusion opened a new opportunity to CAD adoption by the small and medium firms of the portuguese mould industry, reducing the barriers to entry in the technologies of CAD and CAM. At the end of the 80s numerical controlled machines and machining centres were common in the shop floor of mould making firms. They dominated the manufacturing technologies during the 90s. At the end of the 90s integration of CAD and CAM became a reality widespread in the industry.

The high fiability of automatically generated machining programs from 3D geometric models at the end of 90s made the three shifts intensive exploitation of machining centers feasible, including the automatic change of pallettes and machining tools. The capacity to achieve that is not anymore a competitive advantage in the industry, but becomes a competitive requirement to survive in the industry.

CAE tecnologie begun to be used during the middle of the 80s, but with a low intensity. The CAE level of adoption increased during the 90s, as long as the fast prototyping technologies.

Drawings and design standardization, as well as components standardization, has been a continuous trend during the 70s and 80s (Hugo(2002); see also Menezes (1983), Eusebio (1983) and Neto(1983b) ). The importance of this issue can not be ignored. Mould bases and other mould components were now manufactured individually, considering the dimensions and tolerances of their individual design drawings. The practice of tracing desapears (20).
5.3. Management issues

From the 60s the mould making industry adopted the modern techniques for the management of the shopfloor operations, including layout (figure 25).

PERT and CPM techniques were used from the 60s, and also systematic job programming and scheduling through “work preparation” departments (figure 26). Computer based cost control of operations (and budget control) per mould has been a concern from mid 70s and during the 80s (21).

Quoting techniques developed with the planning of control of operations. Regular “progress reports” per mould for the customer was an important control tool and also a marketing and communication tool (Pedro, 2002).

International marketing has been discovered during the 70s with the strong support of the Fundo de Fomento da Exportação (then the export agency at the government level), that supported a regular program of presence of the industry in the important international trade fairs (figure 27).

6. A cluster?

Cefamol (2002) claims the mould sector has around 300 firms in Portugal, small and medium enterprises, employing around 7200 people. But data in the last directory from Cefamol (that updates the directory published in 1998 / 99 by ICEP and Cefamol (ICEP, 1998)) suggests different numbers. May be the directory is not fully complete, but anyway it seems to include all the important companies related to the sector, specially mould makers and component suppliers.

The directory includes 144 firms with 7600 workers (22). 22 of the 144 firms can be classified as non mould makers for plastics (including one plastics moulding company and two mould makers for glass) with 800 people. Ten of these firms are
commercial firms – an important component of the sector – with a total of 250 people (25 per company).

Among the remaining 122 mould making companies there is a core group of 32 firms (3400 people, around 110 per company) and another group of 90 smaller firms (37 people per company).

More than 100 firms in the directory are based in Marinha Grande, representing 60% of the total payroll.

The core group of 31 firms should represent around 70 to 80% of the total production, employing around 45% of people. This picture of the sector seems more realistic.

Around one hundred companies are based on the Marinha Grande region (60% of the total payroll).

Figure 28 shows the distribution of firms in the directory by foundation year. Figure 29 summarizes the same data by 5 year periods. The boom of entries in the sector from 1975 to 1995 is very clear, specially during the second half of the 80s in Marinha Grande. Figure 28 also suggests a more dynamic demography in the Marinha Grande region.

Figure 30 shows the distribution of firms by number of people: almost 75% of the companies have less than 75 people. Figure 31 plots the number of workers per company against the age of the firm. The well known limit around 100 people per shopfloor can be recognised. As expected the size of companies during the first years is crescent.

Figure 32 shows the evolution of the average price per metric tonnage of exported moulds. Data suggests a continuous growth of value: during last 20 years it increased 5 to 6 times. Such a growth can not be explained only by inflation and exchange rates. Growth in mould complexity can explain part of it. But some growth in the productivity should also be present, associated with the permanent introduction of new technologies and management practices. But this needs a more detailed analysis to be confirmed.
Porter (1994) has identified the mould cluster as one of the most important and well-developed regional clusters in Portugal.

