An Infodynamic Engine Approach to Improving the Efficiency of Information Flow in a Product-Service System

C. Durugbo, A. Tiwari, J.R. Alcock,
School of Applied Science, Cranfield University, Cranfield, UK
c.durugbo@cranfield.ac.uk, a.tiwari@cranfield.ac.uk, j.r.alcock@cranfield.ac.uk

Abstract
In this paper, literature was used to identify and present a worked example of the use of an Infodynamic engine. It shows that: (a) Product-Service System (PSS) information flows can be characterised by such an engine; (b) the engine can measure the efficiency of information flow in a PSS; (c) the engine can be used as a tool to make recommendations about improvements in information flow efficiency in a PSS.

Keywords:
Product-Service Systems, Information flow model, Efficiency

1 INTRODUCTION

Manufacturers in an attempt to stay competitive continually seek opportunities for innovations and value creation. Product-Service Systems (PSSs) are provisions which offer customer value by highlighting the benefits of integrated offerings of product and service artefacts.

PSSs are also 'social constructs' for realising goals, delivering results and solving problems following information gathering [1]. These social constructs consist of actors and their roles as well as possible scenario and representations. These representations could be used to depict and model components for the delivery of a service or information exchanges within and between systems. Established links and communication paths can then be used to support information flow especially in integrated processes involving flow of materials [2]. Modelling this information can be crucial in identifying repeatable and inefficient system processes as drivers for improving quality, efficiency, and financial performance in accordance with ISO 9000 and ISO 14000 [3].

This paper begins with an overview of the PSS concept. The Infodynamic engine approach will then be introduced. This information flow model offers a high-level abstraction of information exchange. Its selection was based on three criteria: efficiency, adaptability and reusability. Information flows in a PSS will then be demonstrated based on a worked example of the Infodynamic engine. Finally, recommendations based on the findings during the worked example will then be used to suggest improvements in information flow efficiency in a PSS.

2 PRODUCT-SERVICE SYSTEMS

A PSS is a concept which offers a medium to foster competitiveness and promote sustainability for the manufacturer and the environment. It is a function-oriented business model [4], in other words it is a technical approach, which seeks to offer commercial value for manufacturers while adding value for customers. Function oriented design is a strategy which involves the decomposition of a system into interacting units [5] while the business model offers value creation.

The PSS approach promotes the need for codesign of product and service subsystems much like traditional hardware/software (HW/SW) codesign methodologies. Codesign or collaborative design recognises the need for designs to realise a goal [6]. Design activities in this approach can run concurrently, improving the time-to-market and optimising solutions.

A PSS is a process system which offers avenues to shift company and organisational focus from 'product thinking' to 'system thinking' in an enterprise [7]. It is a system consisting of product and service systems as well as productized services and servitized products (Figure 1). Servitization in PSS is a practice which closely links and incorporates services with offered products for servitized products just as productization does the converse for services. Products are tangible and domain specific whereas the service offering is made up of intangible artefacts or services such as upgrades and recycling.

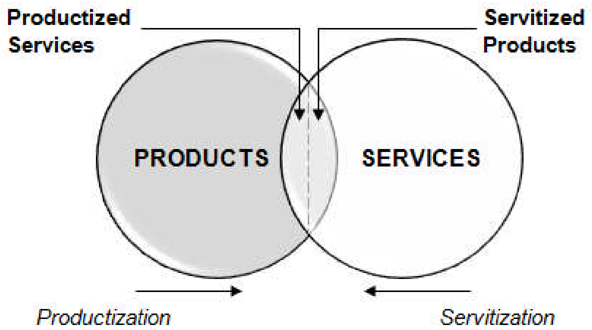

Figure 1: PSS model.

The domain of application, investment and resources are important considerations for choice of service strategy. A service is an activity offered by the one who provides to affect or influence the one who receives. Tomiyama [8] identifies three important features of a service: service environment, service content and service channel. He identifies material, energy and information as forms of service content which are consumed by the service channel within the service environment. Much like a service, information is non-physical but unlike a service, information flow and exchanges especially in organisations and companies usually requires some form of integrity, confidentiality or security. Information models in these institutions could aid in identifying patterns and manners of information exchange.

