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Journal:	*International Journal of Production Research*
Manuscript ID:	TPRS-2007-IJPR-0087.R1
Manuscript Type:	Original Manuscript
Date Submitted by the Author:	25-Apr-2007
Complete List of Authors:	Wagner, Helen; Loughborough University, RMRG @ Wolfson School Dainty, A R J; Loughborough University, Civil and Building Engineering Hague, Richard; Loughborough University, RMRG @ Wolfson School Tuck, Chris; Loughborough University, RMRG @ Wolfson School Ong, Min-Huey; Loughborough University, Wolfson School of Mechanical and Manufacturing Engineering
Keywords:	RAPID MANUFACTURING, HUMAN FACTORS
Keywords (user):	Skills, Prosthetics

The effects of new technology adoption on employee skills in the prosthetics profession

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Rapid Manufacturing (RM) is an emerging technology that is set to revolutionise how products are manufactured. Past research has centred on processes, materials and costing, neglecting the vital issue of how the implementation of this new technology will affect the skills of workers. This work aims to evaluate how the skills of professionals working in the field of prosthetics are likely to be affected by the introduction of RM. Currently a highly skilled, manual process, this paper explores the hypothesis that the manufacture of prosthetic sockets would change fundamentally with the introduction of RM technology. This was evaluated through the use of the Job Characteristics Model, which assesses the skills change and job satisfaction implications of applying new technology to traditional manufacturing processes. Conclusions showed that RM would have a significant impact on job roles in the prosthetics industry. Analysis found a positive outlook for the prosthetist, with the new technology increasing computer-based skills, and traditional prosthetic

skills continuing to be used. The prosthetic technician bears the major impact, deskilled by the, loss of many of the craft skills. However, the new role may appeal to the younger generation, and lowered skill requirements may help increase prosthetics services worldwide.

Keywords:, Rapid manufacturing, Skills, Prosthetics, Job Characteristics Model

Introduction

Rapid Manufacturing (RM) is defined as ‘the use of a computer aided design (CAD)-based automated additive manufacturing process to construct parts that are used directly as finished products or components’(Hopkinson et. al., 2005). Whilst researchers continue to develop the technology and search for potential applications, little is known about the effects this technology will have on the workforce of the industries which choose to adopt it. The prosthetic industry, particularly sockets, is an area of significant potential for RM as it makes use of one of its great strengths; the ability to create cost-effective, bespoke (body fitting) products without tooling, at the required accuracy of 1mm (Ng et. al. 2002). However, the effect that this computer-based, automated system will have on the highly skilled individuals currently producing the sockets manually is not yet known, but may prove to be significant for the implementation of this technology within the prosthetics industry.

A further reason to explore the possibility of RM for prosthetics comes from the unfulfilled needs of the world’s amputees, both in developed countries, due to problems of an aging population battling obesity (Diabetes UK 2004) and in developing countries affected by problems from poverty and land mines (Horvorka 2002, ICRC 2004, Gratzl 2001).

This paper sets out to address the lack of knowledge on the potential impact RM will have on workers, the possibility that it could cause significant changes to working practices and skills currently used, and the potential positive and negative outcomes. It reports on research which aimed to establish what effects the changes brought about by RM will have on the skills of a) the prosthetist, b) the prosthetic technician, and to what degree these changes might the overall experience of job satisfaction on a day-to-day basis. The potential impact on the world-wide shortage of prosthetic services was also assessed.

Rapid Manufacturing Prosthetic Advancements

Medical applications for RM have been considered for many years and are thought to present a significant opportunity. RM has been linked to implants and pre-operative planning tools (Wimpenny et. al. 2001), and often to prosthetic sockets (Ng et. al. 2002). Research on socket manufacture goes back to the early days of Rapid Prototyping (RP), with a study being published in 1991 (Rogers et. al. 1991) centred on Selective Laser Sintering (SLS) only two years after the patent was granted (Deckard 1989). The process was considered to offer advantages in both manufacture and design for stress reduction on the socket. Further studies have been carried out using this technology as well as Stereolithography (SLA), which proved inadequate for prolonged use (Freeman and Wontorcik 1998), Fused Deposition Modelling (FDM) (Tay et. al. 2002), and 3D Printing (Herbert et. al. 2005), both of which showed promise for definitive sockets for full-time use but were held back by time and cost. In 2002, Ng, Lee, and Goh, furthered work by creating a bespoke system, based on the principles of FDM, for the manufacture of sockets named Rapid Manufacturing Machine (RMM) (Ng et. al. 2002). This system was able to reduce time in manufacture to approximately 3.5 hours for a transtibial socket, which compares very favourably with the FDM time of 29 hours, and the 8 full-time, person hours required for manual manufacture (Faustini 2004). Ng et. al (2002) and Tay et. al. (2002) found that sockets produced using RMM and FDM had very similar functional characteristics to manual sockets. The studies mentioned concentrated on the technical aspects of producing a socket by RM, with little regard to the impact on staff or amputees. However, some work suggested that that the process of RM in its entirety, regardless of chosen technology, may reduce the amount of manual labour needed and could be performed by an individual without high level craft skills (Faustini 2004), however no indication was made on just how great the losses would be.

