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Early Supplier Involvement in New Product Development: A Casting-Network Collaboration Model

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***Abstract*—**Early supplier involvement (ESI) benefits new product development projects several ways. Nevertheless, many cast-user companies do not know the advantages of ESI and therefore do not utilize it. This paper presents reasons why to utilize ESI in casting industry and how that can be done. Further, this paper presents advantages and challenges related to ESI in casting industry, and introduces a Casting-Network Collaboration Model. The model presents practices for companies to build advantageous collaborative relationships. More detailed, the model describes three levels for company-network relationships in casting industry with different degrees of collaboration, and requirements for operating in each level. In our research, ESI was found to influence, for example, on project time, component cost, and quality. In addition, challenges related to ESI, such as, a lack of mutual trust and unawareness about the advantages were found. Our research approach was a case study including four cases.

***Keywords*—**Casting Industry, Collaboration Model, Early Supplier Involvement, New Product Development.

I. Introduction

MANY previous studies have focused on the impact of early supplier involvement (ESI) in new product development (NPD) projects e.g., [6], [21], [22], [23], [28]. The benefits of ESI can be, for instance, reduced new model costs, improved quality, faster development, and shorter time-to-market [6]. According to Johnsen [16], the majority of studies in the field of ESI are based on the responses from customer companies. Our study was focused on both customers and suppliers and will present in this paper reasons why to utilize ESI in casting industry and how that can be done. ESI occurs when a customer involves its supplier at the early phase into NPD process. NPD is often complex and consists of several areas that require expertise. This means that one company is rarely an expert in all those areas and for this reason, companies face make-or-buy situations. Because of this, companies often utilize suppliers' expertise in those areas that do not belong to their own core competencies. Nevertheless, in casting industry, companies do not collaborate often in NPD. One reason is that only little information about the impacts of ESI in casting industry exists and the advantages are not well known.

In this paper, advantages and challenges of ESI in casting industry are presented. Through ESI, the companies in a network can save time and money. In the early phases of NPD process, it is possible to affect on the features of components, but at the late phases, these possibilities decrease, and the costs of engineering changes (EC) increase. Beginning the production of a new casting requires a substantial investment in tooling. Optimizing part functionality and manufacturability before this stage can result in lower tooling cost [26]. According to Saarelainen et al. [24], Finnish cast-customers have stated that Finnish foundries could improve their attractiveness by decreasing delivery times, charging lower prices, and providing design cooperation. Our research revealed that ESI enables shorter delivery times, lower prices, and has a positive impact on the quality of cast parts. In addition, it was found that there are challenges related to ESI, such as, a lack of mutual trust and unawareness about the advantages. Saarelainen et al. [24] suggest that collaboration is rare in casting industry because customers are not willing to pay for the design help foundry gives. Furthermore, foundries do not want to tie up resources if there is no guarantee that they will get the manufacturing contract [24].

In this paper is also presented a Casting-Network Collaboration Model that guides companies to achieve the advantages and overcome the challenges of ESI. The model is based on our findings from the case studies and previous literature and it describes three levels for company-network relationships in casting industry with different degrees of collaboration. Because a cast part can be the base of a product or just a bulk part in it, casting projects have different kinds of requirements. The Casting-Network Collaboration Model defines the requirements for the projects in different levels.

This paper is structured as follows. The following section presents related research from the field of ESI. Section III describes the research methodology used in our research. Section IV presents the results from the case studies and section V presents the Casting-Network Collaboration Model.

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Section VI includes the discussion, the evaluation of the findings and the limitations of the study. Section VII presents conclusion and ideas for future work.

II. Early Supplier Involvement In New Product Development

A. *Advantages of Early Supplier Involvement*

Many previous studies have suggested that both the customer and the supplier can benefit from ESI. One suggested advantage of ESI is reduced development and manufacturing times [5], [8], [17], [21], [22]. ESI often includes concurrent engineering and according to Dowlatshahi [5], it leads to better communication between companies. The advanced communication results in better component design [17], [21], [23] with fewer redesign iteration rounds and late ECs [5], [8]. The improved component design results in better manufacturability [5] and faster manufacturing process [17]. The reduced number of redesign iteration rounds and late ECs shorten the development project [5].

The other suggested advantages of ESI are decreased costs and improved quality. The cost per unit decreases because the improved manufacturability of the components results in less rework and fewer scrap parts [5]. The quality of the parts can be improved by ESI because supplier’s knowledge is brought in the process when it is still possible to influence on quality. The quality improvements can be, for example, improved reliability of parts or lower maintenance costs [5].

Petersen et al. [23] suggest that a major reason for ESI is to access more and better information earlier in the development process by leveraging the supplier’s expertise. For example, the automotive industry – a major user of cast components – is constantly trying to shorten the development time for new products through ESI. The companies are forming alliances with suppliers and switching their purchasing strategies from individual components to subsystems to produce maximum added value for their projects [20].