3 THE INFODYNAMIC ENGINE

An 'Information Engine' or 'Infodynamic Engine' approach to model information flow, with considerations of efficiency in systems, has been presented by Sundresh [2]. This model was selected for use here, because it is based on the Carnot Cycle; which is the most efficient, known thermodynamically cycle supporting reversible processes [9].

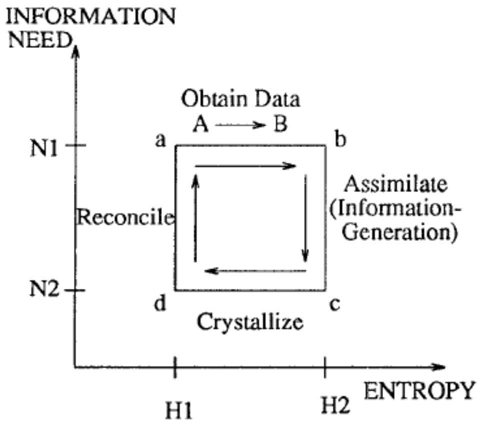

Figure 2: Information Engine Generation Cycle [2]

This Infodynamic engine can be applied for two co-operative, interconnected or integrated processes (or systems) A and B; integrated for the joint realisation of a goal or task by information exchange. The 'Engine's' aim is 'to generate a new piece of directly usable information from the information already in the possession of A and B' [2].

3.1 Measures and operation

'Physical entropy' and 'information need' [2] are the two measures employed in the Infodynamic engine. The physical entropy can be computed as the sum of the algorithmic randomness and the statistical disorder of a given data *d* i.e.

$$S_d = K(d) + H_d \tag{1}$$

Where S_d is the physical entropy, $K(d)$ is the algorithmic randomness (or Kolmogorov complexity) of *d* and H_d is the statistical disorder which is dependent on the conditional probability of the data set.

Zudek [10] refers to the statistical disorder in terms of missing information and the algorithmic randomness with regards to the known randomness (or disorder).

The algorithmic randomness ($K(d)$) for a given data *d* with length d^* is defined as the shortest path which produces *d* and is calculated as

$$K(d) \equiv |d*| \tag{2}$$

The statistical disorder (H_d) provides information about microstates which are unavailable regardless of the presence of *d*. This statistical disorder can be computed as [10]:

$$H_d = -\sum_k P_{k|d} \log_2 P_{k|d} \tag{3}$$

Where $P_{k|d}$ is the conditional probability of the microstate *k* given macrostate *d*

Each microstate *k* can be described in terms of this conditional probability ($P_{k|d}$) with respect to a macrostate *d* which it constitutes. A *microstate* is used in this context to refer to system configurations or arrangements which combine to give a system's *macrostate*. For instance, fluids (gas and liquid) can be thought of as a macrostate, for which concentration of samples (analytes) and fluid dynamic phenomena (fluidics) can be microstates.

'Information potential' is a concept of the model used to describe information held by either A or B, which the other needs to complete a task. Entities with a higher information potential can satisfy the needs of those with a lower information potential.

'Information need' describes this concept in relationship to a particular application. It is defined as 'additional information', i.e. over and above that already existing in the system, required for realising a goal or performing a task. This is equal to the probability of successfully performing a task without possession of information, *m*, i.e. [2]:

$$N = P(\neg m)^1 \tag{4}$$

Where *N* is the information need, ¬ means 'without' or 'not' and *P* is probability.

From the model shown in Figure 2, four phases can be identified. In the first phase (a-b), A is the source and B the recipient of the data. Next, B starts to process the data in isolation. The next stage, b-c, corresponds to an information transformation stage in which the information is processed with respect to the task to be done. At point c the data has now been transformed and begins the process of being separated, 'crystallized,' into the parts usable and unusable for the specific application being considered. In the final step, A and B, 'reconcile', i.e. come up with a piece of information that B needs, based on the prior processes. The reader is referred to reference 2 for the detailed information entropy and complexity arguments which underlie this model.

3.2 Analysis of information flow

In terms of analysis, some characteristics of information exchange can be used to study the information flow such as value of the 'usable information' and 'information flow efficiency'.