Job Redesign Implications

As with any major business implementation it is essential to consider the effects of change on workers of all levels and their interaction with each other. Studies on the effects that technology has on the worker have been going on for over a hundred years. Many appear to have had political as well as academic motives with early works of authors such as Marx (1867), who studied factories around the Industrial Revolution, and Braverman (1974) who completed much of his work in a time where computers were beginning to become popular, receiving much attention. It was their view that increases in technology caused a deskilling of workers and consequently, a depletion in the numbers of workers needed to carry out the same tasks. Not all who have entered the debate hold such negative views as theirs; in *Computers and Employment* (Borodin and Gotlieb 1972) it was stated that '*after more than a decade of study the consensus is that skills levels are both increased and decreased'*. Taking a different approach, Co et. al. (1998) concluded '*AMT (*Advanced Manufacturing Technology*) expands the technical complexity of the jobs, while relieving workers of the routine tasks*'. This view fits with the ideas of Functional Allocation (FA) methodologies, which are used to decide which tasks are best suited to the machine sub-system and the human sub-system, (Kantowitz and Sorkin 1983) and therefore control the level of impact the technology has on the individual. Nemeth (2004) acknowledges that during FA, tasks at either end of the range of complexity scale are easily allocated, with the most simple and boring of tasks allocated to the hardware/software of the system, and the more highly complex tasks being reserved for the human. The Job Characteristics Model (Figure 1) proposed by Hackman and Oldham (1980) is a tool for analysing the satisfaction and motivating potential offered by a job role (Thakor and Joshi 2005), the calculation of which is facilitated by the Job Diagnostic Survey (JDS) or Job Rating Form (JRF) (Hackman and Oldham 1980). Some authors have sought to improve on the questions of the JDS (e.g. Idaszak and Drasgow 1987), but when their revised questioning was tested by others, in a direct comparison, no improvement was found and the authors recommended continued use of the original questionnaire (Kulik 1988). Although created in the 1970s, the model is still used and is seen by Greasley (p187, 2006) as one of the '*three theories which have had a significant impact on the behavioural aspects of job design*', along with sociotechnical systems and empowerment. The model has also often been used in case studies to look at different aspects of the motivational aspects of job roles (Thakor and Joshi 2005, McKnight and Chervany 1998, Lee-Ross 1998).

Research on RM is quite substantial and growing as the pace of the technology increases; however, there have been few investigations into the management issues, with nothing found to date on the skills effects on the workers and the business. The prosthetics industry has been shown to be a potential application for RM technology but has not yet embraced this it as a manufacturing technique. In light of this, the work on RM implementation, focusing on skills, was undertaken in the prosthetics industry in order that its potential impact can be evaluated prior to its widespread adoption.

The Role of the Professional within Prosthetics

Within a prosthetic clinic two major roles exist, which are in turn supported by other hospital staff. These are the prosthetist (interview data referenced in text as (a)) and the prosthetic technician

(Chief Technician referenced in text as (b)), both of whom have differing roles, responsibilities and levels of patient interaction.

The Prosthetist and Education

The role of the prosthetist is quite wide ranging requiring skills and knowledge in biology, engineering and working with people (Strathclyde University 2006). Having completed an undergraduate degree in prosthetics and orthotics, only at either Strathclyde or Salford University, an individual is then state registered with the Health Professions Council and British Association of Prosthetists and Orthotists (BAPO) (Salford University 2006), which allows practice both within the National Health Service (NHS) and privately. The University of Strathclyde offers only 28-30 places per year, even though it receives 95-100 applications (Figgins 2006) and it is recognised that there is a shortage within the profession. Additionally, the number of prosthetists due for retirement is rising and young graduates are not being trained fast enough to stem the flow (Kapp and Fergason 2002).

Day to Day Tasks and Competences of the Prosthetist

At a clinic within a UK hospital, the prosthetist, who is most likely to be male as 90% of the profession are (Kapp and Fergason 2002), works to a tight schedule and would see on average four patients an hour (a). However, clinics sometimes overrun by several hours (Allied Health Professions Federation 2004) due to the holistic role the prosthetist performs for the patient, which can also include counselling. The relationship formed with the patient is a special one of continuity; where other healthcare professionals can often change, the prosthetist usually remains linked to the patient on an ongoing basis (a).