B. *Challenges Related to Early Supplier Involvement*

A lack of trust often hinders relationships between companies [1], [8], [22]. It makes companies protect their know-how because they fear losing a part of their competitive advantage [22], thus, communication becomes poor and formal. The lack of trust also prevents open-book costing because suppliers are afraid that once a customer knows cost information, the supplier will lose its negotiating power and profit margin will be squeezed [15]. When using open-book costing, the customer has access to the supplier’s cost information. The lack of trust can also be a consequence of a poorly developed performance measurement system. Measurement systems should emphasize teamworking and long-term thinking, but buyers are often rewarded for how low prices they can negotiate [22].

Change resistance can be a barrier for ESI. Customer’s designers may not be willing to let the supplier’s designers participate in the design process [6], or the customer’s management may not be ready to let go the control of the design responsibility related to a component [1]. However, if a supplier is not involved at the early phase, the specifications of other parts may be fixed so, that the supplier's possibilities for designing a particular part may be reduced considerably [28]. In that case, the customer cannot fully utilize the supplier’s expertise in the development of the component.

C. *Keys to Successful Early Supplier Involvement*

The strength of the relationship is important in collaboration between companies. Mutual trust and good communication between a customer and a supplier are the keys to strengthen the relationship [15], [22], [23]. Open communication and information sharing develop trust and motivate the supplier to high-class performance [15], [27], [29]. According to Dowlatshahi [6], suppliers are often expected to provide parts without knowing what they are being used. However, there are companies such as Toyota, which provide a layout of the area surrounding the suppliers' component system for early-involved suppliers [17]. The suppliers' engineers can then better understand how the parts they make fit surrounding parts.

Long-term commitment is a way to build trust. For example, one way Toyota creates long-term commitment is that once suppliers have a contract for a part, it remains as long as the model is manufactured [17]. Willingness to share risks also creates trust between a customer and a supplier and makes long-term commitment easier [15]. A customer can motivate a supplier, for example, by agreeing to give a certain share of the total production volume to the supplier [22].

The collaboration should benefit both the customer and the supplier. Successful relationship with ESI requires principles for sharing the rewards of collaboration. Kulmala et al. [19] have identified issues leading to the requirement of profit sharing: First, when the customer concentrates on a few key suppliers these suppliers should be able to account the influence of volume increase in their profits. Second, instead of supplying individual parts, these suppliers should be responsible for bigger assemblies, and the increased responsibility should be rewarded. Profit sharing requires trust and transparency in cost accounting, for example, through open-book accounting on both supplier and customer ends [4]. One possibility for profit sharing is to give each partner an agreed share of the product’s total revenues. Giannoccaro and Pontrandolfo [12] have proposed this model for revenue sharing between the manufacturer, the distributor, and the retailer. Wynstra and Pierick [28] have mentioned that customer’s every department must fully understand the supplier’s role in a product development project, or problems occur. This is valid also in profit sharing.

One major key to successful ESI is a customer’s ability to manage its suppliers’ involvement in all projects and appropriate procurement methods for each project. The customer should decide which suppliers get design responsibility in each project and how much. If a customer does not manage the total supplier involvement, it may end up spending as much time on coordinating and managing supplier involvement as it saves by giving suppliers more development and engineering responsibility [28]. To be able to manage the total supplier involvement well, a customer must also understand what kind of procurement operations different components require. For example, procuring a strategic or noncritical component sets different needs for supplier involvement. For instance, Kraljic [18] and Gelderman and van Weele [11] have presented principles for procurement, based on how critical the components are for a customer and how difficult they are to procure. Stjenström and Bengtsson [25] point out that ESI suits better for strategic, more complex products than for stock items.

D. Collaborative Design in Casting Projects

In the cast-component design process, the geometrical shape and dimensions are defined for a part. General casting design rules can be used to guide the design process. These rules cover the most important casting design considerations but are not sufficient to ensure the quality of the cast components [2]. The quality can be simulated in advance by casting simulations. Casting simulations are process specific analyses done with special software, which can numerically simulate the filling and solidification in the casting process for a designed part and casting layout [14].

In casting process, filling a 3-dimensional shape with molten metal is a complex phenomenon. For many casting processes, mould filling determines the quality and mechanical properties of the final product. Excessive turbulence, air or gas entrapment or premature solidification during the filling can spoil the final product [14]. Adding a feature to part design can change the flow pattern and cause casting defects and locally reduced mechanical properties if not corrected by re-design of the casting system and assured with new simulations. Every new casting should be examined with simulations and the casting layout and process parameters designed accordingly. This type of analysis has become a standard in the casting industry. Simulation of the process gives the user – typically a foundry engineer - a thorough understanding of the outcome of the casting process and, among other information, a forecast of casting defects and their locations. User experience is required to interpret the simulation results and to suggest modifications to the part design or casting system.