The value of the usable information is the first simple measure, which is determined from the product of the information content and the information need i.e.

$$(H_2 - H_1) \cdot (N_1 - N_2) \tag{5}$$

Information flow efficiency can be determined from three concepts of efficiency [2]. These concepts are:

- Information generation efficiency *(IGE)* – comparison of the algorithmic information generated with the total information available;
- Information utilisation efficiency *(IUE)* – comparison of the algorithmic entropy for satisfied need with the initial need;
- Information system efficiency *(ISE)* – comparison of the information value generated with the total maximum information value in the data received. It compares actual use to possible use of information.

These concepts are based on the entropy change between H1 and H2 as well as the information need value difference between N1 and N2. They can be computed as follows [9]:

$$IGE = 1 - H_1/H_2 \tag{6}$$

$$IUE = 1 - N_2/N_1 \tag{7}$$

$$ISE = (H_2 - H_1) \cdot (N_1 - N_2)/(H_2 \cdot N_1) \tag{8}$$

4. Information Flow in a Product-Service System

For PSS, with integrated processes for product P1 and services S1, an Infodynamic engine can be demonstrated. The Infodynamic engine can be either based on a predictive model of eitherP1 or S1 as dictated by the domain of application. For instance, in the transport sector, identifying a new transport route service (S1) in a town can be used to decide the means of transportation (P1) such as ferries or double-decker buses. Similarly, new high speed trains (P1) may be acquired and its facilities can be used to decide its use for service provision such as carrying postal freight or inter-continental connections (S1).

An example of a PSS implementation based on the operation of a major healthcare provider will now be applied to demonstrate the use of the Infodynamic engine. This company offers a ‘service agreement’ based on providing mission-critical equipment for sale backed, with 24 hour service for remote clinical and technical expertise. Products sold include X-ray machines, CT, MR, ultrasound and nuclear medicine imaging equipment. Service support for software is provided by means of updates while services are offered to support hardware facilities by means of planned maintenance, exchange or parts replacement/ repair.

Information exchanges will be identified for which the Infodynamic engine will be used to generate new pieces of directly usable information. This information can then be used for the delivery of a service. Information exchange is used in this context to describe a phase in which information are accessed or delivered between systems or within a system. Information flow on the other hand is used here to describe the phases in which a new piece of directly usable information is generated from information already possessed by the system(s).

3.3 A PSS worked example

A simple case of an information exchange is presented based on the healthcare provider’s ‘service agreement’. For demonstration purposes, it is assumed that four forms of provisions *(AS)* can be offered in this PSS – sold products, planned maintenance, parts replacement and parts repair. Similarly, for a service to be provided, three pieces of information *(IS)* will need to be determined – the availability of service, the right to receive the service and the availability of a service team to provide the required service. The information flow centres on the need to replace a fault part in a CT (computed tomography) machine and to follow that up with a scheduled maintenance.

As an example, for this case, four pieces of information, to uniquely identify a service request *(UI)*, are obtained from a laboratory technician in the company hosting the CT: product name, model, company name and department. Four additional services *(AOS)*, outside the scope of those of the service provision depicted in Figure 3a, will also be required to fulfil customer requirements: parts procurement, transportation, installation and disposal of old parts. Similarly, two additional pieces of information *(AOI)* are required: the location of the parts and the department to deal with request.

Information exchange

In this example, a laboratory technician requires replacement parts and maintenance for a CT machine (See Figure 3a). Information exchange can include the following steps:

i. Technician requests assistance via phone support;

ii. A request for service is made by a support staff; and

iii. The service is delivered by the service team and the system updated by a support staff.

