Digital Re-distributed Manufacturing (RdM) Studio

RECODE Network

Cranfield University

RECODE-NETWORK

RDM STUDIO
CHRIS TURNER
CLOUD TECHNOLOGIES
WHAT IS IT?
DIGITAL STUDIO
RdM
DISTRIBUTED
CONNECTED
LOCALISED
PRODUCTS & SERVICES
SOFTWARE TO TRIAL BUSINESS MODELS DIGITALLY
EXPERIMENTING ON A DIGITAL PLATFORM
INPUTS
COST
POPULATION SIZE
SYSTEM DYNAMIC MODELS
MAIN CASE STUDY
SHOELAB
SMARTER SUSTAINABLE SHOE...
AGENT BASED MODELS
BODYBUILDER
FASHION
WANTS LATEST COLOURS & STYLES
ACTIVE
SOLES WEAR OUT
SENT FOR REPAIR
MONTHLY
SUBSCRIPTION
LUXURY PRODUCT
PERSONALISED & UPDATED DEPENDING ON USAGE, FASHION PREFERENCES & INDIVIDUAL NEEDS...
LIFECYCLE ASSESSMENT
3D PRINT
LOCATION? - LOCAL
ON SITE?
PRINTER RENTED?
BOUGHT OUT RIGHT?
BATCH NO'S
CO_2 EMISSIONS
RENEWABLE ENERGY
SUSTAINABLE IMPACT
HE'S PERFECT
RIP
FROM CRADLE TO GRAVE
ABILITY TO ANALYSE & COMPARE COST & ENVIRONMENTAL IMPACT ETC...
THE FUTURE
UTILISING BIG DATA
WORK WITH REAL COMPANIES
RESEARCH ON REAL WORLD COSTS
AI OPPORTUNITIES
MINING DATA FROM SENSORS
USAGE
FITNESS
FASHIONS
MARKETING DATA

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About Us

RECODE Network

The EPSRC-ESRC funded Network in Consumer Goods, Big Data and Re-Distributed Manufacturing (RECODE) has been created to develop an active and engaged community to identify, test and evaluate a multi-disciplinary vision and research agenda associated with the application of big data in the transition towards a Re-distributed Manufacturing model for consumer goods.

The exponential growth of available and potentially valuable data, often referred to as big data, is already facilitating transformational change across sectors and holds enormous potential to address many of the key challenges being faced by the manufacturing industry including increased scarcity of resources, diverse global markets and a trend towards mass customisation. The consumer goods industry, has remained largely unchanged and is characterised by mass manufacture through multi-national corporations and globally dispersed supply chains. The role of Re-distributed Manufacturing in this sector is often overlooked, yet there is great potential, when combined with timely advances in big data, to re-define the consumer goods industry by changing the economics and organisation of manufacturing, particularly with regard to location and scale.

The RECODE Network conducted five feasibility studies led by the academic core partners, steering group partners, and new partners who joined through the RECODE Sandpit on 02-03 March 2016. A multidisciplinary team comprised of internationally renowned experts from Cranfield University and University of Cambridge and practicing industry leaders in the fields of sustainability, manufacture and big data were involved in the delivery of this feasibility study.

RECODE has developed novel methods and undertaken innovative events to engage communities of academics, international experts, user groups, government and industrial organisations to define and scope a shared multi-disciplinary vision and research agenda. To find out more, visit our website: **http://www.recode-network.com**

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Introduction

The vision of this project is to pilot future Re-distributed Manufacturing (RdM) business models to dynamically identify optimal scenarios for the consumer goods industry. The project will develop a Digital RdM Studio that will enable data-driven experimentation with different business models for the consumer goods industry. The long-term ambition of this project is to develop a national RdM studio that will allow industry to experiment with RdM business models and supporting data needs.

This project addresses the need to predict a future RdM business model based on data-driven experimentation with a range of possible scenarios. There are no current tools in research or practice that support this. The research question we are addressing in this study is "How can data-driven decisions predict a future RdM business model?" The research aims to develop a set of RdM business models for the consumer goods industry and outline a Digital RdM Studio that will enable data-driven experimentation with business model designs.

Objectives:

- Identify current RdM business models
- Develop selected future RdM business models
- Contribute to the RECODE roadmap of research

As demonstrated in figure 1 below, the research methodology is based on the identification, analysis and testing of multiple RdM business models based on simulation. The proposal focuses on collecting, integrating and analysing real-time manufacturing data and external data (e.g. marketing trends, social media, etc.) relevant to business model decision making.