It is possible to identify some of the typical cluster attributes: a territorial base, strong interactions between cooperating but also competing agents, a pool of human resources and knowledge, strong relationships with upward and downward sectors, the role of local and associated institutions, the “commonalities” and the complementarities that Porter talks about in another paper (Porter, 1998), the complex network of personal and professional links (a kind of “social glue” (Porter, 1998)) and the interfirms interactions in a dense subcontracting network, even the capacity to align common agendas to improve productivity and profitability.

Literature about clusters has two different origins with different terminologies. The Porter vision is based on the corporate strategy, entrepreneurship and public policies framework. This vision often differs from the cluster concept and theory from geography and economic geography. The concept of cluster has obvious potential and contributed to a fresh analysis of the process of geographic agglomeration and associated sociology. But the cluster based approach to the economy, instead of the traditional industrial sectors, has proved difficult. A good illustration is the recent clusters map of the United Kingdom (DTI, 2001): although based on sophisticated tools of analysis, the final result is not very different from a classical analysis of the territorial distribution based on the classical industrial sectors (23).

The key point is the conclusion that clusters have a stronger competitive potential in the international economy than a classical industrial sector, due to agglomeration economies and spillover effects. The Portuguese mould making companies seem to be a good example.

The competitive advantage of a cluster is rooted in different reasons:

- easier access to specialised human resources, other inputs and to business information, minimizing the coordination costs and the problems due to the asymmetric access to information by competitors.
• easier access to and diffusion of knowledge and easier endogenization of innovations
• spin-off incentives to new firms constitution within the cluster communities

The interactions typical of a cluster network facilitate the operation of a new local start up and the diffusion (voluntary or not) of knowledge, reducing the cost of access to information and also the transaction costs through economies of territorial agglomeration.

A cluster has an horizontal dimension (firms with the same type of business) and a vertical dimension (the supply chain, including firms offering specialized services and support institutions). The horizontal dimension facilitates the diffusion of knowledge and innovation by imitation and a permanent experimentation of new practices through the diversity of firms. The vertical dimension facilitates the creation and diffusion of knowledge through the functional specialization of work. A cluster should grow along both directions (Maskell, 2001).

The growth of the mouldmaking industry along the horizontal dimension has already been covered. There were around 50 companies and 2200 workers in the beginning of the 80s. The actual size, based on Cefamol directory, has been previously discussed. The horizontal dimension has more than tripled during the last two decades.

The cluster has also grew along the vertical dimension, where a growing structuring is easy to identify: a broader area of business and new adding value and complementary services. Firms specialised in plastics product design during the 90s has been an important trend, upgrading the level of intervention in the supply chain. During the 90s there is a growing partnership of the most important mould makers with clients for shared product design responsibility and for final product prototyping activities.

Economies of scale provided by simultaneous or concurrent engineering during the design phase, when CAD based, can be substantial. During the last years new
design oriented companies entered the sector, as can be seen from Cefamol directory.

The evolution along the vertical dimension of the cluster has a first phase with the local activities of suppliers of materials and services (steel, mould components, tools, machine tools, heat and surface treatments, banks and insurance, express courier services) and then a second wave of firms specialized in services around certain phases of the mould production (polishing, electroerosion, special machining, ...), data processing and information technologies and now design oriented services.

Sturgeon (2003) claimed that in the well developed industrial clusters there is a strong cooperation between the most important firms and the key suppliers around areas of difficult formal coding, like design, prototyping and manufacturing process feasibility analysis. His analysis is based on Silicon Valley firms, with the linkages between firms of electronics, information technologies and telecommunications and their multiple suppliers. In mould making there is a similar pattern, but between the most important firms and their key clients (much more that suppliers). But the logic is the same and it shows how developed the cluster is.

The “institutional thickness”, associated with the cluster vertical dimension, is visible. The local institutions and associations had an important role during the last decades, especially in Marinha Grande, where the local culture and “buzz” seems to have been very useful as a “clustering milieu” favorable for the local networking and the informal flows of information and knowledge exchange. The linkages with the local and national institutions of education have always been strong in the Marinha Grande area and the thickness of the linkages has increased along the years. New institutions, based on the sector, have reinforced that thickness (Cenfim and Cemtimfe, for instance). These are important forces of the sector for the challenges of the future.

