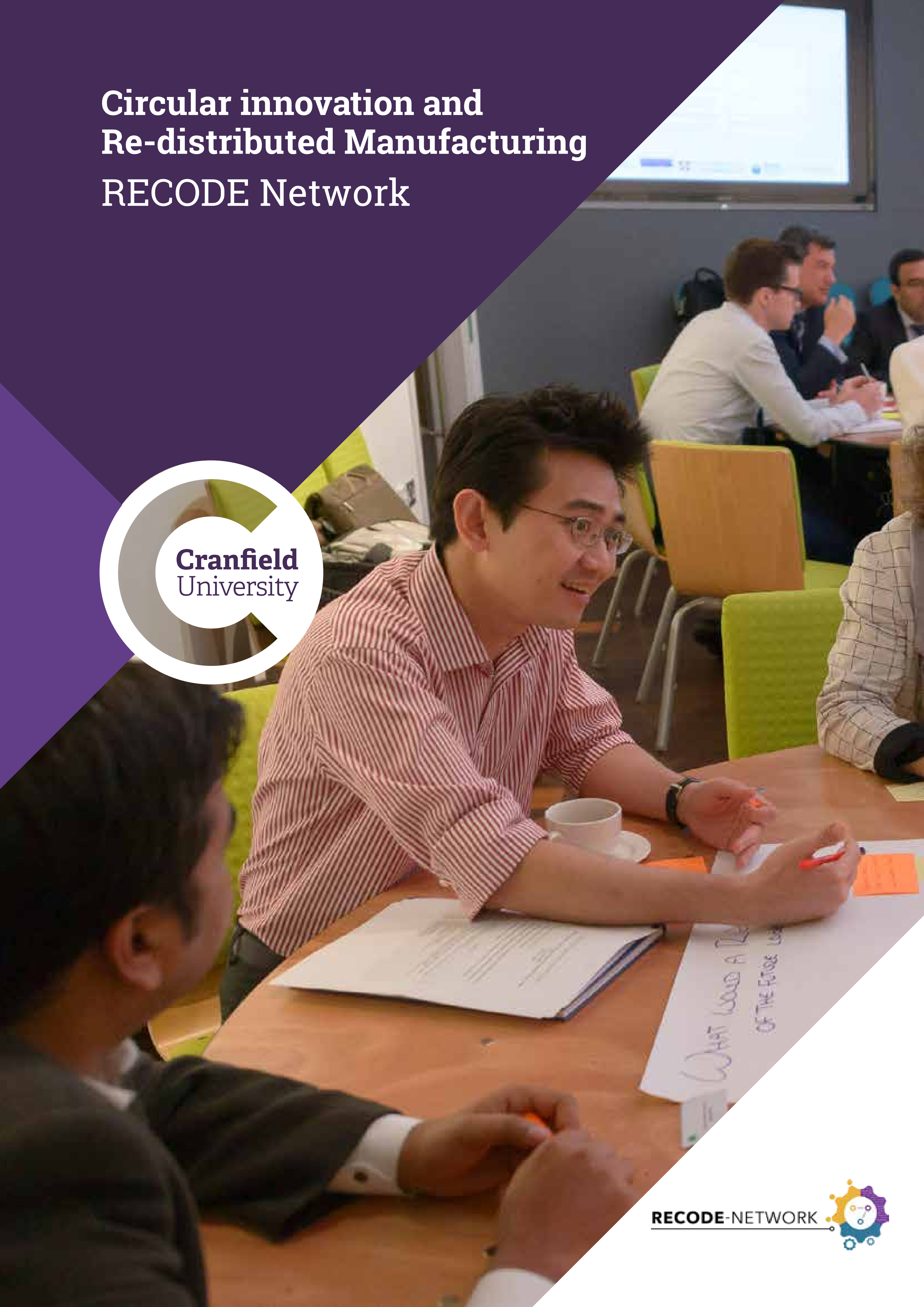
Circular innovation and Re-distributed Manufacturing

RECODE Network



Cranfield University

RECODE-NETWORK

RdM & CIRCULAR INNOVATION

CHAIR: DR. MARIALE MORENO

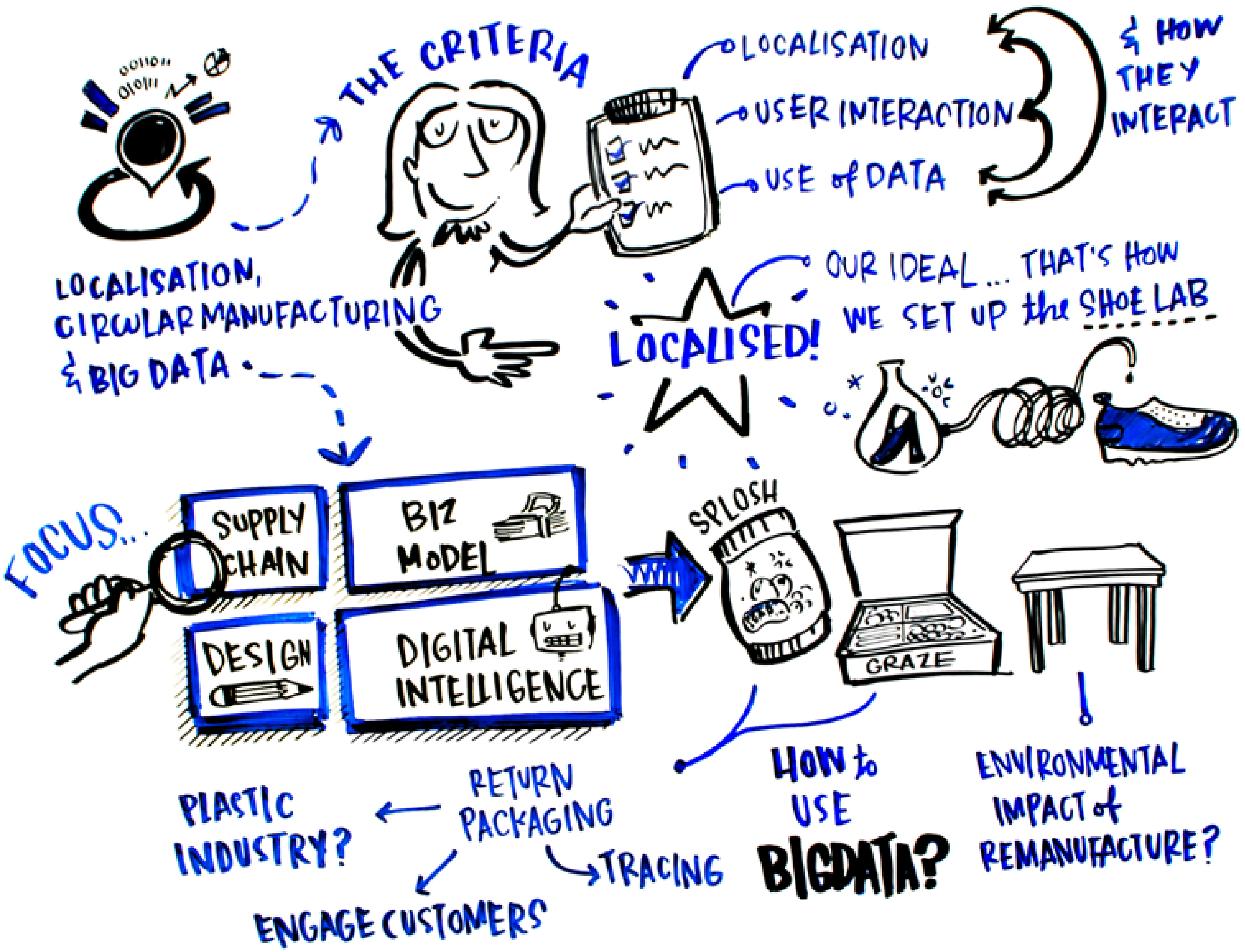
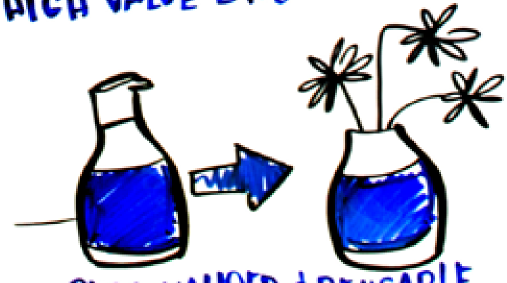


TABLE 1...

RESTAURANT SPECIFIC MAGNUM...
..PIZZA Vs AMAZON DELIVERY

TABLE 2...

HIGH VALUE END COSMETICS



PERSONALISED & REUSABLE
or REVERSE LOGISTICS?

STARBUCKS PRODUCTS Vs PACKAGING...

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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 Teesside University and practicing industry leaders in the fields of manufacture, big data, circular economy and consumer goods, 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 RECODE Network envisages a connected, localised and inclusive model of production and consumption that is driven by the exponential growth and embedded value of big data. The use of data to narrow the gap between manufacturers and end users to enable user-driven design of customised goods and services at a local scale through ad-hoc supply chains and on-demand production also enables significant opportunity for circular innovation and localised, regenerative models of production. Estimates indicate that the total material value of consumer goods is US$3.2 trillion, with approximately 80% of materials ending up in landfills, incinerators or wastewater removing the potential to feed these valuable materials back into the system. Data driven insight has the potential to inform and incentivise circular models of production and, uncovering opportunities for new revenue streams for manufacturers and suppliers and developing new circular business models based on local and connected value streams. This 6-month feasibility study aimed to investigate the opportunities, challenges and requirements for big data and re-distributed manufacturing in the development of localised and circular models of consumer goods production and consumption. This aim was fulfilled through undertaking the following objectives:

- Review and analyse existing local and regional business models to identify and compare examples of circular and re-distributed activity and the associated opportunities, challenges and requirements,

- Identify and select three local use cases, from within the consumer goods sector, that demonstrate, or have the potential to enable, circular and re-distributed activity,

- Map, model and analyse the flow of materials, data, revenue and stakeholder interaction for each case to demonstrate the potential opportunities, challenges and requirements for re-distributed manufacture and circular innovation,

- Use findings to contribute to the RECODE Network roadmap to define areas of future research necessary to move towards a data-driven model of localised and circular production and consumption.

Fundamental drivers of circular economy and Re-distributed Manufacture

For the purpose of this report, a circular economy will be defined as an "*industrial economy that is restorative by intention and design where transformational changes through innovations are applied to decouple human wellbeing form resource use and environmental impact*[1,p7]." In addition, Re-distributed Manufacturing (RdM) will be defined as *'the shift from centralized to decentralized manufacture with the aim to create a more resilient and connected system taking advantage of digital intelligence and newly emerging technologies, to provide agile, user driven approach that will allow for personalisation and customisation of products to local markets'.*

The investigation at the interface of these two concepts, resulted in identifying the fundamentals drivers of a circular economy and RdM, to define a set of criteria that describe the similarities and differences of both models to distinguish the opportunities to deliver more regenerative and resilient systems of production and consumption.

In respect to the circular economy, three fundamental drivers are identified: resource constraints, technological development and socio-economic opportunities[3]. These drivers are not too dissimilar to the drivers that could enable the decentralisation of manufacturing. Although, RdM is not primarily driven by a need to address sustainability issues, it is predicted that the introduction of digital intelligence and connected objects would potentially reduce resource use and will enable circular systems[2]. Emerging technologies such as automation and robotics, big data analytics, the Internet of Things (IoT), additive manufacturing, cloud computing, mobile technologies, social networks, and modular design amongst others support the transition towards more connected decentralised manufacturing systems[4]. A clear strategic vision of the capabilities of digital intelligence to enable RdM is the German vision of Industry 4.0. INDUSTRIE 4.0 is described as the *"paradigm shift from 'centralised' to 'decentralised' production made possible by technological advances which constitute a reversal of conventional production process logic*[5]*."*

To enable RdM in the consumer goods sector there is clear evidence of the opportunities that could be enabled by the application of digital intelligence. To relate these opportunities to the circular economy it is important to analyse the environmental and socio-economic benefits that their application in the consumer goods sector could bring. In terms of environmental benefits, digital intelligence will support new business models to effectively manage resources within markets, ensure waste is eliminated and monetized, and support selling products as services which will enable keeping products in longer use to minimise waste and resources[4,6]. In addition, if technologies such as additive manufacturing are intentionally designed to reduce the amount of materials required in production, it could contribute to reduce the use of resources and waste. Emissions from transportation could also be minimised by increased flexibility and greater control provided by the use of digital intelligence. Shifting to regional and localised manufacturing increases the potential to minimise transport and internalise material flows by being closer to the consumer[7].

To better understand the socio-economic benefits, would require an understanding of where real value could be created by addressing a set of system issues, and enabling new business models for the consumer goods sector[9]. For example, the use of digital intelligence can improve productivity and production efficiency. It is predicted that Industry 4.0 will be embraced by more companies, boosting German productivity by €90 billion to €150 billion in the next five to ten years[6]. In addition, it is evident that companies are constantly constrained by risks resulting from climate change, currency fluctuation and resource security affecting global supply chains. Thus, digital intelligence can be useful to run more resource-productive supply chains by optimising operations, setting in place an optimised inventory, and predicting maintenance[8]. Take for example new technologies that allow trace and return systems. These systems are enabled by digital and physical technologies that allow products to be traced and transferred from end users to the manufacturer or a third party, keeping track and control of assets. By using real time data, it would be more cost-effective for companies to monitor, predict and prevent breakdowns of products and at the same time enable collection for service repair, recover, reuse, or refurbish. With advanced recycling technologies, trace and return systems will also drive new opportunities to collect, process, and reuse materials, leading to more interconnected markets in which outputs are used across industries as inputs.