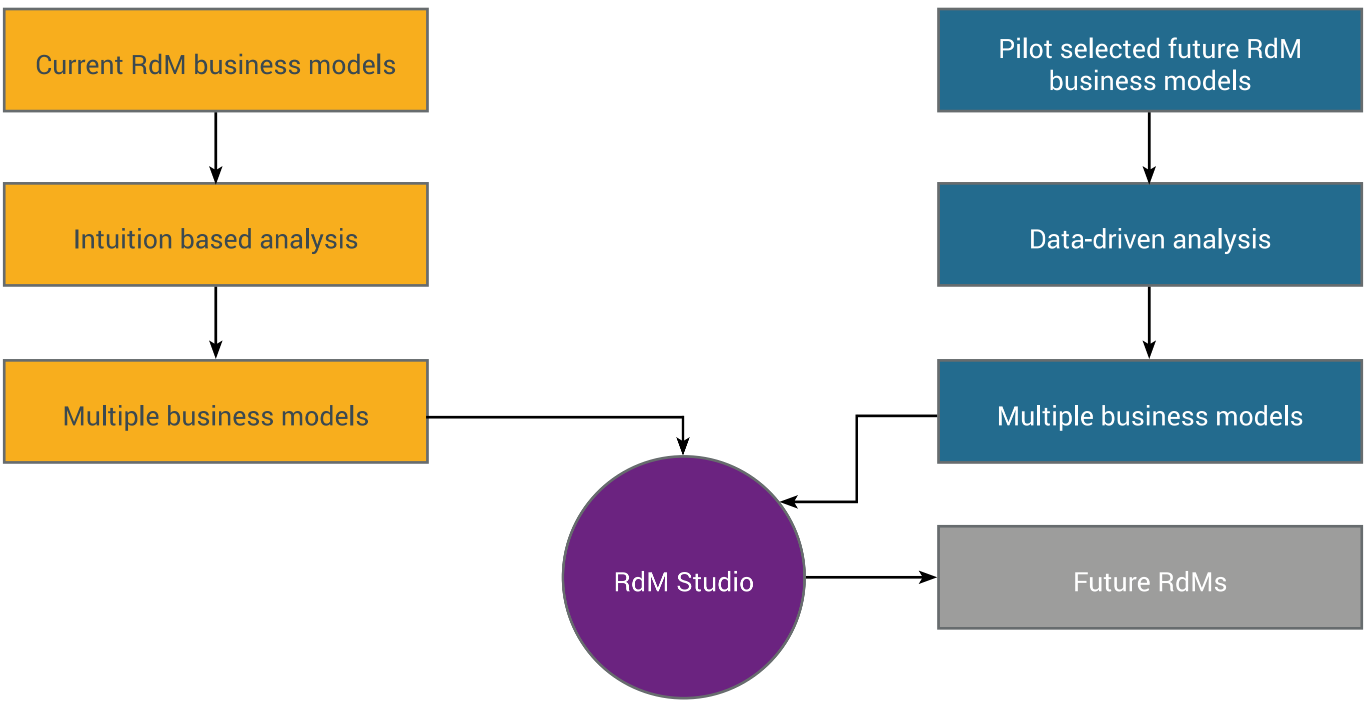


Figure 1 RdM Studio Methodology

Background literature review

As can be seen in Table 1 the small number of identified publications relating to RdM is evidence for the novelty of the field and the research gap in the area of Re-distributed Manufacturing business models.

Driven by the need for mass customisation and more sustainable production, some researchers and practitioners predict that manufacturing operations will transform towards a more geographically distributed production, known as distributed manufacturing[1,2]. The UK Engineering and Physical Sciences Research Council (EPSRC) coined a related concept which is called re-distributed manufacturing (RdM), defining it as "technology, systems and strategies that change the economics and organisations of manufacturing, particularly with regard to location and scale"[3,4].

Search term	Database	Number of Results
"Re-distributed Manufacturing" OR "Re-distributed Manufacturing"	Web of Science	1
	Scopus	7
	Google Scholar	33
business model*" AND "Re-distributed Manufacturing" OR "Re-distributed Manufacturing"	Web of Science	0
	Scopus	0
	Google Scholar	12
"Re-distributed Manufacturing" AND "sustainability" OR "Re-distributed Manufacturing"	Web of Science	1
	Scopus	1
	Google Scholar	15

Table 1 Search terms used to identify RdM papers

Re-distributed Manufacturing

Re-distributed Manufacturing requires a transformation from traditional centralised large scale mass production towards localised smaller scale production[5,2,6]. This transformation is largely enabled by digitalisation and the advanced manufacturing technologies, such as additive manufacturing and Internet-of-Things[7,8]. There is an increasing interest in the impact of big data on Re-distributed Manufacturing[9], and data-driven decisions are essential to the transition towards re-distributed manufacturing, featured by community-based digital, small scale factories producing and supplying the products locally. This transformation also requires the innovation of business models and the reconfiguration of supply networks, as this could lead to radical change of the distribution of manufacturing on a system level[2]. Recent research also shows the potential of Re-distributed Manufacturing in moving manufacturing towards more sustainable production, as it is expected that additive manufacturing reduces the amount of products through only producing what is needed, and the localised factories enable the reduction of energy consumption through shortened supply chains[6,10,8].

The business model concept became widely known during the e-commerce boom of the 1990's, and the subsequent emergence of previously unseen revenue mechanisms. Initially, the concept was employed to time-efficiently present complex business ideas to investors[11]. Subsequently, the concept developed to become both an instrument for the systemic analysis, planning, and communication of the configuration and implementation of organisational units and their environment in face of the associated complexity[12,13], as well as an intangible organisational asset to create competitive advantage and increase firm performance[14,15,16,17,18]. Sustainable business models (SBM) are "business model[s] that incorporate pro-active multi-stakeholder management, the creation of monetary and non-monetary value for a broad range of stakeholders, and which hold a long-term perspective"[19].

While initially aiming to utilise private industry's resources and capabilities to leverage the transformation to a more sustainable system by integrating sustainability considerations into companies and providing support to achieve their sustainability ambitions[20,21,22,23], today the notion of sustainable business model innovation is increasingly seen as a source of competitive advantage[24,25,26], and thus, might eventually replace the conventional business model concept, analogue to the concepts of competitive advantage and sustainable competitive advantage[27,28]. For decision making in organisations with regards to re-distributed manufacturing, the business model concept is an interesting framework as it allows for the extrapolation of potential customer and value chain benefits along with the implementation of other business model elements[29,30,27]. Thus, the conceptual ambiguity of RdM can be reduced to a decision making solution space that comprises a finite number of potential business model choices.

Conceptual framework

The characteristics of re-distributed manufacturing and sustainable business models emerging from literature are summarised in Table 2. Re-distributed Manufacturing is characterised by digitalised, personalised and localised production, through enhanced user and producer participation, driven by new enabling technologies. Sustainable business models require a system of sustainable value flows among multiple stakeholders including the natural environment and society, and the sustainable value incorporates economic, social and environmental benefits.

Characteristics of RdM	Characteristics of SBM
Digitalisation	Sustainable value creation
Personalisation	System of sustainable value flows among multiple stakeholders including the natural environment and society.
Localisation	Value network with a new purpose, design and governance.
New enabling technologies	Systemic consideration of stakeholder interests and responsibilities.
Enhanced user and producer participation	Internalizing externalities through product-service systems.

Table 2 Characteristics of sustainable RdM BM(2,31)

Based on the characteristics of RdM and SBM (Table 2), together with the studies on data-driven decision making[9,32], we develop a conceptual model (Figure 2) which provides a theoretical foundation for sustainable RdM business models based on data-driven decision making.

The conceptual framework incorporates three parts: data collection and analytics, data-driven decision making, and the sustainable re-distributed manufacturing business models. This framework explains how to develop sustainable RdM business models based on data analytics and simulations. The data is collected from internal sources (e.g. manufacturing processes, production planning, and quality fault systems) and external sources (e.g. point-of-sales, customer feedback, and social media). The collected data is analysed through various kinds of techniques, such as predictive, prescriptive, descriptive and diagnostic analytics. Decision making for sustainable RdM business models is based on the result of data analytics, starting from the concept design of sustainable RdM business models, through the modelling and simulating the RdM business models and the eventual selection of business models that best meet the characteristics of the sustainable RdM business models based on the simulation results.

