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Re-distributed manufacturing to achieve a Circular Economy: A case study utilizing IDEF0 modeling

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Abstract

The minimization of energy, waste, and emissions in operations are the foremost sustainability goals in industry. The shift from a linear product lifecycle to a circular one is required, along with increased energy efficiency and reduced resource use, to achieve these goals. This paper examines how the use of Re-Distributed Manufacturing (RdM) and a Product-Service System (PSS) approach, while leveraging the latest digital manufacturing technologies, enables the shift to this new economic model. A case study illustrates this new approach and relates it to the shoe manufacturing industry. The ShoeLab case study includes an outline of the business model options supporting this new approach to sustainable production highlighting the circularity that may be achieved in employing RdM and the latest digital manufacturing technologies in the form of 3-D printing. The research conducted indicates that using IDEF0 modelling could help to realize the full potential of RdM such as the manufacturing and transport of products involving less material, energy and waste.

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Keywords: Re-distributed manufacturing; Product Service System (PSS); 3-D printing.

1. Introduction

The emergence of new technologies such as the internet of things, big data and advanced robotics [1] together with risks such as climate change, changing labor costs and a dynamic global economy are challenging the current UK manufacturing model [2]. Based primarily on offshore and centralized facilities with large scale assembly lines to supply a mass market, the current manufacturing model is driven to change, by the aforementioned risks and opportunities, into a decentralized, on demand, localized and customizable manufacturing model known as Re-Distributed Manufacturing (RdM). The advent of this manufacturing paradigm has brought on the need for new models and methods that manufacturers can rely on as guides for the transformation of their manufacturing operations.

RdM can be defined as "…an emerging concept which captures the anticipated reshoring and localization of production from large scale mass manufacturing plants to smaller-scale localized, customizable production units, largely driven by new digital production technologies [3]. The ShoeLab project will be utilized as a case study to collect and analyses data and evaluate new business models for use in the manufacture of products such as shoes. The developed business models will be used to investigate how data captured from, and communicated between, supply, production and distribution and integrated into the design process.

2. Literature review

According to Moreno and Charnley [4] benefits from the implementation of Re-Distributed Manufacturing (RdM) in the consumer goods sector could bring ways to "…effectively

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manage resources within markets, ensure waste is eliminated and monetized [5], and support selling products as services which will enable keeping products in longer use to minimize waste and resources [5][6]". RdM is beginning to influence industries such as food manufacturing [7] and pharmaceuticals [8] leading to local production initiatives and the proposal of modifications to existing supply chains. RdM, still in its early stages, faces some barriers to its wider adoption by industry. Barriers include, technology readiness and capabilities regarding the scale of production needed, infrastructural capability, governance and regulatory issues, and consumer acceptance. These barriers are because RdM does not imply just having dispersed locations of manufacture, but implies changes on the value chain, with further market implications as well as changes on organizational structures [9]. Srai et al. [9] argue that transformational changes on the business model need to happen. These transformations could be based on the delivery of Product Service Systems (PSS) [10].

Providing solutions through a combination of products and services implies more participation between the manufacturer and customer during the product's life. The focus could then be placed on providing a purposeful service model that would mostly make "manufacturers or retailers retain ownership of their products (or have an effective take-back arrangement) and, where possible, act as service providers, selling the use or performance of products, not their consumption." [11].

This new paradigm of manufacturer-customer relationship and product/materials use and re-use could be related to the Circular Economy (CE). The concept of CE is in response to the traditional, linear manufacturing and consumption model predominant during the last century in which products are made from raw materials to be sold to the customer for their use and later disposal as waste. This linear model is characterized by "being material and energy intensive; it relies on economies of scale, and typically builds on complex and international supply chains. All these supply chains have a common goal—the consumer" [11]. As such, it could be said that RdM and CE models could be related to those around the creation of PSS [9,12]. Prendeville et al. [3] introduces the concept of makespaces as a link between RdM and the Circular Economy. Makespaces are 'Community-based digital fabrication workshops' [3] and provide a localized manufacturing format capable of achieving more sustainable forms of production. A further exploration of CE in relation to manufacturing is provided by [13].

