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REVIEW ARTICLE

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Priorities when designing a service-focused delivery model for mobility devices: a systematic review

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ABSTRACT

Purpose: Throughout the world, mobility devices are usually distributed using product-based business models, where a device is provided to a user, and serviced or replaced when the user returns to the clinic with an issue. Moving to a service-based business model can provide continuous and customised support for the user, and provide the clinicians and manufacturers with better data to base their decisions on. This study reviews papers on assistive technology service-based business models and considerations in designing such a model to optimise economic and social value. It then applies the findings to the mobility device space.

Method: A systematic literature search was undertaken in PubMed, Web of Science, and OVID databases to analyse studies that discuss service delivery models used to provide assistive products. Inductive thematic analysis determined the themes, facilitators and barriers associated with providing a service. Findings were applied to mobility device service provision.

Results and conclusion: Themes from the 29 relevant papers were grouped into four categories: **Access** (affordability/availability/education), **Utility** (customisability/usability/adaptability), **Integrity** (quality/sustainability/impact), and **Compliance** (policy/privacy/security). The most common themes were customisability, affordability, availability, and education. There is a need for service-based delivery models to replace conventional product-based models, and many considerations to optimise their design. No publications discussed the design and implementation of a service-based model for mobility device provision that uses modern sensors, software and other digital technologies to optimise the service. Service-based models that use modern digital technologies are new for the mobility device field, but much can be learnt from other fields.

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Assistive products; mobility devices; as-a-service; barriers; facilitators; servitisation; thematic analysis; systematic search

IMPLICATIONS FOR REHABILITATION

- Service-based business models that make use of modern digital technologies are likely to improve ongoing individual rehabilitation, but they are new for the mobility device field and currently lack research and evidence-based practice.
- The systematic review found that modern digital technologies like sensors, apps, and AI might be useful for providing ongoing support and more personalised rehabilitation for users of assistive products.
- To provide ongoing support for end-users, a successful design of service-based business model for assistive products should be accessible, both physically and financially, as well as easy to customise and adapt over time.

Introduction

Business globally is moving from a *goods economy*, where people pay for a one-off product, to a *service economy*, where products are provided as part of an ongoing service for the end-user [1,2]. This shift in focus is often called *servitisation*, and can add economic and social value to products through the addition of services [3]. Throughout the world, mobility devices (defined as any device that assists individuals with limited mobility to move around, such as prosthetics, wheelchairs, and walking aids [4]). are usually distributed using product-based business models, where a device is provided to a user, and serviced or replaced when the user returns to the clinic with an issue [5]. In light of the UN Convention on the Rights of Persons with Disabilities, the World Health Organization's Global Collaboration on Assistive Technology (GATE), the Association for the Advancement of Assistive Technology in Europe (AAATE) and the European Assistive Technology Information Network (EASTIN) have all stated a need for mobility and other assistive product service delivery systems to move from a focus on device provision to a focus on a wholistic assistive solution that includes ongoing support, environmental adaptions and user empowerment [6]. A service-based delivery system can be designed to achieve these goals, providing continuous and customised support for the user, and provide the clinicians and manufacturers with better data on which to base their decisions. Despite the importance of healthcare providers providing ongoing healthcare to their patients, services for mobility device users lag behind the servitisation trend.

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Servitisation is beneficial for the device-users, the clinicians, the service providers, and the manufacturers:

Benefits to the device-user: A service-based delivery model can give assistive product users access to recent technology advances, easy maintenance and servicing of their device, fast support if the product has a fault or is no longer suiting their needs, and access to their health statistics and how these compare to the population. Because the device they use is not owned by them, but by the service provider, they do not need to pay up-front the whole cost of the device, nor dispose of the product at its end-of-life [7]. The user can swap devices when another device would suit better because the focus is on the service provided, rather than the device.

Benefits to the clinician: Using sensors, remote monitoring, and remote manufacturing and servicing has the potential to support mobility device provision in smaller and more remote communities that lack clinicians with appropriate skills and training, or where service provision is currently inaccessible [7,8]. It can also provide objective data about the individual's lifestyle, needs, anthropometric properties, and what part of the device has a fault, to help guide the clinician to provide a better individualised prescription and service. Automation can reduce the time experts spend on repetitive tasks, and can reduce the expert judgements required [7]. Remote debugging of software can reduce product maintenance time.

Benefits to the service provider and manufacturer: Service providers and manufacturers can gain insight into which parts and devices are most useful in different contexts, and for different patient populations, where stresses and faults occur on devices, and the lifespan and use of a device. It also allows them to better target their research and development to the end-user, the clinician, and the health service. Remote support means they can reach a broader clientele. They also gain ongoing business throughout a product's life, and often a device-user's life.

Moving towards a service-based business model from a product-based model requires planning. The process of servitisation falls into two categories: *incremental servitisation* consists of taking steps towards a service-based model by continuing to do what the business is already doing, but gradually improving the service provided; *radical servitisation* achieves the same product goal, but in a new way, disrupting the industry [7].

It is important for healthcare professionals and policymakers to understand the different service models available to them, and how the different models might suit different contexts. Prior research shows that users' needs and priorities vary between regions within a country, as well as between countries, but most studies have identified consumers' perspectives on a national basis [9]. Mobility device service delivery and product design also often lack user-centred approaches, despite research showing that it is the users of mobility devices who are usually the experts on their current and anticipated mobility needs [9].

This study reviews papers that discuss service-based business models for the assistive technology field, and the considerations in designing one to optimise the economic and social value for the given context, the device-user, the clinician and the service provider. Observations from the findings in the wider assistive technology field are then considered in regard to the mobility-device context to gain insight into how mobility device service provision can be improved using servitisation methods.

Methods

Search strategy

The systematic literature search was undertaken in June 2022. Databases searched were PubMed, Web of Science, and OVID, using three groups of keywords to identify all studies that discussed the service delivery models used to provide assistive devices and the corresponding services to patients.

