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A Framework to Inform PSS Conceptual Design by Using System-in-Use Data

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Abstract

Both the Product-Service System (PSS) literature and industry express a need to close the design loop by using product-in-use data to inform PSS Conceptual Design. Nevertheless, how to actually accomplish this is largely unknown. This research makes use of the literature as well as findings from interviews and case studies with industry as the basis for a framework which could utilise system-in-use (rather than just product-in-use) data from in-service records and receiver needs regarding the use of large, capital-intensive, technical assets to generate solutions which could aid the conception of PSS at the Conceptual Design stage.

Key words: Product-Service System, Closed-loop-design, PSS Conceptual Design

1. Introduction

The strength of today’s engineering designers is, in some ways, also a weakness; the designer’s mind tends to be product-centric and often misses the point that the customer is not in need of a product but is, in fact, in need of fulfilling a task which is unique to their business operations and specific to their contextual demands, resources, competences and constraints. The framework outlined in this paper forces a shift in mind-set of the designer away from this product-centric view to more of a systems view. Rather than utilising just product-in-use data, this framework utilises system-in-use data which is data collected from the various elements in a system in which a PSS or a product is embedded. It can utilise system-in-use data from interviews, in-service records or ethnographic means to create a picture of the task devised to meet that customer’s needs and how, within the customer’s environment, their available competences and resources measure up to the fulfilment of that task. It parameterises each element within the system so that gaps between what is desired and what is actually happening can be pinpointed within the system and it then utilises a Proposals Framework which allows generic recommendations of changes to different parts of the system to be applied to the case in hand. These proposals can be used by the provider and customer as suggestions as to how the gaps could be closed so that the customer’s goals could be met more fully. Such recommendations can be then used by PSS Conceptual Design to evaluate if the customer, provider and supply chain have the capability to support any of these suggestions; if so, this could lead to the creation of new, upgraded or customised system designs.

2. Research objectives and methodology

The aim of this paper is to expound a framework which informs Capability-based PSS Conceptual Design. The framework has been based on identified gaps within the literature as well as interviews and case studies with industry. The interviews were conducted with fifteen maintenance experts in industries which produce large, technical and sensored PSS such as aerospace engines and related systems, naval ships, land vehicle systems and infomated trains. The case studies have been based on interviews with relevant experts and the systems analysis of large infomated HVAC (Heating, Ventilation and Air Conditioning) systems, laser systems and sensored trucks. The proposed framework is illustrated by reference to a laser job shop case study; besides this job shop, two other proprietors of job shops and then two senior sales managers of two laser OEMs (Original Equipment Manufacturers) were interviewed. The framework has been applied step-by-step to the case study and then validated with a senior manager of a sensored-HVAC consulting company, a senior laser industry expert and a senior industry and academic expert in Industrial PSS and aero engines. This paper now presents the literature review, then the framework, a case study to exemplify the framework, the initial validation and, lastly, the discussion and conclusions.

3. Literature Review

Both the literature and industry stress a need to close the design loop by feeding product-in-use data into PSS Conceptual Design but how to actually accomplish this is largely unknown[1]. Mont [2] highlights the potential benefits that can be achieved by learning from a PSS in-use but does not propose how the benefits can be achieved. In the wider engineering literature there is a substantial body of research relating to collecting and analysing product usage data. This literature covers health monitoring, prognostics and other information collection methods that can be used to acquire feedback about a product-in-use [3] [4] [5]. However, the emphasis is mainly on maintenance and the avoidance of service interruption rather than closing the loop back to design. Sakao et al. [6] state that although user involvement methods could facilitate the feedback of information to successfully operationally adapt offerings, this is not currently reflected in existing PSS-development methodologies. Furthermore, approaches to Service such as Service Dominant Logic, IHIP qualities and Unified Process Theory lack a framework with the specificity of knowledge, practices, solutions, general problems and scope that is required by a specialised discipline such as PSS [7]. Likewise, although Value Engineering can be useful for understanding systems and can deal with the substitution of materials and methods, it lacks specificity to the concerns of PSS [8]; for example, the term "value" in Value Engineering is defined as function over economic cost whereas within PSS and Service Engineering (as defined by Sakao and Shimomura), the concern of value lies with the value-in-use that the customer experiences [8]. For example, any potential function that a product may afford can only be realised if the receiver has the requisite competences, resources and environment to realise that function and the value of that product will be determined by the degree it helps to accomplish that receiver's goals as compared to other products or services.

Tukker and Tischner [9] state that it is necessary to discover the '*the need behind the need'*. This can be made possible by considering the system in which a PSS or product is embedded as the deeper needs of what the customer is trying to achieve overall would become more transparent. This should also help to reveal the business ambitions of the customer [10]. This contrasts with focussing on just the requirements of product and service offerings as they tend to furnish scant information as to how products and services are actually used in a system to meet an overall objective. A framework to utilise customer information from system-in-use data such as experiences, expectations or suggestions [11] should allow identified receiver problems (experiences) to be depicted and the gaps between what was desired (expectations) and what had actually happened to be constructed; the framework also requires a way (from the identified gaps) to allow for considered suggestions to be constructed and evaluated. Stalk et al. [12] define capability as a set of individual business processes that are connected to customer needs and state that a capability is strategic only when it begins and ends with the customer. To depict such customer processes (that is, the customer's overall aims), Service Blueprinting [13] could be used as, in effect, the customer (by using products and services) is providing a service to themselves to achieve their objectives. As such, any service process that a customer has attempted to integrate a product into could be described as a PSS as this would be an integrated product and service that offers value-in-use [14]. By closing any gaps in the process, more value-in-use would be fostered and it could well be the provider of a product who is best placed to do this by, for example, providing additional services alongside the product that they have granted; that is, moving from being a traditional product provider to becoming a PSS provider. Thus, such a framework could be used to inform PSS Conceptual Design with data from a system in which a product-in-use or a PSS-in-use is embedded. As value-in-use is only manifest at the point of consumption [15], the use context (the resources, competences and environment) under which the products, services or provided PSS is utilised all have to be considered which would mean that data from each and all of these elements in the system is necessary to inform PSS Conceptual Design.

