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INDUSTRIAL STUDY OF CAST PART DEVELOPMENT

Tanja Saarelainen[1], Petri E. Makkonen[1] and Eric Coatanéa [1]
[1]Helsinki University of Technology, Finland

ABSTRACT
The European foundry industry is facing an increasing cost pressure coming from low-cost countries. Because European manufacturers cannot compete with production costs, they have to find other means. The authors believe that European foundries can improve their competitiveness by providing designing cooperation to their customers. 70 – 80 % of the production costs are determined already in the design phase. If the supplier is involved in the product development, the potential benefits can be remarkable both to the supplier and the customer. This study concentrates on the cast part development process. The first aim was to find how a cast part is developed, what the contribution of different actors (foundry, customer, pattern maker) is and what kind of designing cooperation occurs. The second goal was to find what kind of designing cooperation customers want and foundries can provide. To gain the information, semi-constructed interviews were held in a Finnish foundry, in two cast utilizing companies and in a pattern shop.

Keywords: cast iron part, product development, concurrent engineering, casting design

1 INTRODUCTION
Finnish as well as West European foundry industry is facing an increasing cost pressure coming from low-cost countries, especially from China. According to Friedrichkeit [1] China's attraction is based on rapidly growing market with hundreds of millions of consumers and unbeatably low-cost production. If 12,000 engineers in China cost the same as 2,000 in Germany, it is no wonder that mobile phone manufacturers cannot anymore afford to manufacture in Europe or US in the long term in spite of total automation of the assembly lines [1]. Because European suppliers, including foundries, cannot compete with production costs they have to have a strategy how to maintain their share of production. The strategy can be, for example, to specialize, concentrate on lower volume and quick delivery or provide added value. Added value can be increasing processing degree (for example machining, painting, and assembling) or offering services such as designing help. At the moment most Finnish iron foundries can be considered as raw casting suppliers. Some can be considered to be component suppliers.
The authors believe that European foundry industry could improve its competitiveness by offering designing help to their customers. This is due to following reasons:

- It is commonly believed that 70 – 80 % of the manufacturing costs are determined during the design phase (for example [2], [3]).
- Gating and feeding systems have a significant effect on formation of casting defects [4]

When those comments are combined, it can be thought, that early supplier involvement in component design would be beneficial both to the supplier and the customer. For the customer, the benefits are reduced new model development time and costs, and improved product design and design for manufacturability [5]. Thus the result is less expensive casting. The benefits for the foundry include less defective castings because of better castable construct. That results to more flexibility in the production and lower production costs.
In theory, designing cooperation can be a competitive advantage to a foundry. The main aim of the study was to find out if that is true. Previous research about cast part development process or foundry's involvement in customer's product development process could not be found. That forced us to find out first how a cast part is developed currently, what the contribution of different actors (foundry, customer, pattern maker) is, and what kind of designing cooperation occurs between these actors. Another aim was to find out, what kind of designing cooperation foundries can provide and

customers want. In theory, early supplier involvement has many benefits, but in practice there are several obstacles. Third aim of the study was to list down these obstacles and challenges related to the cast part development process and designing cooperation.

In this paper, we present an industrial study made in Finland. This study was restricted to sand molds and cast-iron castings. In this paper the term "development process of a cast part" covers the steps from customer's product development process to production ramp-up. It also means the development process of a new part. Development of parts, which are already in production, is discussed shortly.

1.2 Methods

The research in this paper can be characterized as empirical research. Information has been gathered to gain insight into cast part development process and how different actors (foundry, customer, pattern maker) contribute to that. Semi-structured interviews (for example [6]) have been held in one Finnish foundry, in two cast utilizing companies (called customer A and customer B in this study) and in one pattern shop. Depending on the company's size, product development engineers, sales/ purchasing personnel and production personnel were interviewed. Interviews were conducted between the end of year 2005 and the spring 2006.

Semi- structured interview was chosen for the research method because no previous research about the topic could be found. Semi-structured interviews enabled to highlight aspects that the interviewers had not thought about. All interviews were tape-recorded and later transcribed into written text. After that the interviews were analyzed by coding into meaningful groups.