Casting simulations are an essential function of the collaborative approach with sub-contracting suppliers. Effective use of these simulations requires supplier involvement in the product design phase and the simulations with resulting design modifications allowed before the final design freeze point [26]. If process simulations are conducted by suppliers after designs have been completed and the part formally sourced, the possibilities are limited to adjusting process parameters and the opportunity to improve manufacturability is lost [26]. Thorough understanding of the component's design specifications is needed to produce well performing, cost efficient solutions for volume production. Product cost structure can be leveraged best early in the development process [26], as presented in Fig. 1.

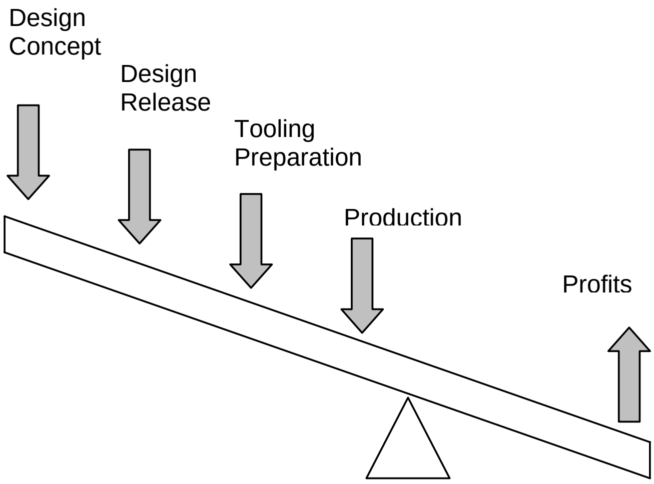

Fig. 1 Project-cost lever illustrating returns as a function of when an investment is made [26]

Post-casting manufacturing operations increase the total manufacturing cost for the component. Cast components have typically multiple machined features, such as planes, pockets, holes, and threads. Manufacturing operations and their related parameters need to conform to castings exactly as they are when delivered for machining. Any minor change to part design or its casting process may cause need to adjust or modify machining fixtures and to update setup instructions. Adding a new feature to design at this stage may require added machining operations and again results in increased total production cost. To produce maximum value to the customer the common goal for the sub-contractor network should be set at optimizing the complete process from design to delivery for the components.

III. Methodology

Our research was an empirical primary research and the research approach was a case study with multiple cases [30]. The number of cases was chosen following Eisenhardt's [7] suggestion for the reasonable number of cases. Our research included four cases.

The case-foundries were selected so that others had more experience from ESI and others less. The customer companies for the cases were chosen together with the foundries' representatives from their current customers. Interviewed people in the foundries represented top management, sales, and design. The customers' interviewees represented strategic purchasing and design. All the companies were located in Northern Europe. Three foundries were small and medium-sized firms and one foundry was a part of a larger corporation. Foundries used different casting processes, for example, sand casting, and die-casting. Customers were large corporations operating in the area of machine building industry and in construction industry.

The data was gathered by semi-structural interviews. Interviews covered 14 people from four foundries and three customer companies. In one of the cases, the foundry belonged to the same corporation with its main customer and that foundry's customer was not interviewed. Data was gathered relating to collaboration between a customer, a foundry, and other relevant suppliers (e.g., tool manufacturer and production machine shop) in the customer's NPD process, including the process flow between companies, the advantages of ESI, the challenges related to ESI, the enabling factors of ESI, and also the customers' purchasing policies and supplier choosing criteria. In this research, the collaboration process was set to begin when a customer contacts the foundry for the first time concerning a NPD project, and to end when the foundry delivers the first parts to the customer. Nevertheless, the time after the delivery was also considered, because the causes and the consequences between the design process and the following time cannot be separated.

The interviews were recorded and notes were made during them. The recordings were transcribed and added to a research database. Relevant issues from the transcribed text were sorted with selected key words with Atlas.ti software. Each case was first studied individually and then the case results were compared and conclusions drawn. Based on the results of the interviews and previous literature the Casting-Network Collaboration Model was built.

The structure of the Casting-Network Collaboration Model is based on the idea of maturity levels. Maturity levels describe the maturity of an organization from a certain aspect and aim at a structured description of the organization's processes. The idea of maturity-levels is presented, for example, in Capability Maturity Model Integration (CMMI) whose purpose is to provide guidance for improving an organization's processes and its ability to manage the development, acquisition, and maintenance of products or services [3]. Likewise, maturity levels are described in the researches of Farrukh et al. [9], Fraser et al. [10], and Graaf and Kornelius [13].

After the interviews and building the Casting-Network Collaboration Model, three validation rounds were gone through to achieve saturation for the correctness of the case results and the usefulness of the model. The first validation round was done in the same companies with the same people as the interviews, and additionally, some complementary data was gathered. The second validation round took place in a seminar with 23 foundry and customer participants. Discussions were mostly done in three workshop groups and they were guided by semi-structured interview questions. Concluding discussion was done in one group with all the participants. The third validation round took place in a seminar with 148 foundry and customer participants. The results of the case studies and the model were presented to participants and comments were collected.