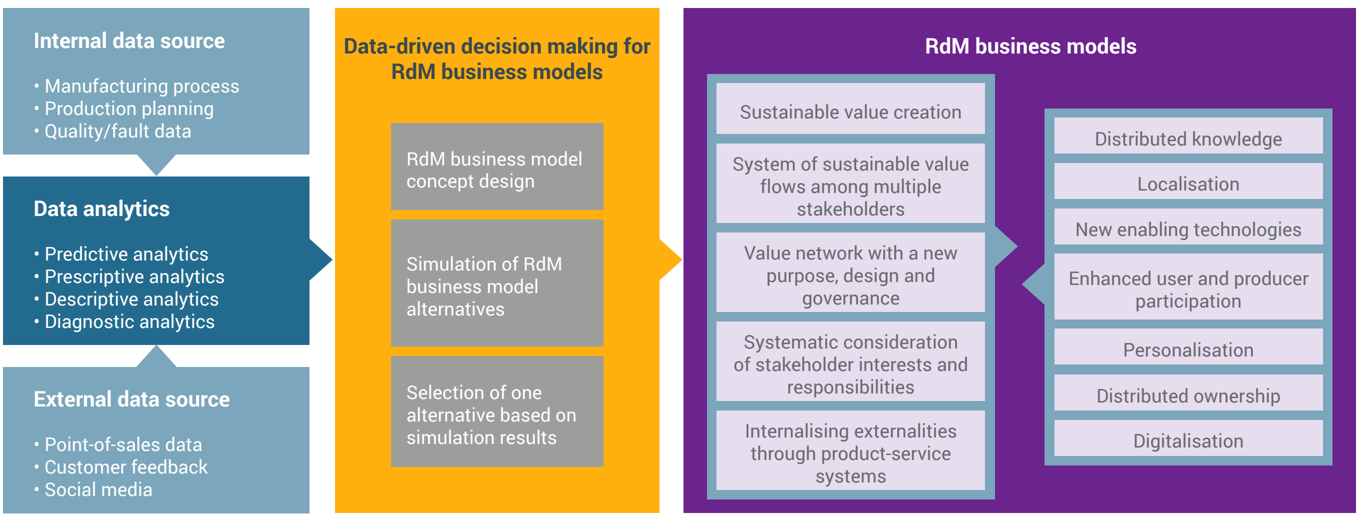


Figure 2 Conceptual framework for sustainable Re-distributed Manufacturing business models based on data-driven decision making

Outline of case study (ShoeLab)

Big data and digital technologies combined offer genuine opportunities to re-think the industry by changing the economics and organisation, particularly of location and scale. ShoeLab is a 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. 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 is perceived as the most suitable for answering research the question of - How we could 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.

IDEF0 business model for RdM

In preparation for the ShoeLab case study, a generic shoe manufacturing As-Is model was created as a reference model (Figure 3). The ShoeLab ToBe business model was then developed (shown in Figure 4). The ShoeLab business model starts with the User Profile Creation (A0, Figure 4) function. During this function the customer provides his general information as input (name, age) and details regarding their preferred payment method. 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 4), 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 4) 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.