Simplified cast part development process is visualized by drawing process models by modifying cross-functional flowcharts [7] to own needs. The interview results are compared to literature findings to the extent that it can be done.

1.2 Presentation of the Interviewees

Both of the cast using companies are customers of the foundry and the foundry is a customer of the pattern shop. Both customers order serial cast iron castings, and they use several subcontractor foundries. Customer A uses mainly domestic foundries and a few European. Customer B purchases most of the volume from low-cost countries, but they use also West-European foundries. The companies were chosen for the study because they were considered to be good examples of how suppliers are involved in the cast part development. In this study one specific product was not followed, but the study is concentrated on general experiences the interviewees had. Interviews were continued with other companies later in year 2006, and some of those results are also referred to.

2 LITERATURE REVIEW: SUPPLIER INVOLVEMENT IN PRODUCT DEVELOPMENT

According to Humphreys et al [8] during the last decades there have been trends for companies to concentrate on their core activities and outsource a variety of functions, which previously have been performed in-house. The reasons for this trend are global competition, which puts pressure to reduce costs, and the need for faster product development. The design and development of complex engineering products is an example of an activity that is transferred back in the supply chain. It happens to different extent [8]:

- most of the development work is outsourced to suppliers,
- the design of subassemblies or components is outsourced, or
- designing is done with the supplier

Suppliers can contribute to the development process variously. Different supplier types with characteristics can be seen in Table 1.

Table 1. Typology of supplier involvement [9]

Supplier input	Characteristics
Assembler in-house design	core competences/ aesthetic critical
Concept and specialist engineering	"Brand" image and styling
Proprietary parts	Major systems and subsystems
Black box: critical specifications	Subassemblies; major design authority with supplier

Detail-controlled: functional parts	Specification by assembler; design for performance; technical (process related) knowledge sought
Detail-controlled; aesthetic parts	Specification by assembler; design for cosmetic aspects
Less complex parts	Specification by assembler; minimal supplier input, mainly process-related
Standard catalogue parts	Assembler specifies and purchases from supplier's catalogue

Another classification of product types and supplier roles in product development has been developed by Laseter & Ramdas [10]. They have identified four different groupings of sourced products. The grouping is done based on the nature of the sourced products, their cost structures and the nature of the original equipment manufacturer – supplier interaction in product development. The four different groupings of sourced products are [10]:

- Critical systems are highly differentiating, high cost, highly complex systems. OEMs provide widely information to the suppliers and suppliers are involved early in product development.
- Hidden components are less differentiating, low-cost simple components that are defined by physical specifications. Suppliers are involved later in product development.
- Invisible subassemblies are non-differentiating, moderately costly and complex systems. Suppliers are given information via a mix of performance specifications and detailed physical dimensions
- Simple differentiators are highly differentiating, moderately costly, simple assemblies or components.

Benefits gained through supplier involvement in the product development are for example [11]: reduction in product development cycle time, redesigns can be avoided, more efficient operations and higher productivity, overall cost savings, easy to manufacture parts and more reliable products.

3 CAST PART DEVELOPMENT

In Figure 1 the traditional product development process is presented. Based on the interviews, we found, that in most cases customers contact the foundry for the first time when they ask for offers. At that point the concept development and the system-level design have already been performed, and quite often the detail design is almost fixed. This means that foundries can make only minor changes to the geometry of the part. Based on this founding, this paper concentrates on the development process from detail design phase on (see Figure 1). It was difficult to form a uniform picture of how the process proceeds, since it is product-specific. Also human and technical resources affect that. That is why this study concentrates on a generalized description.