Population: (patients OR users OR clients OR humans) AND

Device: ("medical device*" OR "assistive device*" OR "assistive technolog*" OR "assistive product*" OR "mobility device*" OR "walking device*" OR wheelchair* OR prosthe* OR "orthot*" OR "orthos*" OR "crutch*" OR "walking aid*" OR exoskeleton*)AND

Business model: (servitisation OR "as a service" OR "wholistic care" OR "holistic care" OR "service model*" OR "model of service" OR "service delivery model*" OR "ongoing service provision" OR "home monitoring" OR "out-of-hospital monitoring" OR "continuous remote monitoring")

Study selection

The study selection was performed in line with the PRISMA flow diagram method [10]. After removing duplicates, the title and abstract of each publication were reviewed to determine its relevance. Where the relevance was not clear from the title and abstract, papers were read in full to determine relevance and usefulness. Papers were included if they were about assistive product service provision, and they discussed or gave examples of service-focused delivery models, mentioned barriers and enablers to consider in the service design, or discussed methods of servitisation. Papers were excluded if they were not in English. For each included paper, the reference lists and forward citation reports from each database were consulted to identify any additional relevant articles that were not found in the automatic search.

Analysis of studies

Inductive thematic content analysis was performed on the included papers. The analysis determined the emerging themes, and the barriers and enablers to service provision created by different models. Each paper was read, and the relevant sections were highlighted, to become familiar with the data. Each highlighted section was then manually coded to describe the content, then all the coded data was collated into groups identified by code, and combined into themes, making sure that all data was included under a theme, and that the themes represented the data. These themes were grouped into overarching categories.

Results

The literature search identified 245 papers, after removing duplicates (Figure 1). Of these, 29 papers met the inclusion criteria and were read in detail and used to develop an understanding of the service-focused delivery models in use, the contexts in which they are beneficial, and the barriers and facilitators to accessing appropriate services.

The included papers are summarised in Table 1, and the relevant themes of each are listed.

The areas to consider when designing a service-focused business model for mobility device provision, according to the inductive thematic analysis, are shown in Figure 2. The primary finding is that the model needs to consider the device, the service, and the technology required to support the service. The themes were grouped into four categories: **1. Access** - containing the themes of affordability, availability and education, **2. Utility -** containing the themes of customisability, usability and adaptability, **3. Integrity** - containing the themes of quality, sustainability and

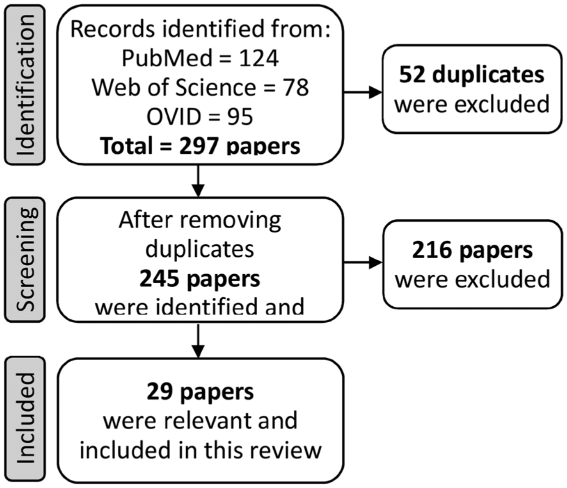

Figure 1. Flow chart of systematic search and identification of studies via databases.

impact, and **4. Compliance** - containing the themes of policy, privacy and security. These align closely with the areas of evaluation for assistive technology service models previously recommended [11–14].

The most commonly cited themes were customisability, affordability, availability, and education. Usability was also a common topic, while privacy was rarely considered. Most papers focused on the provision of devices and improving current services, rather than developing a new service-focused business model. New technologies have been tested and reported on for supporting service-focused delivery models, but these have been research studies, rather than service rollouts. Service-focused business models are just starting to be developed and reported on in mobility device service provision, with as-yet limited research and evidence backing them. However, there are successful examples from other assistive and medical device services, whose research can inform the mobility device field.

Access

Access was the category most commonly discussed in the reviewed papers, with all three of its themes raised consistently as barriers that require addressing for a service delivery model.

Affordability

There are many costs involved in assistive product provision, including the cost of device procurement, maintenance, running, and depreciation, clinic operational costs, and research and development costs [7,9,15,16]. There is also a lack of funding to support assistive product provision [16–19]. Where the cost is placed on the end-user, this can be prohibitive [18]. In some assistive technology cases, using mainstream technology as assistive products can reduce costs [17]. Smartphones are equipped with accelerometers, gyroscopes, cameras, and pressure sensors that can record physiological data, and apps can connect with external sensors, analyse, display, store, and share physiological data. This provides many opportunities to make use of everyday mainstream technologies, such as mobile phones, to improve mobility device service provision without significant costs [20,21]. Challenges with using mainstream technology include: personalised apps needing to be compatible with device updates, difficulty accessing disability funding for mainstream products, requirements for Wi-Fi access, difficulty obtaining technology support, security and privacy concerns, and having too much extraneous data on the device for the user to understand [17]. Using mainstream sensors already on, for example, a smartphone, also mean that physiological data cannot be tracked if the user does not have their phone on them [17].

The device design and manufacturing method, business model and size, and method of financing the product (such as owning, loaning, subscription or charity-funded), affect the affordability of the service to the patients, healthcare providers, and payers. Costs must factor in the training of staff and device users, and maintaining the device in the individual's environment as well as the up-front device cost, physician visits, outpatient care, skilled nursing facility stays, therapy visits, home health visits, and acute hospitalizations [14,22]. Healthcare systems need to objectively demonstrate the value of an intervention, compared to its cost, and often the way this is evaluated suggests a lack of time/cost benefits to providing mobility devices [22,23]. However, a Siva Cost Analysis Instrument analysis of 40 cases found that in >50% of the cases, assistive product intervention leads to important social benefits and long-term healthcare cost savings [24]. Likewise, a study of people with a lower-limb amputation found that the additional healthcare services among persons with lower-limb amputation who do not receive a prosthesis, often exceed the initial procurement costs associated with the prosthesis [22]. It is important to assess the social impact of assistive products in areas of health, school, work, community, and family, to understand that assistive product provision is an investment, rather than an economic burden [24].