A successful implementation of this new manufacturing paradigm will combine all the new technologies and methods into a coherent system. The best way to meet this challenge is by first creating a coherent business model. As such, the business model design should consider various aspects such as information flow, product and service architecture reflecting the roles of the different manufacturing elements involved with their own description of their benefits [14].

IDEF0 (Icam DEFinition for Function Modelling (IDEF0) [15]) model could prove useful to develop a coherent business model with a systematic perspective to fully "connect and deliver value" through associated supply and value chains both internal and external to the organization [16], as required within this new re-distributed manufacturing paradigm.

The IDEF0 modelling standard is one of the most popular graphical notations for business system and process planning [17][18] IDEF0 can provide an appropriate level of description for the task of business model development. In addition, it can provide a clear picture of how value can be created and then transferred through the help of different functions and resources during the implementation of a circular business model. Based on the review of existing literature, it is evident that there are no business models designed using IDEF0 that can directly support the implementation of redistributed manufacturing. This paper addresses that gap. The paper is divided up into methodology, case study and business model development, validation and discussion sections.

3. Methodological approach

To carry out this research, a methodology was developed based on initially conducting research on key subjects, such as those mentioned in the literature review section, and then extracting main functions that could be applicable to an As-Is and a re-distributed To-Be business process. The main procedures for the development of the models will be followed according to IDEF0 model creation methodology which is commonly used in industry. The methodology is outlined below:

1. Research
   - State of the art business models, RDM, servitization, CE and consumer goods industry
   - Gaps definition
   - Criteria definition
2. Map
   - Map generic consumer goods model & shoe manufacturing value chain model
3. Develop
   - Develop use case model in collaboration with ShoeLab
4. Validate
   - Validate models with experts
   - Create new ShoeLab concept model based on feedback from validation
5. Deliver
   - Compare models and generate discussion
   - Validate models and conclusions

Prior to the development of the models, a value chain approach helped determine the main functions that each of the models would roughly contain, providing a general flow to define inputs and outputs from one function to the next. Furthermore, criteria were developed based on the understanding of the subjects in the literature review in order to provide guidance for the definition of controls and resources that each function would contain. These criteria consisted of parameters identified around four major concepts dealing with transportation, customer involvement, Servitization and circularity.