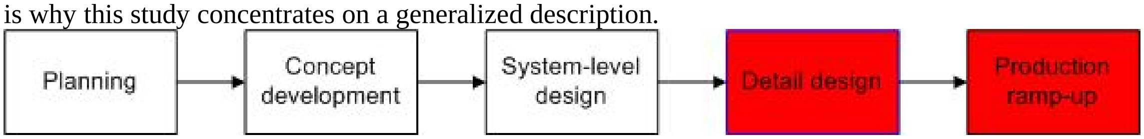

Figure 1. Product development process [12]

Simplified cast part development process based on the interviews is visualized in Figure 2 and Figure 3. The process is modeled in chronological order. Designing cooperation is marked to the models in red arrows. In reality, the processes are much fuzzier and not unambiguous. In Figure 2, the development process from the customer's detail design phase to the price negotiations is presented. In Figure 3, the production ramp-up process is presented. Sometimes the cast parts are machined by the foundry or by a foundry's subcontractor. In these cases the customer asks offer for the machining as well. This study is restricted to the casting process, so the post cast processing is not included. However, it was mentioned in the interviews, that a foundry can achieve bigger benefits and savings, if it also machines itself.

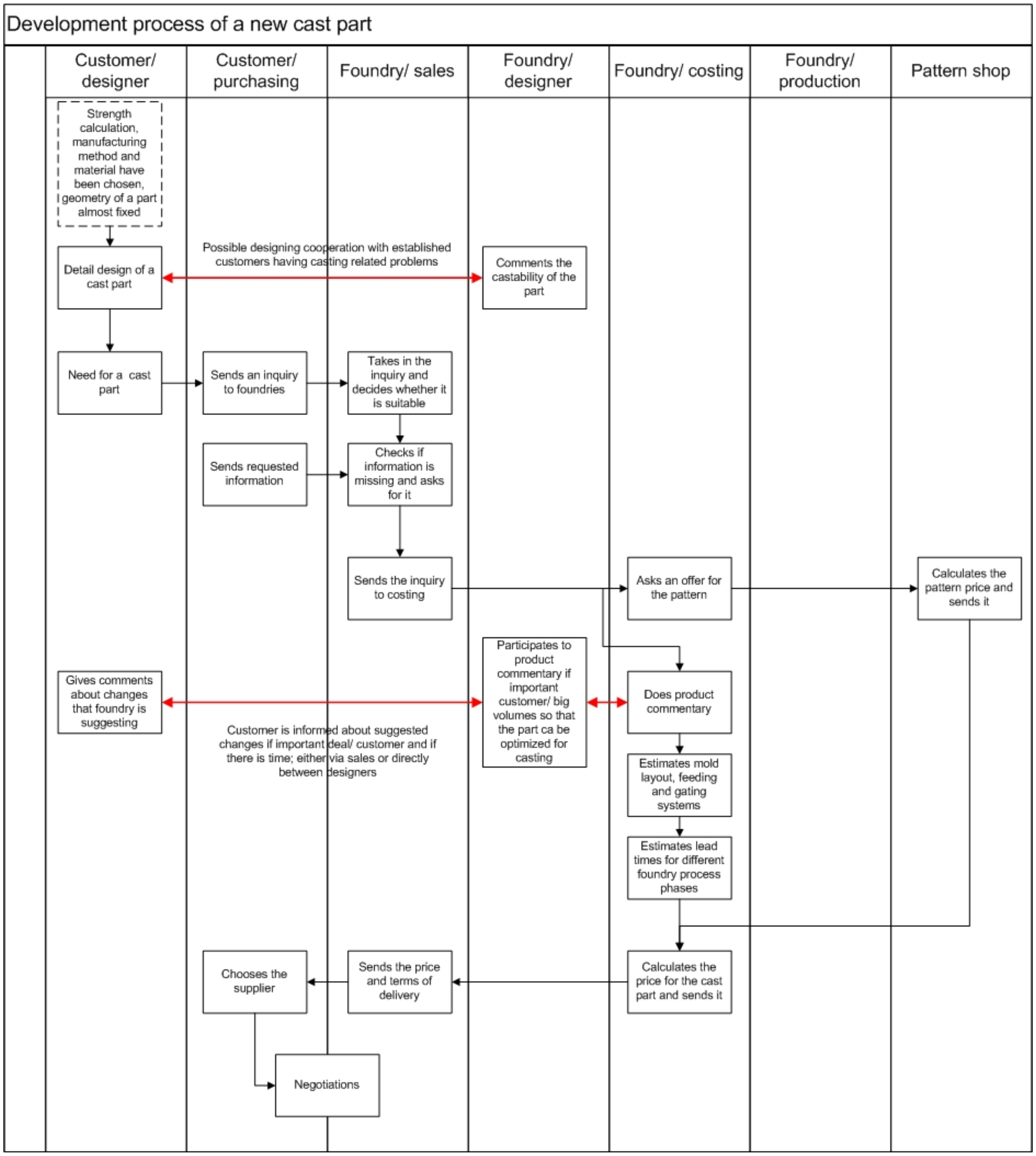

Figure 2. Simplified cast part development process: offer process

Before contacting the foundry, the customer has already selected manufacturing method and material. Customer has also almost fixed the part geometry. According to the interviewed foundry personnel, the design cooperation done with the customers is connected to inquiries. Established customers might send 3D-files of parts before sending the actual inquiry. Then the foundry can comment on the geometry and make suggestions for improved manufacturability. This happens especially, if the customer is developing a new product. They want to get comments of the part's castability before prototyping. In these cases, the part can be simulated to see how to make it more castable. This kind of designing cooperation happens mainly with domestic customers who have enough big production volumes.

With most customers, the first customer contact is the inquiry. No actual designing cooperation happens in these cases. Foundry might give comments like "this hole will be machined, not cast; a feeding filling is needed here; the parting surface goes like this; here is a counter draft that has to be modified; with these changes a core is not needed". These comments are then sent to the customer. The offer is conditional, assuming that customer makes the changes. Customers do not necessary ask for improvement proposals, but foundry give them to stand out from others. In some cases, if the customer is enough significant, these suggestions are discussed with the customer before the actual costing and sending of the offer. This is done in order to get customer's approval for the changes in advance, so that time would not be wasted on unnecessary work. If there are fillets and drafts missing, those do not need to be commented, because they are considered to be known. Cast parts are not typically simulated during the offer process.

Foundry usually gets the 3D-file of the cast part from the customer. The same file is then used in the whole chain. Quite often the 3D-file is incomplete, for example drafts and fillets are missing, and they need to be added. Pattern offer in calculated based on the part geometry, and estimation of how many pieces there are per mold. The pattern maker then estimates, how many CAD-hours and machining hours are needed.

Foundry might continue development of the cast part after the first offer, if the offered price was close enough, and if the deal is enough significant to the foundry.