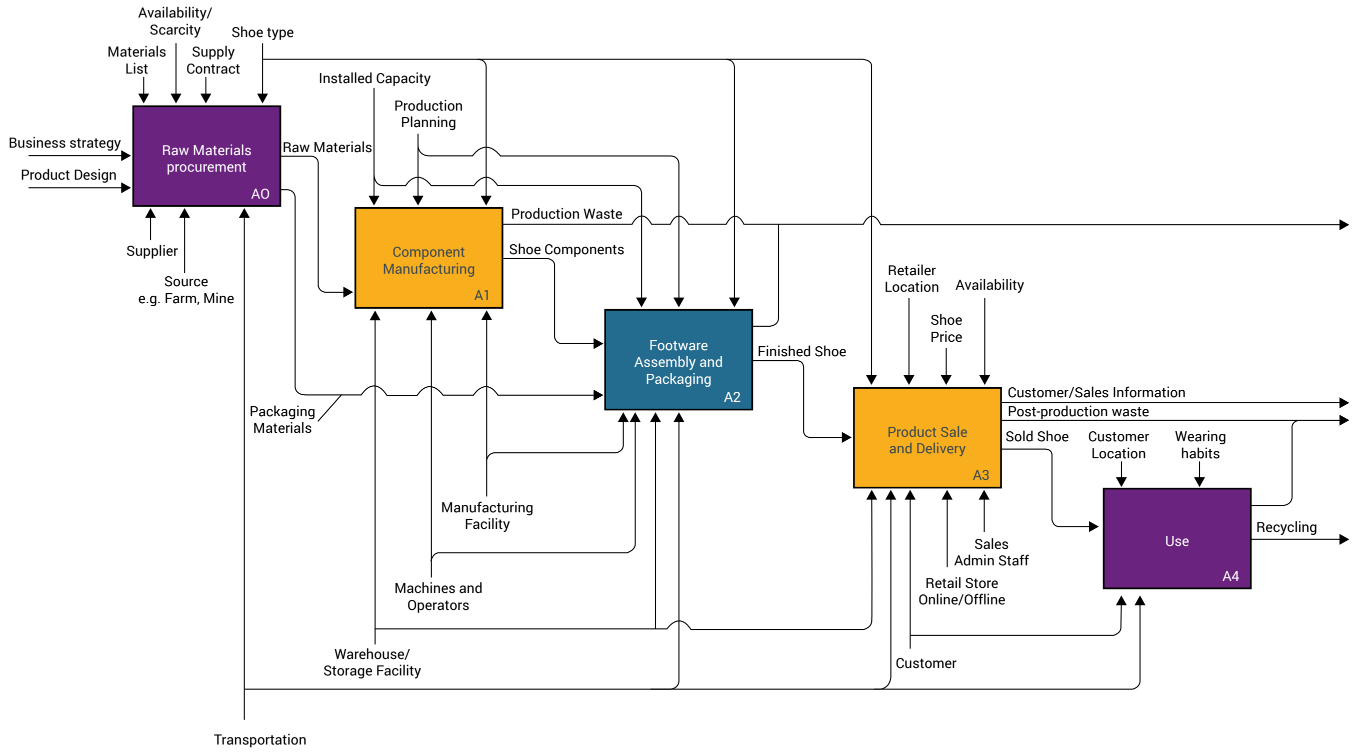


Figure 3 Shoe Manufacturing As-Is Model

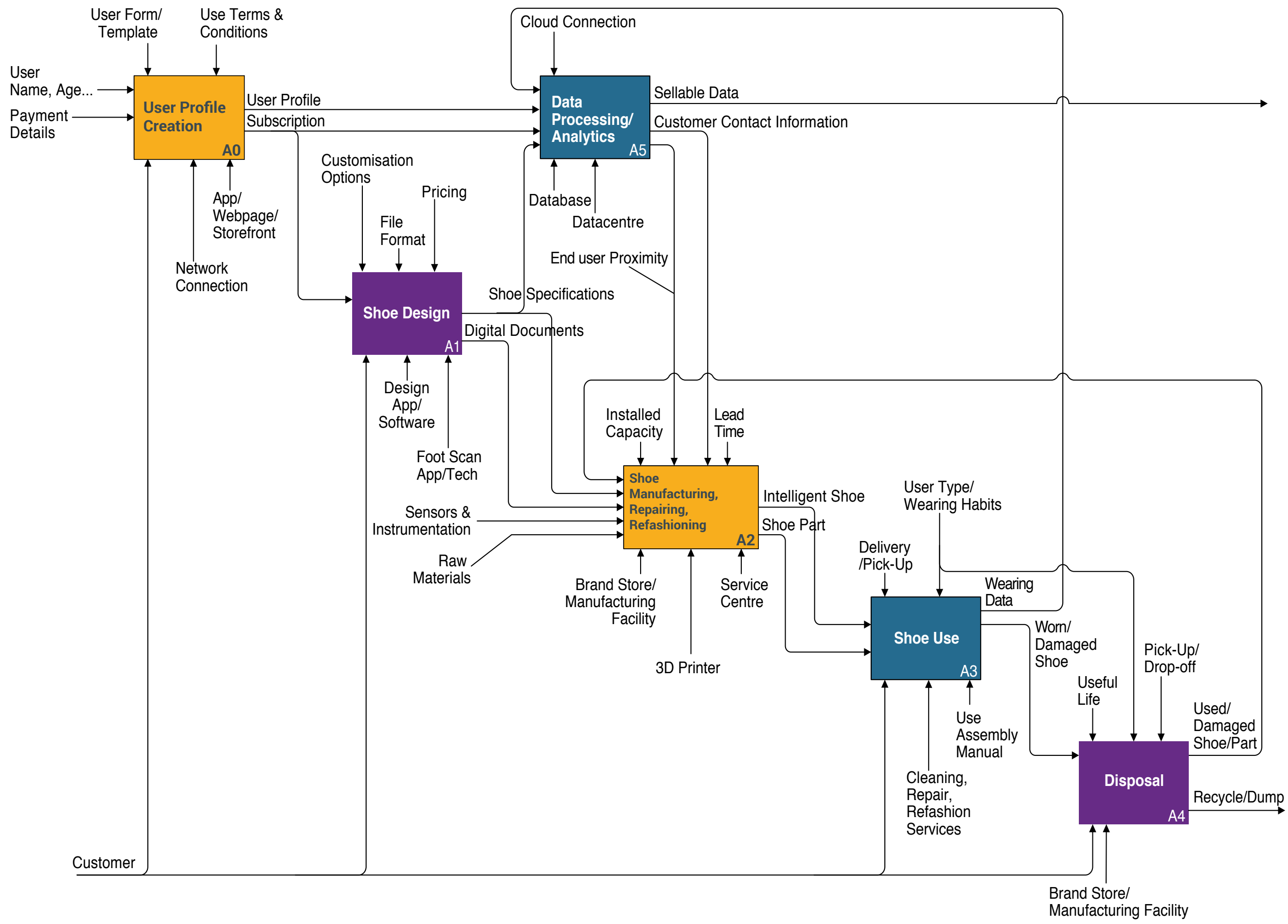


Figure 4 ShoeLab Business Model

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 4). The manufacturing function (A2, Figure 4) 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 that's 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 4).

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 physical in the form of a worn/damaged shoe. The use data is transferred to the Data Processing/Analytics function (A5, Figure 4) which uses them as input to for example activate a service offering or provide other useful information for the manufacturer to support the customer.

The worn/damaged shoe is transferred to the Disposal (A4, Figure 4) 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 return 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 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 4) 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 datacentre.

The feedback from the expert validation of the ShoeLab model was used as input for development of a concept model called ShoeLab Hybrid Business Model (shown in Figure 5). 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 4) function called Servicing, Refashioning, Repair. This function is controlled by the Data Processing/Analytic function (A2 in Figure 5) 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 in Figure 5) function in the way of providing refashioning and/or repair services. The Disposal (A4 in Figure 5) 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 4) function and waste material from the Disposal (A4 in Figure 5) 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).