Digital intelligence will also create added value through high customisation of products and services. Mass customisation is foreseen as a dominant model for satisfying varying consumer needs[9]. This will not just drive revenue growth as consumers would be prepared to pay a premium up to 10% for personalised goods, but also will enable closer relationships between companies and the communities they operate within[10]. Consumers would gain more value through convenience, time saving, and more attractive customised promotions. High customisation will also provide a significant breakthrough in health and wellbeing. Digital intelligence is already being used to monitor and treat illness, and it is foreseeing that it will improve wellness by using data generated by wearable technologies to track and modify diet and exercise routines. It is predicted that these technologies will cut the costs of chronic disease treatment by as much as 50%[11].

The application of digital intelligence within the consumer goods sector will increase the demand for employees with certain skills in software development and IT technologies[12]. However, the decentralisation of manufacturing might not lead to the creation of significant numbers of new jobs as greater automation will displace some of the often low skilled labourers[8]. As such, greater education and training to adopt good analytical capabilities as well as software development capabilities would need to be a feasible option for many. Thus a shift in the skill profile is required to deliver significant value.

Background research

Different characteristics were identified to define RdM and circular innovation. As both fields of research are still in their infancy, the available literature is disjointed, with multiple perspectives. The characteristics were therefore developed based on the current review of literature and the most well used definitions of RdM and circular innovation, introduced before. Findings from the literature review were thematically analysed and categorised into themes and sub-themes by the researchers. This analysis resulted in five themes and 19 sub-themes to define RdM and four themes and 17 sub-themes to define circular innovation. These themes became the criteria against which to analyse 33 chosen case studies of existing local, regional and global business models within the consumer goods sector. To choose the case studies they had to demonstrate: 1) the use of digital intelligence, 2) de-centralised, re-distributed and circular production and consumption, and 3) had to be business to consumer in which the final user is an individual or household. The case studies analysed, referred to in Figure 1, belong to different sub-sectors of the consumer goods industry according to Euromonitor International Database[a]. The sample of case studies was sourced from online resources such as reports, news, blogs , and websites.

RdM and circular characteristics

The RdM characteristics were classified into Localisation, Customisation, Distributed Ownership, Distributed Knowledge and Distributed Structure.

a. **Localisation:** RdM is about decentralising the raw materials and methods of fabrication, so the final product is manufactured very close to the final customer[12]. As such elements of localisation such as **regional** and **urban** settings needed to be considered. **On-shoring,** where the repatriation of production from low cost locations is a continued trend, **off-shoring** in certain consumer goods sub-sectors will continue to happen in the short term due to proximity of raw materials and costs[5]. Thus in the short term, we will see a **geographically distributed production system** in which will be based on a decentralised production structure with different facilities[13].

b. **Customisation:** Distributed production brings a range of emerging practices where households can affect what is produced from product personalisation to personal fabrication. In addition, the use of digital intelligence enables these practices to enter a mainstream of customisation in different forms[11]. Thus, distributed production could be classified according to its landscape regarding the level of customisation and control over user versus its scale. For example, **mass customisation** refers to individual mass production for a large market meeting different needs; **bespoke fabrication and information,** tailors individual products and services according to users needs; and **mass/personal fabrication,** uses open source design platforms to enable the democratisation of design. Customisation is also related to providing **wellbeing, fitness and tailored promotions**[8]**.**

c. **Distributed ownership:** The use of digital intelligence in distributed models of production and consumption are facilitating new business models in which ownership is shifting to access through providing robust products alongside long-term services[5]. Distributed ownership has been studied by different scholars over the last 20 years under the topic of product service systems (PSS). The common classification of PSS is **Product Oriented, Use Oriented** and Result Oriented[14]. The latter is not considered as a category of distributed ownership as the the production system is completely replaced by a service. E.g. BlablaCar[b] is a ride sharing platform in which drivers share their ride with other users heading to the same direction. In this case the production of ‘new’ cars are replaced by a service that uses existing cars.

d. **Distributed knowledge:** Distributed production needs the adoption of production networks, which are coordinated. Thus distribution and transfer of knowledge will be essential to facilitate RdM. Knowledge is seen in different forms. **Open source innovation** offers a closer interaction between consumer, designer and producer in which co-creation is busted through shared knowledge[11]. To take advantage of the opportunities that **connected manufacturing** could bring through the application of cyber-physical-systems known as **Industry 4.0,** support and knowledge to **develop the sufficient skills** to be able to use demanding technologies would be essential[13]. **Industry 4.0** has the capacity to address the increasing complexity of products and their supply chain, by providing a full integration of information and knowledge between production and planning levels, and further to customers and suppliers. Distribution of knowledge can be finally referred to the use of ancient skills such as **craft skills** and bridging them with digital technologies. In addition, large benefits could be seen from transfer knowledge of **craftsmanship production** with digitalised production.

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[a] http://www.euromonitor.com
[b] https://www.blablacar.co.uk

e. **Distributed structure:** Distributed structure refers to the structural changes needed to facilitate RdM. De-centralisation of manufacturing processes will need to have an effective use of global capabilities and adaptable logistic systems to achieve an **integrated supply chain** enabled by the use of digital intelligence[5]. RdM might also disrupt current retail environments. This is continually increasing by shifting from physical retail to online retailing. Localisation and de-centralisation of manufacturing enabled by digital intelligence could enable manufacturers to become the retailer allowing a **distributed retailing** process.

Circular innovation characteristics were classified according to the 5 principles of the circular economy, which were interpreted as value optimisation (principle 2), resource efficiency and sufficiency (principle 1 & 3), continued ownership (principle 4) and economic viability (principle 5)[15].

a. **Value optimisation:** The main focus of the circular economy is to increase the optimization of value creation through an intelligent management of all resources including: **human labour, skills and experience, health** (including minimizing social issues) **and healthcare, education and knowledge, culture and cultural heritage, and natural capital** (comprising biodiversity and natural resources)[16].

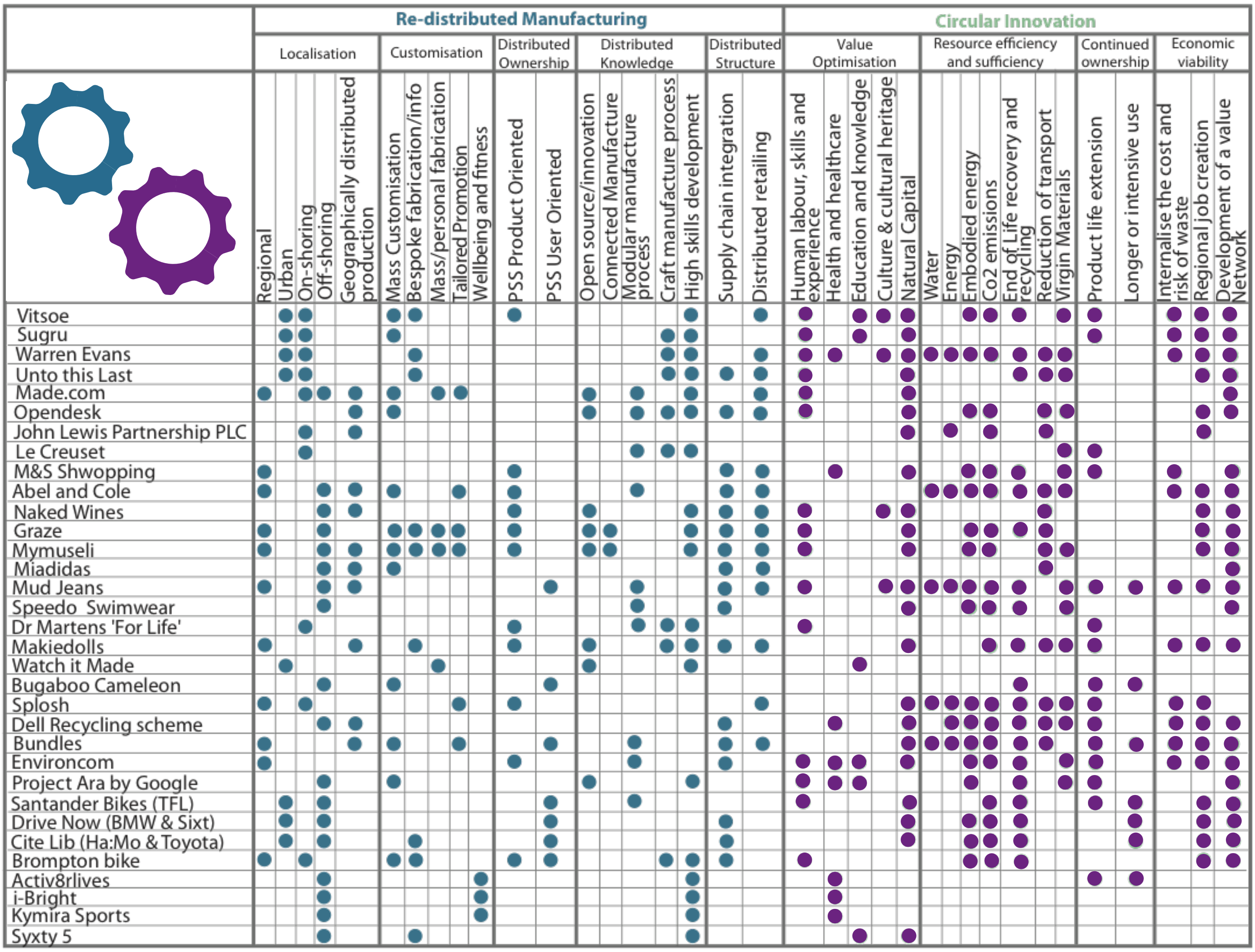
b. **Resource efficiency and sufficiency:** Efficiency and sufficiency are metrics to quantify material efficiency and reductions in material consumption and emissions. Efficiency and sufficiency should be achieved in: **water, energy, embodied energy, Co2e emissions, end of life** through recovery and recycling, **reduction of transport and virgin materials[16].**

c. **Continued ownership:** Continue ownership by selling goods as services or performance could internalise the cost of risk and of waste, and could provide future resource security. **Longer and intensive use** (based on leasing and share use respectively) are explored as potential circular models for continued ownership[7]. In addition, **product life extension** is one of five circular business models based on continued ownership to recapture value of products through reuse, repair, remanufacture and remarketing goods[4].

d. **Economic viability:** A circular economy needs functioning markets. Thus, economic viability is essential. To shift towards a circular economy that is economically viable, companies will need to think about **internalising the cost of risk and waste,** have an **intelligent use of human labour** and foster **regional job creation,** and **developing a value network** that is based on supply chain integration[17].

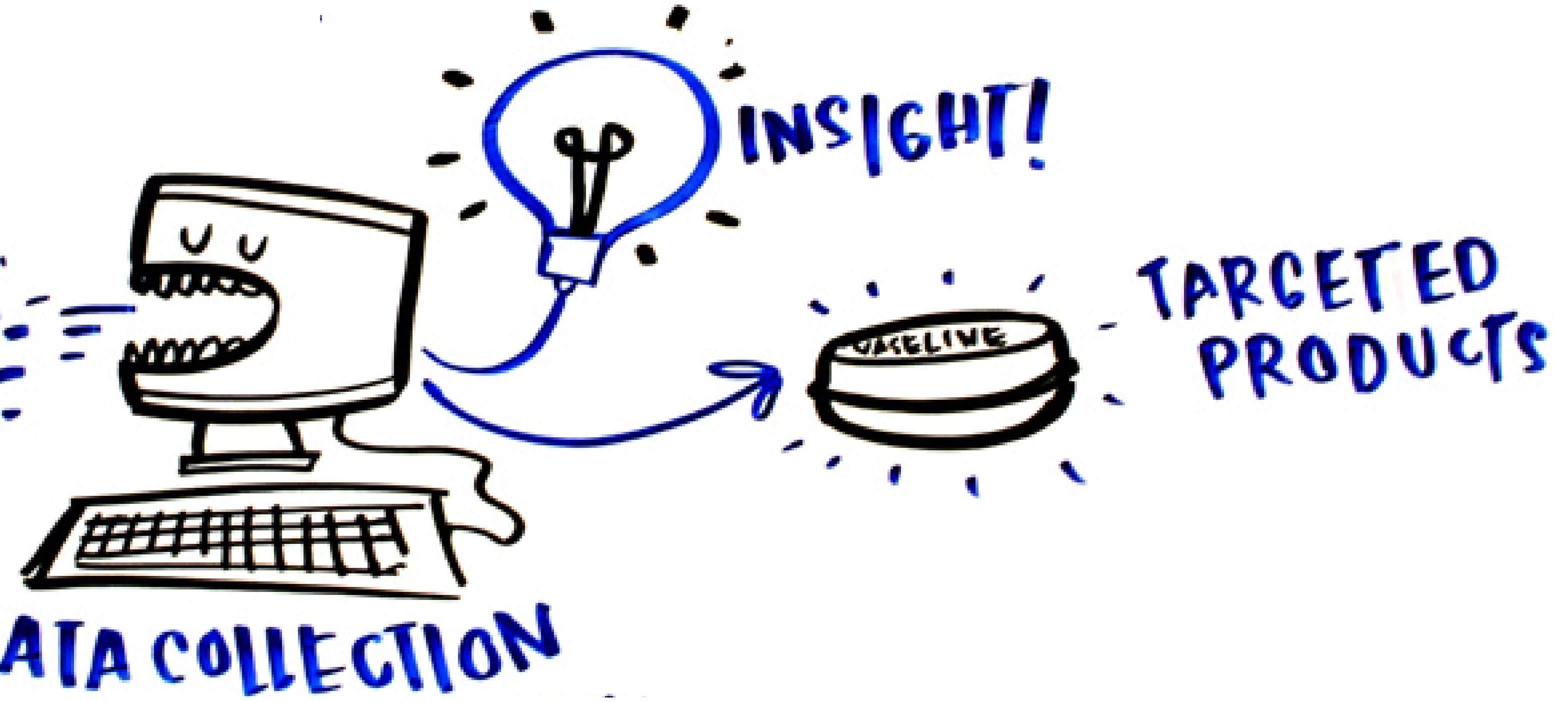
Circular and re-distributed case studies

The case studies were analysed, case-by-case, against the characteristics of RdM and circular innovation explained above. Through using secondary data each case study was assessed to understand if they met or not each criterion (Figure 1) where a characteristic was not found to be represented in a case study the field was left blank. The analysis was undertaken by the researchers through two iterations of analysis. Once the analysis was complete a workshop was undertaken with a panel of three experts from across the fields of design, consumer goods and digital intelligence, to validate the criteria, selection of case studies and analysis. Figure 1 represents a matrix in which 33 case studies (vertical axis) were analysed against the RdM and circular innovation characteristics (horizontal axis). A circle was used to depict what criteria was met by each case study.