The cluster concept is a fuzzy and non precise one. Martin and Sunley (2003) called it “a cahotic concept”. Territorial limits are undefined, as well as the minimum or maximum size. The concept seems to be more efficient as a driver or framework for
public policies (OECD, 1999, 2001) than as a tool of economic analysis. No surprise that the demography of clusters is very crude (van der Linde, 2003).

In this case of mould makers for plastics, do we have only one bipolar cluster or two different clusters (Marinha Grande and Oliveira de Azemeis)? Or is it a (sub)cluster included in a larger regional cluster, including mould making, plastics moulding and even glass industries along the horizontal dimension (and perhaps more according to the Porter (1998) concepts)?

7. And what about the future?

After fifty years of sustainable and competitive growth, the future of the Portuguese mould making industry seems to be constrained by the fast development of mould making competences in Southeast Asia (also discussed in the USICT (2002) report, with a strong emphasis on China) and by the delocalization of plastic moulding to the countries in the same region by the large clients of the Portuguese industry. Next years will be a challenge to the competitiveness and innovative capacity of the Portuguese mould makers.

Technology new developments will continue to be important. High speed machining (Faria, 2002), laser digitalization, laser welding and even “virtual” and / or “augmented” prototyping (24) are expected to know important developments. Moulds will be more and more complex and demanding. After moulds for multmaterial injection, injection over textile tissue and other materials, after “in mold labelling” new concepts about “in mould assembling” are beginning to appear.

There is a market for moulds themselves as a “product”, which can be attractive and will continue to grow. We are talking about moulds demanding shorter and shorter moulding cycles for very high volume standard plastic products as a competitive advantage, like moulds for CD boxes, thin drinking cups, ... Producers of these products buy several moulds per year and are always looking for new
economies in moulding. These are becoming very sophisticated and high technology moulds, complex machines. Some mould makers may become specialists of that kind of moulds.

The sector is now a mature one, with demanding management skills. A new change of generations in a traditionally family owned business will also have an important impact in an industry of small and medium enterprises. Financial requirements will increase. In this context a restructuring of the corporate landscape is expectable, may be including new international partnerships.

The movement towards Southeast Asia will have important strategic implications to USA and Europe (it is already happening, see Aeppel (2003)). Implications about product innovation and about the critical area of weaponry and military products can not be ignored.
Acknowledgments

Ana Prudente, graphic designer, contributed with the artwork for figures 4, 5, 17, 18 and tables 1, 2 and 3. Ricardo Fernandes contributed for the analysis of the sector data.

Nuno Beira was responsible for the photos of the plastic parts from AHA collection. Ângelo Santos, Armando Dimas, Carlos Monteiro, Francisco Teixeira, Francisco Frazão and Manuel de Almeida contributed to the identification of the parts.

Photos of moulds in figure 15 and 16 were also by Nuno Beira. Thanks for the cooperation of Catarina Carvalho, manager of the Museum of Glass, in Marinha Grande.

The remaining photos are part of the Centimfe collection, including photos from Anibal H Abrantes and Edilasio C Silva companies records.

Contributions and recollections from Ana Maria Jongelemen, António Silva, Emília Silva, Henrique Neto, José Joaquim Soares and Manuel São Simão, as well as Cefamol staff, were important for the paper.
Notes:

The first event was from 28th to 30th of January, 1983, in the new building of EP3 (Pilot School 3) in Casal da Malta, Marinha Grande. The second Congress was two years later in the brand new installations of Sport Operario Marinhense (SOM), a popular and cultural association in Marinha Grande, then leaded by the lawyer Jose Vareda. SOM had rebuilt an old glass factory, from Covina. The proceedings of the first Congress were published in 1985 by Cefamol – Associação Nacional da Industria de Moldes, close to the opening of the second Congress.

Aires Roque may have produced the first mould for plastics between 1935 and 1937. It may have been the top of a glass ink vessel, moulded in backelite.