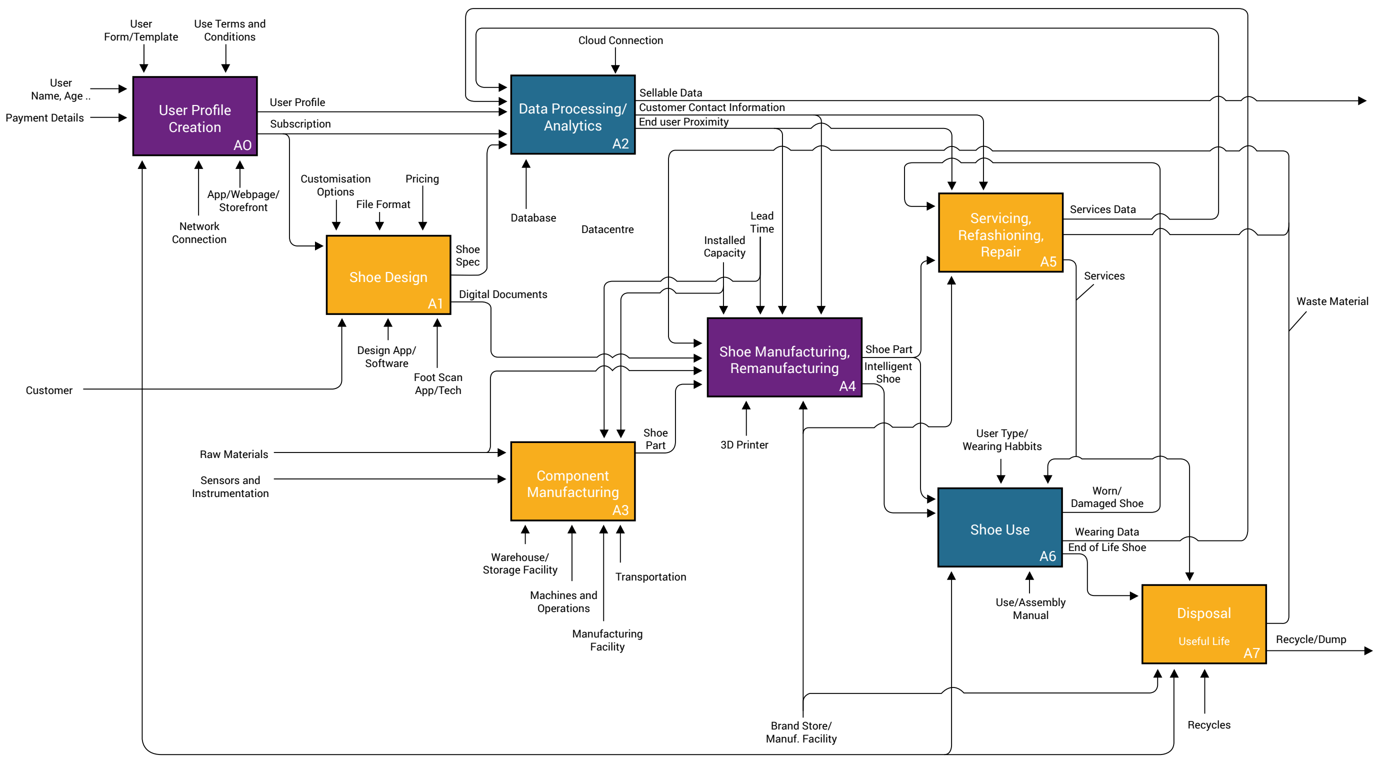


Figure 5 ShoeLab Hybrid Business Model

System dynamics business model for RdM

Building on the findings from IDEF0 Business models it was then possible to develop a dynamic model utilising Anylogic System Dynamics simulation tool. Qualitative analysis allowed the identification of the following actors within the SD model:

- Producer: Manufactures the Shoes according to the customer demand. This element integrates the supply chain, fabrication and transport.
- Retailer: Is in charge of the retail and delivery of the product. It delivers the product to the client and receives the subscription fee paid by them.
- Service provider: Ensures services such as repairing or refashioning of the shoe. Again, responding to the customer's demand for these services.
- Data Manager: Pays a fee for the data gathered from the clients' shoes.
- Recycling Partner: Processes the material coming from 'thrown-away' shoes

The RdM SD simulation of the ShoeLab case study has five main objectives: Obtain the temporal response (retard) of the system to the client demand; Analyse the cost implications for the Product Service System (PSS) approach and its profitability; Make recommendations on product prices and capacity requirements for ShoeLab; Enable data-driven experimentation to allow for multiple scenarios.

The model is composed of five main subsystems (Marketing, Production, Customer Service, Material Supply and Accounting) modelled with a System Dynamics (SD) approach and one additional subsystem describing Customers modelled with an Agent Based approach. The marketing subsystem details how publicity and word of mouth affect the rate of adoption of the product service system; in effect the demand for hiring the service is modelled here. The marketing subsystem is then linked to the production subsystem which how manufacturing and transport capabilities affect the lead time and delivery time. The raw material resources of the system are modelled by the material supply subsystem which includes inventory management, the material supply and the recycling of wasted products with the potential to provide feedback loops into other subsystems. The subsystems are now described in more detail.

Marketing subsystem

The aim of this subsystem is to model the demand for hiring the service. Publicity and word of mouth affect the rate of adoption of the product. Figure 6 shows the simplified system flow and causal loops for this subsystem. The "Order/Adoption Rate" depends on the adoption due to "Advertising" plus "Word of Mouth" (WOM); the "Fulfilment Rate" depends on the Production, described below. This subsystem enables the modelling of the system transient response to the demand (retard), driven by the "Fulfilment Rate". The customer demand subsystem focusses on satisfying customer demand for services rather than products and is linked into the production subsystem.