Availability

The availability of the service includes how many people can access the service, from how widely afield, and what demographics it caters for. Business size and whether it is local, regional, country-wide or global, impact service availability [11]. There is also a shortage of assistive technology professionals; both clinical staff and maintenance technicians [16]. and difficulty attracting and retaining staff, particularly when understaffing causes additional stress on staff [18]. Telehealth, automation of repetitive tasks and machine learning algorithms can reduce staff workloads [25], and sensors can provide data to reduce unnecessary in-person check-ups [26].

Many patients have long journeys to the clinic, or difficulty accessing appropriate assistive technology and healthcare services in rural and remote locations [18]. The time required off work, as well as the cost can make the healthcare services inaccessible [18,27]. Long waiting lists [27] and procurement lag time also hinder access to services. To overcome long waiting lists and streamline services, a pre-assessment process or one-on-one support can be delivered by training locals, with telehealth and sensors to provide data to clinicians working remotely [8,12,27]. A single-point referral system could also prioritise cases depending on complexity, to reduce administration and wait times, as demonstrated in a posture and mobility service [28]. However, businesses that have adopted online and advanced technology to provide remote support typically rely on end-users having access to reliable electricity and a data connection [21].

Using technology to enable patients to undertake rehabilitation at home with fewer clinician homecare visits, can reduce costs, and clinical workloads, and allows people in rural areas to have access to rehabilitation support that they may not be able to easily access with traditional rehabilitation services, as they do

Table 1. Summary of included papers.

Author, date	Title	Overview of service delivery model considerations	Themes
Adya, 2012 [11]	Assistive/rehabilitation technology, disability, and service delivery models	Product-based delivery models include individual empowerment, entrepreneurial, universal design, charity, recycling, community-based rehabilitation, and globalization models. It is important to consider the consumer, context, sustainability, and impact.	Availability, sustainability, customisability, usability, policy, impact
Alqahtani, 2021 [30]	Current state and conceptual framework of assistive technology provision in Saudi Arabia	It is important to match the device to user needs and goals, use a multidisciplinary team, and adapt to changing needs. Authors suggest using the Policy, Human, Activity, Assistance, Technology, and Environment (PHAATE) model as a guideline for assistive technology stakeholders developing service delivery systems in Saudi Arabia.	Customisability, policy, education, adaptability
Alqahtani, 2019 [9]	Stakeholder perspectives on research and development priorities for mobility assistive-technology: a literature review	There is a lack of user-centred approaches in assistive product research, service delivery and product design. Users' needs and priorities vary between regions within countries, so assessing consumers' perspectives on a national basis is not detailed enough. The device users are the experts on their current and anticipated mobility needs.	Availability, customisability, usability
Andrich, 2016 [6]	Re-thinking Assistive Technology Service Delivery Models in the Light of the UN Convention	The UN Convention on the rights of persons with disabilities highlighted a need for assistive product services to move from focusing on device provision to wholistic assistive solutions that include ongoing support, environmental adaptions and user empowerment.	Education, sustainability, usability, customisability
Bandini, 2021 [37]	Perspectives and recommendations of individuals with tetraplegia regarding wearable cameras for monitoring hand function at home: Insights from a community-based study	Using wearable cameras to monitor rehabilitation of upper limb function in people with tetraplegia can lead to better assessments of function, but also creates privacy concerns.	Usability, privacy, safety
Bell, 2020 [8]	Functional Mobility Outcomes in Telehealth and In-Person Assessments for Wheeled Mobility Devices	Telehealth Functional Mobility Assessment scores showed telehealth visits may provide an advantage for clinicians addressing transfer issues in the home.	Quality, availability
Bensi, 2011 [24]	Assistive technologies and other solutions for independence: cost or investment?	Assistive technology provision must cope with changing policies, trends, awareness and economic restrictions. The Siva Cost Analysis Instrument found in >50% of cases, there were social and financial benefits over 5 years. Assistive technology is an investment, not an economic burden.	Policy, affordability, customisability, adaptability
Bradford, 2018 [33]	Watching over me: positive, negative and neutral perceptions of in-home monitoring held by independent-living older residents in an Australian pilot study	This smart homes pilot in Australia sought to ascertain barriers and facilitators of assistive technologies that provide home monitoring to support older people to stay in their own homes. Outcomes included increased family communication, health autonomy and advances in technology uptake.	Affordability, usability, safety, privacy, quality
Carranza, 2010 [38]	A literature review of transmission effectiveness and electromagnetic compatibility in home telemedicine environments to evaluate safety and security	Telemedicine systems that use wireless networks are subject to transmission failures or errors, low-coverage areas, and interferences in medical instruments.	Policy, safety
Chadha, 2014 [16]	Understanding history, philanthropy and the role of WHO in provision of assistive technologies for hearing loss	Hearing devices in low- and middle-income countries are typically provided using unstable philanthropic service delivery models. Barriers to service delivery include low level of education about hearing aids, stigma, lack of professionals for device fitting and maintenance, cost, and evolution of the disability movement.	Education, sustainability, availability, affordability, adaptability
Craddock, 2002 [27]	Delivering an AT service: a client-focused, social and participatory service delivery model in assistive technology in Ireland	Long distances to clinics place a time and financial burden on patients, and clinicians are unfamiliar with the home environment, making it difficult to recommend appropriate technologies. A local pre-assessment process could reduce long waiting lists. Local Technology Liaison Officers were trained to pre-screen clients to streamline the assistive technology services available to them and build relationships.	Availability, affordability
Ding, 2021 [17]	Providing mainstream smart home technology as assistive technology for persons with disabilities: a qualitative study with professionals	Mainstream home automation and smart speaker technology can be used as assistive devices, if the technology can fit the individual's needs. Challenges of using mainstream technology include adjusting to technology updates and compatibility, funding, Wi-Fi access and quality, accessing tech support, and security and privacy concerns, as well as the technology often being too complex.	Customisability, usability, affordability, adaptability, safety, privacy
Dolan, 2013 [12]	Clinical standards for National Health Service wheelchair and seating services in Scotland	Authors suggest the adoption of the Institute of Medicine's Dimensions of Quality for systematic improvement of wheelchair services: person-centred, safe, effective, efficient, equitable, and timely. Emerging themes when consulting stakeholders: anticipatory and integrated approaches to care, information management and communication, staff education and training, and safety.	Customisability, usability, safety, impact, sustainability, availability, education
Draffan, 2015 [23]	Barriers and Facilitators to Uptake of Assistive Technologies: Summary of a Literature Exploration	Telehealth professional barriers include lack of evidence, lack of education, devices not easily upgraded, and challenges navigating government policies. Patient barriers include need for technical expertise and lack of education, threat to independence, unreliable products, tendency to use reactive rather than preventative approaches, stigma, and changing needs.	Education, usability, quality, availability, adaptability, policy