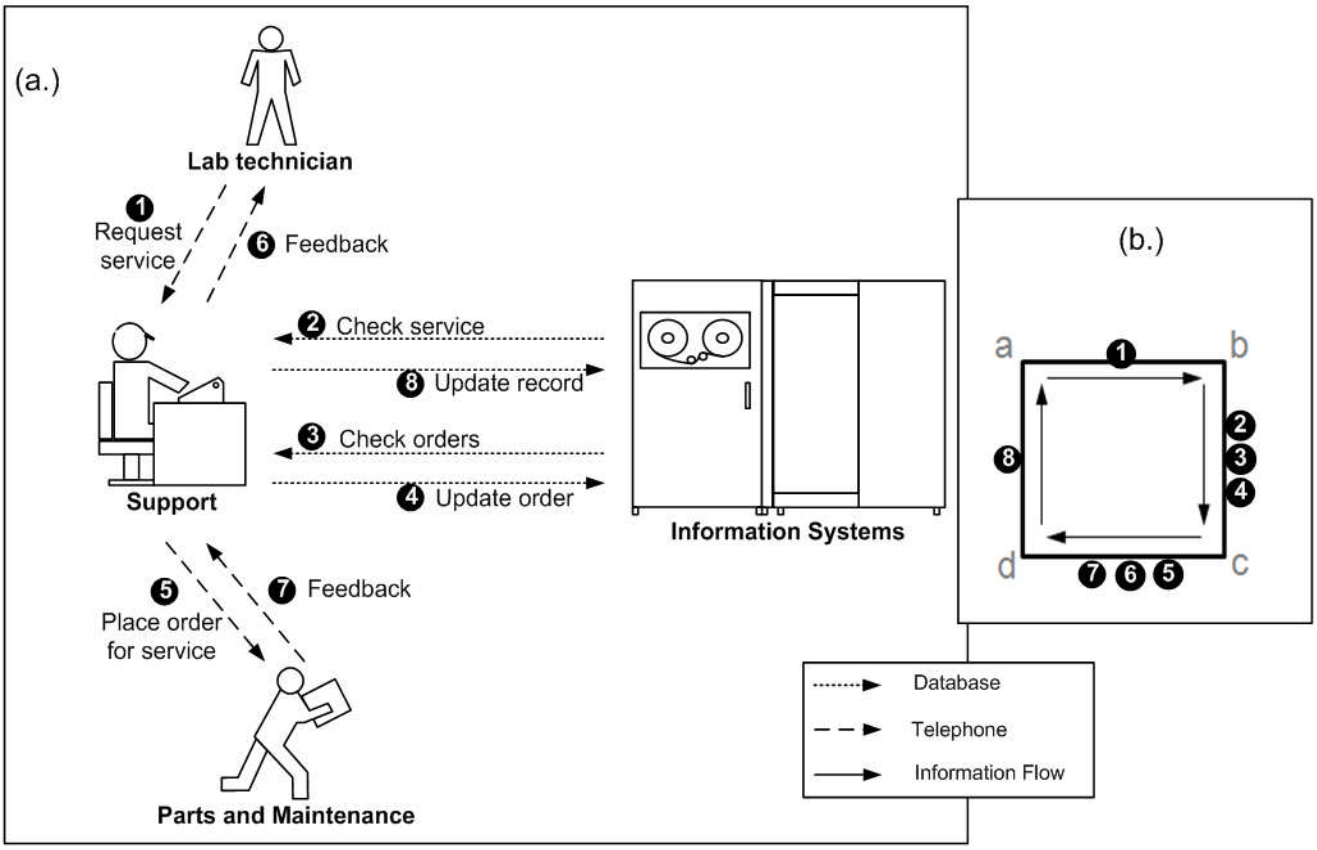

Figure 3: Path in an information exchange for service provision (a.) actual exchange (b.) Infodynamic engine representation

The actual exchange is represented in Figure 3a. In database management, indicated by *dotted arrows*, each arrow indicates that the support staff either feeds in inputs or gets outputs from the stored data. For telephone conversations the *broken arrows* imply a call to or from a source.

The path involving, Request service → Check service → Check orders → Update orders in Figure 3a equates to step i where the technician requests assistance. In step iii, service delivery and system update is accomplished by Place order for service → Feedback (to technician) → Feedback (from service team) → Update record. Step ii, in which the request is made, is realised by, Check service → Check orders → Update orders → Update record. The 'check service' is used to access the availability of a service and to check if the company for which the laboratory technician works can be provided with the service. The 'check order' on the other hand is used to access the availability of the service team.