With Service Blueprinting, lines of visibility and interaction within the method also help to distinguish the roles and responsibilities of the stakeholders. Extended Service Blueprinting is a modelling method which describes a service process which consists of service activities and product behaviours [16] [17] and so, for processes in which the issues are more heavily related to detailed product operation, this may be a more suitable method.

Gaps in an existing capability could mean that either the requirements of the capability have not been fully met or that the requirements have changed. Kontoya and Somerville define requirements as '*…descriptions of how the system should behave, application domain information, constraints on the system's operation, or specifications of a system property or attribute. Sometimes they are constraints on the development process of the system*' [18]. These aspects would appear to map to: the process which makes up a capability, competences and resources required to create the capability, the environment and uses to which the system is subjected to and the required parameters of the capability, respectively. As, Alexander and Stevens describe requirement as '*…a statement of need, something that some class of user or other stakeholder wants*' [19], this suggests that, ideally, the framework should be designed to accommodate any stakeholder with any process issue. Five typical approaches have been described by Rios et al. [20] which includes ECSS-E-10A [21], Hooks and Farry [22], Robertson and Robertson [23], Kontoya and Somerville [18] and Pahl and Beitz [24]. These have some overlap with the dimensions of value for services within the context of PSS which have been proposed by Toossi [25] such as reliability and availability which should be particularly useful for this research. However, for PSS development, there is a need for customer requirements to be translated into a process depiction [26] where the designer (and customer) can see exactly where in the process value is lost as well as which aspect and under which circumstances so that this value loss can be designed out. Furthermore, there is also a need to understand what is behind the requirement: for example, a requirement of maintainability could be due to the customer not having easy access to specialist maintenance staff. However, besides an improvement in maintainability, other solutions could also be considered such as the training of local maintenance staff, minimising the causes of the need for maintenance and so forth. This points to the need for a systemic depiction of the process and a systemic set of solutions to be evaluated against each other to improve the value-in-use for that customer.

To conclude, for PSS, a framework is required which can allow the receiver's problems to be depicted as gaps within their existing system within which a PSS or product is embedded. These gaps would show the difference between the desired outcome and what is actually occurring so that new designs could endeavour to fill these gaps. To achieve this, the system needs to be parameterised; Mont suggests that to develop PSS offerings, a trade off between the design of products and services can be made on the grounds of function fulfilment against that of economic value [27] thus functionality and cost could be two such parameters. The responsiveness of the system (how quickly the capability is achieved) can also be an issue for customers as well as availability [28] and so these could be two further parameters. The framework should also allow roles and responsibilities to be depicted so that co-creation can be charted. Suggestions from the customer as to how the system could be changed to address the identified gaps are also required to inform PSS Conceptual Design as well as a scheme to evaluate the suggestions akin to that proposed by Pahl and Beitz [24].

4. A Capability-Based Framework to use System-in-use-Data to Inform PSS Conceptual Design

An existing PSS can be evaluated in terms of the capability that it offers. This evaluation must take into account the customer's unique use-context: the environment, use aims, competences and resources. A technique is also required so that suggestions for solutions can then be devised so that any of the elements (in effect, any part of the system) that make up the capability could be altered to lift the overall capability to a more desirable level. This can then be used to inform PSS Conceptual Design [29].

This paper proposes a capability-based framework which can utilise data from an existing system in which a product or PSS is embedded to inform PSS Conceptual Design; the overall framework steps are shown in Figure 1. In the framework, the capability required is represented by a Service Blueprint (Figure 2). Although Extended Service Blueprinting could be used, Service Blueprinting is used here to aid clarity and also because detailed product operation is not the issue in this particular case, as will be shown later. The environment is labelled on the Blueprint and each element in the Blueprint could be regarded as a sub-capability (a competence, resource or both) for that overall capability. As such, each sub-capability could also be Blueprinted in its own right; this allows for decomposition and the identification of causality. For the purposes of this research, an overall capability has been parameterised, along with the sub-capabilities (the elements in the Service Blueprint) it is composed of, so that any gaps can be ascertained. Four generic parameters have been identified from the literature; these are cost, responsiveness (termed here as span), availability and functionality.

The Proposals Matrix attempts to depict the possible ways that the system could be adjusted to close the gaps of a sub-capability by: adjusting the environment (local or wider), changing the sub-capability where there is a gap (remove it, add to it, substitute it or modify it), or create a new conceptual design (a totally new way to address customer needs) to reduce or remove the gaps. Another way to reduce or remove the gaps is to concentrate on other market segments or clients where the gaps do not occur. The framework offers a problem-solving approach using gap analysis and does not start with the assumption that a PSS is the only solution. The Proposals Matrix proposes ways to adjust the system to maximise value-in use. The suggestions can be more conventional changes or can suggest the creation of a PSS. This way, the value of any PSS proposals can be compared against other suggestions.