(*Continued*)

Table 1. Continued.

Author, date	Title	Overview of service delivery model considerations	Themes
Ennion, 2017 [18]	A qualitative study of the challenges of providing pre-prosthetic rehabilitation in rural South Africa	Barriers to prosthetic rehabilitation and service delivery in low-income countries include inaccessibility of healthcare services, a lack of trained personnel, difficulty retaining staff, lack of evidence-based practice, unavailable appropriate assistive technology, unsupportive government health systems, costs, cultural challenges, and a need for referrals and follow-ups.	Availability, education, policy, affordability
Giokas, 2014 [31]	Smart adaptable system for older adults' Daily Life Activities Management - The ABLE platform	This platform integrates a number of low-cost technologies to create an adaptive Daily Life Activities Management environment to support older people to stay in their own homes.	Privacy, usability, customisability
Gladden, 2015 [13]	Tele-audiology: Expanding Access to Hearing Care and Enhancing Patient Connectivity	Global technology innovation that improves effective and efficient information transfer and fosters patient/family engagement will improve healthcare delivery models. Patients want technology to improve: timely access to care, informed patient decision making, self-management, patient/provider communication, follow up-care, health outcomes, satisfaction, and costs of care. Infrastructure must be sustainable, cost-effective, and meet standards.	Education, availability, usability, affordability, quality, sustainability, impact, policy
Gravina, 2017 [20]	Cloud-based Activity-aaService cyber-physical framework for human activity monitoring in mobility	Body Sensor Networks (BSNs) must be managed to utilise e-health services to increase global access to healthcare. Cloud-Assisted Body Area Network infrastructures can efficiently and securely collect, store, manage and analyse the massive amounts of data generated by BSNs. This Activity as a Service cyber–physical framework uses a platform-independent communication protocol to support on-line and off-line human activity and mobility recognition and monitoring.	Quality, impact, availability, sustainability, safety
Heinemann, 2020 [36]	Patient and Clinician Perspectives on Quality-of-Care Topics for Users of Custom Ankle-Foot Orthoses	The quality of orthotic practice must be improved, starting with determining what aspects of healthcare quality are meaningful to measure. Themes deemed important by orthosis-users and clinicians were: organisational characteristics, communication, care coordination, device fit and comfort, body function and participation, environment of care, clinician competencies, and device characteristics and usage.	Impact, quality, education, sustainability, customisability
Hosking, 2016 [28]	Impact of the single point of access referral system to reduce waiting times and improve clinical outcomes in an assistive technology service	A single point referral system that prioritises clients depending on case complexity significantly reduced maximum waiting times for a Posture and Mobility (Seating) Service, had shorter Episode of Care completion times, and had fewer Episodes of Care completed per annum.	Availability, usability
Johnson, 2017 [19]	The Ponseti Method for Clubfoot Treatment in Low and Middle-Income Countries: A Systematic Review of Barriers and Solutions to Service Delivery	This review evaluates the barriers to service delivery of clubfoot treatment, and proposed solutions. Barriers included financial constraints, transportation, difficulties with brace and cast care, self-perceived health status, lack of physical resources, and provider's lack of knowledge and skill. Solutions included provider and patient education, financial assistance, and placing clinics close to population centres to ensure an adequate supply of materials are available.	Affordability, availability, education, usability
Larizza, 2014 [15]	In-home monitoring of older adults with vision impairment: exploring patients', caregivers' and professionals' views	People with visual impairment felt home monitoring was beneficial for detecting falls, and maintaining independence, but not for appointment reminders, managing medications, reducing isolation, or monitoring changes in activities. Most did not feel the need for home monitoring justified the costs, and found it important to control when they were monitored. They did not want detailed activity monitoring, except for hazardous activities, or knowing whether the person was home. Concerns were raised around costs, privacy and who could access their data, security, technology faults, ease-of-use, and education.	Safety, affordability, usability, privacy, education
Love, 2022 [35]	Lessons learned in the development of a nurse-led family centered approach to developing a holistic comprehensive clinic and integrative holistic care plan for children with cerebral palsy	The Comprehensive Cerebral Palsy Program implemented a nurse-led interdisciplinary team approach to provide care coordination to patients, to reduce the potential for conflicting plans of care provided by different service providers. The trial found cost savings, and improved access, communication, and coordination of care.	Quality, affordability, availability, education, impact
Mandeljc, 2022 [26]	Robotic Device for Out-of-Clinic Post-Stroke Hand Rehabilitation	Telehealth is beneficial for rehabilitation of stroke patients to alleviate the workload of physiotherapists and occupational therapists. This robotic device provides rehabilitation support and monitors use. It was considered safe, customisable and affordable.	Availability, affordability, customisability, safety
Mulfari, 2015 [34]	Providing Assistive Technology Applications as a Service Through Cloud Computing	Cloud computing and virtual machines allow personalised programs and settings for assistive product users, so they can control their virtual desktop from any computer with an internet browser, without needing to install software on new devices. However, it requires internet access.	Availability, customisability (education?)
Ran, 2020 [25]	Basic principles for the development of an AI-based tool for assistive technology decision making	There is a global need for assistive technologies, and many innovative and affordable products, but a low rate of assistive technology uptake, partly due to low access to information and assessment services. Inconsistency of: data, assessment methodology, and competence of assistive technology professionals, has led to requests for AI to support decision-making processes. A self-assessment feature, with an AI-based algorithm, recommends the most suitable assistive technology solutions for the persons' goals and needs, easing pressure on professionals' caseload.	Education, availability, customisability, quality

(*Continued*)

Table 1. Continued.