Information Flow

This example will focus on the **information flow between the support staff and laboratory technician**. This can be mapped unto the Infodynamic engine as shown in Figure 3b. This is because the Infodynamic engine is initiated by an 'obtain data' (a-b) phase as shown in Figure 2. This equates to the 'Request service' in Figure 3a. The 'assimilation' (b-c) phase in which information is generated corresponds to the Check service → Check orders → Update orders. The crystallised data during phase c-d is used to accomplish Place order for service → Feedback (to technician) → Feedback (from service team). Similarly, phase d-a in which P1 and S1 are reconciled corresponds to the 'Update record' process in Figure 3a.

In an ideal Infodynamic engine, as shown in Figure 2, phase a-b matches c-d i.e. the entropy difference between P1 and S1 when service data is obtained must match the reversed process when the service data is crystallised into usable and unusable parts. Similarly, information need variance at phase b-c must match d-a. At phase b-c, information need moves from high to low as information is processed. This is then reversed at d-a, i.e. low to high to reflect the presence of a higher information potential. This high information potential highlights the need for additional information to complete a task.

The macrostate in this case would be the service to be provided while microstates are encompassed by *AS* and *OAS*. Frequency of request for these services can be automatically logged and used to determine conditional probabilities (earlier identified in eqn. 3). For instance, if the support staff receive 50 requests for service (the macrostate) and 10 of these requests are for planned maintenance; then the conditional probability for the planned maintenance is given as 10 out of 50 (or 0.2). Table 1 presents the conditional probabilities which have been simulated for use in this worked example.

Service Type	Service Component	Conditional Probabilities
Artefacts Supplied *(AS)*	sold products	0.6
	planned maintenance	0.2
	parts replacement	0.1
	parts repair	0.1
Other Artefacts Supplied *(AOS)*	Transportation	0.5
	Parts procurement	0.2
	Installation	0.2
	Disposal of old parts	0.1

Table 1: Service request frequencies for worked example

H_1 is the entropy at the point of service request and k (see eqn. 3) denotes the individual microstates for the service (or macrostate) **requested**. H_2, in contrast, is the entropy at the point before it is delivered and k denotes the individual microstates required to **realise** the service.

N_1 is information need at the point of request and the value of m (see eqn. 4) is the number of information items required to **distinguish** a service receiver. N_2, on the other hand, is the information need at the point when a service has been **identified** and is ready to be delivered. At this point, m can be computed from both the information required to identify a particular service receiver and any other additional or internal information in an organisation used to identify a particular user.

For the laboratory technician (as the receiver), data about two services is being sought i.e. $K(d)$ at H_1 is equal to 2. These services, planned maintenance and parts replacements have service request frequency (or conditional probability) values of 0.2 and 0.1 respectively (see Table 1). Consequently, from eqn. 3, H_1 can be calculated as

$$-\left[(0.2\log_2 0.2)+(0.1\log_2 0.1)\right]+2=2.8$$

For the support staff (as the provider), two services and four additional services *(OAS)* are identified i.e. $K(d)$ at H_2 is equal to 6. Using Table 1 as before, the service request frequency values can be identified. From these parameters, H_2 can be computed as

$$-\begin{bmatrix}(0.2\log_2 0.2)+(0.1\log_2 0.1)+(0.5\log_2 0.5)\\+(0.2\log_2 0.2)+(0.2\log_2 0.2)+(0.1\log_2 0.1)\end{bmatrix}+6=8.6$$

Total information in the exchange is the sum of information about the availability of a service (IS), the receiver (UI) and information of additional services required to realise service requested *(AI)* i.e. 3+1+2 = 6. For this case, it is assumed that all information required to complete a task have the same probability. For information need, the laboratory technician provides a unique ID from which the name, model, company and department is used to identify the product in P1. Additional information is then obtained to aid the delivery of the service by S1. Consequently m at N_1 equates to 0.5. From this information, N_1 can be calculated as

$$=(1-0.5)^1=2$$

Similarly, the value of N_2 can be computed as

$$=(1-0.1667)^1=1.2$$

The value of m at N_1 is 0.1667 (or one sixth) because the unique ID supplied is the only data obtained from P1 by S1.