	Re-distributed Manufacturing																			Circular Innovation																
	Localisation					Customisation					Distributed Ownership		Distributed Knowledge					Distributed Structure		Value Optimisation					Resource efficiency and sufficiency							Continued ownership		Economic viability		
	Regional	Urban	On-shoring	Off-shoring	Geographically distributed production	Mass Customisation	Bespoke fabrication/info	Mass/personal fabrication	Tailored Promotion	Wellbeing and fitness	PSS Product Oriented	PSS User Oriented	Open source/innovation	Connected Manufacture	Modular manufacture process	Craft manufacture process	High skills development	Supply chain integration	Distributed retailing	Human labour, skills and experience	Health and healthcare	Education and knowledge	Culture & cultural heritage	Natural Capital	Water	Energy	Embodied energy	Co2 emissions	End of Life recovery and recycling	Reduction of transport	Virgin Materials	Product life extension	Longer or intensive use	Internalise the cost and risk of waste	Regional job creation	Development of a value Network
Vitsoe		●	●			●	●				●						●		●	●		●	●	●			●	●	●		●	●		●	●	●
Sugru		●	●			●										●	●			●		●		●								●		●	●	●
Warren Evans		●	●				●									●	●		●	●	●		●	●	●	●	●	●	●	●	●			●	●	●
Unto this Last		●	●				●									●	●	●	●	●				●					●	●	●				●	●
Made.com	●		●	●	●	●		●	●				●		●		●		●	●				●												●
Opendesk					●	●							●		●	●	●	●	●	●				●			●	●		●	●				●	●
John Lewis Partnership PLC			●		●																			●		●		●		●					●	
Le Creuset			●												●	●	●														●	●				
M&S Shwopping	●										●							●	●		●			●			●	●	●		●	●		●		●
Abel and Cole	●			●	●	●			●		●				●			●	●						●	●	●	●	●	●	●			●	●	●
Naked Wines				●	●						●		●				●	●	●	●			●	●						●					●	●
Graze	●			●		●	●	●	●		●		●	●			●	●	●	●				●			●	●	●	●					●	●
Mymuseli	●			●	●	●	●	●	●		●		●	●			●	●	●	●				●			●	●		●	●				●	●
Miadidas				●	●	●												●	●											●						●
Mud Jeans	●			●	●							●			●			●	●	●			●	●	●	●	●	●	●		●	●	●	●	●	●
Speedo Swimwear				●											●			●						●			●	●	●		●					●
Dr Martens 'For Life'			●								●				●	●	●			●												●				
Makiedolls	●				●		●				●		●			●	●	●	●					●				●	●	●	●	●		●	●	●
Watch it Made		●						●					●				●					●														
Bugaboo Cameleon				●		●						●																	●			●	●			
Splosh	●		●						●		●								●					●	●	●	●	●	●	●	●	●		●	●	
Dell Recycling scheme				●	●													●			●			●		●	●	●	●	●	●	●		●	●	●
Bundles	●				●	●			●			●			●			●	●					●	●	●	●	●	●	●		●	●	●	●	●
Environcom	●										●				●			●		●	●	●		●			●	●	●		●	●		●	●	●
Project Ara by Google				●		●							●				●			●	●	●					●		●		●	●				●
Santander Bikes (TFL)		●		●								●			●					●				●				●	●			●	●		●	●
Drive Now (BMW & Sixt)		●		●								●						●						●			●	●	●				●		●	●
Cite Lib (Ha:Mo & Toyota)		●		●			●					●						●						●			●	●	●				●		●	●
Brompton bike	●		●			●	●				●	●				●	●	●		●							●	●	●						●	●
Activ8rlives				●						●							●				●											●	●			
i-Bright				●						●							●				●															
Kymira Sports				●						●							●				●															
Syxty 5				●			●										●					●		●												

Figure 1 Matrix: `analysis of case studies in relation to RdM and Circular Innovation criteria



Circular RdM models in the consumer goods sector

From this analysis, it became evident that there were several different types of RdM in which circular innovation characteristics were identified. Further analysis of the case studies was undertaken, particularly focusing on: the application of digital intelligence, the integration of distributed knowledge between the production and consumption processes, the levels of customisation that can be achieved, the potential to optimise and deliver value whilst at the same time enabling closed-loop systems of production and consumption, and the scale of de-centralisation and localisation. From this analysis three types of RdM with circular innovation characteristics were identified (Figure 2).

Distributed production and services

This model represents distributed manufacture that captures big data to monitor the processes of production and consumption. From the three models, this is the one that has the least potential of capturing and delivering value and is most closely linked to our current system, therefore the most cases were identified. This is because most of its capabilities relies on monitoring production and consumption processes. Also, it mainly happens off-shore with some on-shore capabilities of manufacture and re-manufacture as well as local capabilities to manage logistical operations. Big data is used to enable mass customisation as it flows just in one direction. Some closed loops of material flows could be captured through monitoring end users. Case studies that were analysed as having these characteristics and represent this model, include Sugru, M&S Shwopping, Splosh and Environcom.

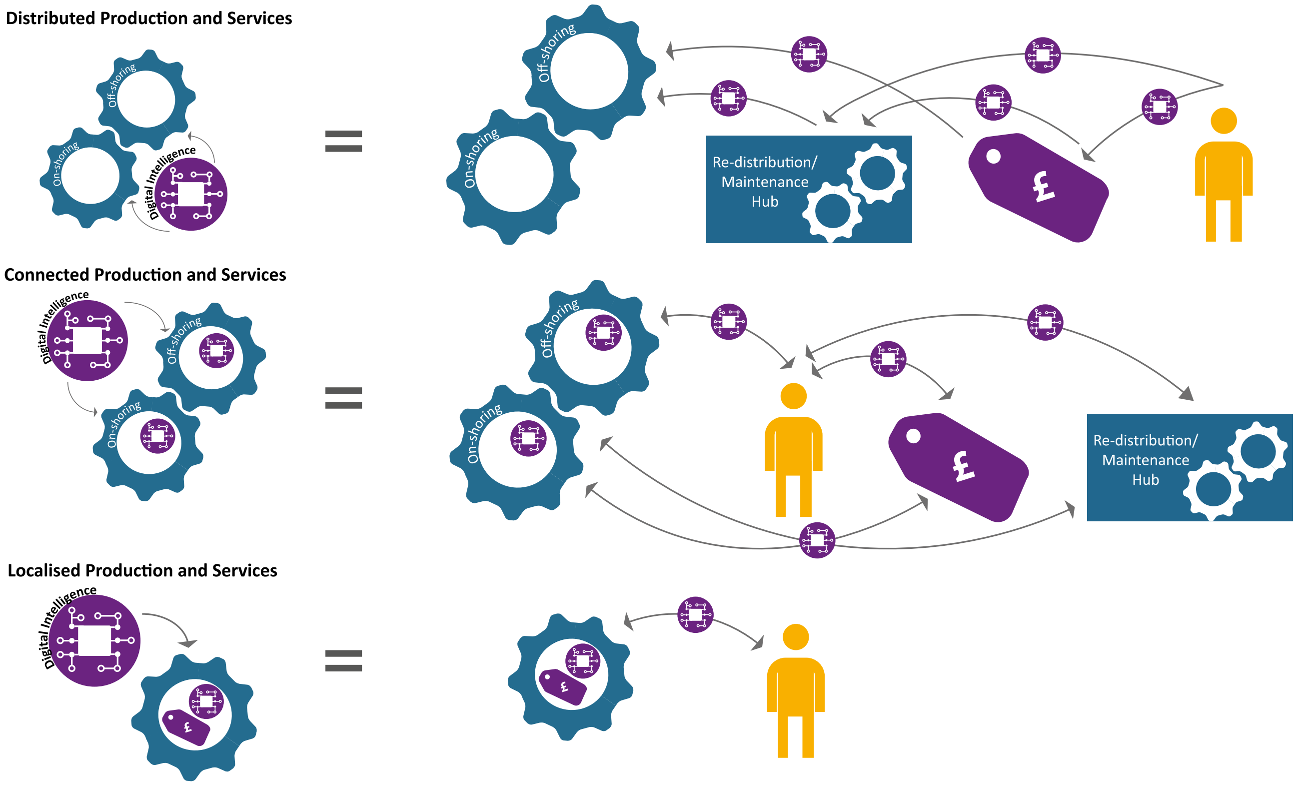


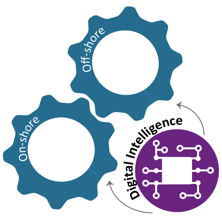
Figure 2 Types of RdM models with circular innovation characteristics

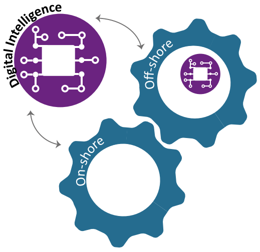
Connected production and services

This type represents a distributed and digitally connected model. This model can considerably capture high optimisation and delivery of value. This is because, despite manufacture still taking place off-shore and on-shore, it demonstrates a closer proximity to the end user that allows a radical model of consumer goods production, purchase and use. With the use of big data, users can engage in a data-driven open innovation process in which high level of customisation occur as demonstrated in the Opendesk case. It also demonstrates high optimisation of manufacturing processes and logistical operations through the use of digital intelligence such as used by Abel and Cole. In addition, the two-way flows of big data represented in this model allows material flows to be closed easily by the monitor, control and optimisation of resources.

Localised production and services

The third type identified represents a localised and highly digitally connected model of RdM where everything is done on-shore and the retail ecosystem is completely re-distributed contributing to the potential of capturing the highest value amongst the three models. This is because users are highly involved in an open be-spoke design and manufacture process, where consumer goods are produced and sold in the same physical or digital space. Personalisation is the key driver as well as shorter supply chains. This model enables high control and optimisation of resources as material flows happen in proximity to the factory and retail floor. The case study Unto- This-Last is an example of this type of RdM. This type of RdM was identified as being the least represented by the case studies as it is the most radical model requiring the biggest transformation to our current system.

Distributed Production and Services 	Digital Intelligence									Capabilities			
	Mobile	Machine to machine	Cloud computing	Social Media	Big data analytics	Modular design tech.	Autonomous robotics	Adititive Manufacturing	Trace and return systems	Monitoring	Control	Optimisation	Autonomy
Vitsoe			●			●		●	●	●	●		
Sugru	●			●						●			
Warren Evans								●		●	●		
M&S Shwopping									●	●			
Mud Jeans									●	●			
Splosh	●			●						●			
Dr Martens 'For Life'										●			
Dell Recycling scheme									●	●			
Bundles	●	●			●				●	●	●		
Environcom									●	●			
Santander Bikes (TFL)	●	●		●					●	●	●		
Drive Now (BMW & Sixt)	●	●		●					●	●	●		
Cite Lib (Ha:Mo & Toyota)	●	●		●	●				●	●	●		
Brompton bike	●			●					●	●			
Activ8rlives	●	●			●					●	●		
i-Bright	●	●			●					●	●		
Kymira Sports	●	●			●					●	●		
Syxty 5	●	●			●					●	●		

Connected Production and Services 	Digital Intelligence									Capabilities			
	Mobile	Machine to machine	Cloud computing	Social Media	Big data analytics	Modular design tech.	Autonomous robotics	Adititive Manufacturing	Trace and return systems	Monitoring	Control	Optimisation	Autonomy
Opendesk	●	●	●	●		●		●		●	●	●	
Made.com	●			●	●					●	●		
Naked Wines	●			●	●					●	●		
Abel and Cole	●			●	●					●	●		
Mymuseli	●	●	●	●	●					●	●	●	
Graze	●	●	●	●	●					●	●	●	
Miadidas	●		●	●	●			●		●			
Project Ara by Google	●		●	●	●	●				●	●		

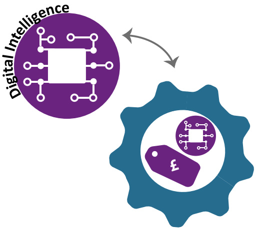
Localised Production and Services 	Digital Intelligence									Capabilities			
	Mobile	Machine to machine	Cloud computing	Social Media	Big data analytics	Modular design tech.	Autonomous robotics	Adititive Manufacturing	Trace and return systems	Monitoring	Control	Optimisation	Autonomy
Unto this Last	●	●		●				●		●	●	●	
Makiedolls	●			●		●		●		●	●	●	
Watch it Made								●		●	●	●	

Figure 3 Digital intelligence and capabilities of each analysed case study

Application of digital intelligence

A further analysis of the case studies and their use of digital intelligence was conducted, to better understand how the case studies represent the three types of RdM represented in Figure 2.