The Framework	Outcomes
1. **Depict the System:** Create the blueprint for an existing task (in which the product or PSS is embedded) for which there is dissatisfaction. Examples of possible data sources are interviews with the receivers (the problem statement) and systems analysis of processes.	Shows how the customer's goal is currently achieved.
2. **Define the Desired Overall Capability Parameter Values:** These are dictated by the customer.	Depicts the level and type of performance that is required for the receivers' goal to be accomplished satisfactorily
3. **Define the Actual Overall Capability Parameter Values:** Collect data for this from past performance data. An example of a possible data source could be in-service records.	Depicts how the system actually behaved.
4. **Find the Overall Capability Parameter Gaps:** Find the difference between the Actual Overall Capability Parameter Values and those of the Overall Desired Capability Parameter Values.	Shows what the gaps are between the actual and the desired capability
5. **Define the Desired Sub-Capability Parameter Values:** These are defined by the process-owner and could be defined in supplier contracts.	Depicts the desired or expected level of performance for each sub-capability
6. **Define the Actual Sub-Capability Parameter Values:** Collect data for each sub-capability from past performance data. Examples of possible data sources could be in-service records or product operation data.	Depicts how each sub-capability actually behaved.
5. **Find the Sub-Capability Parameter Gaps:** This is the difference between a sub-capability's Actual Parameter Values and its Desired Parameter Values. Note the sub-capability of where the gaps are.	Shows the location of the gaps within that capability
6. **Find the Gap-Located and the Causal Capability:** For large gaps, decompose the sub-capability by creating a more detailed blueprint of it (a gap-located capability) and, again, find the gaps. Calculate which sub-capabilities contribute most to gaps in the Overall Capability. This can be repeated until no more gaps are found or the lowest level of decomposition is reached – this gives the causal capability.	Locates the *gap-located* capability and the *causal capability* of the gaps within the Overall Capability
7. **Compare different instances of the overall capability:** this will help to find the probable reason for the gap	Infer the reason for the gap
8. **Propose Solutions:** Complete a Proposals Matrix based on the inference above. For each row in the matrix, there is a generic recommendation to be applied to the case in hand to fill the gaps (see Figure 4).	The matrix can be applied by the stakeholder who owns the process, perhaps with the input of the client and provider.
9. **Appraise the Solutions:** Rate and explain the rating for each recommendation in the Proposals Matrix	Stakeholders can select suitable proposals for further evaluation at the PSS Conceptual Design Stage
10. **Conceptual Design:** The solutions are then offered to PSS Conceptual Design to be evaluated and developed by the stakeholders	Co-production

Figure 1: A Roadmap of the Framework to Inform PSS Conceptual Design Using System-in-use Data

To explain the proposed framework, a simple example from a case study with a laser job shop is used. The selected case study has been defined using a limited set of parameters to allow the process to be followed more easily.