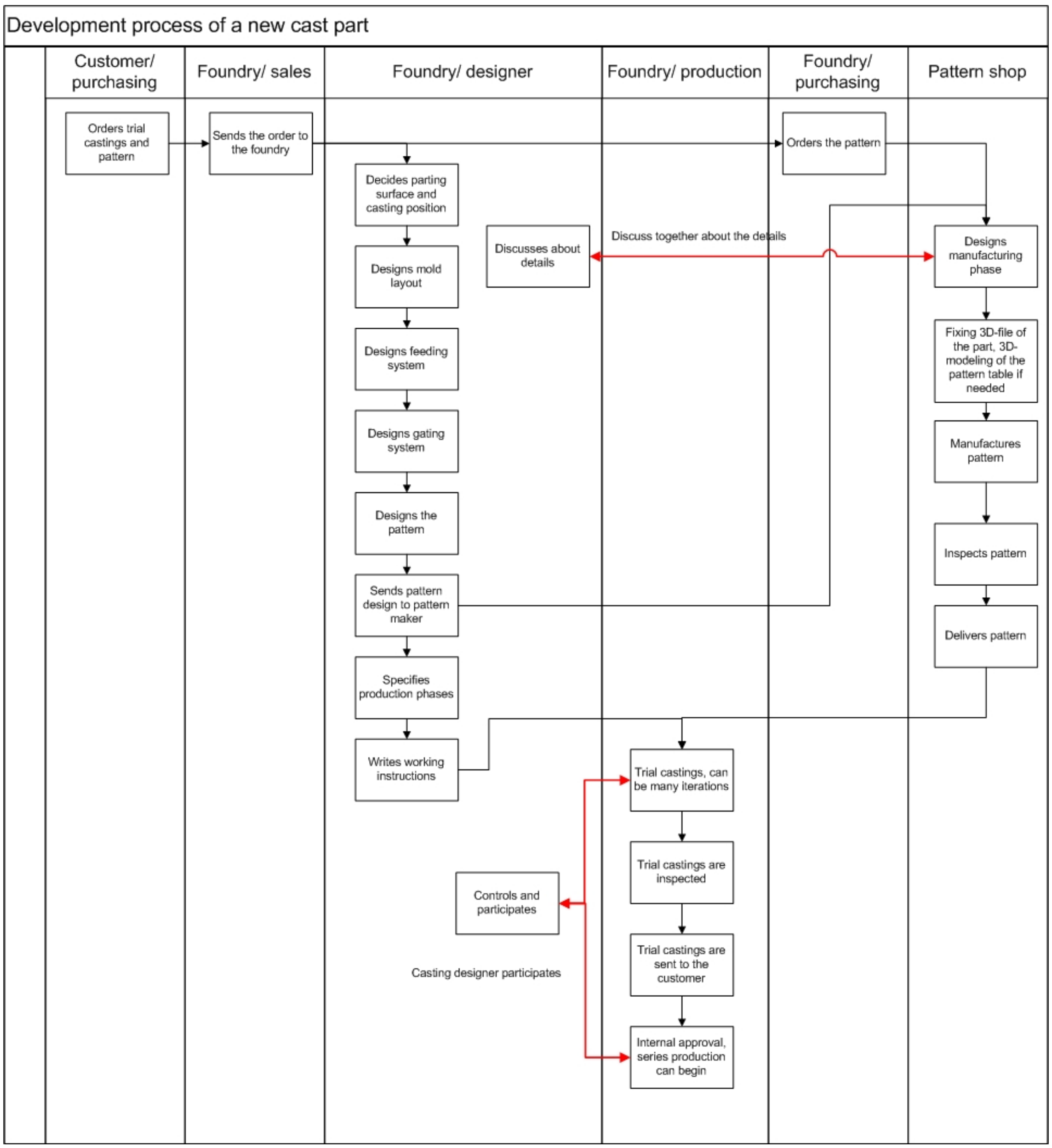

Figure 3. Simplified cast part development process: production ramp-up

While designing the pattern, the foundry's casting designer may contact the customer, if something is unclear or the part geometry needs to be modified. This happens rarely. Usually pattern is designed in 2D. The drawings are then sent to the pattern shop, where 3D-modeling is performed when necessary. During the production ramp-up process, the solidification of the cast part is usually simulated while filling is not.

Typical problems in the trial casting phase are:

- the part does not form in the molding or core making or
- there are shrinkage cavities in the casting

Time-scale for production ramp-up is 6 – 8 weeks.

When the cast part is in production, the costing might be redone. It can be reconsidered, how the production could be made less expensive. Usually there are yearly price negotiations between the foundry and the customer. Especially customers with big volume production use this tactics. The foundry has a target to earn further, and the customer wants to cut down prices. The foundry has to modify the part's geometry or try by other means to make the production costs lower.

3.1 Designing Aspects

When the cast part is developed, several aspects are to be taken into account. The most important to foundries and customers is to have good quality castings as low cost as possible. Based on the interviews, customers try to minimize the number and size of cores, and need for cleaning. Attention is also paid to roundings, drafts, thickness variation, and what would be optimal product to a specific flask. Customer B pointed out that they use only standard materials, and no heat treatment is needed.

Foundry's designers try to cut down the manufacturing costs by making the part more suitable to the foundry's casting process without changing the part's functionality. The optimization of the part is difficult. The foundry is aware of the material and geometry of the part, but typically does not know about the loading conditions or assembly drawings. Costs are cut down by minimizing the need for grinding, or that grinding can be easily performed. Volume products need to be optimized to be able to have the deal. With smaller volumes the yield is not optimized, but the defective rate is tried to be minimized. The interviewees said that cast parts can always be improved.