To do this analysis, the researchers looked at four different capabilities that emerging technologies have (i.e. monitor, control, optimization and autonomy)[18] that will enable opportunities for circular and distributed systems. *Monitor* refers to using data to assess a product's condition, external environment, product's operation and usage, and allows notification of changes on production or consumption processes. *Control* is enabled by software embedded in the product to regulate product functions and to personalize user experiences. *Optimization* is possible by using algorithms that enhance product operations, performance and allows predicting diagnostics for servicing such as maintenance and repair. *Autonomy* combines the other three capabilities to have an autonomous product operation, in which a consumer product communicates with other products and systems and is able to conduct self-diagnosis for servicing. These capabilities build on the preceding one helping companies to define the value that they want to capture and deliver.

Figure 3 depicts the different case studies represented by each type of RdM, according to their digital intelligence capabilities. Furthermore, a consultation was undertaken with a panel of three industry experts from across the fields of design, consumer goods and digital intelligence to select a suitable case study per type of RdM to be further analysed. This selection was done according to the consumer goods sector that the case studies belong to, their use of digital intelligence and their capabilities to enable circularity within their business model. Figure 3 also presents the three selected case studies: Splosh, Graze and Unto This Last.

Key areas to achieve circular RdM models

A further review looking at digital intelligence and RdM, identified four key areas to consider when looking to apply circular economy principles to develop a framework to further analyse the selected case studies. The review identified four key areas to analyse the value that can be created by applying circular economy principles. These areas are: system enablers, supporting systems, product design, and business model.

System enablers

The shift to a circular economy model will require a number of enablers to facilitate and support the required systemic change. One way to enable systemic change is through the generation of digital intelligence to gain a better understanding of our current systems, (i.e. current infrastructure, policy and technological systems, amongst others) and identify opportunities for innovation[2]. Digital intelligence through smart, connected devices known as IoT, and the application of big data analytics could transform how current systems are managed. Analysis of these datasets can be used to generate intelligence, which can substantially improve decision making, minimize risks, and reveal insights that would have previously remained hidden. Additionally, big data analytics can allow for automated decision making or augmentation of human decision making, by aiding in the analysis of massive datasets that cannot be analysed using a traditional spreadsheet[8].

Systemic changes in the manufacturing spectrum are already happening and are triggering the next industrial revolution in which humans as well as machines communicate between each other in a cyber-physical-system[19]. The concept of RdM is in line with the strategic vision of Industry 4.0, as it foresees that transformation of current production and consumption systems will change due to the integration of digital intelligence.

Supporting systems

The introduction of digital intelligence is also enabling a transformation of the supporting systems along supply chains. Smart production processes are enabling faster, flexible and efficient manufacturing that delivers higher quality of goods at reduced costs[20]. In the retail segment, consumer data is being exploited to generate insights and analysis of consumers' preferences and behaviors[21]. Digital intelligence will also significantly increase understanding of the post-use stage of the supply chain. The introduction of digital intelligence will provide the capability to "trace materials anywhere in the supply chain, identify products and material factions, and track product status during use[1, p41]." Insights generated from these datasets can help move toward a resource management approach that works toward balancing the forward and reverse loops of the supply chain[22] and allow for the the development of an efficient collection system that can capture the value remaining in material goods once they are used or consumed.

In addition, expansion of digital intelligence along the supply chain will allow for the development of re-distributed manufacturing models that shift production away from a small number of central locations to a more distributed network. Moving manufacturing to decentralized locations, closer to consumers, supports the development of circular systems that incentivize the reuse, redistribution, remanufacture, refurbishment, and recycling of material goods.

Product design

The ability to monitor and control physical objects will also drive radical changes in how products and services are designed. Smart, connected capabilities are making substitutions for ownership possible leading to the servitisation of products[23]. As companies shift to retaining ownership of their assets a whole new set of design principles will be required[24]. These principles include the standardization /modularizations of components, use of pure materials, and design for easier disassembly[1]. At the forefront of these new design principles is improvement in material selection. This requires a shift away from complex material combinations to a set of pure materials. By recognizing the need for pure material flows and designing out leakages from the start, companies are able to create arbitrage opportunities that generate economic benefits and make investments in reverse cycle setups profitable[23]. The design of planned obsolescence used to drive a perpetual cycle of sales can also be removed. Instead, it is replaced with a set of design principles aimed at extending product longevity.

Business model

The development of innovative business models allows companies to transform the way that they provide value and engage with customers. The introduction of digital intelligence and redistributed manufacturing models has the potential to fundamentally change the ways in which businesses operate and allows for the development business models that move beyond incremental efficiency gains to radical systemic transformations that involve consumer-centric approaches to creating, delivering, and capturing value[3].

In particular, digital intelligence facilitates the development of product service system (PSS) business models that aim to increase competitiveness and profitability[25] by creating a marketable set of joint products and services to fulfil user's needs[26]. In addition, these business models drive continuous improvement in relation to business practices, product and service quality, customer satisfaction and could be associated to secure a more resilient supply chain[27].

Four Lens Framework

Taking into consideration the four key areas described above, a conceptual framework was developed to analyse the value that can be created by applying circular economy principles. The framework uses four different lenses to evaluate a company's current business practices and examine how these could be transformed through the application of circular economy principles. Figure 4 depicts the four lenses used in this framework (i.e. Design, Supply Chain, Business Model, and Digital Intelligence).

The Four Lens Framework was developed as a tool to allow companies to develop an understanding of the current system and explore the potential opportunities for the application of circular economy principles. The framework provides a systematic way for businesses to analyse each of these four key areas. This allows companies to develop an understanding of the whole system and the interrelationship between the various subsystems. Additionally, companies can create a benchmark of the current system by evaluating current business practices through each of the four lenses, which can then be compared to the proposed future systems. Examples of potential areas of analysis for each lens are provided below.

a. **Design:** Develop an understanding of the current product/service. Explore how the product or service could be re-designed to facilitate a closed-loop system through questions such as; are there opportunities to improve the materials used, create modular components, design for disassembly?

b. **Business model:** Develop an understanding of the current business model. Explore opportunities for business model innovation through questions such as; can a business case be created for the application of circular principles?

c. **Supply chain:** Develop an understanding of the current supply chain. Explore how the supply chain would have to be transformed to support a circular system through questions such as; are their opportunities for a Re-distributed manufacturing model? What would be the associated benefits?

d. **Digital intelligence:** Develop an understanding of current digital intelligence capabilities. Explore future opportunities in which data and digital solutions can be used to drive innovation through questions such as; what impact will the introduction or advancement of digital intelligence capabilities have on design, business model, and supply chain?

By taking a systematic approach the framework provides a way for companies to better understand and explore the value that can be generated through application of circular economy principles. The application of circular economy principles exists on a continuum. Circularity can be applied by companies in a small degree, through activities such as down-cycling material instead of disposal, or to a more substantive degree through complete closed loop activities that include reuse, refurbishment, and recycling. The framework aids companies in the development of understanding the potential value of applying these principles. By considering all aspects of the system, businesses can shift from making decision based on cost-benefit analysis to making decisions based on the compounding of benefits across the whole system.

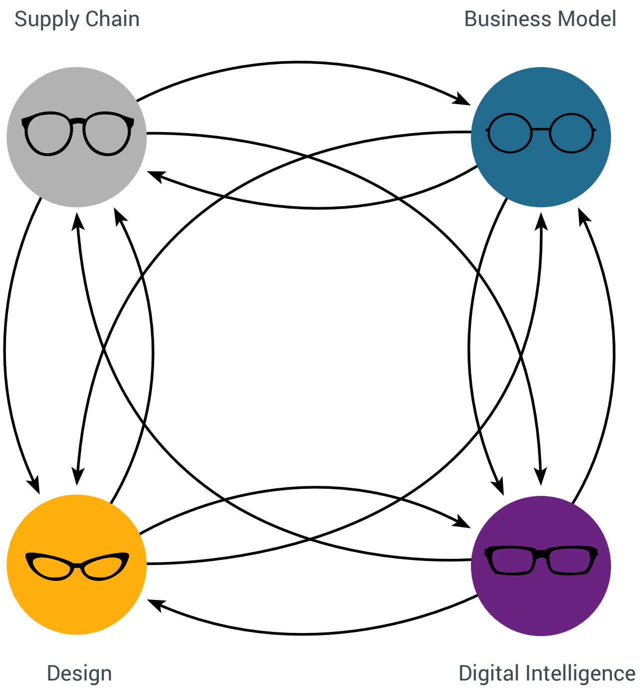


Figure 4 Four Lens Framework

In-depth case study analysis, identification and simulation

A cross-case synthesis analysis was conducted between Splosh, Graze and Unto-This-Last.

a. **Splosh:** is a UK manufacturer that produces concentrated sachets of different cleaning products. They provide the user with re-useable bottles in which to insert the sachet along with hot water. All their formulations are created with the environment in mind, with ingredients that are sustainable and biodegradable. They cut out the retailer as all orders are made online. At the moment they do not deliver outside the UK, as they use the postal services to deliver the products.

b. **Graze:** Is an online retailer and manufacturer based in East London. They provide healthy snacks that are personalized and delivered in boxes directly to the end user. They have developed a range of over 100 snacks and designed an intelligent algorithm (DARWIN - Decision Algorithm Rating What Ingredients Next), used to customize each portion and optimize the freshness of each ingredient used. DARWIN determines how the snack portions are sorted into punnets, how Graze boxes are labelled, and how they are packed directly into postal vans. It also records the customer's history and preferences; monitors stock levels and tracks the location of workers on the factory floor. They work with small suppliers in Britain and all over the world to provide the best quality ingredients. They use recyclable and sustainable materials in their packaging. They started selling snacks in the US in 2013.

c. **Unto-This-Last:** is an 'open workshop' which enables micro manufacturing at the point of sale in the city. Their manufacturing process is controlled by digitally controlled cutting tools using technology such as parametric modelling, digital tools and lean manufacturing, as well as having a flexible production system through the development of their own software. They produce be-spoke furniture meeting the requirements of their clients (based locally in London) using certified and non-toxic materials.

From each case study analysis 16 conditions where digital intelligence and RdM act as enablers of circularity, were identified through a thematic analysis. Table 1 presents the cross-case synthesis regarding the conditions identified for each Lens of the framework and the relationship to the previous Circular Economy and RdM themes previously identified. The conditions identified are within the premise that digital intelligence would enable further circular opportunities as explained before. Thus, the 'Digital Lens' is described within the conditions identified.

Lens	Theme	Condition
Design	*Customization*	The three case studies are concerned to deliver **high quality products** that are **made to order.** Their ability to be **customer focused** and apply **user-driven innovation** to improve the value proposition delivered, is due to the application of digital intelligence. The use of manufacture technologies enables them to produce with extreme quality specifications, exactly what is ordered without overproduction. With data analytics, they can process orders effectively and tailor the product towards customer's requirements. In addition, in the cases of Splosh and Graze, they could redesign the packaging for further reuse, and potentially enabled by track and trace systems.
Supply chain	*Localization*	The three case studies are categorized as small and medium enterprises with a relative **small scale** operation. Also the three of them praise their **decentralization** as the success of their business model. The use of digital intelligence could help them to keep the small scale, decentralized operations if they try to expand into a micro-factory franchise model. In addition, in the case of Splosh and Graze could help them to develop their own optimized delivery system for multi-regional locations.
	Distributed knowledge	The three case studies showed opportunities for **system integration** with the use of digital intelligence. In the case of Splosh, they could have a single system that captures online orders from different products. Same could happen with Graze. In addition, **open sourced innovation** could be enabled in the three cases, however circularity could be enabled further through promoting user attachment to the goods produced and sold by Unto This Last.
	Distributed structure	The three case studies **removed the traditional retailer** by selling online and through owning their supply chain. Also Unto This Last takes a transparent approach in which goods are sold in the workshop space. In addition, further **supply chain integration** should happen. In the case of Graze and Unto This Last, both could encourage more local regional sourcing by matching customer preferences to locally source ingredients for snacks and materials for furniture. Also they could work with suppliers according to demand.
Business model	*Distributed ownership and/or Continued ownership*	Splosh and Graze, both offer a product oriented **product-service system (PSS)** which could only be possible due to the use of digital platforms such as the Internet. However, a PSS type of business model could potentially be explored by Unto this Last.
	Value optimization	Graze and Unto-This-Last had invested in their **own software development** to **optimize operations.** Optimization includes recording customer's order history and preferences, monitoring stock levels and material/ingredients used, and tracking the location of workers on the factory floor. Splosh misses an opportunity by not having this system in place.
	Resource efficiency and sufficiency	The three case studies have **environmental and social sustainability** in mind, and thus their operations run to **minimize the costs of risk and waste.** All of them had invested in providing a value proposition that is less harmful to the environment and society in general. Circularity opportunities through the use of track and trace systems rely on including further services such as take back schemes.
	Economic viability	The three case studies demonstrated opportunities to scale up through **micro-franchises.** Use of digital intelligence could help to monitor, control and optimize operations.