3.4 Reengineering for efficient information flow

As demonstrated, information exchange in the provision of the service for the laboratory technician can be mapped unto the Infodynamic engine. However, the information exchange process could be further optimised based on the identified information flow path. For this reengineering process, two approaches could be applied:

i. Aggregating and restructuring information to reduce processes and exchanges; or

ii. Reducing the number of actors and scenarios in the information exchange for which processes can be automated.

Both approaches as shown in Figure 4 adopt separate schemes to handle redundancy inherent in the processes involving 3-4-5-6 which is shown in the Infodynamic engine representation in Figure 3b.

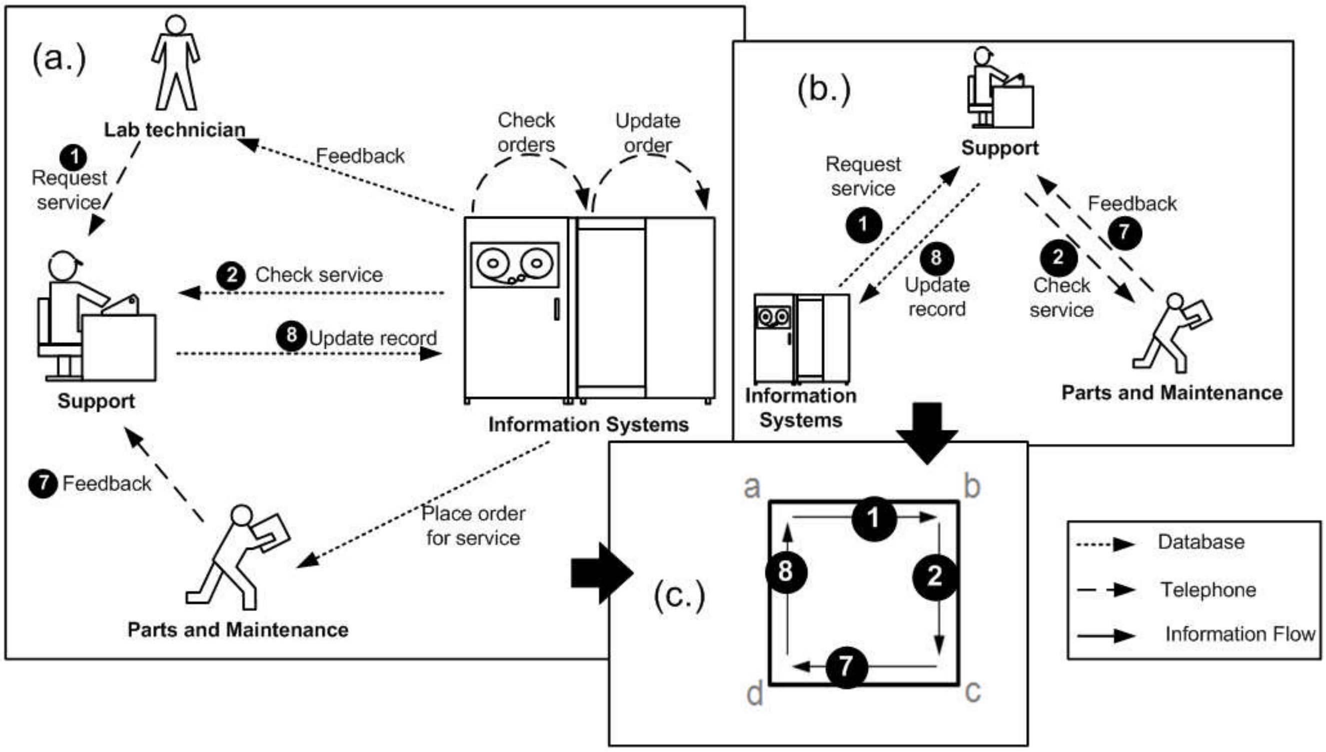

Figure 4: Re-engineering the information flow (a.) aggregating and restructuring information (b.) reducing actors and scenarios (c.) optimised information flow

Restructured Information Exchange

In the first approach (aggregating and restructuring information), the information system can be configured to perform order processing and to provide and receive feedback to and from the laboratory technician and the service support team as shown in Figure 4a.