IV. Results of the Case Studies

A. Advantages of Early Supplier Involvement in Casting Industry

It was found that the advantages of ESI in casting industry are time saving, cost saving, and the improved quality of the cast parts. These advantages and factors leading to them are presented in Table I. One place where time saving realizes is after a request for quotation. Often it takes several weeks for a foundry to quote a part, because at this point the foundry needs to check, whether the part is possible to cast and if there is a need for engineering changes. In addition, customer needs, quality requirements, and material requirements need to be clarified. Usually customers are in a hurry to start production when they send a request for quotation and therefore additional clarifications waste critical time. If the clarifications were done concurrently in the earlier phases of the customer's product development, the quotation could be done faster and critical time would be saved. Another reason for time saving is that a foundry can prepare for the customer's order in advance and start production quickly, because it knows the part's requirements thoroughly. Time saving is possible also in production because ESI improves the castability of the parts. Foundries are specialists in castability issues and therefore the castability improves if a foundry has a chance to influence on the part design. When the castability improves, the foundry's production runs into fewer problems, which leads to fewer rejected parts. One foundry representative gave an example that the percentage of rejected parts can be as high as 50-75% for poorly designed parts at the beginning of the production.

ESI enables cost savings in several ways. Reduced time in a customer's design process and a foundry's production process can be used to productive work, which means lower unit costs. Costs decrease also when fewer rejected parts are produced. When a foundry is involved in a design process at an early stage, it can influence to a part design so that the further part handling is possible with less manual handwork. One foundry representative pointed out that in one case the tooling costs for processing the parts reduced about 80 percent with the right kind of design. In addition, ESI increases the possibility for finding new design solutions for a cast part, because a foundry views the customer's component from a different point of view. One example of a new solution is integrating the functions of multiple welded parts into one cast component to reduce the number of parts needed to the assembly. An example of gaining advantages from ESI was presented in a seminar arranged by us. The customer involved the foundry in a product development process and collaboratively they examined the whole system a cast part was planned to be a part of. They managed to decrease the number of parts in a component from 20 welded to one cast. In addition, the weight of the component reduced 39% and the costs of the component reduced 35%.

The quality of cast parts improves through ESI because quality-improving changes are possible at the early phases of

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the NPD project while the designs of the surrounding parts are not yet frozen. A foundry's designer can contribute to, for example, material decisions, and the geometry of a casting. Material decisions have influence on the length of a part's life, and the geometry influences on the cooling and solidification of a part. These both have a great influence on the quality of the part.

TABLE I
ADVANTAGES OF ESI AND FACTORS LEADING TO THEM

Time saving	Cost savings	Improved quality
- Reduced need for additional clarifications on critical path - Early preparation for customer orders - Improved castability	- Improved castability - Reduced time - Eased handling after casting - New solutions	- Material choices - Geometry decisions

B. *Challenges of Early Supplier Involvement in Casting Industry*

Two main challenges hindering the implementation and utilization of ESI were found. The first is that relationships lack a mutual trust. The second is that the advantages of ESI are not clear nor benefit each participant of the project. The foundries' lack of trust resulted from an uncertainty of compensation for their inputs. Even if a foundry uses its resources to support a customer's NPD process, compensation or manufacturing contract is not certain, because usually the companies do not have contracts before making the order. Furthermore, customers were afraid that their competitors would gain knowledge of their products' technical solutions if the foundry was serving both companies.

A lack of trust causes several harmful consequences. Customers often contact foundries too late in their NPD process because of the lack of trust. At the late phases of the NPD process, the designs of components are already frozen and only minor changes to parts are possible. Even if a customer did contact a foundry at an early phase, the foundry would probably not be willing to participate in designing if there was no contract for a compensation of the foundry's inputs. The lack of trust causes also poor communication and information exchange between companies. Often customers do not provide enough information concerning the part and the project and as a result, foundries often need to comment and cast parts without the knowledge of surrounding components or even the function of the part.

The advantages of ESI are not clear to all companies because clear measurements do not exist and there are few publicly available reports of the experiences of ESI in casting industry. Because advantages are not clear to all companies, they do not believe that ESI could benefit them enough compared to needed resources. In addition, all the participants of a project do not always benefit from ESI. That happens because there are no measurements and no clear contracts for sharing the advantages. If some participants of the project do not benefit from the collaboration, they are not willing to continue such relationship. Table II presents the causes and consequences of the main challenges of ESI.

TABLE II
CAUSES AND CONSEQUENCES OF THE MAIN CHALLENGES OF ESI

Causes		Consequences
Lack of trust		
-Compensation for inputs -Confidential information	→	-Unwillingness to participate in designing -Late contact -Poor communication
Advantages not clear and do not benefit each participant		
-Lack of measurements -Lack of contracts	→	-Not believed that ESI has enough advantages -Relationship is not attractive

V. THE CASTING-NETWORK COLLABORATION MODEL

On the basis of the results of our case studies and previous literature, the three-level collaboration model for casting industry was built. The model describes three different kinds of company-network relationships in casting industry with different degrees of collaboration, and requirements for operating in each level. The most suitable level for a project depends, for example, on the companies involved, the complexity of the part, the planned volume of production, and the part's importance in a customer's product. Fig. 2 presents processes included in the model. Customer's process covers the design of the cast part and foundry's process covers designing a gating system and the production of the cast part. Supporting network's process covers the involvement of other relevant participants; for example, tool manufacturer and production machine shop.