Table 1 Conditions identified for each lens and the relationship to circular economy and RdM themes

Discrete Event Simulation Model

The Discrete Event Simulation (DES) method was used to provide quantified material flows from the opportunities identified. The DES method specifically tracks "entities" within a dynamic (i.e. time evolving) model of the system under study. Hence DES can be used as a way of uncovering the complex interactions between: a) the existing material (i.e. the entities) flows along the supply chain from supplier, through the business (manufacturer) and on to the end-user, and b) the reverse and hence "circularizing" material flows that could be introduced to enable circular material management.

Splosh – DES Model

A DES model representing material movements from the detergent manufacturer to the customer, and the end-of-life disposal options is shown in Figure 6. The model is focussed on the bottles of a laundry detergent non-bio 100ml, and the end-of-life disposal options, but also includes the sachets of detergent solutions; polymer storage trays; cardboard packaging and film wrapping (see Figure 5 - Current Splosh Supply Chain). The key aspects investigated by the model are the effect of the Splosh business model on the number of bottles required in order to provide the customer with detergent, along with how the Splosh business model might be part of a re-distributed manufacturing system.

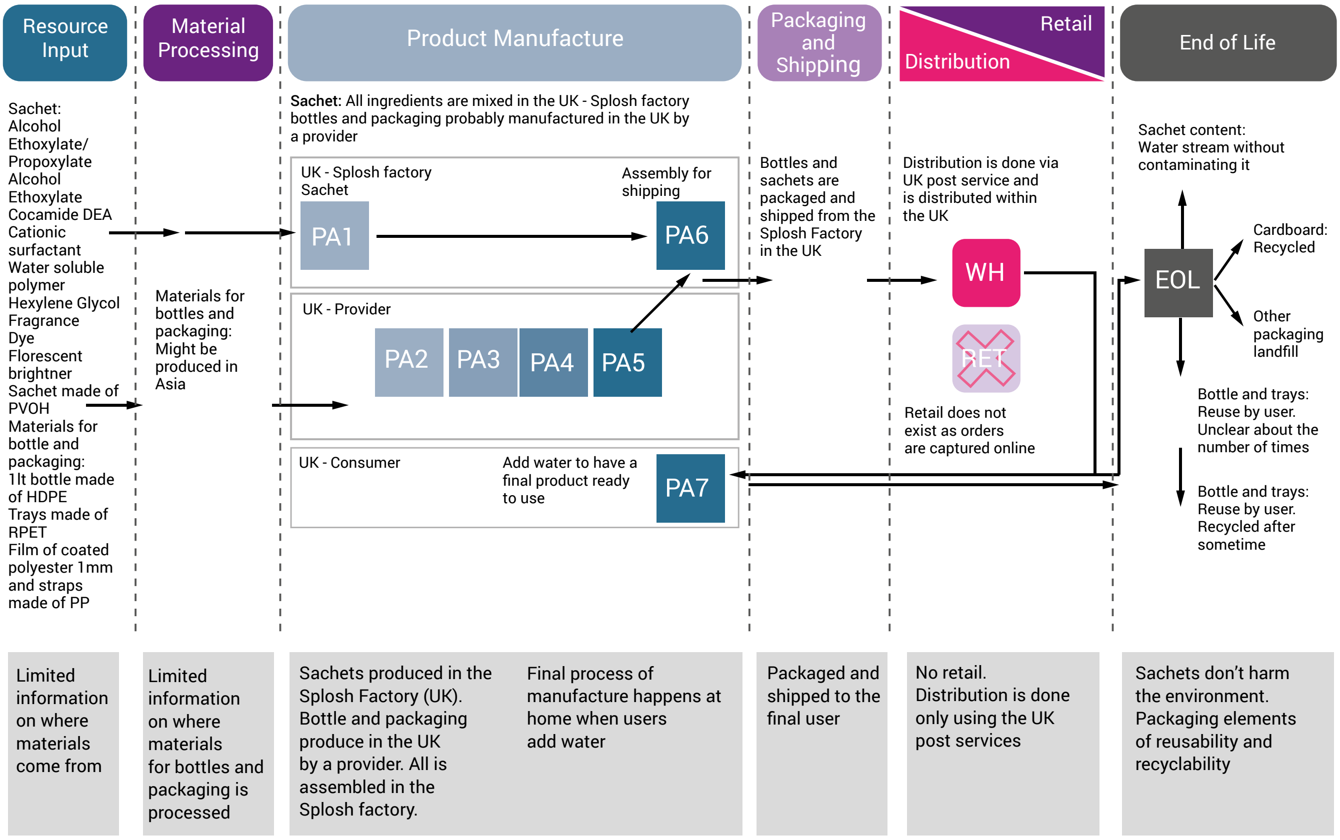


Figure 5 Current Splosh Supply Chain for a Laundry detergent non-bio 100ml bottle

The Splosh business model is for the customer to keep and re-use the detergent bottle, and only a sachet with concentrated detergent is supplied when more detergent is needed. This contrasts with a conventional business model that supplies a standard detergent solution in bottles – although bottles are made of recycled material. The model can thus be run to represent either a conventional detergent supplier, which would be 100% of bottles on the recycling route, or with the Splosh business model with bottles kept for re-use, and only detergent sachets supplied.

The model is run from the perspective of a customer, and how many bottles need to be supplied over a 10 year (520 week) period. Two situations were considered with bottles needing to be replaced after either one year or 3 years of use, and modelled three different scenarios with the following considerations:

- Standard (conventional), with detergent supplied in a bottle every time more detergent is required (approximately every 7 weeks),
- Splosh, detergent in sachets, with a replacement bottle needed after approx. one year of use,
- Splosh, detergent in sachets, with a replacement bottle needed after approx. three years of use.

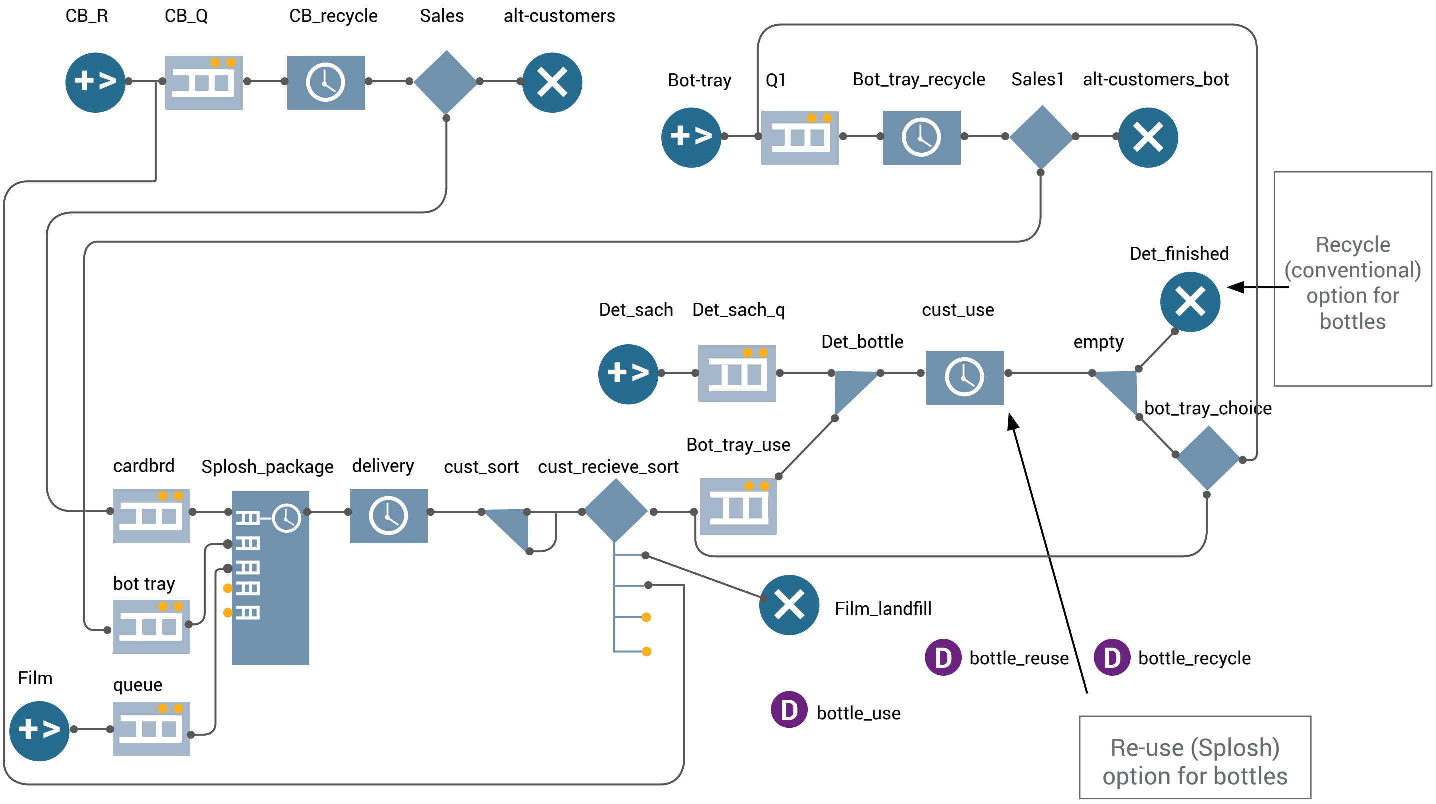


Figure 6 The DES model of detergent supply to customers representing either the Splosh or standard business models.

How the number of detergent bottles used and/or supplied changes over the 10-year period of the simulation is shown in Figure 7, with a summary of the total number of bottles over the 10-year period given in Table 2.

The results show the very significant effect of re-using bottles by the customer, with numbers of bottles needing to be supplied reducing greatly – from 74 down to 9 or 3 over the 10-year period. From an environmental perspective this is very significant, as much lower masses of material need to be transported with reduced emissions, with customers benefiting from cost reductions due to only having to buy detergent and not bottles. However, for the Splosh business there is very little direct effect from introducing circularity in their bottle supply, with most of the impact deriving from the customer use stage, with then very significant impacts in other parts of the supply chain.

These significant effects in other parts of the supply chain will be particularly felt by the businesses involved in recycling materials and in bottle manufacture, which will see large reductions in volumes of material and numbers of bottles required for manufacture, with significant loss of revenue. The businesses so affected would need to find new business activities in order to remain viable.

The major conclusion from this study of circularisation of material flow in a "Splosh" like business model, reveals that for circularisation at the very local level, i.e. at the use stage, supporting infrastructure is required for recycling and re-manufacture, but that significant environmental impacts will be derived from the reduced volumes of material transported to final users.

Scenario	No. of bottles used	No. of bottles supplied to customer	No. of bottles re-used by customer	Bottles in-use
Standard	75	74	0	1
Splosh bottle replaced after 1 year	75	9	63	1
Splosh bottle replaced after 3 years	74	3	70	1

Table 2 Summary table of results for 10 years of detergent use.

Graze - DES Model

Analysing the Graze business with the Four Lens framework (Figure 8) suggests the following opportunities for increasing circularity in the supply chain:

- Further customization from the use of data captured through orders
- Improving the design of the packaging and having a tracking and take-back system in which boxes, punnets and skewers could be reused
- Setting up micro-factories as franchises in other areas to expand their market
- Initiate more local regional sourcing by matching customer preferences to locally sourced ingredients for snacks
- Working with suppliers to match demand and to connect suppliers to consumers so they can know where the snacks come from.

Of these opportunities, the take-back scheme for packaging is a specific example of circularisation that could be added to the existing business model, and this aspect was modelled using DES. Graze already uses 100% recycled cardboard, and other recycled packaging. Direct take-back of packaging gives Graze the opportunity to inspect the packaging and reuse it if possible. This reduces material costs (balanced against the cost of arranging returns), and if packaging cannot be reused, Graze can provide a "stewardship" role, by maximising material that is recycled.

It is assumed that each Graze box consists of one cardboard box, four PET polymer punnets, four film lids, three bamboo skewers and food content (Figure 9). Graze delivers 300,000 of these boxes per year[28]. The recycled material is already part of a circular material flow. The DES model proposes new feedback loops to enable packaging reuse by Graze, with recycling where reuse is not possible.

A diagram of the DES model is shown in Figure 9. The key parts are:

- Assembling 5 items to ship – food, skewer, PET tray, film lid, cardboard box
- The cardboard supply and existing recycling option for end-of-life (EoL)
- The PET polymer supply and existing recycling option for end-of-life (EoL)
- Use of the food and disassembly of packaging with EoL options – percentage choices for recycle or disposal for some materials
- The new option of materials take-back by Graze, rather than use of recycled material from their suppliers.