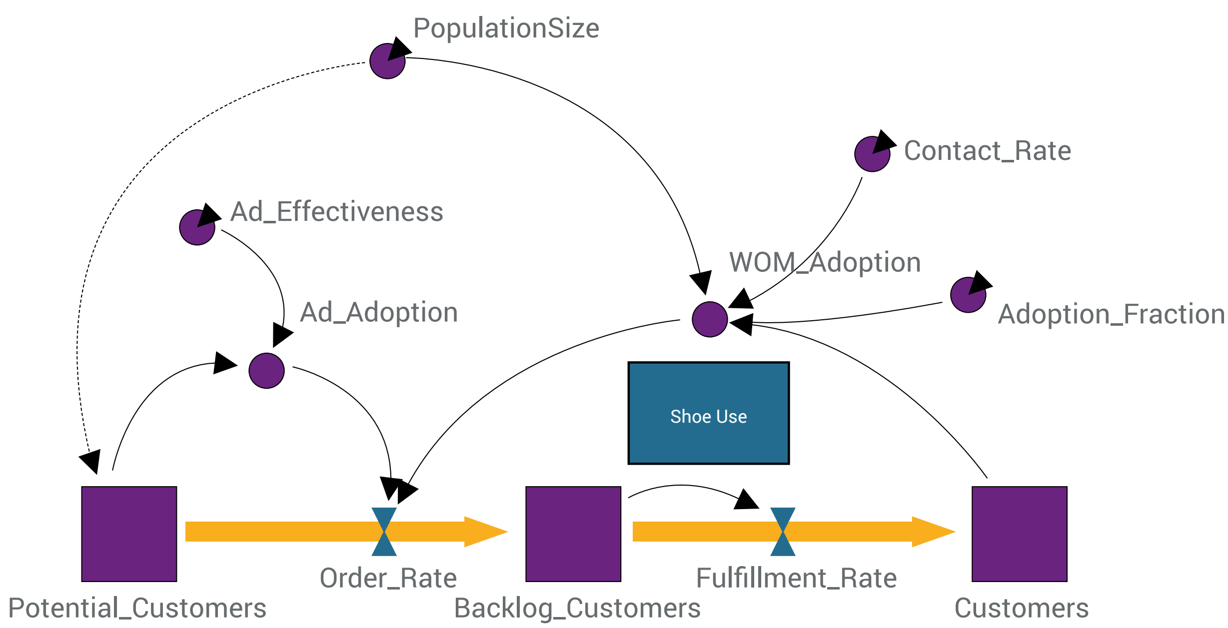


Figure 6 Marketing Subsystem

Production subsystem

The purpose of this subsystem is to measure how manufacturing and transport capabilities affect the lead time and delivery time. The primary output of this model will be the "Fulfilment Rate". Figure 7 depicts a simplified version of the SD diagram for this part. In this case, the stocks represent products, going from "Backlog Orders", which represent the pending orders computed by the Marketing Subsystem; to the products fulfilled to the "Retailer".

Customer demand, accounting and material supply and customer subsystems

The customer demand subsystem acts as analogue to the production subsystem but focusses on satisfying customer demand for services rather than products. In this subsystem, the stocks contain services, where "Backlog Services" includes the pending services to be completed (shown in Figure 8). The raw material resources of the system are modelled by the material supply subsystem which includes inventory management, the material supply and the recycling of wasted products. An accounting subsystem (not shown) is provided to calculate the costs within the model and output a set of statistics to quantify the financial impact of the scenario. It collects data from the primary cost driver and income sources. An Agent-Based Model (ABM) is used to describe the customer subsystem. The aim of this subsystem is to model a population of customers by means of statecharts.

The statecharts determine the state of every customer in terms of service requirements. The transition between states is triggered by timeouts or conditions, varying on each client depending on the distribution of the three ShoeLab customer types ("Fashionable"," Active" or "Body Builder").

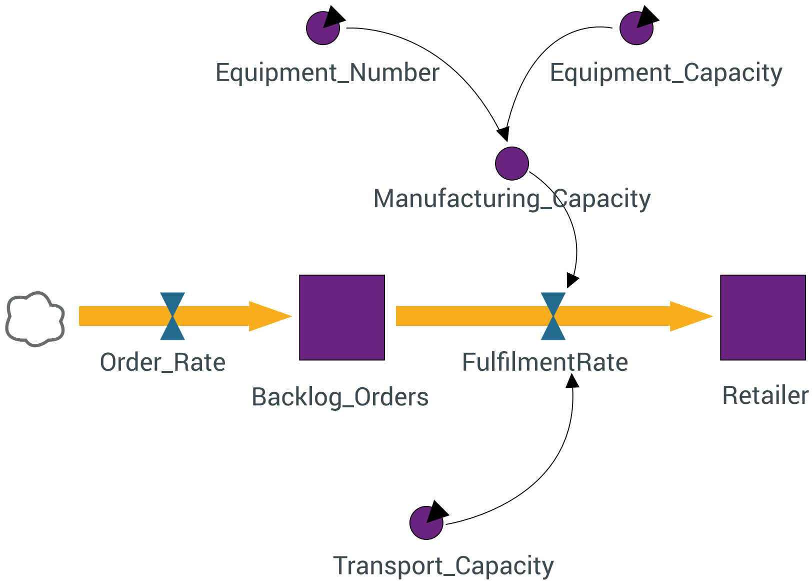


Figure 7 Production Subsystem

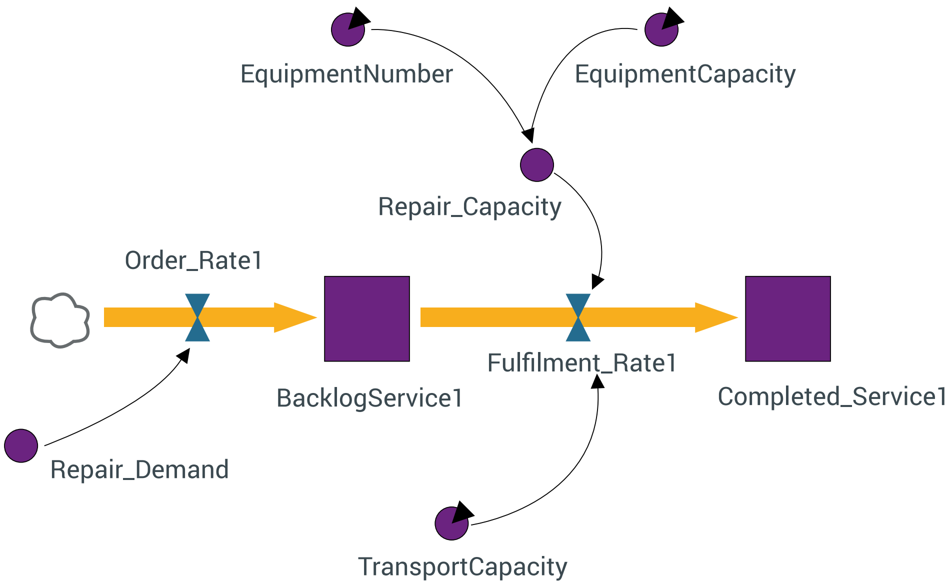


Figure 8 Customer Service Subsystem

Results

With the to-be model the "new product demand" starts with an abrupt increase with the release of the product to the market, this demand cannot be fulfilled instantaneously by the system until its stabilisation. A similar observation is true for the "service demand" (triggered by the Agent Based Customer subsystem). In the as-is model, with the planed £15 monthly one year is required to compensate the initial investment costs for manufacturing the shoes and reach break-even, from where the revenues begin to exceed the costs (shown in Figure 9). The total cost is higher in the beginning, when the new customers start demanding their shoes. Once the "new product demand" has been fulfilled, the cost increase slows down, despite continuing to grow due to the services provided.