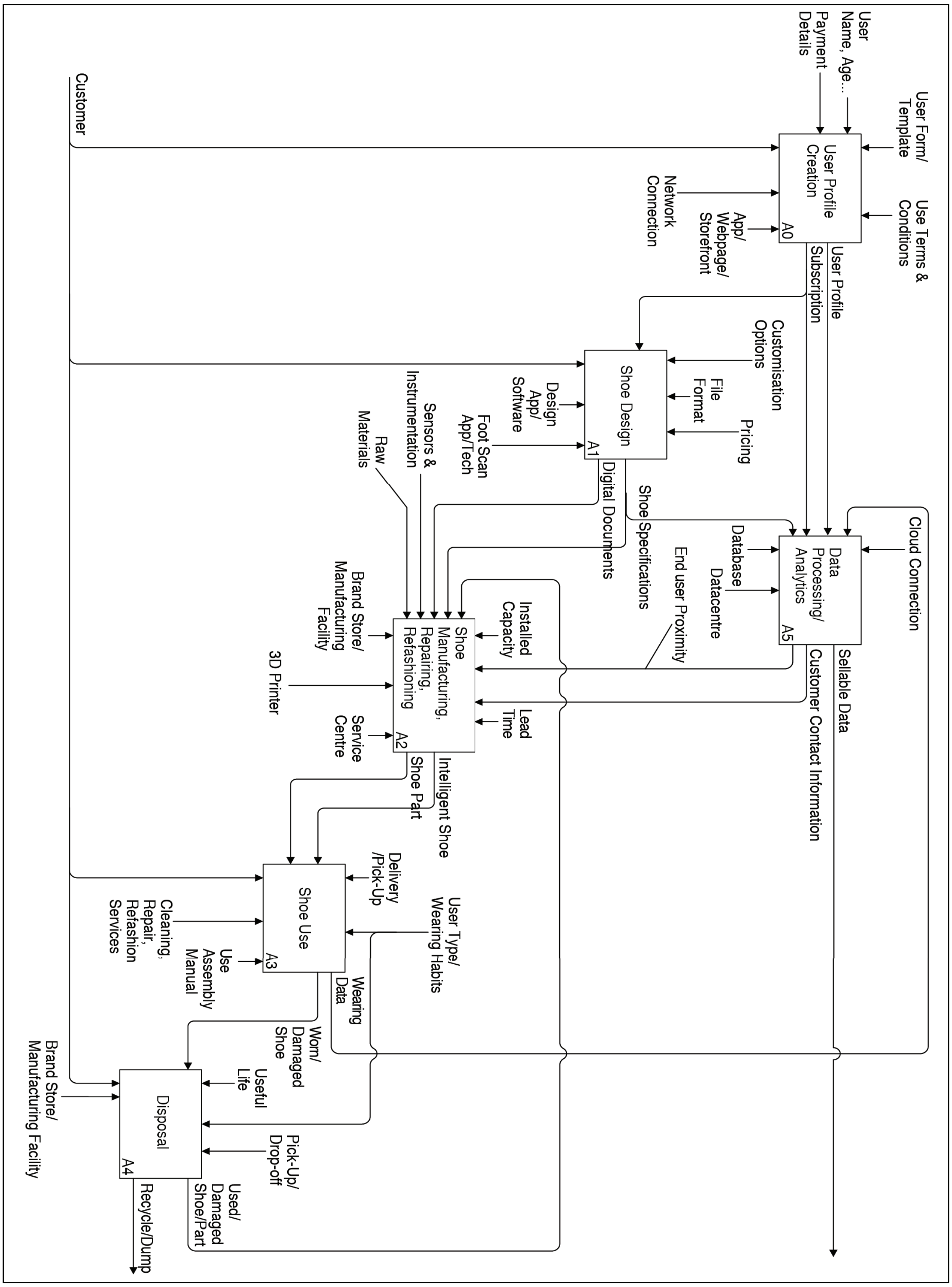

Figure 1: ShoeLab Business model

The business model was validated through the creation of a closed question questionnaire with open comment sections. The questionnaire was completed by 10 experts drawn from both industry and academia. The feedback was requested to validate the ability of the ShoeLab model to deliver on the original criteria. For this reason, the validation questionnaire was divided into four sections, each one corresponding to one of the four criteria points of transportation, customer involvement, circularity and servitization.

4. ShoeLab Case Study and Business Model Development

ShoeLab is an initiative collaboration by Cranfield University, Cisco Systems, and The Clearing – a branding consultancy, which aims to develop a proof of principle for a smart and sustainable shoe. ShoeLab is a small project drawn from a feasibility study funded by the EPSRC RECODE Network [19]. A case study drawn from the ShoeLab project is used to develop an initial distributed and circular business model. Case study as a research method is employed because it focuses on contemporary events [20] and is perceived as the most suitable for answering research question of – How could we develop a re-distributed and circular business model?

A ShoeLab proof of principle business model was developed on the knowledge gathered throughout the project. The model was created to explore other possible variations on the redistributed manufacturing models already identified from literature. This would allow further contrast between the As-Is manufacturing process models, ShoeLab case study and concept model. The concept model is shown in Figure 1. In preparation for the ShoeLab case study, a generic shoe manufacturing consumer goods As-Is model was created to have a reference model to be compared to (not shown).

The ShoeLab business model starts with the User Profile Creation (A0, Figure 1) function. During this function, the customer provides his general information as input (name, age) and details regarding their preferred payment method. The 'Use Terms & Conditions' control was included to consider intellectual property and other legal considerations. The User Form/Template presents the customer with the structured form with the required fields. The resources are the tools that the customer will need to input their information, mostly a Network Connection and the Application, which could be in a device app, web app or in the store. This function provides main customer information and their subscription and product preferences as outputs.

These outputs, and other information related outputs, are centralized in a Data Processing/Analytics function (A5, Figure 1), which will be discussed later. The main use of the information provided by the A0 function is to activate the Shoe Design function (A1, Figure 1) so that the customer can provide personal preferences in the form of customization options for the product. Based on these choices a pricing is determined and in the background a file format shapes the way this information is captured and transformed in such a way as for the 3D printing machine to process. The resources are technological in the form of applications and/or software to help the customer scan their foot dimensions and other technology to carry this out if the customer is in store. The main outputs from this function are in the form of shoe specifications (shoe spec.) and digital documents. Both are in essence the same information being transferred in different formats and for different purposes. The shoe specifications provided by the customer are stored in the Data Processing/Analytics function and this same information but in a 3D printer readable format is provided as a digital document to the following function of Shoe Manufacturing, Repairing, Refurbishing (A2, Figure 1).