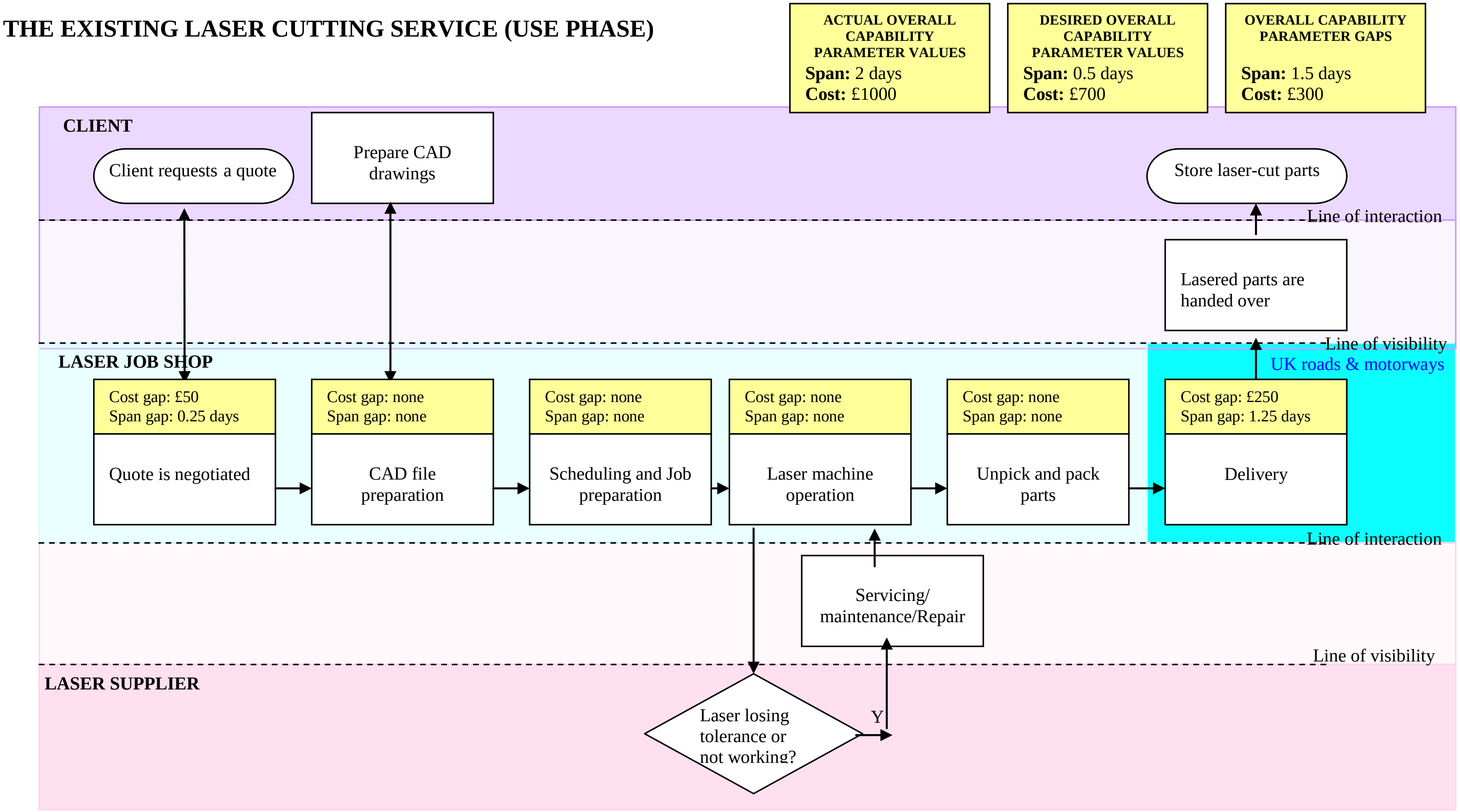

Figure 2: Blueprint for the Current Laser Cutting Service

4.1 Laser Job Shop Case Study: A Simple Illustrative Application of the Framework

Case Study Background: This company provides laser cutting services to industry which, typically, comprise of the cutting and then a delivery service of metal component products based on their client’s CAD drawings. The overall capability here is to provide laser cut parts quickly and at low cost. The reliability, speed, uptime and the ease of use of their series of laser cutting machines was extremely high and the bundled maintenance service was speedy and effective; certainly, the laser job shops, overall, were really quite satisfied with this. Nevertheless, from the interviews, it was apparent that some of this laser job shop’s clients were unhappy with the length of time it took from instructing the job shop to the time that the parts were delivered. For these clients, the costs were also high which made the job shop uncompetitive. This was an issue because, from interviews with three laser job shops, it appears that laser-cut parts have been commoditised; generally, the capability to cut laser parts tends to be fairly uniform amongst the laser job shops and so, at the moment, it is just speed and cost that tends to differentiate the job shops.

Application of steps in the Method:

- ***Step 1*: Depict the Process –** A primary Service Blueprint for the laser cutting service (the overall capability) in which the PSS from the laser OEM (the laser machine and the corresponding maintenance service) is embedded was created (Figure 2). The process under consideration could be an existing PSS or a traditional business relationship. This was then parameterised as *span* (the length of time that it takes for the capability to be effected) and *cost* (the cost of the capability). See Figure 2 - the Blueprint
- ***Step 2*: Define the Desired Overall Capability Parameter Values** - For this client (depicted here), the customer’s desired capability was a span of 0.5 days and a cost of £700. See Figure 2 - The Desired Overall Capability Parameter Values.
- ***Step 3*: Define the Actual Overall Capability Parameter Values –** The time from when the job shop received the request for laser-cut parts until the time that the driver reported that the parts had been delivered. See Figure 2 - The Actual Overall Capability Parameter Values.
- ***Step 4:* Find the Overall Capability Parameter Gaps -** The difference between the Desired Parameter Values and the Actual Parameter Values were then surmised as a difference in span of 1.5 days and a difference in cost of £300. See Figure 2 - The Overall Capability Parameter Gaps.
- ***Step 5*: Define the Desired Sub-Capability Parameter Values -** Each element in the capability (in the Service Blueprint) is a sub-capability and these were also similarly parameterised.
- ***Step 6*: Define the Actual Sub-Capability Parameter Values –** For the parameter of span, the length of time that it takes for each sub-capability to complete was calculated from when it was started until the time it instructed the next sub-capability. For the parameter of cost, the cost of each sub-capability was estimated based on the plant, machinery and staff used for the duration of that capability in this instance.
- ***Step 5*: Find the sub-capability gaps -** Differences between each sub-capability’s actual parameter values and its desired parameter values were reckoned – this gave the gaps for the sub-capabilities. See Figure 2 – the sub-capability parameters of cost and span. The proportion that each sub-capability gap contributed to the actual overall capability parameter gaps was then gauged. It was found that the sub-capability of “Delivery” contributed most of all – this gave the ***gap-located*** capability – the location of the gap within the capability.
- ***Step 6*: Find the cause of the gap:** When the “Delivery” sub-capability was decomposed (Figure 3), it was seen that the size of the parameter values for *Travel to the customer* of span (the amount of time travelling) and cost dictated the size of the span and cost in the higher (the super-ordinate) capability of *Delivery of Lasered Parts*: this gave the ***cause of the gap.***

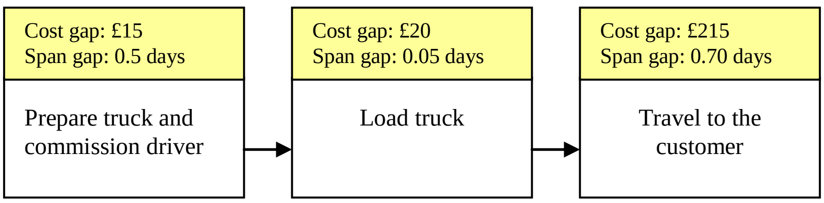

Figure 3: A decomposition of the sup-capability of delivery

For some of the clients of this laser cutting service, delivery took at least half of the total time (the span) and greatly increased costs. For example, although an order of laser-cut parts could be obtained, laser-cut and delivered all in one day for a reasonable price, this process could actually take two or more days if the client was situated a long way from the job shop. This long delivery distance also resulted in a much higher cost.

- ***Step 7***: **Infer the reason for the gap -**The span of the delivery for these clients was also compared to the span of delivery to other clients where there were very small or no Overall Capability Gaps; all of these showed that the deliveries had a small amount of time and cost – these were local deliveries. This gave the ***reason for the gap*** – the amount of kilometres between the customer and job shop showed direct proportionality to the size of the gaps in the overall capability.
- ***Step 8:*** **Define a Proposals Matrix*:*** From the gaps, a Proposal Matrix was constructed (Table 1). The first column postulates several generic ways that any capability can be changed by changing separate elements in the system (see Figure 4).