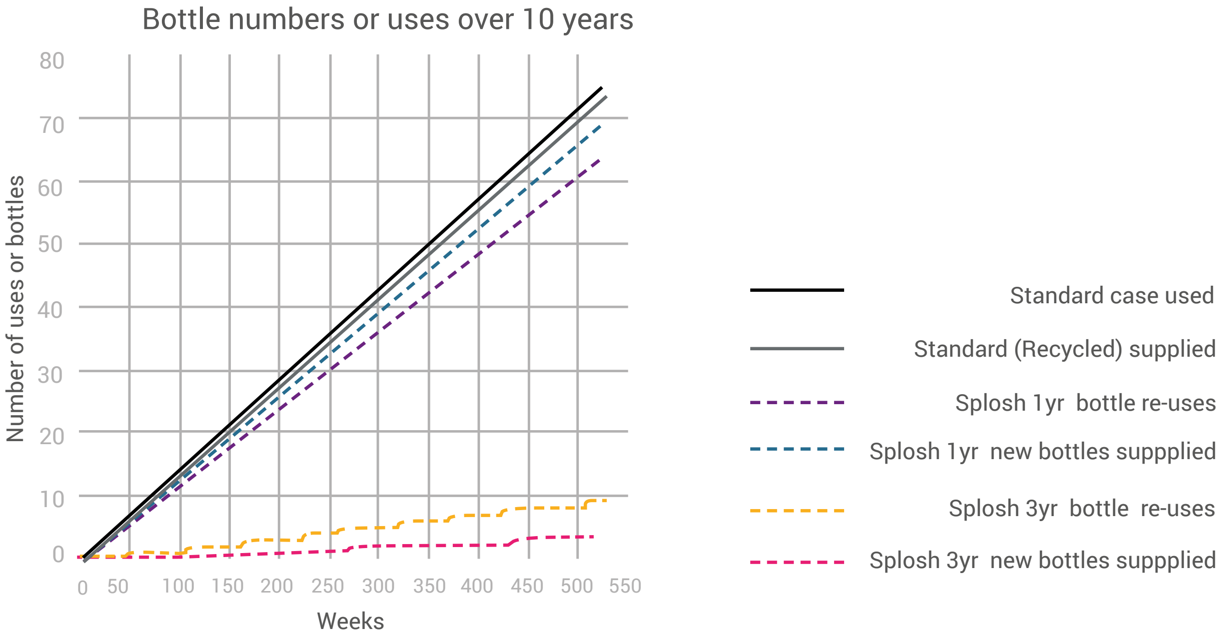
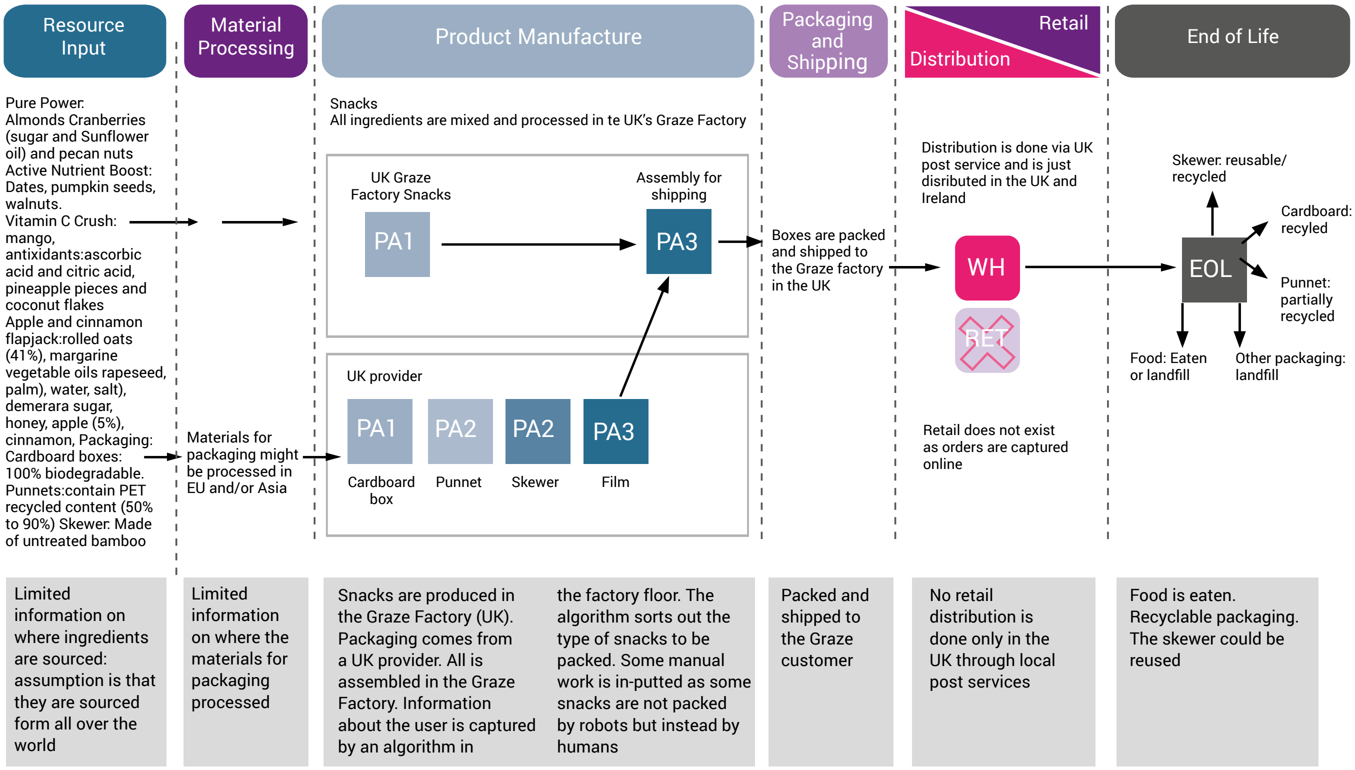


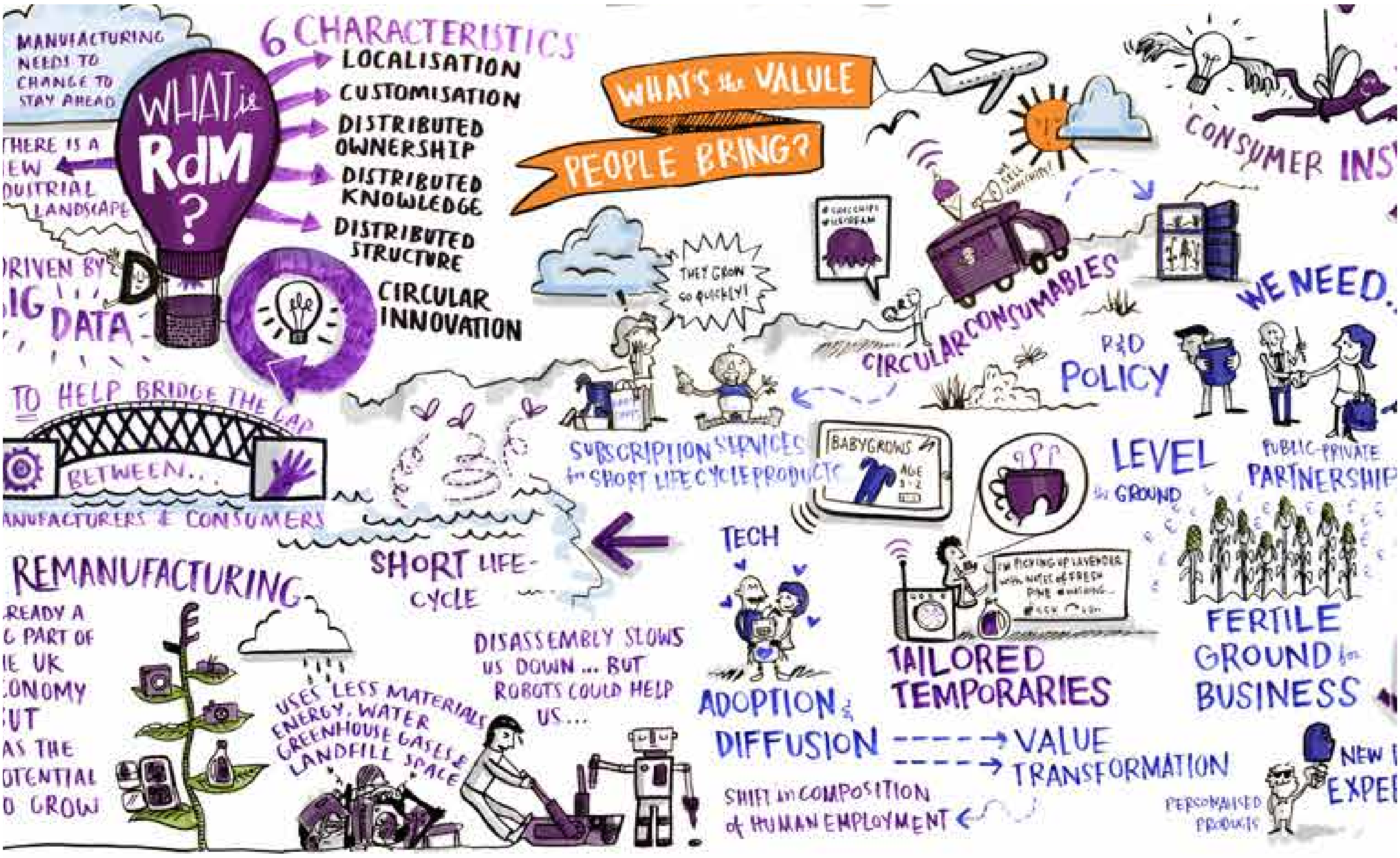
Figure 7 Number of bottles supplied and/or used for the three supply scenarios.

Case study: Variety box with 4 snacks: Pure Power, Active nutrient boost, vitamin C crunch and apple and cinnamon flapjack



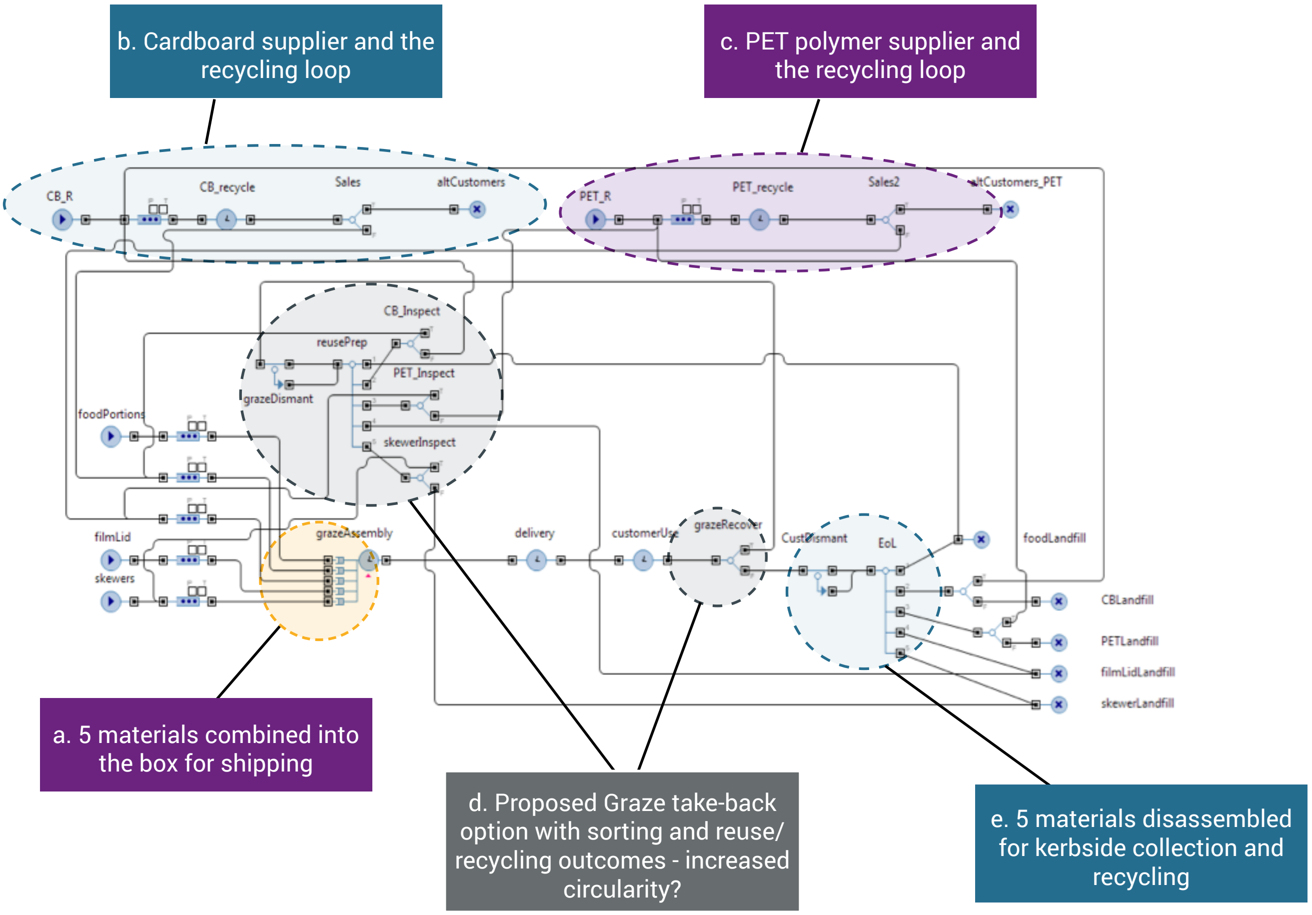
Resource Input	Material Processing	Product Manufacture	Packaging and Shipping	Distribution / Retail	End of Life
Limited information on where ingredients are sourced: assumption is that they are sourced form all over the world	Limited information on where the materials for packaging processed	Snacks are produced in the Graze Factory (UK). Packaging comes from a UK provider. All is assembled in the Graze Factory. Information about the user is captured by an algorithm in the factory floor. The algorithm sorts out the type of snacks to be packed. Some manual work is in-putted as some snacks are not packed by robots but instead by humans	Packed and shipped to the Graze customer	No retail distribution is done only in the UK through local post services	Food is eaten. Recyclable packaging. The skewer could be reused

Figure 8 Current Graze Supply Chain for a Variety Box with 4 snacks: Pure Power, Active nutrient boost, vitamin C crunch and apple and cinnamon flapjack



The DES (Figure 9) provides options for exploring the effects of circular material flows, and the key interest for the simulation of this case study is the effect of increasing the amount of material being taken back directly by Graze (part e of the model). This will have direct effects on the amounts available for recycling (Part d), offset to some degree by having the chance to directly reuse material with no additional processing. The DES model is implemented at the system level of the Graze supply chain, focusing on the flow of packaging materials within the system, enabling the industry to consider the relatively short-lived packaging as an asset, rather than a consumable.