Author, date	Title	Overview of service delivery model considerations	Themes
Ripat, 2005 [14]	Characteristics of assistive technology service delivery models: stakeholder perspectives and preferences	A service delivery model should match assistive technology to the individual in context by identifying client priorities, abilities and needs, and considering their future abilities and needs. It should provide information on resources and supports available, involve the user, and assess the financial implications of using assistive technology.	Customisability, affordability, adaptability, education
Russell, 2015 [21]	Smart Environments using Near-Field Communication and HTML5	Home healthcare and automation allows seniors to maintain independence. Near-field communication (NFC) enabled smartphones facilitate a smart environment without significant infrastructure. NFC tags are passive electronic devices which communicate with an active reader. They can access the sensors and actuators in a mobile phone, and send the data to a remote server *via* Wi-Fi or 4G. This study provided emergency location, context-aware speech, and patient monitoring when the user tapped the back of the smartphone onto a tag.	Privacy, safety
Stevens, 2019 [22]	Measuring Value in the Provision of Lower-Limb Prostheses	When weighing the cost against the benefit of a healthcare intervention, the discussion needs to shift from cost to value, considering physical function, health outcomes, chronic illness, and quality of life.	Affordability, impact

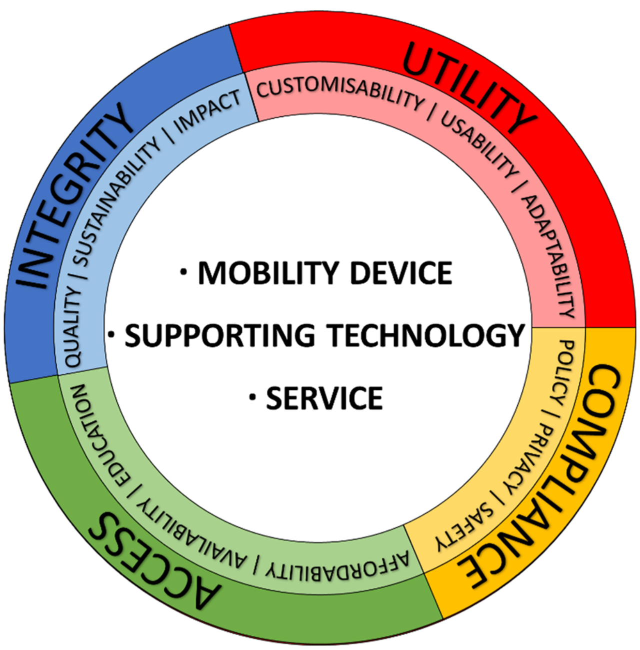

Figure 2. Main categories and themes when designing an at-as-a-service business model.

not need a practitioner to visit their house daily [26]. An example of this is using robotics for stroke rehabilitation. Practitioners do not need to be there to support the individual's daily exercises, and the equipment can feed back the objective rehabilitation performed and the progress made [26].

Education

There is a wealth of innovative, affordable, and accessible mobility and assistive products, but a low global rate of uptake. One of the reasons for this is because there is not enough access to the information and to assessment services [25]. The end-user and clinician must have the knowledge and skills to know what is available, access the services, select the most appropriate device, and make the most of it [15,19,25]. Device-users who live in rural and remote areas in particular, need better education about how they can access appropriate services. If information was made freely and easily accessible online, on smart-phones, and in clinics, device-users would be better informed about their options. Using technology, remote staff can provide support for local staff, which enables local staff to provide the necessary medical support with less education and not as much specialisation. This overcomes some of the issues with staff shortages as well as providing rural amputees with local support. Often health beliefs, racial prejudice, or other cultural challenges can affect a user's access to services, so local-lead initiatives are often better suited to solving local challenges [18].

Some of the reasons given for professionals avoiding moving to telehealth initiatives are the lack of: training in how to use telehealth services, evidence of their benefits, and incentives to change current practices [18,23]. In addition, they feel limited in their ability to assess the patient's condition from afar and find navigating government policies challenging [23]. Using technology and increasing professional education in how to use the technologies could help overcome these barriers.

Patients can feel ill-equipped to use technology to engage in telehealth, and therefore feel that it threatens their independence. Some patients raised a lack of education which can cause them to fear they would miss-use the assistive products or telehealth supporting technology [23]. There were reports that technology used by patients to engage in telehealth, lacked reliability, and patients were hesitant or unable to use data or Wi-Fi to access services. Thus far, the use of telehealth has been reactive rather than preventative, and there remain issues of stigma around the use of telehealth and assistive products [16,23] and an inability to adjust to changing needs [23]. The service provider can facilitate assistive product uptake by providing access to technical expertise, ensuring technology is durable and reliable, and providing online information about the technology and how to use, maintain and enhance it [23]. Current devices are often complex, and patients and staff are required to learn a number of different technologies. It would therefore be beneficial to develop an integrated system for multiple medical and assistive products for telemonitoring and support [29]. If an integrated digital system is used, there is likely a need to deal with management of a large number of cooperative and non-cooperative Body Sensor Networks. A cloud-based cyber-physical framework can efficiently and securely collect, store, manage and analyse large amounts of data to increase global access to e-health services [20].

Utility

Utility was also a major recurring category, with *customisability* and *usability* of the device itself being the main themes consistently addressed. *Adaptability* of both the device and the service to the changing user needs, the growing understanding of best-practice and changing government policy was brought up to a lesser extent.