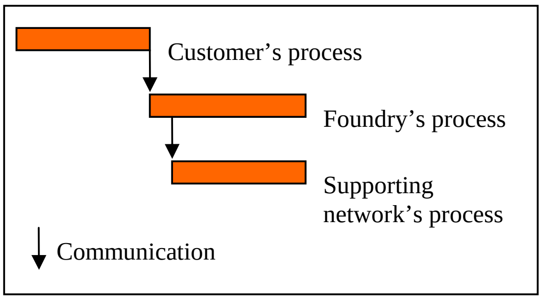

Fig. 2 Processes included in the model

A. *Order-Delivery Level (Level I)*

At the order-delivery level, a customer designs a part and contacts a foundry when the design is ready for sourcing. Hence, ESI is not utilized. The first contact is usually a request for quotation. At this point, the design of the part and related components are frozen. Therefore, only minor changes are possible, such as, adjusting wall thickness or adding drafts. At the order-delivery level, the customer sends request for quotations to several foundries and compares quotations based on the price per kilogram of the parts.

The order-delivery level suits well for simple parts, which do not need collaborative designing for being easy to manufacture. At this level, information exchange between the participants is very limited. In extreme cases, a customer supplies only a drawing and a delivery date of the part to a foundry. A foundry and other suppliers participate only in production and thus the roles in customer's NPD process do not need detailed definitions. Similarly, there is no need for special contract arrangements because the roles are simple and only little information exchange occurs.

B. Cooperative Level (Level II)

At the cooperative level, processes are partly overlapping and the companies cooperate in designing. The suppliers have a chance to comment and evaluate the part's design before it is frozen. This enables changes that make the casting process easier. This level suits for semi-challenging parts, because the collaboration enables castability improvements reducing problems in production and improvements for post-processing.

Contracts become more important at this level than at level one. Because suppliers are now improving the customer's components and using resources for it, the price-per-kilogram praxis is not enough for compensation anymore. This means that there has to be guarantees that the suppliers inputs pay off. A customer can compensate the inputs, for example, by an hourly fee based on the hours that the supplier uses on design work. Another option for the compensation is to contract a production amount that the customer will surely order from the supplier. The foundry instead can motivate the customer by convincing that with the foundry's design expertise, the production will be less problematic and, for example, customer price will be cheaper and delivery faster. The contracts need more attention also because of the increased information exchange and the more advanced roles of the suppliers.

C. Partnership Level (Level III)

At the partnership level, the participants of the network are chosen at the beginning of a project and the processes are fully overlapping. This enables focusing each supplier's expertise to the customer's project at the right time. This level suits for complex parts and parts that have an important role in the final product. Instead of trying to find the lowest quotation, partners develop new value-adding solutions in collaboration. At this level, optimizing the product and the production chain is possible, including, for example, materials, castability, post-processing, and combining separate parts. By inventing new solutions, opportunities for cost and time reductions are much greater in the long run than by price competition.

Close collaboration requires open communication and clear contracts. Every participant needs to have a clear view of the whole project and related components in the product. At this level, companies share plenty of information about their processes and technical solutions. To enable efficient collaboration and ESI the customer needs clearly define its own NPD process, for example, a point when purchasing is involved in the process. Suppliers have such a big role in the customer's process that the role needs very clear definition. Open information exchange and suppliers' big role set strict requirements to contracts. For example, responsibilities, tasks, intellectual property rights, sharing the advantages of collaboration, and the usage of knowledge learned during collaboration need to be agreed upon in contracts.

The partnership level enables more advanced compensation methods than order-delivery and cooperative levels. Instead of paying according to kilograms or hours, compensation could be based on the added value that a supplier produces to a customer. Another possibility is to consider the supplier's input to the project as an investment in the final product. If the final product is a success, the partners share the rewards, but if the product flops, they also share the risk and its consequences. A customer can prove its commitment in a relationship also by investing in the supplier's production machines. At this level, also the principles of price setting could be open. Advanced compensation methods and open price setting add requirements to the contracts.

D. Requirements for and the Effects of Operating on Different Levels

If a customer and a foundry want to start building a closer relationship and move to a higher collaboration level, they need to qualify several requirements. The higher the level the participants want to operate on, the more important the related requirements become. The participants must achieve mutual trust and be convinced that their inputs pay off. On higher levels, also open communication and information exchange become necessary. Moreover, the suppliers' designing skills and understanding about the customer's product and the project become important to enable adding value to the customer.