The DES model is used to investigate the effect of changing the ratios of materials collected for a take-back system, with various scenarios studied, as detailed in Table 3. For each of the scenarios A – E, the simulation allows the effect on reuse rate, recycling rate and landfill volumes to be determined.



b. Cardboard supplier and the recycling loop

c. PET polymer supplier and the recycling loop

a. 5 materials combined into the box for shipping

d. Proposed Graze take-back option with sorting and reuse/ recycling outcomes - increased circularity?

e. 5 materials disassembled for kerbside collection and recycling

Figure 9 The DES model of the Graze supply chain showing the connections between materials being brought together for supply to the customer and the potential end-of-life options.

Operation		Take-back	Graze Inspection		
Scenario and description	Runs	Packaging recovered (%)	Cardboard reused (%)	PET reused (%)	Skewers reused (%)
A. No take-back scheme (base case)	1	0	50	30	20
B. Simulates increasing success of the proposed take-back scheme for packaging, with packaging increasingly recovered.	2 - 6	20, 40, 60, 80, 100	50	30	20
C. Simulates increasingly durable cardboard box design leading to greater reuse rate.	7 - 12	60	0, 20, 40, 60, 80, 100	30	20
D. Simulates increasing durable plastic punnet design leading to greater reuse rate	13 - 18	60	50	0, 20, 40, 60, 80, 100	20
E. Simulates increasingly durable, reusable skewers	19 - 24	60	50	30	0, 20, 40, 60, 80, 100

Table 3 Variables studied for the Graze DES model, Scenarios A – E, consisting of Runs 1 – 24. Results are given as percentages of individual units, i.e. a cardboard box, a PET punnet and a skewer are all worth one unit.

The results from performing the simulations are presented in Figure 10, which shows the outcomes of post-consumer materials processing depending on each scenario. The materials considered were cardboard boxes, PET punnets and skewers. Boxes and punnets can be reused; recycled or landfilled, skewers can be reused or landfilled. Film lids cannot be recycled and so are landfilled. Food is eaten or landfilled. Film lids and food are simulated, but are not counted in the results.

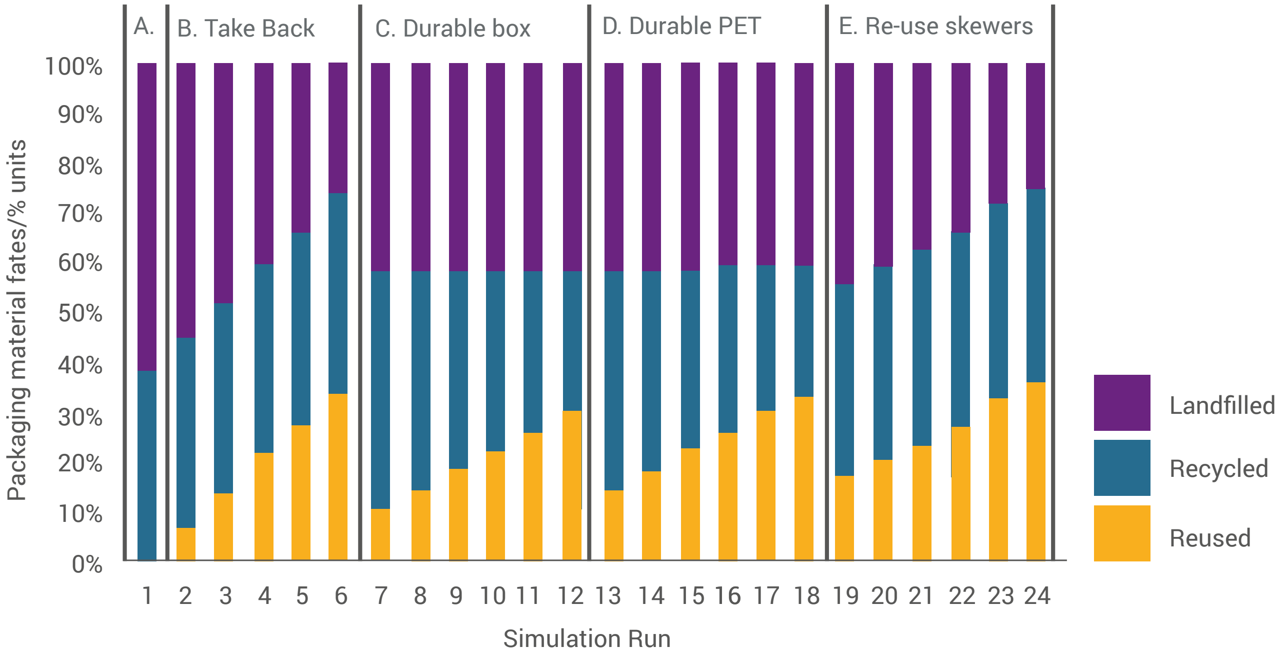


Figure 10 Average material fates by simulation run. Scenario groups are shown above the diagram.

In the base case, 37% of units of material can be recycled with the remainder being landfilled. In the take-back simulations, increasing volumes of EoL packaging are collected by Graze. The result of increasing take-back is reduction in flows to landfill from 63% to 27%. The overall flow of recycled material is almost constant throughout, with a slight increase as Graze takes stewardship of EoL materials, ensuring recycling where reuse is impossible.

Increasing packaging durability is modelled in Scenarios C and D, i.e. increasingly reusable cardboard boxes and PET punnets. The overall volume of circular material (reused or recycled) is constant in both scenarios. Landfilled material is steady at 42%. Variation within the circular material flows arises from the changing ratio of reused to recycled material. More durable packaging allows higher reuse rates, and a proportionate decrease in recycling, as material from the recycling stream is diverted for reuse.

From a materials perspective, the simulation results are intuitive in that greater take-back reduces flows to landfill, and greater reuse of a material component results in proportionally less recycling. However, this information can be used to understand the economic feasibility, business case or energy use aspects of the supply chain, and forms the core of any proposed change in waste management strategy.

The value of the take-back scheme from a circularity point of view is to divert material from landfill – whether it is reused or recycled is less significant, as long as the material continues to flow through the supply chain. However, the value of material take-back is a balance of costs and savings. Costs would include return material collection, inspection and cleaning, and disposal of non-reusable material. Savings would include reduction in material purchased. The proportions of re-used to recycled material are key to this calculation, with the simulation providing values for the quantities of material. A key practical consideration is whether there would be sufficient numbers of returned items and on predictable timescales. If there is too much “leakage”, then the take-back scheme could falter through lack of available items, and the DES model allows for this potential problem to be investigated.

For Graze to introduce a successful take-back scheme, the packaging and its distribution operations would require re-design to maximize the potential for reuse. More durable packaging leads to a higher potential for reuse, with more benefit from the take-back scheme. The scheme needs to attract a return rate for packaging sufficient to offset the cost of packaging redesign and establishing the scheme. Greater durability is particularly important for the non-recyclable because reuse of this packaging directly diverts material from landfill where no recycling option exists.

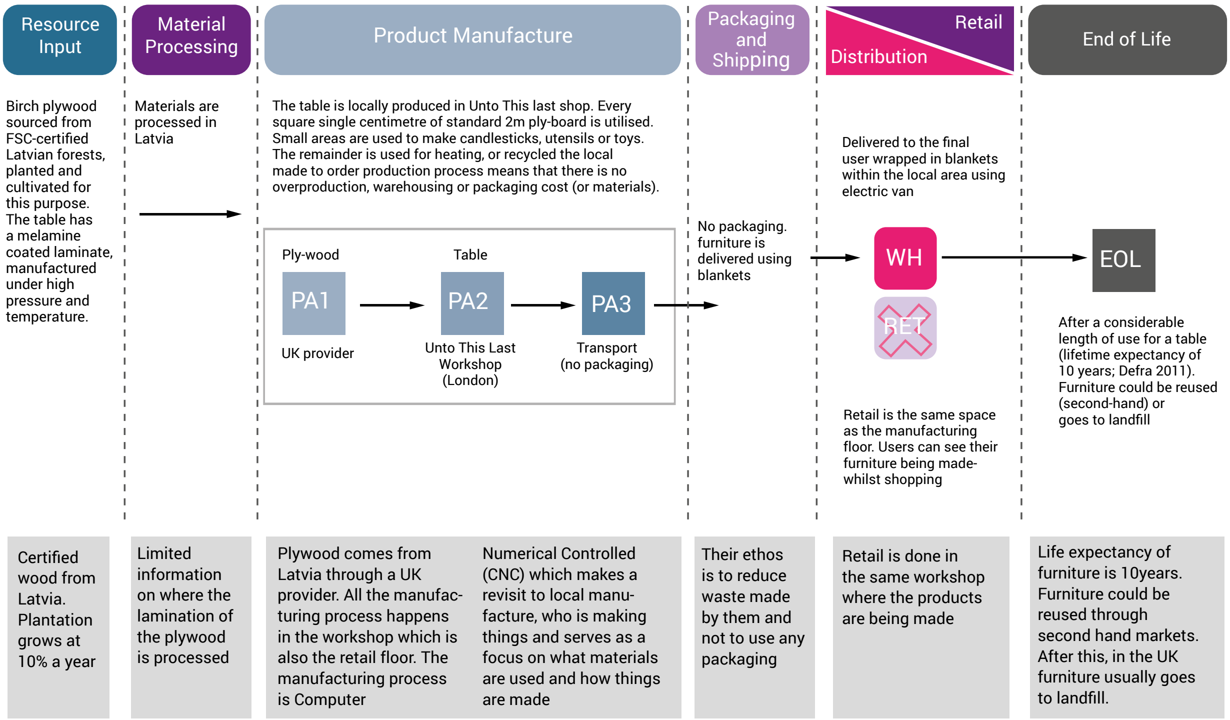
The DES model results indicate that digital intelligence and re-distributed manufacturing could enhance current infrastructure in developing circular models, such as implementing asset tracking to support take-back schemes. According to the Ellen MacArthur Foundation report[2], intelligent assets are already unlocking new forms of value creation, as they enable significant changes in business operations, from product design to the supply chain, as demonstrated in this study. Further opportunities for the food and drink sector exist to use trace and return technologies (e.g. bar codes, sensors, wireless communication and mobile devices), to account for ‘short use’ items as assets[29] to divert these from landfill and reduce disposal and material costs, balanced against the cost of arranging returns. Other companies in the same sector (e.g. Abel & Cole) already have packaging take-back schemes, to allow re-use.

Furthermore, circular distributed models of consumption, with the aid of digital intelligence, could enable premium customized services[20]. In the example of take-back of packaging, personalized incentives and promotions could be given by Graze to encourage customers to return their packaging. However, these personalized and premium services will need to prove cost effective for both customers and the business.

Unto-This-Last - DES Model

The Four Lens framework was used to analyse Unto-This-Last’s business model (Figure 11), and a DES model of Unto-This-Last’s manufacture and supply was created, based on a trestle table (Figure 12). The rate at which tables arrive with customers for all of the scenarios is set initially by the supply of plywood sheets that are used to manufacture the tops, legs and cross-pieces for the table, and this supply is set at two per month, which then becomes the rate at which Unto-This-Last can manufacture new tables. The model then tracks how many tables are in use through time, and how many are supplied to customers.

Case study: Trestle Table: A demountable table with no glue or fixings 160x80x75



Birch plywood sourced from FSC-certified Latvian forests, planted and cultivated for this purpose. The table has a melamine coated laminate, manufactured under high pressure and temperature.

Materials are processed in Latvia

The table is locally produced in Unto This last shop. Every square single centimetre of standard 2m ply-board is utilised. Small areas are used to make candlesticks, utensils or toys. The remainder is used for heating, or recycled the local made to order production process means that there is no overproduction, warehousing or packaging cost (or materials).

No packaging. furniture is delivered using blankets

Delivered to the final user wrapped in blankets within the local area using electric van

Retail is the same space as the manufacturing floor. Users can see their furniture being made-whilst shopping

After a considerable length of use for a table (lifetime expectancy of 10 years; Defra 2011). Furniture could be reused (second-hand) or goes to landfill

Certified wood from Latvia. Plantation grows at 10% a year

Limited information on where the lamination of the plywood is processed

Plywood comes from Latvia through a UK provider. All the manufacturing process happens in the workshop which is also the retail floor. The manufacturing process is Computer

Numerical Controlled (CNC) which makes a revisit to local manufacture, who is making things and serves as a focus on what materials are used and how things are made

Their ethos is to reduce waste made by them and not to use any packaging

Retail is done in the same workshop where the products are being made

Life expectancy of furniture is 10years. Furniture could be reused through second hand markets. After this, in the UK furniture usually goes to landfill.

Figure 11 Current Unto-This-Last Supply Chain for a Trestle Table: A demountable table with no glue or fixings 160X80X75

The DES model (Figure 12) is used to explore the effects of customer choices over length of time used and the options once the customer decides to not use the table. The options explored are:

- Customers send tables to disposal
- Customers choose to re-sell tables to a second customer
- Customers return the table to UTL for re-manufacture
- The length of time the tables are used is varied from 10 to 5 to 2 years.