When designing the pattern, the designer considers what the optimal mold weight is; what the cycle time for pouring is; how to minimize need for post castings operations, for example by attaching risers to surfaces which will be machined; how the gating system is easily removed after casting; and what kind of risers should be used. The feeding system is designed by modulus method [13].

3.2 Communication and Tools

The foundry has a named sales person to each customer. The sales person is the interface to the customer. Sales person and purchaser discuss during the offer process. Quite often the customer contacts the sales person, if there are delivery or quality problems with the castings. Sales person does not usually have accurate information about the situation, so he has to contact the responsible ones at the foundry to get the needed information. If the foundry's and customer's designers do not know each other, the communication at least begins via sales and purchasing organizations. If the designers know each other, they may discuss directly about the development of the part. In the interviews it was mentioned that contacting the customer is easy, but it can take a long time before getting the needed information. Both foundry personnel and customers pointed out, that it is much more effortless to contact and discuss with domestic partner than with foreigners.

The foundry's designer has no contact with the customer's production personnel. Foundry's casting designer has close contact to the pattern maker when the pattern is being manufactured. On the other hand, foundry's casting designer and foundry's machining designer discuss together seldom when optimizing the part for production. Therefore huge potential for the optimization of the whole chain is missed. Foundry's casting designer does not discuss about the pattern design with the foundry's production personnel either.

Most of the communication between different parties happens by phone or by email. Sometimes designers of the foundry and the customer discuss face to face as well as the foundry's designer and the pattern maker. Lot of communication is undertaken through CAD-files or other documents, and they are typically sent by email. Some established customers send 3D-CAD files in native format, but mostly neutral formats like STEP or IGES are used. In the development of the cast part most used tools are different CAD-softwares. Casting simulation softwares, modulus calculating software and some FEM-analysis are used at the foundry. Also PDM, production management system and costing template are essential tools.

3.3 Benefits and Obstacles for Design Cooperation

According to the interviews, the biggest benefits of the design cooperation are:

- faster lead-time for prototype and series production, because the geometry of the part is optimized for casting and it can be done right in the first time
- cost-effectiveness for the foundry and for the customer
- foundry gets new work that is optimal to their production
- better castings and better delivery reliability

Mentioned obstacles for deeper designing cooperation are:

- designing is often customer's own core business; customers designers are jealous and they want to do the actual designing themselves
- lack of resources at the foundry
- foundry has to be competent on that specific field
- customers have to see that designing cooperation provides value to them
- big houses have buyers that guard that you can get in only with money
- foundry does not get any information about operating conditions of the part, surrounding parts, loads etc
- product liability
- foundries do not to put resources to the development if the order is unsure
- customers do not want to commit to one foundry

4 DISCUSSION

Customer A discusses regularly with its suppliers about forthcoming projects, so that foundries can prepare. Time is important factor to customer A. The reason for their use of 3D-fles of parts is to make the chain as short as possibly. Customer A models the parts as ready castings with parting surface, fillets and drafts to be sure that the part fits to the assembly, and the whole chain is shorter. From foundry, they want comments about the castability. They are not interested to outsource designing to a foundry. After the part is developed together with the foundry and prototypes are accepted, the series production of the part is competed. They, the customer, see that with its own know-how the foundry can get the production to stay. The customer is willing to take into account foundry's wishes if it is possible. At the moment they buy most of the castings from Finland, even though they could get cheaper castings from abroad. One of the reasons for this is the designing cooperation.

Customer B has developed problematic parts with domestic foundries. With new products, the customer B discusses about the castability with a foundry. The mass production goes typically abroad, to China or East-Europe. The foundry that has done development work can have the back-up foundry position, if negotiations about the price and other terms of delivery are successful.

Both interviewed cast utilizing companies said, that designing cooperation is a significant competitive advantage for Finnish foundries. Neither of them pays separately for the designing help, but they think that the consulting work is covered by the pattern price. The cast using companies are not interested in outsourcing designing to the foundries. The designing help about the castability of the parts is sufficient. Both say that cooperation works well with Finnish foundries, and it is easy to contact. Both of the customers consider that designing cooperation is beneficial to them, but they are not interested in deeper design cooperation than improving castability of the parts.