Operating at higher levels increases dependency, resource need and the likelihood of advantages. When collaboration is intensive, it requires a relatively bigger share of the companies' resources thus increasing mutual dependency. Dependency is beneficial because it forces the participants to invest in the relationship, but the downside is that it makes it difficult to get out of the relationship, if needed. Higher levels require also more design resources than lower ones. Furthermore, the probability of gaining advantages increases when operating at higher levels. The advantages include, cost saving, time saving, a better manufacturability of parts, better delivery reliability, faster delivery speed, and the improved quality of parts. Fig. 3 presents the three levels of the Casting-Network Collaboration Model.

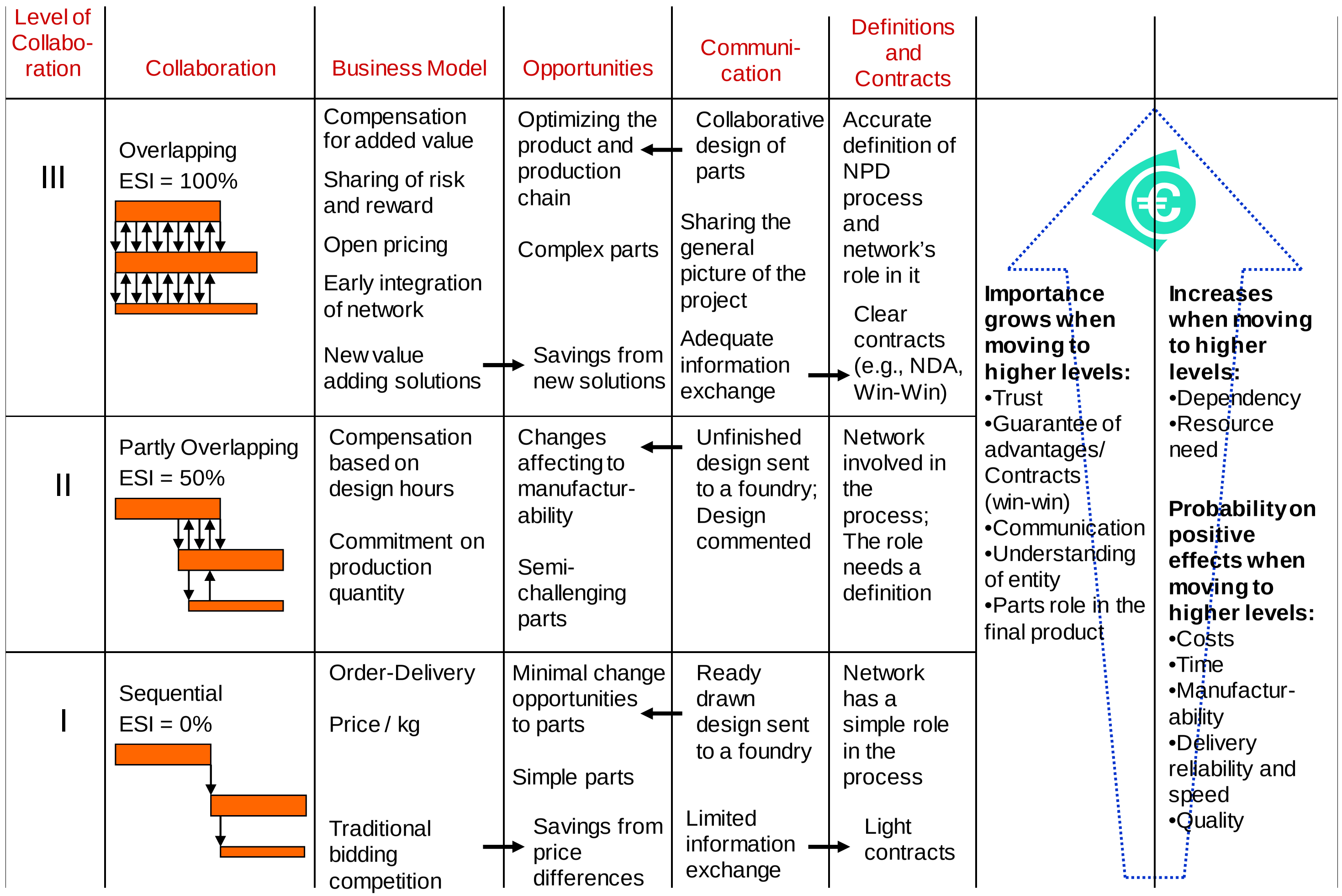

Fig. 3 The Casting-Network Collaboration Model

VI. Discussion

A. Advantages of Early Supplier Involvement

According to our results, ESI can reduce the total process time from an idea to a completed part. Dowlatshahi [5], Kamath and Liker [17], Monczka et al. [21], and Peter [22] present similar findings. Through ESI, the process contains fewer problems and ordered parts are ready faster. This enables better delivery reliability and faster delivery speed. Faster delivery can shorten the time-to-market of the customer's product, because often cast parts have the longest delivery times of the components in final products. Time saving in manufacturing enables also more efficient process for the foundry.