Customisability

In the reviewed papers, great importance was placed on using a business model that includes customising the device to the individual's unique current and future needs, and to the local environmental factors. A sustainable business model also needs to be and to be adaptable and customisable to changes in business circumstances, location, user needs, and available technologies [14]. For successful assistive product provision, it is important to identify the end-user's priorities, current abilities and needs, future abilities and needs, and which activities the assistive product will be used for [14]. Uncustomisable mass-produced products are unlikely to be suitable, even if Universal Design principles are used, because of the large range of variability in physical function and structure, co-morbidities, environment and lifestyle [22]. One-size-fits-all devices are often abandoned and can cause additional health-related issues to the user [11,30]. Customising sensing systems to support assistive product use remotely is also important. For purposes such as home monitoring systems for older persons, a sensor system with a wide range of functionality that allows users or clinicians to turn off unwanted functions may create enough customisability, while reducing the complexity and the learning required to use the technology [31]. Machine learning can assist with recommending a device design that suits the user's needs and goals [25].

Usability

Moving from a conventional clinic-based care system to a digital home monitoring system can provide additional data to support clinician and end-user healthcare decisions, but the technology needs to be simple, fast and intuitive to learn and use, and to provide easy access to daily readings and trends [15,32,33]. Sensors should not require daily donning, and should automatically upload data and charge, or not require a battery [32]. Implementation issues and technology faults can deter patients and clinical staff, so using reliable, durable technologies and having technical support available is vital to a successful service [15,23]. Cloud computing and the use of virtual machines allow personalised programs and settings so the assistive product user can control their customised remote virtual desktop from any computer with internet access, with no need to install or set up the software on new devices [34].

Patients are more likely to find their assistive products useful if they are given various options and allowed to try them at home before a solution is selected for them [17]. This is particularly important when working with patients from rural and remote locations, who have either travelled to a clinic or are accessing services *via* telehealth, because the clinicians cannot observe the home environment, so it is difficult for them to recommend appropriate technologies [27].

Adaptability

A business needs to adapt to the complexity of assistive products and services, the evolving technological advances and the changing user needs [14]. An individual's needs and goals change over time, and their assistive product and the service provided must be able to adapt with these changes [23,30]. Because of the ongoing and changing needs of the individual, a service-based business model provides better customisability for ongoing relevance to the end-user than a product-based model [25].

Mainstream technology and knowledge of best-practices change rapidly, and assistive product service provision should be able to make use of the technology, research and best practices available. This means there needs to be support for device, service and supporting technology upgrades [7,23]. Machine-learning algorithms can be used to support decision-making processes, leveraging the increasing amount of data available, to guide assessment methodology and product design choices [25]. Assistive product provision must also cope with changes in welfare policies, population trends, cultural awareness and economic restrictions [24].

Integrity

The *integrity* themes of *quality*, *sustainability* and *impact* are more focused on the big-picture and are more esoteric in nature than the other themes. These topics came up less frequently, but when they were raised, the focus was typically on developing a service-focused delivery model, rather than providing a suitable device for the individual, as the more commonly raised themes prioritised.

Quality

The quality of service should result in increased quality of life for the end-users across domains of mobility, self-care, social functioning, daily activities, pain and discomfort, and mental health [22]. End-users can be supported and assessed across these domains with the involvement of a multidisciplinary team, such as a physiatrist, occupational therapist, physical therapist, speech and language therapist, rehabilitation engineering technologist, rehabilitation counsellors, nurses, and personal care assistants [30,35]. Having a programme that oversees the coordination of care across varied services can reduce the potential for conflicting plans of care, save on costs, and improve access to care [35]. A shortage of multidisciplinary team members creates a push for a clinician to be cross-disciplinary, which puts stress on the clinician and means the clinician works unsupported, outside their area of expertise [18]. To provide a quality service, there is also a need for follow-up and on-going rehabilitation services [18].

The device must also be of a high quality in function, comfort, reliability and durability, and consideration must be taken as to how the quality will be controlled [32,33]. Data collection is also a valuable but often forgotten topic when it comes to quality of care [36]. Any sensing equipment must be accurate and used correctly, including being stable and collecting useful data, as potential sources of error can contribute to inaccurate measurements or unreliable representation of trends [32].

Sustainability

A mobility device user requires not only the device, but ongoing service for rehabilitation support, device maintenance, replacement, and modifications if issues arise. A sustainable business must be able to provide these ongoing services [6,16]. The assistive products and supporting technology developed also needs to be able to evolve to adapt to changing user needs, economic changes, and business development [11]. Using a Software-as-a-Service cloud-based platform can provide real-time storage, on-line and off-line management of physiological signals, enable decision-support from data generated from sensors worn by end-users, and analyse data, allowing development and management of applications without the complexity of building and maintaining the infrastructure [20].

Impact

It is important to consider the long-term impact of a service on individuals, communities, and the economy. Impact is often measured by only looking at the direct financial costs and how user-goals and satisfaction requirements are met, not at the wider long-term social and healthcare cost-savings of providing assistive products. A key consideration when designing a service for impact is ensuring timely access to care. Good patient communication and engagement with the healthcare provider, and access to follow-up care, can improve patient health outcomes and satisfaction. A well-implemented referral system and telehealth possibilities can reduce face-to-face patient/provider visits, which reduces the burden on providers and transport challenges for patients [13,28,35]. Patient decision-making and self-management can be improved through access to data, resources, education and connection to support systems [13]. This also reduces the burden on the healthcare provider and reduces the costs of care while maintaining quality [13].

Compliance

Compliance was the category least commonly addressed. *Privacy* was only raised when discussing in-home monitoring for older people and people with disabilities, to increase their independence. Government *policy* was touched on quite often, particularly in regard to a changing climate for service delivery, and challenges with navigating policy and regulations. *Safety* included end-user safety when using assistive products and cyber security threats when digitising a service and using monitoring technologies that store and transmit personal data.