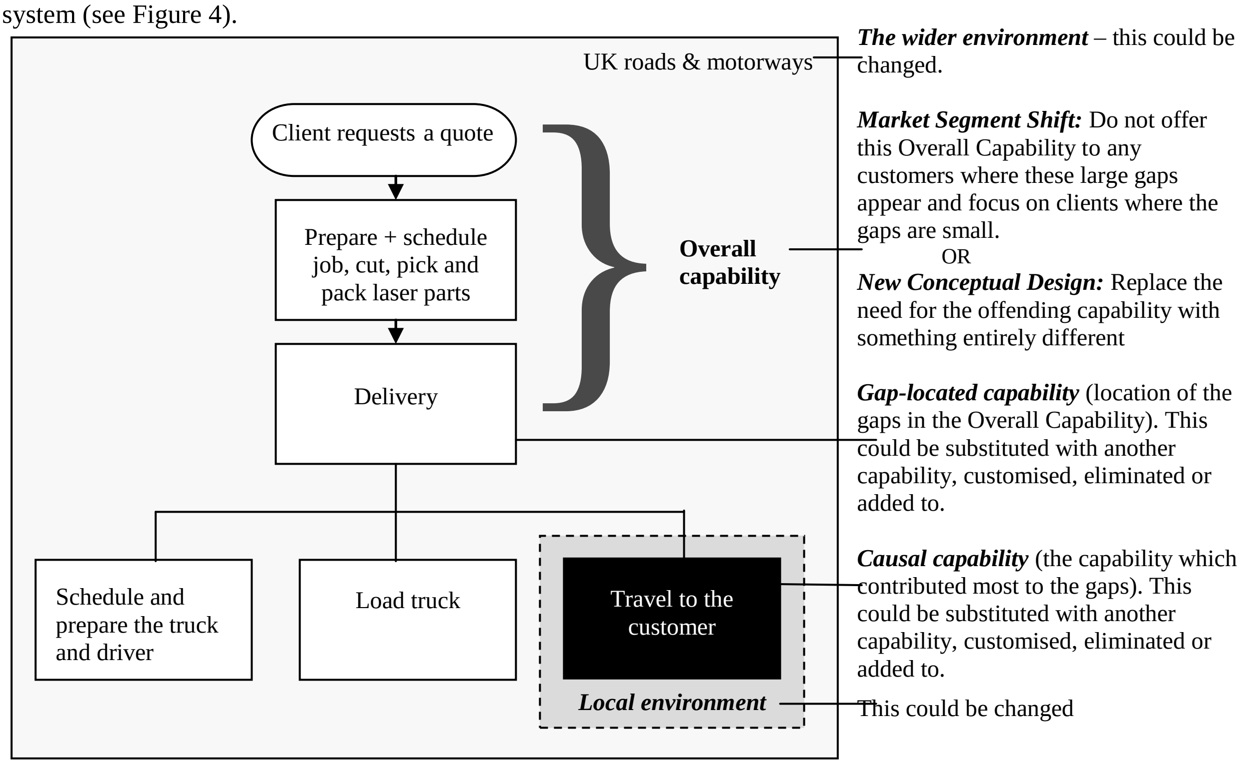

Figure 4: The different elements in a capability and how they could be changed to reduce capability gaps.

It is then for the job shop (with perhaps the help of their provider as well as their client) to apply the generic recommendations to their unique situation (the last column in the Matrix). Although statistical techniques could have been used to develop comparisons of the time and cost of travel as compared to the Overall Cost of the capability and hence pinpoint disproportionate time delays and costs due to deliveries, in this case this was achieved qualitatively from interviews.

- ***Step 9:*** **Appraise the Solutions –**These specific recommendations can then be evaluated and rated for the particular case in hand (Table 1 – last column). From the Proposals Matrix, it was clear that for clients who are far from the job shop that it was the great distance which caused the large gaps of time delay and cost. From the interviews, this job shop was keen to retain their larger clients, some of whom spend in excess of a million pounds per year on laser-cut parts. The job shop's concern was that these clients may either decide to use a more local job shop to eliminate the gaps regarding speed and cost or that, in the near future, there could be laser manufacturers who could offer their clients a new generation of machines that are more easily operable or that are bundled with operator services and offered on a pay-per-use (availability) basis, thus bypassing the need for a laser job-shop. At this stage, the proposals are evaluated to see which ones could be worth putting forward to PSS Conceptual Design. The degree to which each proposed solution is anticipated to close the gaps of span and cost are rated as high, medium or low and then at the PSS Conceptual Design phase, the exact degree to which these gaps should actually close can then be ascertained by assessing the capability of all of the stakeholders to close these gaps. In the Proposals Matrix, the job shop did not put forward proposals 1 or 2 as both of these solutions were totally unacceptable to the job shop although both of these would completely close the gaps. Proposals 3b and 4a were put forward to the PSS Conceptual Design phase to assess their acceptability as well as the capability of the stakeholders to effect them. Figure 5 offers a basic Service Blueprint for the strategy of putting a laser cutting machine onto the client's site. This method of representation is compatible with the IDEF0 system representation of PSS Conceptual Design solutions as proposed by Annamalai Vasantha et al. [29]. It can be seen that the line of visibility shifts so that the processes involved become more transparent to the client. It should be noted that this close partnering could actually be counter to the interests of the laser job-shop as, with time, such transparency could cultivate the client into devising their own services.