Another finding was that ESI enables cost savings. The studies by Dowlatshahi [5], Kamath and Liker [17], Monczka et al. [21], and Peter [22] support this finding. Cost savings enable lower cost per unit in a foundry and for this reason lower price per part for a customer and higher gross margin for the foundry.

It is also suggested by us that ESI enables quality improvement to cast parts. This finding is in line with Dowlatshahi [5], Monczka et al. [21], and Peter [22] who have discovered that ESI improves quality. ESI makes it possible to design casting for controlled cooling and solidification, which both improve part quality. Similarly, ESI enables higher length of life for the part. Through ESI, critical quality requirements for a part can be more likely fulfilled without special arrangements in a foundry's production. This means that ESI enables a customer to receive parts with demanded quality.

Table III presents how ESI enables time saving, cost saving, and improved quality in casting industry.

TABLE III
THE CHAIN FROM ESI TO TIME SAVING, COST SAVING, AND IMPROVED QUALITY IN CASTING INDUSTRY

	ESI	
- Reduced need for additional clarifications on critical path - Early preparation for customer orders - Improved castability	- Improved castability - Reduced time - Eased handling after casting - New solutions	- Material choices - Geometry decisions
- Improved delivery reliability and delivery speed	- Lower cost per unit in foundry	- Higher length of life - Controlled cooling and solidification
- Shorter project cycle time for a customer - More efficient process for a foundry	- Lower price for a customer - Higher gross margin for a foundry	- Demanded quality for a customer - Less difficult arrangements in a foundry's production
Time saving	**Cost saving**	**Improved quality**

B. Challenges of Early Supplier Involvement

One main issue hindering the implementation of ESI is a lack of mutual trust. One consequence is that companies take first contact too late in NPD projects. This means that if a customer contacts a foundry too late, it cannot fully utilize the foundry's expertise to improve component design. One suggested reason why a customer is not willing to involve a supplier earlier and give more responsibility to it is change resistance [1], [6]. The lack of trust causes also poor information exchange. Often customers do not share enough information about the project nor the product and, for this reason, it is difficult for a supplier to propose improvements. Dowlatshahi [6], Peter [22], and Petersen et al. [23] have also found evidence for the lack of trust resulting in poor communication. They have presented that customers and suppliers fear losing part of their competitive advantage if they share information openly. Nevertheless, the cause and effect of trust and communication is not that simple because Wen-li et al. [27] and Wynstra et al. [29] have presented that open information sharing develops trust.

Another main challenge discovered by us, was that the advantages of ESI are not clear to all companies and, in addition, all the participants of a project do not always benefit from ESI. There should be measures to show advantages explicitly. If the advantages are not proved, it is difficult to justify why to start a new collaborative relationship or to continue an old one. Peter [22] points out that sometimes measures exist, but they measure wrong things. For example, buyers might get rewards based on how cheap they can buy, instead of how value-adding supplier they can find. There should be also clear principles and contracts for sharing the advantages. If collaboration does not benefit all participants, the relationship is not attractive and will probably fail in the long run.

C. The Casting-Network Collaboration Model

The model is divided into three levels, each suiting best for the certain kinds of projects. A partnership-level project would be difficult to implement in a new relationship. Achieving that level requires a long-term relationship. Each project is unique, and intensive collaboration in all projects would require massive resources from the company. This means that a customer should always decide what the desired level for collaboration in each project is. Wynstra and Pierick [28] have presented a supplier involvement portfolio that represents how a customer can get a maximum advantage from collaboration with optimal amount of resources. Considering the three levels of the Casting-Network Collaboration Model, different kinds of components are purchased depending on the level, and different components require varied purchasing methods. Kraljic [18] and Gelderman and van Weele [11] have presented, for example, the difference between purchasing a strategic and a noncritical component. Stjenström and Bengtsson [25] present that ESI suits best for strategic, more complex components.

One challenge for ESI is a lack of trust. At level two, a customer can create trust by paying the supplier based on hours used in designing. Another way is contracting a certain share of the total volume to the supplier. Peter [22] has presented that contracting a certain share of the total volume is one way to create trust. At level three, one way to create trust is sharing the risks and rewards of collaboration. Humphreys et al. [15] suggest that sharing risk is one way to create trust. Additionally, Humphreys et al. [15], Peter [22], and Petersen et al. [23] have presented that mutual trust is one key to strengthen the relationship. In our research was found that the lack of trust causes poor communication. In fact, communication can be limited at level one but at level three, it needs to be comprehensive. Dowlatshahi [6] mentions that some customers expect suppliers to produce parts without knowing the purpose of use. This can be the case in our model's level one, but at level three, customers should provide information about related components to suppliers, which is the case Kamath and Liker [17] present.