Policy

Mobility device service provision must be able to adjust to changes in welfare policies and economic restrictions [24]. Developing the appropriate strategy for the design and distribution of assistive products depends on the availability of personnel, raw materials, device parts, manufacturing facilities, and the interaction of different agencies: government agencies, disabled peoples' organisations, and non-government organisations [11]. Considerations include government policies, device regulation and regulatory approvals, business liabilities, procedures, security of data being transferred wirelessly to a remote system, and who has access to the data at the receiving end [7,18,23,32]. These processes can be time-consuming and expensive.

Privacy

The number of older people who prefer to live independently is significantly increasing. Assistive products, and services that include home monitoring can support longer independent living for older persons, which enables better quality of life, reduces healthcare costs, and addresses a key concern for many older persons, which is the invasion of privacy of dependent aged-care living arrangements [17, 33]. However, home-monitoring can in itself raise privacy concerns [15,31,33]. A small study of participants with spinal cord injury found that 85% of participants were fine with researchers and clinicians having access to their summary movement data, as long as they were not identifiable. Many were uncomfortable with the intrusiveness of a camera recording them in their home, and more were uncomfortable with one in public. They understood the usefulness of clinicians and researchers accessing their data, but 30% did not see the benefit to them in accessing their own data [37].

It is important when designing a service-focused business model to ensure assistive product users are able to control when they are monitored, and for the assistive products and supporting technology to not interrupt daily routines or unnecessarily invade privacy, or the data to be identifiable or accessible to anyone not pre-approved by the individual [15,37]. More invasive monitoring methods, such as cameras, were only recommended for temporary use and specific purposes [37].

Safety

Assistive products and rehabilitation supports are required to be safe and durable, to prevent injury [12,15]. A service-focused business model that uses sensors to remotely monitor devices can help assess when a device stops performing as it should, which may prevent injury or at least provide information on what caused the injury for future prevention. Remote monitoring of assistive products enables automated alerts and improves patient outcomes, but also introduces cyber security risks when connected to the internet, including vulnerabilities to hacking [38]. Telemedicine systems that use wireless networks are subject to transmission failures, low-coverage areas, errors in the transmission of packets, and cases of serious interferences in medical instruments [38]. There is a need for secure storing and handling of data [7,15,20].

Discussion

There are many considerations when designing a service-based business model for mobility devices, and not yet many papers show successful business models. Modern technologies such as sensors, smartphones, the 4G data network, and machine-learning frameworks can be instrumental in servitisation of mobility device service provision. The business model must consider the device, the service, and the technology required to support the service. The largest themes to appear from these papers on assistive product delivery were the importance of customising the device to the individual, and making the service affordable, and widely available, as well as providing the education to understand what options are available and how to make the most of them. However, it is important to note that though these themes appeared the most frequently in the current research, it does not necessarily mean they should be a higher priority than other themes. Some areas may be easier or more enticing to research or are early-stage research. For example, interviewing clinicians and end-users on how they would like their specific service to be improved is easier than determining how new service delivery models can fit in with and inform government policy, but changing government policy is likely to have a broader and more sustainable long-term impact than adjustments to a single service. Another consideration when reading these results is that the papers are across a wide range of assistive-product areas, rather than just focusing on mobility devices, so the findings will vary in how relevant and adaptable they are to mobility device servitisation. However, the findings provided in other areas of assistive technology mostly also make good sense when using a mobility-specific lens.

Most studies on servitisation have emerged in the last two decades [7]. No academic publications were found that walk through the successful design and implementation of a service-based model for mobility device provision that uses modern sensors, software and other digital technologies to optimise the service for the end-user, the clinicians, the service providers and the manufacturers. Service-based business models that make use of modern digital technologies are new for the mobility device field, but there is much that can be learnt from other fields.

Sensors, technologies for connectivity, autonomisation and assistive technologies that use machine-learning, pattern recognition, and context-aware frameworks provide opportunities for servitisation [39]. These technologies enable smart homes, telemedicine, and monitoring of assistive product failure and falls [39]. Adding technology in the clinics, and sensors in the home to enable remote monitoring of device-use can provide the opportunity for an expert to work remotely to monitor simultaneous locations and support less specialised local healthcare workers to meet the local needs, reducing the number of experts required and the need for on-site training [7]. This can help solve the global clinical skills shortage [40,41]. Businesses that have adopted online and advanced technology to provide remote support can reach clients in rural and remote areas, reducing long journeys to the clinic with time taken off work which often makes healthcare services inaccessible [18,27]. Telehealth, with sensors to provide physiological data and data from within the home, along with a local technically or medically trained person to support the device-user, can provide solutions remotely when the issue does not require in-person attention. However, many of these businesses rely heavily on cloud-based services, video chat, and sensors, which may make them inappropriate in low-resourced areas where clients may not have reliable access to up-to-date computers, electricity and internet. These areas are often where the demand for mobility devices is highest, due to untreated diabetes and infections or landmines etc [42]. Also, sensors on mobility devices have a limited lifespan and storage-space. The device-user is required to recharge them and upload the data regularly, or return to the clinic frequently for the clinician to collect the data and recharge the battery. This makes them unsuitable for many situations. NFCs or passive RFID tags can passively transmit data wirelessly without a battery, to a powered base-station, but this relies on reliable electricity and Wi-Fi or 4G data [21]. Therefore, these technologies are inaccessible for many low-resourced areas. More research is also required to develop mobility devices for rural and remote settings, and policy needs to acknowledge the different requirements for device users living outside cities.

In addition to using technologies for remote support, algorithms are becoming excellent at making optimal decisions, so automation can be leveraged to improve service quality and efficiency [25]. Mobility-device users are highly individual, so clinical experts are vital for understanding the unique needs of a user. However, automation could reduce their repetitive tasks so they can focus on the unique aspects of each case, and data-driven templates could help them optimise their design to meet individual need [43]. Predictive models of demand, based on patterns of use, could potentially also reduce procurement lag time.