Types of Generic Change for the Use Phase	RATING		Application to this Case
	Span gap decrease	Cost gap decrease	
1) NEW CONCEPTUAL DESIGN Basically replace the need for the offending capability with something entirely different– a new Conceptual design.	**High**	**High**	The clients could laser cut their own parts. This would totally remove the need for not just delivery but also the need of this client for the whole laser-cutting capability as currently supplied by the laser job shop. The job shop could receive a large remuneration at the initiation stage for installation and staff training and could be employed at the use phase as consultants. However, this would be far less than what they receive by supplying parts – not acceptable.
2) MARKET SEGMENT SHIFT Do not offer this Overall Capability to any customers where these large gaps appear and focus on clients where the gaps are small. Alternatively, partner with a provider that can fill the gaps more closely.	**High**	**High**	Perhaps smaller clients who are far away could be abandoned although large important clients offering repeat business should be catered for. Partnering with other job shops local to the client could mean a huge loss in revenue and margins are already tight - not acceptable.
3) CHANGES REGARDING THE OFFENDING CAPABILITY			
a) SUBSTITUTE -Find an alternative way to meet the needs of the offending capability. Find substitutes that could reduce or remove the gaps for the capability.	**Low**	**Low**	Alternative methods of transport: There would still be a large time delay even if faster trucks or more competent drivers were used. Planes or trains could be very costly and there would still be a time delay.
b) ELIMINATE -Simply remove the offending capability and do not replace it with anything. However, there could be ramifications for other phases in the lifecycle.	**High**	**High**	Totally eliminate the need for delivery along with its associated costs and time delays. The job shop could place a laser cutting capability on the client’s site. Nevertheless, there would be a large cost and a time delay in setting this up at the initiation phase of this solution.
c) ADDITION -Add a capability alongside the offending capability to reduce the gaps.	**Low**	**Low**	If road works etc held up the drivers then an up-to-date satellite navigation system could help to speed up the journey. Current systems could be updated to provide a small improvement.
d) CUSTOMISE - Modify the offending capability so that the capability gaps will be reduced or removed.	**Low**	**Low**	There would still be a considerable time delay and cost even if the trucks were made faster or more suitable for the terrain.
4) ENVIRONMENTAL CHANGE			
a) CHANGE LOCAL ENVIRONMENT -Change the environment around the offending capability. If an affecting environmental variable is reducing the performance of the capability then this could be enveloped against the effect of the affecting variable.	**High**	**High**	The only environmental variable that impacts upon this capability is the distance between the stakeholders. If this could be reduced or eliminated then the gaps would close; moving closer appears to be the only way to apply this. A laser cutting facility could be set up on or close to the customer’s site. Either way, the initial cost to the job shop could be prohibitive.
b) CHANGE WIDER ENVIRONMENT -Make changes to the wider environment which could close the gaps. This could involve petitioning local government to reduce or remove the affecting variable.	**Low**	**Low**	There are no reasons such as the road quality or lighting which could help the truck to travel faster. Not an issue here.

Table 1: Proposals Matrix – To Reduce the Span and Cost Gaps in Far Deliveries

- ***Step 10:*** **Develop a PSS for the Solution –** At the PSS Conceptual Design Stage, the capability of the stakeholders to create the solutions would need to be assessed [29] and this could be achieved by applying this framework and further solutions found to close any gaps that emerge. Furthermore, the set-up time and the costs of the initiation phase would have to be balanced against the benefits of the use phase of these solutions. The PSS solution of installing a laser cutting machine on the customer's site introduces a new risk for the laser job shop; that is, that the job shop's knowledge and processes may become too transparent to the client. The alternative solution to set up a job shop in the vicinity of the client would help the job shop to protect their knowledge. The relative merits of these solutions will be discussed in the following section.

4.2 Discussion of Case Study Results

The laser case study has illustrated the importance of reviewing the customer's needs for PSS Conceptual Design. Even in this simple example where the main problem faced by the customer is delivery time and cost, the proposed solutions may significantly change the relationship between customer and provider and would have a significant impact on the provider's business model.

In this example, the application of the framework has been instigated by the job shop, but the application of the framework could just as easily have been instigated by the laser OEM to see if a different type of laser system PSS is now more suitable for the job shop. Either way, the outcomes of the framework's application to the job shop's main process would be expected to be the same: that is, for the job shop to investigate the possibility of supplying a laser-cutting PSS to their client or to set-up a laser-cutting service nearby this client and then (after the initiation phase had been considered at the PSS Conceptual Design stage) to see if the laser OEM could help to support the new solution.

The decision whether to provide a laser cutting capability on the customer site or local to the customer site would depend on the nature of the relationship of the client with the job shop and their future concerns. These would be issues to be evaluated at PSS Conceptual Design. Furthermore, if a machine were to be placed on the client's premises, probably only one machine would be installed which could mean that at times of high demand or if the machine is not working that the laser job shop would have to make up this extra capacity (see Figure 5).

At the Conceptual Design Stage, the proposals are evaluated to see if the stakeholders have the capability for the initiation of such solutions and to also ascertain if all of the stakeholders are amenable to them along with any changes in responsibility, roles and ownership. There would be a considerable cost and a time delay in setting up either of the proposed solutions at the initiation phase of this solution and this would have to be traded off against the expected benefits at the use phase. The provision of an on site machine would require careful planning to ensure that the machine is used to capacity and that any overspill to the job shop occurs infrequently so that delivery delays and charges do not cause major capability gaps again. Here, collecting past performance data depicting loads over time as well as knowledge of the client's business strategy could help. Other considerations would be how the operators could be installed; experienced operators could be sent to the client or local people could be trained. Either way, there will be a lead time and a cost involved and supplies would also have to be considered. For the laser manufacturer, offering machines which are easier to operate, allow remote monitoring, offer dedicated laser-cutting processes and perhaps encompass or integrate more of the surrounding processes as well as having a smaller footprint could further facilitate such a solution. The laser manufacturer could consider a more modular design which would allow the laser machines to become dedicated to one or two processes so that many customers could be more easily served in a similar way. It could be possible for the manufacturer to offer the whole solution although this would probably involve the manufacturer stepping outside of its core competences; it is the laser jobs which have the expertise in understanding their client's needs as well as the processes to fulfil them. The business model could consist of a pay-per-use or a leased machine bundled with a process operation service from the job shop for a fixed period; here, the OEM would share the risk with the job shop and the capital investment of the job shop in installing machines near to or onto client's sites would be circumvented. As this could be a PSS where the manufacturer and the job shop are in partnership, it becomes clearer that the need of the job shop (to satisfy its clients) now becomes a need of the laser manufacturer. All of these are challenges for PSS Conceptual Design and simulation of any possible solutions at the use, initiation and end of life phases would help to pre-empt the appearance of any possible capability gaps. If it is found that a selected solution is, at that time, difficult to effect then other proposals from the matrix should be considered. Note that job shop could have stated to the OEM that they were having difficulty in getting their laser-cut parts to clients in time and that the OEM's response could have been to try to make the laser machines faster: whilst this effort would have been admirable, it would not have addressed this particular job shop's concerns. This emphasises the need for a systems rather than a product-centric approach to the analysis and design of PSS solutions.