For the second approach (reducing actors/scenarios), adequate automation facilities can be used to reengineer the information exchange in the PSS (see Figure 4a). The information system could be automated to check and update orders when a check for service is performed. The World-Wide Web or a virtual private network could be used to link systems at the request and delivery ends of the service.

Information flow, in both approaches, as shown in Figure 4b, is established in four steps. Step i involves a request for service which may be automated. This request would also advise on the available orders and could allocate available resources as required. Step ii would involve alerting the service team of the need for a service provision. Step iii (or 7 as in Figure 4c) involves feedback from the service team indicating service delivery. The final step, step iv, would involve updating the database to reflect the completed service provision.

Efficiency comparison of Reengineered Information Flow

In the original example, the value of the usable information based on information need and physical entropy can be computed as (eqn. 5):

$$(8.6-2.8)\cdot(2-1.2)=4.6$$

The Information generation efficiency (*IGE),* Information utilisation efficiency *(IUE)* and Information system efficiency *(ISE)* can likewise be computed as (eqn. 6,7,8) 0.67, 0.4 and 0.27 respectively. In the reengineered information flow (Figure 4), the efficiency measures applied are based on schemes to improve information need. In these schemes, the generation of information is maintained but the utilisation is improved to increase efficiency of the information system.

For the first approach (aggregating information), three reports containing aggregated information can be generated. These reports could contain information about the availability of a service *(IS)*, the receiver *(UI)* and information of additional services required to realise service requested *(AI).* For this approach, the value of m is 1 and 2 for N_1 and N_2 respectively. This is because both *UI* and *AI* are required to make the service available while only *UI* is required to deliver the service. The value of the usable information can then be calculated as:

$$(8.6-2.8)\cdot(3-1.5)=8.7$$

The new *IUE and ISE* can also be computed as 0.5 and 0.34 respectively.

For the second approach (reducing actors/scenarios), the information flow and exchange is restructured. In this new scenario, the information flow is now focused on the support staff and the networked information systems.

In terms of information need, N_1 is now based on *IS* and *AI* while N_2 is concerned with only *AI*. The values of N_1 and N_2 are calculated as 6 and 2 respectively. The value of the usable information can then be computed as:

$$(8.6-2.8)\cdot(6-2)=23.2$$

The new *IUE and ISE* can also be computed as 0.67 and 0.45 respectively.

4 DISCUSSION

Designing and managing the life cycle of a product can be a complex task because considerations have to be made for issues such as obsolescence, costs risk and uncertainties, development costs, process management and concurrent design/development. Integrating design for service in these activities can further complicate the design and management process.

In PSS, where value creation is used to drive a function-oriented architecture, the need for customer focused models and efficiency driven tools are also particularly important. The networks realised from an established information flow model can be used to define the information system in a PSS. These models however have to be developed with flexibility in mind, so as to ease time and financial costs associated with organisation shifts [7].This flexibility can also have the added benefit of fostering the development of conceptual models.

Applying an information model such as the Infodynamic engine in PSS can be beneficial in terms of efficiency and reusability. As demonstrated in the worked example, a path for information flow can be established based on information exchanges. This efficiency is driven by increasing value of generated usable information. Additional optimisation schemes can be implemented to improve the physical entropy to further increase the overall efficiency of the information system.

4.1 Infodynamic engine mapping process

As noted in the worked example, identifying and mapping information exchanges for the Infodynamic engine is an activity which requires human judgement. A key consideration for this activity is the source of data which starts the information generation process. In the worked example, data was obtained based on an interface created for **information flow between the support staff and laboratory technician**. Once this interface is determined the rest of the mapping process for information exchanges can be achieved by collaborating teams of domain experts, system analysts and even stakeholders. When these exchanges have been identified, the operation of the Infodynamic engine can then be automated. In the real world, support for the mapping process in organisations is realised by tools known as decision support system (DSS) [11]. These tools are required to identify the information flow from information exchanges. They are also useful in terms of matching customer requirements based on manufacturing capabilities. A DSS can also be configured to capture technical specification of customer requirements; generate and select alternative configurations to rapidly provide accurate technical solutions; and schedule resources for service commencement.