There was discussion on the importance of providing follow-up and ongoing rehabilitation services [18], and adjusting the service and assistive products to the changing user requirements over time [23,30]. Little research was found as to how often mobility device users get prescribed new devices or modifications, and how much the prescriptions vary over a lifetime. In upper-limb prosthetics in the UK, each patient visits the clinic to receive a new prosthesis on average every 5 years, and has maintenance almost yearly [5]. Among US veterans, those with upper limb amputation have lower annual prescription and repair rates (0.28 and 0.21) than those with lower limb amputation (0.40 and 0.56) [44].

It is important to consider the long-term impact of a service on individuals, communities, and the economy. A key consideration when designing a service for impact is business sustainability. A sustainable business should develop ways of building assistive products without creating excessive waste, and a sustainable way to dispose of old devices [45].

A business requires continued financial investment to be sustainable [7]. There are many models that can be used for finance. You can own a product, loan, lease or rent it, use a pay-per-use or subscription model, or use crowdfunding, charity or freemium models [7]. A charity relies on continued donations, so this business model provides uncertain sustainability of the business [46]. A government-led initiative is often more stable, but requires long set-up times, as policies need adjusting to meet the model, and/or the model needs adjusting to fit the policies [46].

General models for business operations can be: independent-user or clinician-operated; user or clinician-operated with supplier assistance; supplier operated; or supplier remote-operated and semi-automated [7]. Assistive product business models heavily rely on the expertise of clinicians and the customisability of the device for the individual, so supplier remote operation and semi-automation still rely on local clinical expertise to be useful and sustainable. To reduce risks to the clinic, a service provider can provide a product guarantee, warranty, insurance, a subscription model (reduced risk of technology becoming outdated), shared equipment (increased utilisation means reduced investment and depreciation), or outsourcing [7].

In low-income countries, charities often provide either their own designs of assistive technologies, or in some cases, second-hand devices donated from high income countries. This business model often leads to non-customisable devices that do not suit the context and are not maintained, and unsustainable access to devices because they rely on ongoing donor support, and are typically not locally led [47]. Supporting local businesses that are invested in the community and know the local context can improve sustainability, and using parts that are readily available, such as bike parts for wheelchairs, helps with long-term maintenance and supply of parts, as well as reducing costs [48]. The reviewed papers that used mainstream technologies, used digital devices, such as iPads for non-verbal communicators [17], but building wheelchairs out of bicycle parts is a good example of adapting mainstream technology within the mobility device space.

Small local businesses, such as a local manufacturer and service provider, are likely to have limited start-up funding and few skilled workers. They will impact a small number of device-users, but the service is likely to be well-tailored to the context and needs of device-users in the region, and profit goes into the local economy. Large businesses, such as a global company, can reduce start-up and running costs, and reach more end-users, but the service might be less tailored to the needs of the region, and profit goes to a global company, rather than benefitting the local economy [46]. Good patient communication and engagement with the healthcare provider, and timely access to follow up-care, can improve patient health outcomes and satisfaction. A well-implemented referral system and telehealth possibilities can reduce face-to-face patient/provider visits, which reduces the burden on providers and transport challenges for patients [13]. This approach can also reduce the travel-related carbon footprint of health services [45]. Patient decision-making and self-management can be improved through access to data, resources, education and connection to support systems [13]. This also reduces the burden on the healthcare provider and reduces the costs of care while maintaining quality [13].

A study of individuals with tetraplegia found that though participants understood the value of home-monitoring to clinicians and researchers, 30% did not see a benefit to accessing their own data [37]. To make full use of modern technologies to improve service, this lack of engagement from users needs addressing. It suggests that more work is required to understand what sort of data/service model would engage and benefit the end-users. The other consideration is the invasiveness and hassle of monitoring. Most people use smartphones daily, knowing that they are collecting huge amounts of personal data, but the benefit to the end-user and the ease of use overcome their uneasiness with being monitored. Many people see benefit in their smartphone providing them with physiological data such as heart rate and daily step count. If a mobility device service is set up to include monitoring, it is essential that end-users see the personal benefit to being monitored, have control over when they are monitored and what data is collected, and have control over who can access their personal data [15,37]. A usability and feasibility evaluation is required to test technology acceptance and readiness. The technology needs to address user-perception issues and privacy considerations to enable technology adoption [39].

This review is limited to peer-reviewed academic literature. Many of the commercial business models in use will not be documented in academic papers. Therefore, this is not a comprehensive review of all models in use. Few academic papers exist on servitisation of business models for mobility devices or assistive products generally, so this review was unable to include a synthesis of results. It also does not include a report on the risk of bias posed by the papers.

This paper provides an overview of the barriers to overcome when designing a mobility device service provision model, and potential solutions. The next steps are to develop a model that takes into consideration the learnings of this paper and the specific context. Tauqeer and Bang's servitisation model development framework is a useful way to design and evaluate assistive technology service delivery models, using the following steps [7]:

1. Identify the themes emerging from the studies.
2. Identify the product that is being changed to a service, and the reasons for servitisation.
3. Identify the stakeholders.
4. List the barriers and enablers to customers accessing and benefiting from the product/service.
5. Rate the barriers and enablers according to their impact on each stakeholder group, on a scale from *Extreme* to *Minor* for the barriers, and *Essential* to *Nice-to-have* for the enablers.
6. Design different business model options. This stage may require stakeholder feedback or data collection.
7. Apply servitisation options to increase the effectiveness of the enablers and reduce the barriers until the barriers are minimal and the enablers rate as high as possible.

There is a need for service-based delivery models to replace conventional product-based business models, and many considerations to optimise their design, particularly to improve customisability, affordability, availability, and education. No academic publications were found that walk through the successful design and implementation of a service-based model that uses modern sensors, software and other digital technologies to optimise the service for the end-user, the clinicians, the service providers and the manufacturers. Service-based business models that make use of modern digital technologies are new for the mobility device field, and therefore lack research and evidence-based practice [18]. However, there is much that can be learnt from other assistive technology fields, and the evidence is likely to increase as businesses continue to move towards service-based models over the next decade.

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