From the interviews with the laser OEMs, it was apparent that they were not keen to develop any other business models or lasers systems for the laser job shop market as they represent only a very small segment. Nevertheless, it was clear from the interviews in general that there are many other large companies who either have their own dedicated laser cutting processes or who send laser cutting work offshore where the machines used tend to be older and the processes less reliable. It could be the case that customised, process-dedicated laser cutters offered on an availability basis which are bundled with a process operation service could open up these other, larger markets.

Within the PSS context, Toossi. have identified several dimensions of value which are necessary for the provision of maintenance services [25] but which could also apply to services and capabilities in general. Some of these dimensions of value are Delivery, Locality, Cost Saving and Responsiveness. This case study has shown how the speed and cost of Delivery and Locality of the provider can be prime concerns of their customers. The issue of Cost Saving and Responsiveness were also concerns and these have been depicted and addressed. The framework has shown that the cost and speed (the capability parameters) of Delivery resulted in customers paying a much higher price and it took a long time for their laser cut parts to arrive. A possible solution was for the laser job shop to move some capability closer to the customer (increase Locality) which would result in Cost Saving and increased Responsiveness. This would suggest that this framework provides a way to depict customer requirements as determined by the value-in-use they experience by locating and measuring gaps within a capability and then affording a technique to adjust the system in various ways so that these gaps can be reduced to improve value-in-use.

POSSIBLE SOLUTION: A machine is placed at the client's premises and operated by laser job shop personnel – the use phase.

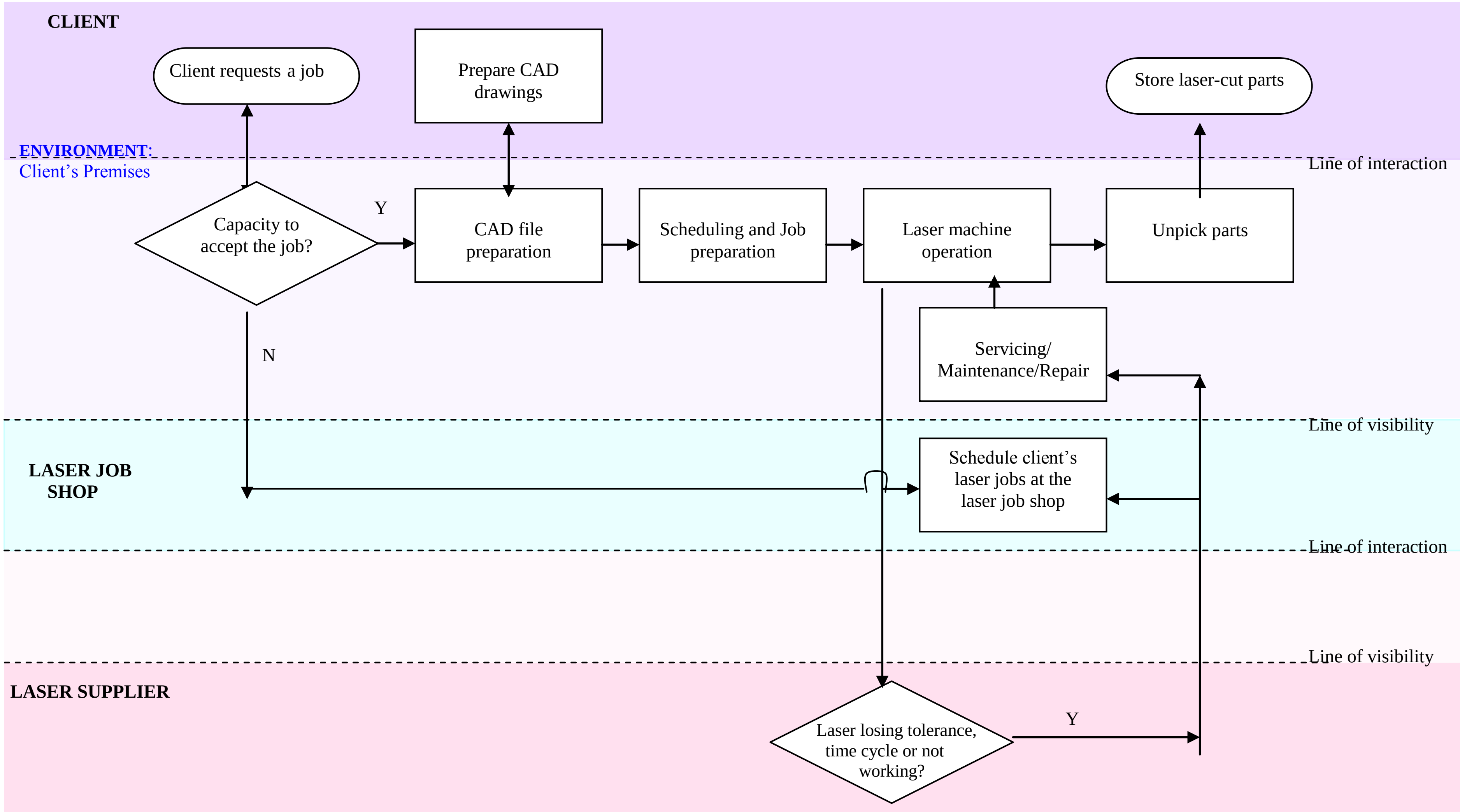

Figure 5: Blueprint - Shift the Capability to the Client's Premises

5. Further Case Studies

A simple example has been offered in this paper to illustrate how the framework can be applied. Besides the laser case study, other case studies of a sensored truck manufacturer and a sensored HVAC Consulting company are also being conducted. This further case study is under way which considers heating and ventilation systems where there is full access to the necessary quantitative data of energy usage, temperature monitoring and sub-system operation as collected from sensors. Although there has also been some debate as to what sort of scaling would be most suitable and effective for the Proposals Matrix, this is expected to be developed further during the course of other case studies where there is more access to detailed data.