The manufacturing function (A2, Figure 1) provides the concentration of manufacturing, repairing and refurbishing actions. Since this is a distributed manufacturing model, these functions can be performed in the same local (in relation to the customer) facility. Sensors and instrumentation are inputs that represent all the technology to be included in the shoe according to the customer's needs; they can provide GPS tracking, health monitoring or others. These are sourced from other manufacturers and thus the assumption is made that they cannot be manufactured in-house or is not the main intention of the ShoeLab manufacturing facility. Raw material is an input, in this case assumed to be the printing material itself since the entire shoe would be manufactured from the least amount of materials as possible. The 3D printer is the main resource together with the brand store/manufacturing facility and the service center. As previously mentioned, the service center and the manufacturing facility are co-located in the store. The service center is the place where shoes are refurbished, extra parts are produced and other services are fulfilled. This same place contains the 3D printing machines that are used for the manufacturing of the shoe.

The outputs from this function are the finished shoe, named as intelligent shoe, and shoe parts which may be requested by the customer to repair a damaged part of the shoe. Since the shoe is produced in a modular method, different parts can be disassembled for repair. The shoe or shoe part are then transformed by the following function which is Shoe Use (A3, Figure 1).

This function is controlled by delivery or pick-up methods of transporting the shoe to the customer and the user type/wearing habits. Additionally, there will be resources provided by the manufacturer in the form of cleaning, repair, refashion services and a user/assembly manual, to align with the circularity concept of the intended business model. The possibility of modifications being made by the customer on his own account is aided by a manufacturer-provided use/assemble manual. The outputs provided by this function are in the form of use data and physically in the form of a worn/damaged shoe. The use data is transferred to the Data Processing/Analytics function (A5, Figure 1) which uses them as inputs to provide other useful information for the manufacturer in supporting the customer, e.g. to activate a service offering.

The worn/damaged shoe is transferred to the Disposal (A4, Figure 1) function which transforms the end-of-life product into a possible input for the A2 function as material to produce other shoes or the end-of-life product can be recycled/disposed of by the customer. The option is free for the customer to choose if they desire to recycle/dispose of the shoe, but the intention of the ShoeLab project is to have the damaged end-of-life product returned to the manufacturer for reprocessing. The shoe is made of a thermoplastic polyurethane, which comes in a powder form. This can be transformed back to a powder to re-enter the 3D printing process. For this reason, the brand store/manufacturing facility is included in the resources for this function. Furthermore, there is a consideration for the pickup/drop-off of the used/damaged shoe/part so that it may reach the place where it will be recycled or reprocessed. Most of the information generated throughout this process is meant to be capitalized on, to make profit and improve processes; therefore, the Data Processing/Analytics function (A5, Figure 1) was included as part of the model. This function gathers all the information about the customer profile, product specifications and wearing data by using resources such as a database and datacenter. The database is a repository for all the information to be stored and the datacenter is the physical space were servers and other technology is hosted and administrated. Through analytics such a data repository can provide controls for the A2 function by locating the manufacturing facility that is closest to the customer as well as providing digital contact points so that the two parties, manufacturer and customer, can get in touch with each other and arrange the production details of the shoe. This is a summary of core possibilities offered by this model; the application of RdM can provide many other uses to improve services and product offerings.