Nobre & Silva was founded in 1927, in Leiria, to produce slippers. During 1945 the factory was moved to Amadora, close to Lisbon (Callapez, 2000).

The causal relationship between the plastic industry and the glass industry localization around Leiria is suggested by Callapez (2000, pg. 96), but it is very dubious. The majority of plastic moulding companies based their operations in other areas of the country (see figure 2).

Demand for moulds for plastics was weak during Second World War, due to short supply of plastic raw materials. During this period Aires Roque & Irmão concentrated again their business on mould for glass. Aires Roque had a preference for this market, that he considered safer and that he knew better. Anibal Abrantes may have commented that “it was difficult to convince my brother to produce moulds for backelite because he was an enthusiast of mould for glass”. Anibal Abrantes was convinced that plastics would be an important substitute for glass, so moulds for glass were the wrong bet.
Pedro Viana Jorge, who has been supervisor of the millind department in AHA, created a company based in Vila Nova de Gaia around 1958 or 1959 (we ignore the name of the company, as well as the date of the end of operations). Gomes (1998) also refers Pinhos & Ribeiro, founded during 1963 in Olveira de Azemeis. Beltrão (2001) publishes a list of companies involved in the first activities of Cefamol, but some of them have not been included in figure 5: Augusto de Oliveira Belchior (viúva) (a metal shop oriented to the glass industry and one of the roots of Intermolde, specialised in moulds for glass, founded in 1973), Carlos Reis (with origins in AHA), Irmãos Cardeira, Mecima, Mesil, Sousa & Sousa, Moldes Meca, Aires Valinha. The first name of Cefamol has been Centro de Fabricante de Moldes (Mould Makers Centre), before the actual name (Beltrão, 2001). We have also identified Metaloura, a firm based in Oliveira de Azemeis, that begun operations around 1950 and that may have worked until 1970.

Gomes (1998) says that Toni Jongenelen was american and worked for a swiss company of music instruments. But he was deutsch and the swiss company produced engines for music boxes, not exactly musical instruments.

Toni Jongenelen was a resistance agent during the Second World War, together with a group of jew musicians acting in occupied zone. He has been captured and sent to a german concentration camp, from where he evaded with the help of family in a recambolesc operation when being transferred between camps. The resistance group was financed by the allies (americans). After war they have settled in USA. That is the origin of Toni network in the jewisch community in America.

The jewisch community in USA had an important role in the development of the plastics moulding industry, specially around New York / New Jersey.
It was a very tough contract. AHA was paid in US dollars at a fixed rate (25 escudos per dollar). Devaluation of the escudo along the years made the contact highly negative to AHA.

Lopes (2000) suggests otherwise. But unfortunately this book is very uncomplete, with important omissions and mistakes.

Anibal Abrantes wanted to send his nephew, Aires Roque, an engineer acting as general manager of AHA, for the commercial mission to USA. But Tony Jongenelen opted for an young mould designer of AHA in order to visit his clients in USA. Toni paid for all the travelling expenses. In his first mission the young mould designer got orders for more than thirty moulds (for toys) at a much better price for AHA. The young mould designer was Henrique Neto and this was his first commercial mission selling moulds abroad, after several years of shopfloor experience in mould assembling works and drawing room experience. Later he would become one of the founders of Iberomoldes, during the 70s (one of the authors, Joaquim Menezes, who had also worked for AHA, has been the other equal partner – a firm structure than has been kept until nowadays). During the 80s Iberomolds acquired the control of AHA.

Toni Jongenelen would continue to work with the mould industry. When the exclusive contract with AHA was terminated, he worked with other companies (Somoplaste was one of them) to export moulds for plastics. It was through him that companies like Ernesto São Simão (based in Porto) begun producing moulds for plastics yet during the 60s.

There were very few vertical milling machines operating in Portugal at the time – milling was then a new emergent technology. Beltrão (1985) identifies some of the first operators in the industry.
But mould companies have always paid “well” (even above the labour market average)

1) Available technologies in the RNPR are: SLS (Selective Laser Sintering, based on Centimfe), LOM (Laminated Object Manufacturing, based on INEGI), SLA (Stereolitography, the first laser fast prototyping equipment installed in Portugal, from 1992, in the IST Instituto Superior Técnico / Lisbon University, and later transferred to CETAP and then to Agiltec), DMSL (Directed Metal Laser Sintering, based on INETI) e 3D Printer – Polyjet (based on Centimfe, 2003).