With the to-be scenario labour costs are drastically reduced due to process automation, requiring just supervision and maintenance of the machines. The reduction of material costs accrued is explained by the recycling activities. Operational costs decrease due to minimisation of transport requirements and the automation of processes.

This improvement in costings allows for an earlier break-even point (210 days) and higher profit margins (shown in Figure 10) and a reduction is costs of 40%. The output of the to-be scenario highlights potential benefits for future RdM, providing quantitative measures in terms of cost savings and income improvements.

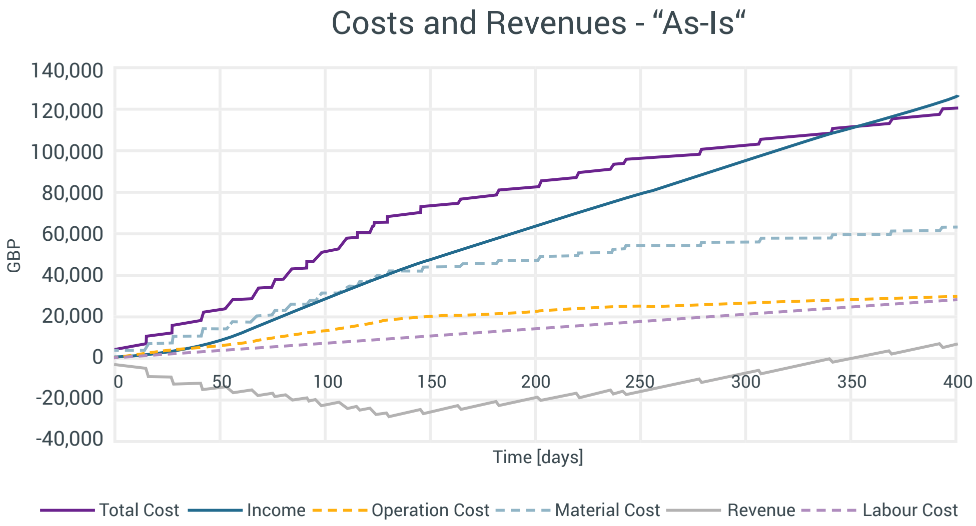


Figure 9 Cost-Revenue histogram ("As-Is")

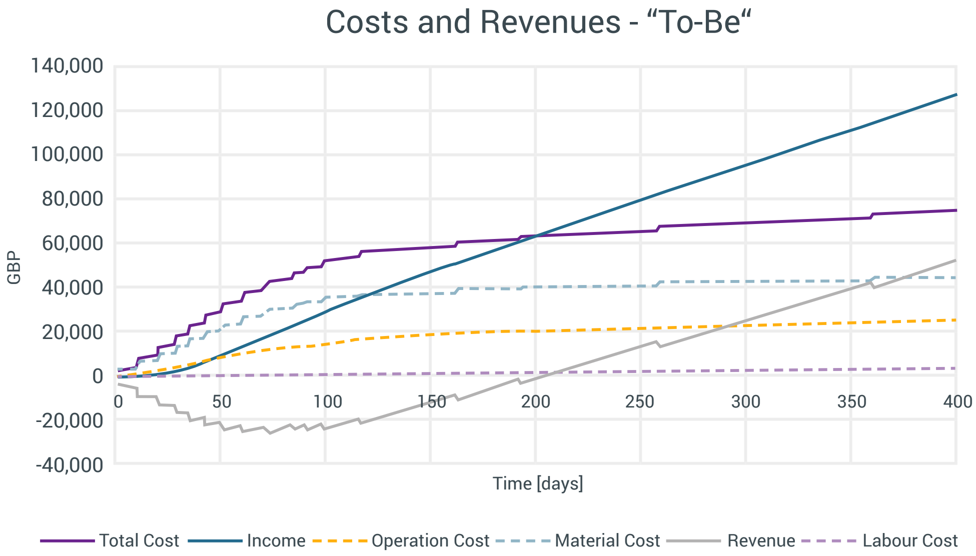


Figure 10 Cost-Revenue histogram ("To-Be")

RdM Studio: Development environment outline

It is the intention for this feasibility study to lead to the creation of an RdM business model development environment. Initially this environment will streamline the development of new models though it is the intention for the software to aid decision making and eventually provide an autonomous platform. The initial version of this software is under development.

LCA factors for RdM business models

A number of LCA (Life Cycle Assessment) models have been created to capture the main impacts of 3D printing production. In ongoing research circular indicators are also being identified within the ShoeLab case study and further analysis made to allow the findings from the aforementioned case to be applied to other forms of 3D printing deployed through an RdM form of production organisation. Figure 11 shows one LCA model relating to the ShoeLab case study, involving the SLS (Selective Laser Sintering) 3D printing process, examining the material and energy needs for production.

Parameters identified in the full lifecycle assessment of production will be incorporated into the SD models produced to provide enhanced circularity within the ShoeLab business model and other models to be developed within the RdM Digital Studio.