For PSS, as in modern organisations, the Infodynamic engine can be particularly useful. This is because modern organisations are characterised by a collaboration of human judgement and computational facilities [11]. Computation facilities are required for coping with possibly large information quantities while human judgement in this respect refers to customer needs being fulfilled with solutions that satisfy their requirements without jeopardising business objectives of manufacturers

4.2 Limitations of the Infodynamic engine

The Infodynamic engine is a tool for modelling information flow at a high-level of abstraction and is limited to a sequential representation of information flow extracted from information exchanges. The engine examines information need in the delivery of a service by a PSS but criticality or timing of the information for the delivery of a service is not identified or supported. It is also vital to note that the Infodynamic engine is not a tool for comprehensively modelling information in a PSS. Neither is it a tool for the implementation of a system or reengineering a PSS for increased servitization or productization.

These limitations of the Infodynamic highlight the need for comprehensive information modelling down to the lower-levels of data modelling and even language specification for concrete/detailed model to offer support for systems implementers. Further considerations could include sourcing avenues for ensuring integrity, privacy and confidentiality of information exchange between consumers and manufacturers.

5 SUMMARY

This paper has attempted to identify information exchange in a Product Service System (PSS) and ways of modelling the flow of information. The concept of PSS was first presented as a function-oriented principle offering value for both manufacturers and customers. The Infodynamic model was then presented as a high-level approach to modelling information flows. The Infodynamic engine was then applied in a PSS for information processes as a way of generating new directly usable information for the delivery of a service. The potentials of the tool for recommending improvements were also highlighted and measured with simple information flow efficiency metrics in a PSS.

6 ACKNOWLEDGMENTS

The authors would like to extend their sincere thanks to the EPSRC, for its support via the Cranfield IMRC, towards the work carried out in the preparation of this paper.

7 REFERENCES

[1] Morelli N, 2006, Developing new product service systems (PSS): methodologies and operational tools, Journal of Cleaner Production, vol. 14, issue 17, pp. 1495-1501

[2] Sundresh TS, 1997, Information complexity, information matching and system integration, IEEE Transactions on Systems, Man and Cybernetics, vol. 2, pp. 1826-1831

[3] Castka P and Balzarova MA, 2008, The impact of ISO 9000 and ISO 14000 on standardisation of social responsibility—an inside perspective, International Journal of Production Economics, vol. 113, issue 1, pp. 74-87

[4] Tukker A, 2004, Eight types of product-service system: eight ways to sustainability? Experiences from SusProNet, Business Strategy and the Environment, vol. 13, no. 4, pp. 246-260

[5] Sommerville I, 1992, Software Engineering, 4th edition, Addison Wesley, London

[6] Wolf W, 2003, A Decade of Hardware/Software Codesign, IEEE Computer, vol.36, no.4, pp 38-43

[7] Baines T, Lightfoot HW, Evans S, Neely A, Greenough R, Peppard J, Roy R, Shehab E, Braganza A, Tiwari A, Alcock JR, Angus JP, Bastl M, Cousens A, Irving P, Johnson M, Kingston J, Lockett H, Martinez V, Michele P, Tranfield D, Walton IM, & Wilson H, 2007, The state-of-the art in Product Service Systems, Proceedings of the I MECH E Part B Journal of Engineering Manufacture, vol. 221, no. 10, pp. 1543-1552

[8] Tomiyama T, 2001, Service engineering to intensify service contents in product life cycles, Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing, pp. 613 - 618

[9] Sundresh TS, 2000, Information flow and processing in anticipatory systems in IEEE Transactions on Systems, Man and Cybernetics, vol. 1, pp. 271-276

[10] Zurek WH, 1989, Algorithmic randomness and physical entropy, Physical Review, vol. 40, issue 8, pp 4731-4751

[11] Patel A, Meade R, O'Sullivan D and Tierney M, 1996, Information modelling for service provisioning - the DESSERT experience, Computer Standards & Interfaces, vol. 18, issue 2, pp. 175-18