See Granja (1985, 1989)

This equipment was known has “the GSP”, the name of the machine manufacturer, and has been fundamental to introduce the parallel manufacturing of different components of the mould, especially the mould base, and to standardize some operations, especially furação. The practice until then was to wait until all the markings have been done and then to make the fixing and extraction holes, what meant longer manufacturing times. It also induced tensions in the mould base plates with implications for the stability of the parts geometry. X and Y coordinates, with a specified Z depth for each hole, were previously programmed in paper sheets by the design and drawings department and then digitized by the machine operator through the control console. The depth (Z axis) were first recorded in a tambor com posicionadores reguláveis que funcionando coordenadamente com o avanço de descida da árvore rotativa accionavam “micro-switchs” e determinavam a cota do furo em Z. The control console and the machine hardware can be seen in pictures reproduced in Beira and Menezes (2003).
Modern Plastics magazine published an article that had an historical impact as an alert to the protuguese mould making community: “Os fabricantes de moldes que queiram ser verdadeiramente competitivos nos mercados actuais, em mudança rápida, talvez tenham em breve de se voltar para as técnicas de CAD/CAM. A razão é que um número crescente de compradores de moldes, incluindo muitas das industrias de material eléctrico e automóvel estão já a usar CAD para desenhar os seus produtos de plástico. Como consequência os desenhos em papel têm uma forte possibilidade de se tornarem obsoletos como métodos de transmitir informações aos fabricantes de moldes. As fitas perfuradas, de papel, também talvez fiquem em breve desactualizadas como forma de transmitir instruções às máquinas ferramentas. Muita dessa informação de desenho está já a ser gerada e transmitida do desenhador do produto para o projectista do molde e para o operador da máquina, usando meios electrónicos. É altamente provável que num futuro não muito distante, toda a informação seja enviada electronicamente. Em consequência os fabricantes de moldes sem capacidade de receber e processar informação na sua forma electrónica podem ficar incapacitados de orçamentar alguns moldes porque não podem transmitir a informação, de e para o cliente. Não é já uma questão de saber se os fabricantes de moldes podem instalar um sistema de CAD/CAM, mas se eles se podem permitir não o fazer”. Reading the magnetic tapes send by the customers was then a real problem for the mould makers, then without Cad systems or CAD compatible ones. The ComputerVision system then based in INETI (Lisbon) has been very often asked to read and to plot drawings from files in magnetic tapes, for quoting by the mould makers. Sometimes the plotting of the same file from different tapes was requested from different mould makers competing for orders of the same client (Fonseca, 2004). ComputerVision was the most popular and important manufacturer of CAD systems during the first years of the 80s.
3) Traçagem, using graminho and esquadros, was not rigorous and not compatible with the increasing complexity and precision required by the industry after the end of 60s. The alignment of graminho traces with the blue traces implied a sequential machining of mould components, what meant longer delivery times. Basically the technique was not compatible with the “portuguese / AHA” mould making model.

4) AHA begun using a Nixdorf computer to control mould costs from 1968. Later, in the 70s, it was upgraded to a Data General based system running especially designed software. See Beira (1983).

5) The number of workers reported in the directory has been reviewed and corrected in order to eliminate duplications between companies in the same group of companies.

6) DTI report (2001) says that many of the listed cases are, in a more detailed analysis, concentrations of industries more than real clusters. In another point it is suggested that clusters with similar business and classified under the same name can in practice be very different clusters. A similar question can be raised about the similarities (or not) between mould making around Marinha Grande and Oliveira de Azemeis areas.