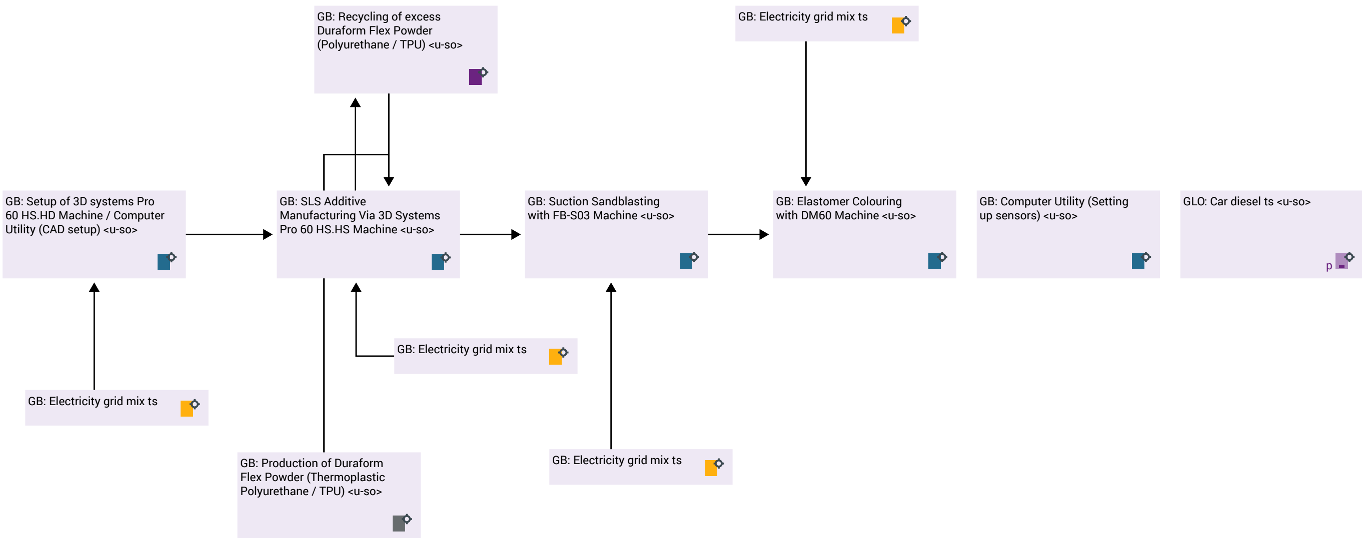


Figure 11 ShoeLab LCA (involving the SLS 3D printing process)

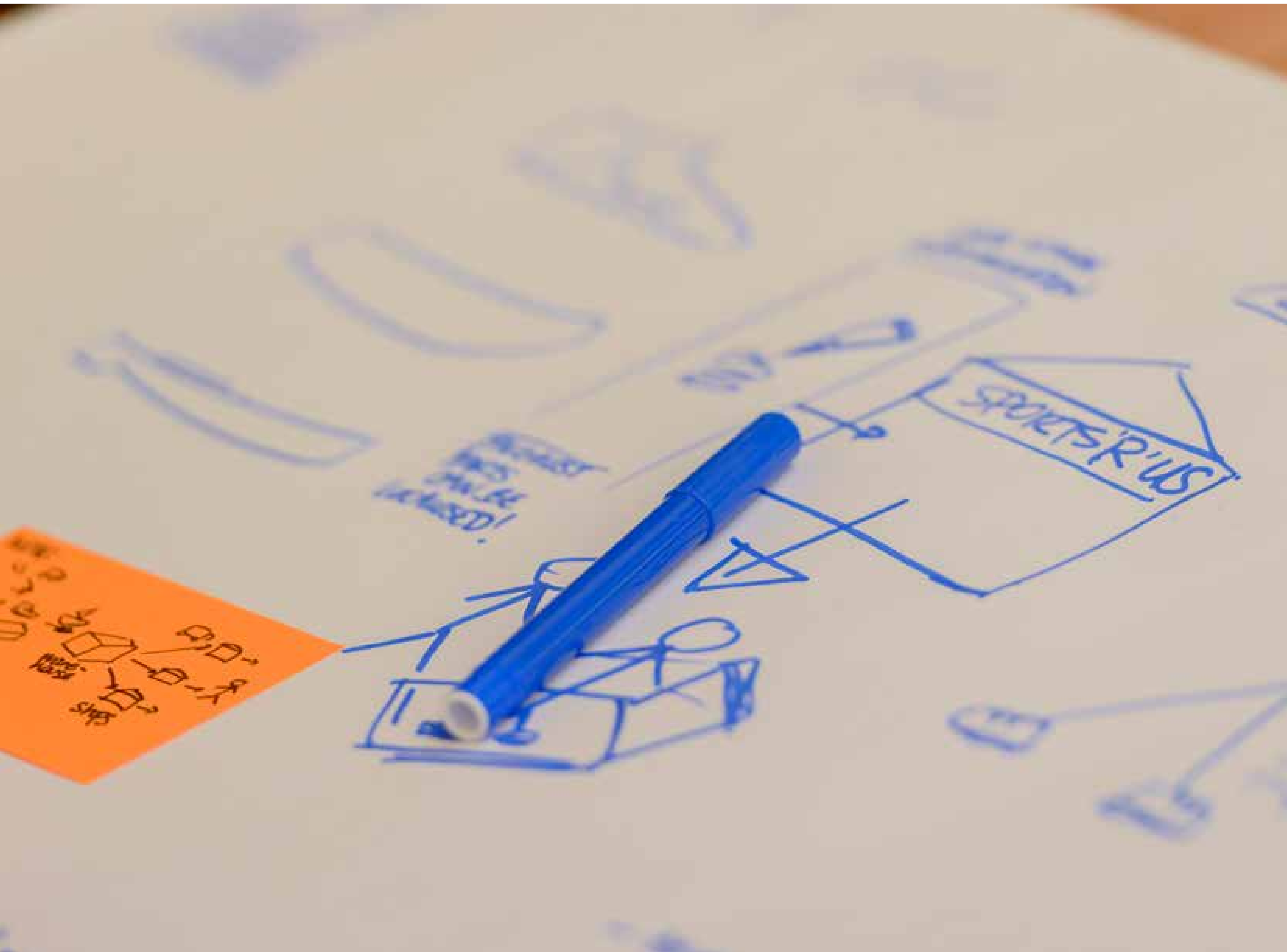
Summary

The overall aim of this feasibility study was to establish if it was possible to construct new business models for RdM production and to scope out an environment for their potential dynamic production based on available big data streams. In developing both IDEF0 and SD models this study has been able to contribute to the area of RdM and provide theoretical underpinning for new forms of business enabled by this form of manufacturing. The further development of an autonomous environment for business model production is a future aim of this project, building on the foundations outlined in this report.

Recommendations and future development roadmap

The EPSRC-ESRC funded Network in Consumer Goods, Big Data and Re-Distributed Manufacturing (RECODE) has been created to develop an active and engaged community to identify, test and evaluate a multi-disciplinary vision and research agenda associated with the application of big data in the transition towards a re-distributed manufacturing model for consumer goods.

In the future development of the Digital RdM studio big data sources such as real-time manufacturing streams and external data (e.g. marketing trends, social media, etc.) relevant to business model decision making will be made available to the system for enhanced decision making in RdM model development. The RdM digital studio will become a fully integrated software platform eventually capable of generating new business models autonomously, based on data points dynamically provided in real time. In order to pursue these developments of the RdM studio an EPSRC Proposal will be submitted via the responsive mode.



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