At level three in our model, one possibility for compensation is a customer paying to suppliers according to added value. To enable that and a fair sharing of advantages, a relationship needs clear measures to show this added value and the advantages. Moreover, the contracts need to include a way for using the measurement system and a way for sharing the result of collaboration. Nevertheless, measuring and sharing the advantages of ESI in a network are problematic tasks. For example, Giannoccaro and Pontrandolfo [12], Kulmala et al. [19], and Cullen et al. [4] have presented ideas for sharing the results of collaboration. The meaning of giving each partner an agreed share of the product's total revenues would be to motivate the supplier to improve the component and its manufacturability in a way that optimizes the whole product, instead of a partial optimization.

At the partnership level, the network's role in a customer's NPD process is very important. This means that the customer needs to define clearly its NPD process to enable an efficient involvement of the suppliers. The definition includes, for example, the relationship between design and purchasing departments. Wynstra and Pierick [28] mention that the relationship between design and purchasing departments often causes problems having bad influence on product development. At the cooperative and partnership levels, deciding which suppliers to involve in the project should be the task of a cross-functional team.

D. *Evaluation of the Findings and Limitations of the Study*

According to the feedback from the companies involved in this research, relevant problems were found. All the foundries agreed with the advantages of ESI discovered in our research. The customers also believed that these advantages could be possible to achieve, except some customers were suspicious if a foundry could generate new solutions. In fact, some of the foundries had been involved in projects where they had generated new design solutions, but none of the case customers remembered projects like this. Likewise, some customers were not sure if they had ever achieved improved delivery reliability, improved delivery speed, or cost savings. One reason for this is that pointing out the advantages is difficult because of the lack of appropriate measurement systems. All companies agreed with the challenges related to mutual trust and the sharing of advantages. Foundries especially emphasized the importance of contracts as a trust-creating factor. Some customers did not believe that ESI could bring enough advantages compared to needed resources, which was surprising for the foundries' representatives.

The companies' representatives agreed that the Casting-Network Collaboration Model defines the levels of collaboration correctly. They agreed that the issues of the model are relevant to understand discuss in casting industry. However, some customers were a bit suspicious about the practical value of the model, although they agreed with all parts of it. The foundries instead believed that the model could work as a valuable tool when planning new projects. The model evoked a lot of conversation and the general opinion was that casting industry needs a common business model that enables collaboration easier than nowadays.

One limitation for generalizing our results is that our case companies were from a small geographical area. Besides, in customer companies mostly purchasers were interviewed. The results could have different nuances if more, for example, designers had been interviewed. Additionally, the advantages presented in the model include tradeoffs, for example, time reductions and quality improvements may require increase in cost. However, these advantages do not foreclose each other. Furthermore, the results of NPD projects with and without using the collaboration model cannot be compared yet because no project has been finished where the collaboration model has been used.

VII. Conclusion and Further Research

Several advantages and challenges related to ESI in casting industry were found. Both were divided to three main categories. Based on these results the Casting-Network Collaboration Model was created. The model guides companies in casting industry to achieve the advantages and overcome the challenges of ESI. According to our research, ESI can provide the following advantages for casting industry.

1. Time saving
2. Cost saving
3. Quality improvement

Moreover, based on our results it can be suggested that the following challenges need to overcome to enable a well functioning relationship with ESI.

1. Lack of trust
2. Obscurity of the advantages of ESI
3. Sharing the advantages of ESI

For a customer, the advantages result in a shorter project cycle-time, a lower price of parts, and fewer quality problems. For a foundry, the advantages result in a more efficient process, a higher gross margin, and less production difficulties. The advantages would motivate companies to apply ESI in relationships but the challenges often ruin the practice.

Based on the advantages and challenges of ESI, the Casting-Network Collaboration Model was created. The model presents a structured way for companies to achieve the advantages of ESI, meaning, time saving, cost saving, and quality improvement. The model also guides companies to overcome the challenges of ESI, meaning, the lack of trust, the obscurity of the advantages of ESI, and sharing the advantages of ESI. In the model are described three levels for different kind company-network relationships in casting industry and requirements for operating in each one. The best suitable level for a project depends on the companies involved, the characteristics of the components involved, the plans of production volumes, and the goals of the relationship. Additionally, the model presents a structured way for companies building long-term advantageous collaborative relationships.

This paper contributes to the research field of ESI and to casting industry. The advantages of ESI discovered in our research supported those of previous literature. This paper described also how the advantages appear in casting industry. The challenges presented in this paper also supported those presented in previous literature. The practical contribution to casting industry is the Casting-Network Collaboration Model. The model works also as a base for further research.

The field of ESI in casting industry is an important issue for future research. One further research activity could be collecting experiences from using the Casting-Network Collaboration Model in practice. In addition, clarifying how to focus suppliers' expertise at the right time in customer's NPD process to add maximum value would be relevant. Additionally, a measurement system for the advantages of ESI should be created because they are difficult to measure accurately. Furthermore, a general contract model for sharing risks and rewards of close collaboration would be valuable.

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