6. Initial Validation

An initial validation has been performed to assess the merits and demerits of the proposed framework. The case studies have been presented to three senior managers with knowledge of PSS, HVAC and laser systems. All agreed that the application of the method seemed to produce reasonable results which could then be used to inform Conceptual PSS design to create PSS solutions that satisfy the client more closely. All three, at this stage, did not identify any omissions or failures in the framework but urged for applications of the method to other differing capabilities and to also adapt the framework for large quantitative data sets from sensors. This further work will extend and further validate this framework.

The limitations of this framework is that, for the provider to apply it, their customer’s process has to be transparent to them at, sometimes, quite a detailed level. However, this sharing of business information and trust between stakeholders is absent in many industries and the collection of suitable data for this research has been a particularly arduous task. However, the framework, in essence, could be simple enough for a knowledgeable customer to apply it to their own processes; the suggestions from the Proposals Matrix could then be shared with the provider. Although it would be more informative for the provider to have access to detailed existing process depictions and detailed data from that process, at least suggestions to improve value-in-use would be a step forward.

7. Discussion and Conclusions

As the utilisation of system-in-use data to influence PSS conceptual design is a new idea, there were several challenges in designing a framework to collect, collate and interpret such data usefully. These issues are described below:

- *Understanding the shifts in capability and role:* The provision of PSS can cause substantial shifts in capability and roles for the customer and PSS provider. Such shifts are also changing and merging stakeholder relationships; more clearly, the provider-receiver relation is starting to appear more like a partnership. In point of fact, the provider (to some degree) now starts to resemble a customer; the provider’s needs are now dependent on the receivers’ needs being fulfilled in the long-term – if these are not achieved then the provider could lose revenue. Because of this, the provider has a stake in understanding and then helping to design and cater for the customer’s *overall* task to accomplish a goal rather than just supplying an asset which the customer has to design their system around. Furthermore, the provider may now have to house and/or service and maintain the asset which, previously, was the customer’s responsibility. Similarly, because the provider would need constant feedback as to how the asset and system is fulfilling the receivers’ needs, the customer starts to become a supplier of vital information which could help the provider to customise, upgrade or totally conceptually redesign their offering. This framework is starting to demonstrate the importance of these concepts.
- *Understanding what data to collect and what that data could represent*: This research has developed a framework that specifies which data is to be collected from a system-in-use, how to utilise such data to represent gaps within a capability and then how to determine the nature and probable cause of those gaps. Recommendations can then be created as to how to close those gaps and these can be considered further at the PSS Conceptual Design Stage. Future work will focus on more automated data collection from sensors as well as in-service records to identify gaps.
- *Understanding the need for the data:* Because of this research, an understanding is now emerging of what system-in-use data represents whereas, previously, there appeared to be little understanding of this area. To sum up, the need for collecting this data and a framework to utilise system-in-use data are now starting to be demonstrated. This is now helping to win industrial commitment to take further steps.

This framework facilitates an understanding of the customer’s deeper needs and the problems within their systems as well as providing suggestions as to how the receivers’ needs could be met. As it is parameterised, it should lend itself well to quantitative data such as that collected by sensors. Moreover, the method also appears to outline the steps that need to be taken in order to servitize as servitization is not just about adding services but, essentially, about *serving* the receiver's needs. It does this by:

1. Allowing identified receiver problems (experiences) [11] to be charted as a process. Here, the receiver's task, the *'need behind the need'* [9] of a product or PSS (the task) is depicted which allows for the customer's business ambitions [10] to become more transparent.
2. The capability gaps between what was desired (expectations [11]) and what had actually happened can then be constructed using parameter values.
3. From this, the *location* of the gaps within the system can be defined.
4. Using decomposition, the probable *cause* of the gaps can then be isolated and the extent of gaps can then be determined.
5. The reason for the gap can then be inferred.
6. A set of suggestions [11] (a Proposal's Matrix) can then be created by applying the generic recommendations of how a capability can be improved given the receiver's unique use context, business aims and clients. These suggestions can then be rated by the stakeholders.
7. These rated suggestions along with the system depiction, the capability gaps, the location of the gap, the cause of the gaps and the extent of the gaps can then be used to inform PSS Conceptual Design to seed designs that could help to fill the gaps.

Although laser cutting equipment OEMs are not currently offering higher PSS business models, the authors would claim that they are still in a process of servitizing; this is because many of the sacrifices [9] that the receivers used to make in order for their overall tasks to be accomplished have now been appropriated by the laser machines. For example, over the past couple of decades, laser cutting systems have become more easily operable, more reliable and less expensive. This means that there has been a capability shift from the job shop processes and resources to the laser machine: much of the sub-capabilities that the job shops had to institute to meet an overall capability are not required to the degree they previously were.

The framework could be applied to different stages in the lifecycle where the receivers report they have issues such as with product integration and product attuning processes and not just to the use phase. At the Conceptual Design stage, the framework could be also used to assess the gaps in capability of the provider and supplier to initiate and then support any proposed solutions. Furthermore, it appears that this could also be a framework which could allow any stakeholder issue with any process to be depicted, the gaps found and initial solutions suggested.

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