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Figure 1

Evolution of non natural plastics.
Based on data from Mossman (1997)
Figure 2

Number of plastic moulding factories in Portugal (1937 to 1956)
Based on data from Callapez (2000)
Figure 3

New Aníbal H Abrantes plant
Marinha Grande (opened during 1953)
Photo from the 60s and original model.
Figure 4

Plastics moulding factories and mould makers in Leiria / Marinha Grande
Years 40s and 50s. Plastic moulding factories based on data from Callapez (2000)
Figure 5

First generation of mould makers for plastics: genealogy (1945-70)
Figure 6

Moulds exports.
Value (million euros). Blue = total; green = USA market
Figure 7
Moulds exports.
Value (million euros). Log scale for the Y-axis.
Figure 8

Mould exports to the USA
Value share (% of the total exports).
Blue bar indicates Portugal entering the CEE (now UE)
Figure 9

Mould exports profiles (USA / Europe / Others)
Figure 10

Exports annual growth.
Blue = total value (as %), red = USA market (as %)
Figure 11

Exports – 5 years periods
Export values (total and USA) in the bar graph.
Exports to the USA market as % of the total exports in the line graph.
Figure 12

Export profiles, by type of final product

- Brinquedos
- Matr. Construção
- Mat. Eléctrico
- Ut. Domésticos
- Electrodomésticos
- Elect./Telec.
- Outros
- Embalagem
- Ind. Automóvel
Figure 13

Aníbal Abrantes and one of the toys (dolls) from his moulds
Photo of the 60s.
Figure 14

Toni Jongenelen
Figure 15a

Moulds for plastics (AHA, 50s)
Head for a doll (toy) (2 moulds)
Figure 15 b

Moulds for plastics (AHA, 50s)
Homeware (spoon)
Figure 16
Mould for glass (40s)
Glass Museum (Marinha Grande)
Figure 17

Plastic parts from AHA moulds (AHA collection)
Years 50s, 60s, 70s and 80s
Figura 18
Plastic parts from AHA moulds (AHA collection)
Years 90s and later
Figure 19

Moulds for plastic parts (toy)
Years 60s. Client: Hasbro (USA).
Figura 20
Moulds for plastic parts (toy)
Years 60s. “Hobby-kit”.
Figura 21

Multicavity mould
Components.
Years 70s. Mould maker: AHA
Figure 22

Copying machine
Years 60s, AHA
Figure 23

Milling machine
Years 60, AHA.
Operator milling directly based on the model (not from a drawing)
Figure 24

Drawing and design room

Around 1965, AHA
Figure 25

Shop floor
Years 60, AHA
Figure 26

Job planning department
Around 1970, AHA
Figure 27

International marketing
AHA stand in fair, 70s
Figure 28

Demography (I)
Base: population of firms according to Cefamol directory (2003)
Total and by regions (Marinha Grande / Leiria e Oliveira de Azeméis / Norte)
Figure 29

Demography (II): 5 years consolidation
Base: population of firms according to Cefamol directory (2003)
Figure 30

Number of workers per company
Base: population of firms according to Cefamol directory (2003)
Figure 31

Number of workers versus firm age
Base: population of firms according to Cefamol directory (2003)
Figure 32

Export price for moulds (euros per metric ton)
Table 1

Trends in mould making for plastics

<table>
<thead>
<tr>
<th>Anos</th>
<th>Molds para</th>
<th>Cluster</th>
<th>Engenharia do Móule</th>
<th>Tecnologias</th>
<th>Mercados</th>
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<tbody>
<tr>
<td>1986</td>
<td>Compressão e escorrimento</td>
<td>Consolidação AVH</td>
<td>Primeiro grupo de empresas de cluster</td>
<td>Máquinas de engenheiras convencionais.</td>
<td>Toyota Linador</td>
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**Note:** The table continues with similar entries for different years, involving various trends in mold making for plastics, along with associated technologies and market information.
Table 2

Types of products and materials

<table>
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<th>Product Type</th>
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</tr>
<tr>
<td>Utilidades domésticas</td>
<td></td>
</tr>
<tr>
<td>EPOCA DA BAQUELITE</td>
<td></td>
</tr>
<tr>
<td>MOLDES PARA COMPRESSÃO</td>
<td></td>
</tr>
</tbody>
</table>

40  50  60  70  80  90  00
Table 3
Mould technologies