Based on the interviews, we found that majority of the cast parts manufactured in the studied foundry are not optimized for casting. Customers have mostly defined the geometry before the part comes to the foundry, so the foundry can make only minor changes. On the other hand, most customers do not know enough about casting designing to be able themselves to optimize the geometry for casting. In the foundries, there are not enough resources to provide designing help to all customers, so cooperation is mainly with established customers. When the emphasis is on volumes (these volume parts are not necessary most profitable work or most suitable), there is a potential risk, that defective castings can eat up the whole margin, when the series are large but the margins are small. Interviewed casting designers said that they have been able to participate to part development, that happens in true cooperation with the customer and the casting designer has a real chance to affect, only few times. In practice, at best the geometry of the part is sent to the foundry before asking offers for prototypes. Even if the foundry's contribution at this point cannot be remarkable the part can still be optimized for casting at least some what.

Even if customers are not interested in deeper designing cooperation, the foundry can still improve its own competitiveness by better internal design. Better internal design includes optimizing the gating and feeding systems and mold weight. Casting yield is one significant factor that needs to paid attention to. A practical guide to improving casting yield is available [14]. As it was mentioned earlier, shrinkage cavities are most typical problems in the production ramp-up. If there are shrinkage cavities, it means that the feeding system does not work properly. By optimizing internal designing, the foundry can cut down its production costs, and that way improve its competitiveness. On the other hand, optimizing internal design requires resources and time which, according to the interviews, are at the moment biggest practical barriers to optimized designing. Casting designers also like to hedge one's bets. The basic pattern designing process in the foundry follows the guiding given in literature [15].

The customers were asked how Finnish foundries can secure their existence in future. The answers were as follows:

- western foundries should concentrate on more complex parts
- foundries cannot live by selling only capacity but they have to sell know-how also; common advantage by designing cooperation
- foundries should make business out of prototyping and small volumes with short delivery times
- a western back-up foundry is always needed if the volumes come from China
- making production more efficient; minimizing internal defective rate; maximising yield; minimizing need for grinding etc
- specialization (material, product families etc)
- automatization of operations
- more flexible production
- upgrading processing degree, for example providing machining, painting and subassemblies

Most of the answers above are more or less related to the cast part development, so it is quite evident that foundries need to put more resources to the casting designing, and provide designing help also to smaller customers.

Different supplier types are defined in Table 1. In general, foundries' input is in most cases "less complex parts", sometimes it might be, if castings are critical, "detail-controlled: functional parts". In the other classification by Laseter & Ramdas [10] foundries fall to the "hidden components" – category. At the moment foundries, as suppliers involved in the product development, are not more than component deliverers, whose contribution is limited to making single parts more castable. On the other hand, customers value already this contribution. The next logical step for the foundries would be to provide more upgrading of the part. Interviewed customers have stated that they would like to buy larger entities. In this case larger entity means machined and painted components or assembly of smaller parts. The interviewed customers did not consider outsourcing of designing to foundries appealing.

6 CONCLUSIONS

The designing cooperation between a foundry and a customer is restricted to designing a cast part more castable. Customers do not require deeper designing cooperation, but value the designing help provided by the foundry. Even if customers are not interested to deepen the designing cooperation, a foundry can improve its competitiveness by better internal casting designing. Product development done in the foundry is about bringing down the costs. The interviewees stated that, in future, a Finnish foundry cannot live by selling just capacity, but it has to sell also know-how. In foundries, biggest barrier to providing more designing help to its customers is lack of resources. At the moment a foundry has the role of a component deliverer. In the future a foundry can secure its existence by upgrading the processing degree of a cast part. The required upgrading by customers, according to the interviews, is machining, painting and subassemblies.

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Contact: T. Saarelainen
Helsinki University of Technology
Laboratory for Machine Design
Otakaari 4
PO Box 4100, Espoo
Finland
Phone +358 9 451 5069
Fax +358 9 451 3549
e-mail. tanja.saarelainen@tkk.fi