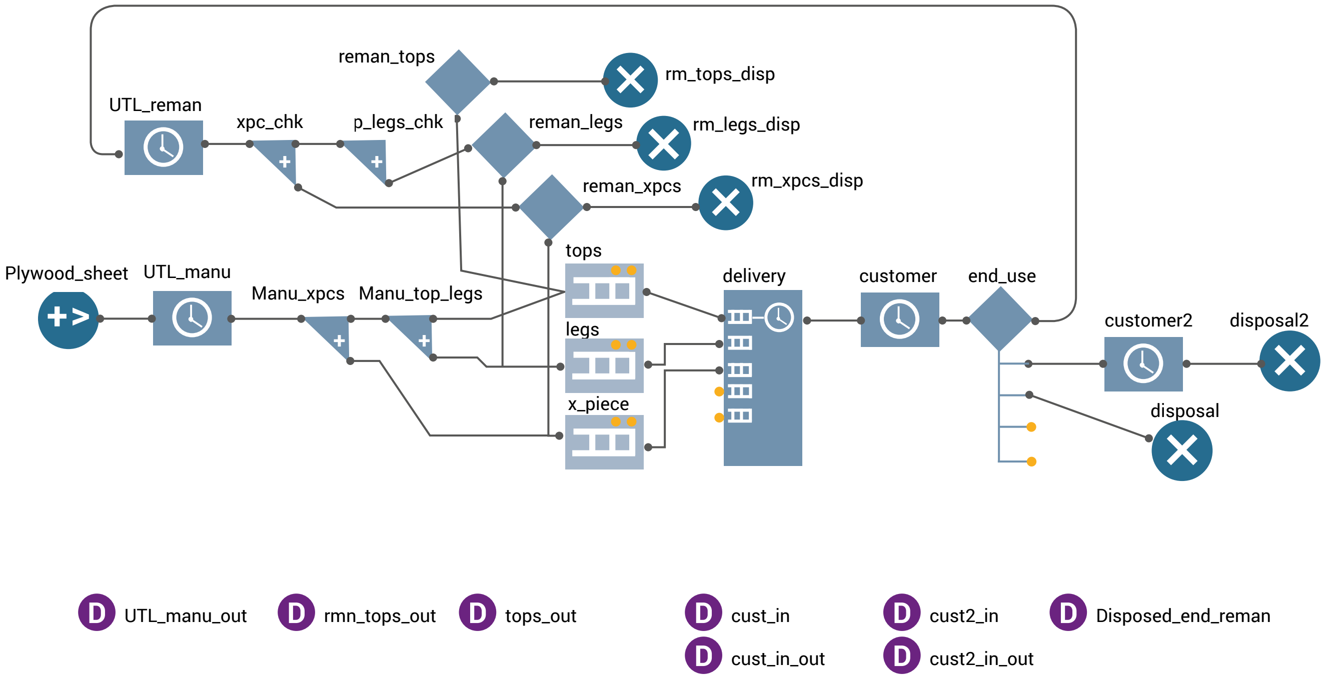


Figure 12 DES model of the Unto-This-Last manufacture and supply of a trestle table

The options explored using the DES model are summarised in Table 4. The Base-case is of tables being used for 10 years with all disposed of after this time. The effect of 50% of customers choosing to sell tables on to a second user is checked in Scenario 2. The effect of tables being sent for either remanufacturing or sold to a second user, is checked in Scenario 3. The a) and b) options can be derived from the same DES model, with the re-manufactured tables either used to replace some table manufacture (representing in effect a fixed demand for tables), or used to supplement the number of tables in use, with additional first-use customers being found (in effect allowing an increase in demand).

The effect of reducing the length of time for which customers are willing to use the table for from 10 years to 5 and 2 years is examined in Scenarios 4 and 5.

Scenario No, and description	Years tables in use	Tables disposed (%)	Tables sold to 2nd customer (%)	Tables re-man by UTL (%)
1. Base-case	10	100	0	0
2. 2nd customer, re-use	10	50	50	0
3a. Re-manufacture & 2nd customer (Re-manufacture tables displaces manufacture)	10	50	25	25
3b. Re-manufacture & 2nd customer (Re-manufacture tables added to manufacture)	10	50	25	25
4a. Re-manufacture & 2nd customer (Re-manufacture tables displaces manufacture)	5	50	25	25
4b. Re-manufacture & 2nd customer (Re-manufacture tables added to manufacture)	5	50	25	25
5a. Re-manufacture & 2nd customer (Re-manufacture tables displaces manufacture)	2	50	25	25
5b. Re-manufacture & 2nd customer (Re-manufacture tables added to manufacture)	2	50	25	25

Table 4 Summary of parameters varied in the UTL trestle table DES model

The base-case model with no re-use or re-manufacturing shows that with a 10 year table use period the number of tables in use stabilises at around 250, and that after 20 years around 500 tables have been manufactured and supplied. When tables can be re-used by a 2nd customer, the total number of tables in use increases from years 10 to 20 to reach around 370, the additional table uses due to the 2nd customers, with the overall number manufactured similar to the 500 in Base-case scenario (Figure 13).

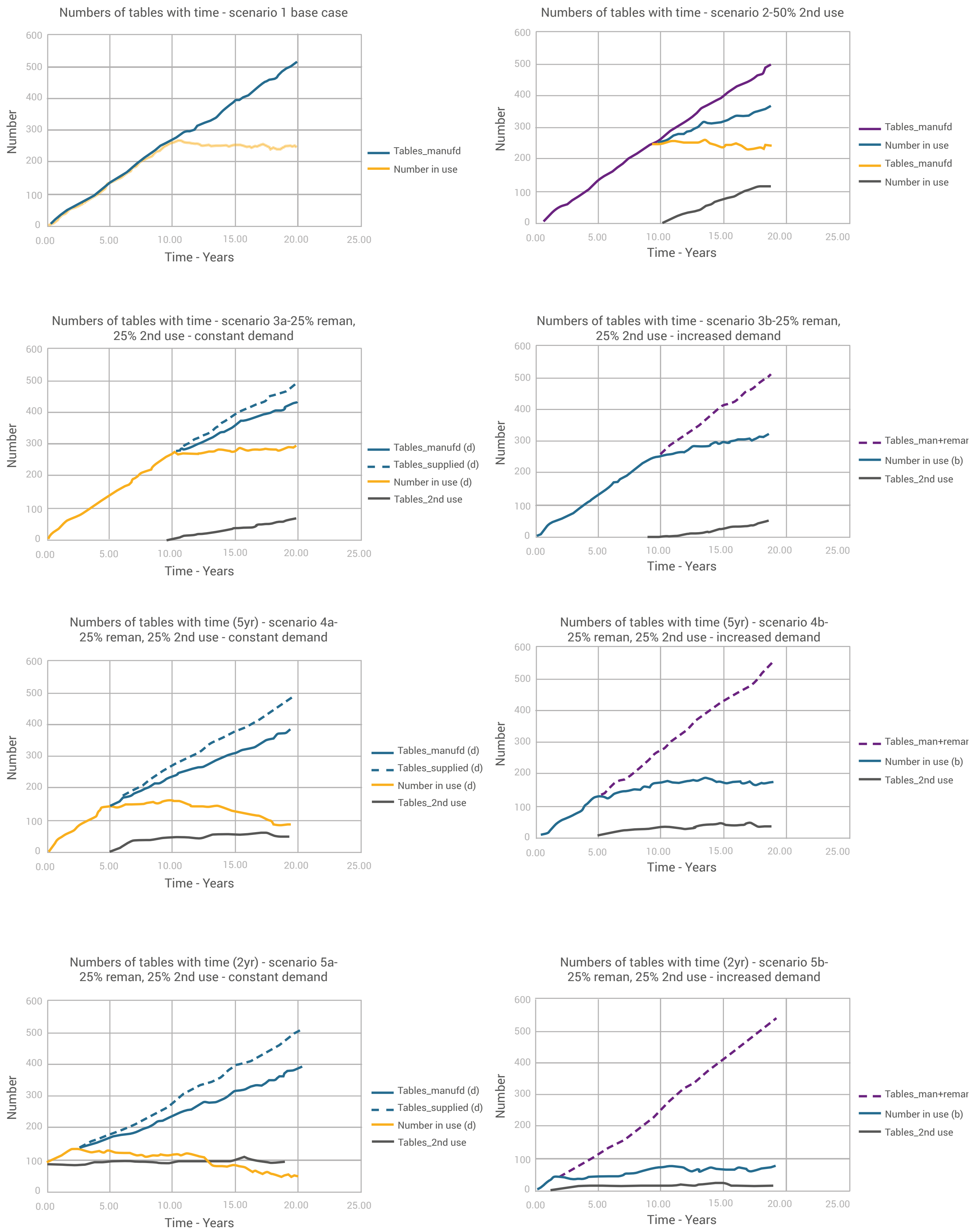


Figure 13 Scenarios 1 to 5b of the DES model of Unto-This-Last table supply

The effect of introducing re-manufacturing is apparent on the overall number of tables manufactured, supplied and in use. A constant demand limits the numbers that are required to be manufactured and over 20 years the number reduces from 500 to around 430, with around 480 tables supplied overall. Using remanufactured tables as additional supply allows the overall number of tables supplied to increase to around 550, with overall numbers in use peaking at 350.

The effect of introducing shortened usage times for tables has a very marked effect on the overall numbers of tables in use, when the manufacturing rate for each table is held constant at 2 per month. In the 5 and 2-year models, table use peaks after a few years and then declines. In fact, in the 2 year model the number of tables in use appears to become negative after around 12 years, which is not possible, but is in artefact of the model and how the "in-use" numbers are calculated when re-manufacturing is used to reduce manufactured tables. What it does indicate is that if customers want to replace their tables too rapidly for the manufacturing supply rate, then a shortage of tables (or goods) will arise. The model shows that if re-manufactured tables can be added to those already manufactured, then at 5 and 2-year replacement intervals for tables, the numbers in use can stabilise at around 180 or 100, although these values are significantly lower than in other scenarios.

The DES models of the Unto-This-Last scenarios are useful in determining which options lead to the more resource efficient use of materials to make tables. In terms of maximising the number of tables manufactured and supplied, the 2-year replacement option gives the largest value of 640 tables, but with the limitation that a much smaller number of tables, between 100 and 180, are in use at any one time. This compares with a 10-year replacement schedule which requires a lower number of 480 to be manufactured and supplied, but which sees 300 to 350 tables in use. Deciding whether the most important criteria is either more tables available for use, or maximising the number supplied, is an interesting dilemma in the resource efficiency and sustainability discussion, and which is also relevant to the re-distributed manufacturing topic, because if furniture companies are operating as Unto-This-Last, where products are supplied to fill the demand, then the company benefits by maximising the number supplied.

The case studies demonstrate that the re-distribution of systems of production and consumption could benefit circular innovation. However, a dilemma still exists on which is the cost-benefit of doing so. The Splosh case study demonstrated that a similar business model scales up, greater environmental benefits could be achieved. On the other hand, the re-use of bottles could impact greatly the plastic industry causing an economic downturn. With Graze, a take-back scheme of packaging brings substantial economic and sustainability benefits and opens a new area of operation in which 'short use' items are considered as assets. In addition, further opportunities exist by the application of digital intelligence, where implementing asset tracking could enhance circularity, which could work better in re-distributed models as these allow local operations. If these opportunities are capitalised, the materials will be less geographically dispersed, increasing their utilization and allows management of their distribution operations locally, through collecting and tracking data of materials being returned by type, location and customer, plus monitoring of its condition for re-use and recycling. Finally, Unto-This-Last, a complete re-distributed model of production and consumption could implement a re-manufacturing system of their products on a local scale. This could bring greater environmental impacts regarding resource and material used. However, a balance between the availability of products in use and the number of products supplied has to exist to be cost effective for the company. As such, to fully understand the economic and environmental benefits, further research would need to be conducted to calculate environmental impacts such as carbon equivalent emissions, as well as a financial appraisal of the cost-benefits of circular opportunities such as the ones presented in this report.

Impact of the feasibility study and opportunities for future research

This feasibility study was one of five feasibility studies on Re-distributed Manufacture, consumer goods and big data. The study identified RdM and circular innovation definitions, fundamental drivers, and case studies to better understand the feasibility of decentralising the consumer goods sector whilst at the same time enabling circular systems. The study revealed that the integration of digital intelligence could enable a distribution of knowledge, structure, ownership and different levels of customisation, offering more connected, meaningful and durable relationships with the end user. Digital intelligence can also allow circular business models through automated monitoring, control and optimisation of resources and material flows. The study also reveals that the use of digital intelligence has incentivised the de-centralised, re-distributed and circular models of production and consumption. However, there is not an ‘ideal’ example of the potential that could be achieved by integrating RdM and Circularity into the business model, and that further value creation needs to be analysed. In addition, the opportunities and challenges of RdM and circular innovation are not still fully explored and questions still persist. For example, could a franchise manufacturing model work? What would scalability look like? What are the implications for intellectual property? What will be the consumer acceptance to these disruptive models? What will be the learning capabilities needed with the use of big data? How will localised versus globalised models will be managed? And, will retail ecosystems be competing with each other?

Finally, it can be said that the potential for Re-distributed Manufacturing and digital intelligence to enable a regenerative economy is promising, but it is essential to understand where the value is captured and delivered to provide the significant opportunities that decentralisation of the consumer goods sector could bring.

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