5. Validation

The ShoeLab model was validated through the creation of a closed question questionnaire with open comment sections. The questionnaire was completed by 10 experts drawn from both industry and academia. The feedback was requested to validate the ability of the ShoeLab model to convey the main criteria that was used to create it. For this reason, the validation questionnaire was divided into four sections, each one corresponding to one of the four criteria points of transportation, customer involvement, circularity and servitization. The feedback regarding the different sections was used as input for development of a concept model called ShoeLab Hybrid Business Model (not shown). This model attempts to improve on the ShoeLab Model based on the observations gathered from the validation questionnaire and meetings with the ShoeLab project members. The main improvements focus around providing a clearer representation of the services and their involvement in the value chain. This was achieved by including a revised A5 (from Figure 1) function called *Servicing, Refashioning, Repair*. This function is controlled by the *Data Processing/ Analytic* function (A2 in Figure 1) by providing customer details such as their contact information and location, both of which are included due to them being critical for the provision of any service. The output is purely services and service data. The services are now controls that shape the *Shoe Use* (A3 from Figure 1) function in the way of providing refashioning and/or repair services. The *Disposal* (A4 in Figure 1) function is also controlled by services that provide the customer the option of returning the shoe to the manufacturer once it has reached its end-of-life. This supports the combination of services with circularity criteria. For this reason, shoe parts from the *Shoe Manufacturing, Remanufacturing* (adapted from A2 in Figure 1) function and waste material from the *Disposal* (A4 in Figure 1) function are inputs to the *Servicing* function, since they're used to provide repairing and take-back services.

In addition to the Servicing function, this model has the inclusion of a new Component Manufacturing function. It's the reason behind this model being called a hybrid model, since it borrows the function in the shoe manufacturing As-Is which represents the manufacturing of components that cannot be made, in this case, using additive manufacturing (3D printing).

6. Discussion

Using an IDEF0 model, helped to visualise the barriers initially discussed in this paper, on each of the steps within the proposed business model. One identified barrier was technology readiness and capabilities. The ShoeLab concept is designed to 3D print the shoes in situ. 3D printing technology has evolved rapidly in the last few years, making it an attractive technology for re-distributed and circular models of production and consumption [3]. However, its capabilities for shoe manufacturing are limited due to its cost and material suitability [21]. Shoes are made of a combination of materials such as rubber, textiles, leather and canvas, which makes it expensive and difficult to 3D print. In addition, the ShoeLab concept relies on the concept of wearable technology characterised by interconnected devices and big data utilisation. These technologies are at the development stage in which connectivity between products, lack of open data standards and limited battery storage are still considered as barriers [22][23]. However, the use of big data analytics could bring massive opportunities by enabling the ability to gain new consumer insights, which could be used to improve the business model and shoe design, improve the organisation's infrastructural processes allowing potential reduction on the use of resources, as well as improve its value chain and costumer relationship by offering better services [4]. Data privacy and security was identified as another barrier. The Shoe Lab concept is based on processing and analysing personal data from users. This must be done in a way in which trust is gain from users, so they feel comfortable in sharing these data.

Finally, consumer acceptance was also identified as a barrier. The proposed business model is based on a subscription model in which users will pay a monthly fee to receive certain services within their shoe purchase. As such, the ShoeLab concept needs to address users' hesitation to adopt this new concept by delivering the best value proposition through delivering a personal experience to assist users to optimise their performance and prevent injury. As such, the proof-of-concept integrates sensors in the shoe, to inform users how to prevent injury when walking or running. The same sensor can also tell if shoes' condition has deteriorated, warning the user about any repair needed.

7. Conclusion

The aim of this research is to develop re-distributed manufacturing business models using IDEF0 to serve as a guide for the implementation of RdM concepts in the consumer goods industry. To accomplish this aim, it was imperative to understand the current state of consumer goods manufacturing and how elements of servitization and circularity, together with technology such as additive manufacturing and interconnected technology, could potentially influence the organization of manufacturing in terms of location and scale. Criteria were developed around transportation, customer involvement, servitization and circularity concepts to support the development of the model presented. Through the ShoeLab case study information was collated to create a model that depicts what a RdM value chain would look like if applied to the shoe manufacturing consumer goods industry. The model has shown that there is a need for robust facilities near the customer which can be achieved by locating production recycling facilities within close proximity of each other. These facilities are store fronts which can also manufacture, remanufacture and provide services. This combination can reduce costs, improve sustainability and provide customizable products and services for customers. Furthermore, the reduction in transportation and increase in customer involvement throughout the process are the main elements that would vary the most if a re-distributed model is implemented. In future work the authors aim to adapt the business models to other industry cases, a task made easier due to the inherent componentisation of the process stages achieved through use of the IDEF0 notation.

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