On a practical level, the prosthetist is the person who has hands-on contact with the patient. For amputees, the socket is a vital component as it forms the link between the body and the prosthetic limb and determines the level of comfort/discomfort experienced. Creating the cast is a skilled operation which traditionally comprises of the application of plaster bandages to the stump to create a mould from which the prosthetic socket can be made. Once the mould is filled with plaster it must be broken to be removed, losing the information and creating an unrepeatable process (Herbert et. al. 2005). The positive stump mould is then shaped according to the markings made by the prosthetist during moulding, using skill and knowledge to remove or add plaster in areas of greater or lesser pressure (Smith and Burgess 2001).

All of the decisions on the type of prosthesis are made by the prosthetist based on information provided by the patient. They will make heuristic judgements, based on their experience and knowledge, to interpret what is being said into what is actually needed. The manufacture of the socket and prosthesis is completed by the prosthetic technician and is then passed back to the prosthetist for fitting to the patient.

Fitting can be difficult. It can take place within days of surgery (a) so the prosthetist must be able to deal with healing wounds as well as the mechanics of producing an artificial limb. It may also be possible in some circumstances for the prosthetist to see the patient before surgery and advise doctors where the most appropriate amputation site would be for ongoing treatment. If the socket is not well fitting, which could be caused by changes in the stump as it recovers post-surgery, it can be altered slightly by reheating and then it is fitted to the full prosthesis assembly.

All of these parts of the job link together into a portfolio of skills and competences, which increase as the prosthetist moves through their career. In 2004 the BAPO Executive Committee clarified the skills and knowledge necessary for each grade of the prosthetist structure by issuing a professional career structure for the field of prosthetics and orthotics (BAPO 2004). The requirements are broken down into twenty categories each with a list of "*elements of competence*"; the most relevant to this case are listed below in Table 1, using the Graduate level as an example.

Table 1: BAPO Proposed Career Structure: Graduate Prosthetist/Orthotist (Practitioner)

[Insert Table 1 about here]

One of the most significant skills missing from this structure is the ability to competently use CAD (Computer Aided Design) software. There is mention, in point 1, of tracing which is the scanning of the stump using computerised scanning equipment, from which data is sent for CAD manipulation, but nothing further on CAD in any of the grades as the process is still predominately manual.

The Technician and Education

Supporting the prosthetist in the role of manufacture of the prosthetic limbs is the prosthetic technician. Unlike the prosthetist there seems to be no formal education system in the UK for this role. The most appropriate system for their qualification is the NVQ (National Vocational Qualification) which would be run in conjunction with a local Further Education (FE) college. Unfortunately this relationship is not always possible leaving individuals to be trained without formally recognised qualifications. There is however, a level of professional recognition through BAPO at the level of Affiliated Technician. Technicians were also included in the career structure set out in 2004 (BAPO 2004), Table 2, but the detailed skills breakdown was not completed for technical levels.

The Jobs and corresponding levels would be:

Table 2: BAPO Career Structure for Prosthetists and Prosthetic Technicians

[Insert Table 2 about here]

Day to Day Tasks and Competences of the Prosthetic Technician

The technician's role is a purely technical one. Once the prosthetist has seen the patient and assessed their needs, the information is passed to the technician and includes details on every part of the prosthetic assembly. When working from a positive cast of the stump, the technician would create the plaster representation for the prosthetist to sculpt to shape. If working from a CAD file, the information would often be sent to a central fabrication centre where the stump representation is milled from polyurethane (PU) foam using a CNC machine (Herbert et. al. 2005, (a)) and returned to the department for socket manufacture. Manufacture of the socket itself is achieved using a sheet of pre-heated polypropylene which must be smoothed down over the cast to form the shape. This process requires significant skill, to know just how much pressure to use, to overlay the sheet at the correct time and work the material while it is still hot to create the correct wall thickness while not overstretching. The prosthetic limb is then assembled from a store of ready made parts, prescribed by the prosthetist, attached to the socket which is always custom-made.

Making full limbs can be anticipated based on new patient intake and therefore scheduled, but they are only part of the role. The prosthesis is an integral part of the patient who cannot fully function without it. Previously patients had a spare prosthesis, but due to NHS cuts, each patient now has only one, so when problems arise they must be dealt with immediately. Each clinic operates a drop-in centre which allows patients to come and wait for repairs to their prosthesis, this work cannot be planned and specific repairs can only be done by more competent individuals. In addition some older patients refuse to move onto the modern prosthesis and therefore some technicians have to be skilled in practices that generally became outdated years ago.

Technology in the Prosthetic Profession

In recent years, computers have become integral to prosthetics. For several years prosthetists have been able to scan the stump of the amputee to create a digital representation that can be manipulated using CAD software. This entire system requires new skills not previously needed by the prosthetist. Once competent the prosthetist can use the software to modify the scan, without losing the original scan data (Herbert et. al. 2005), to a level that can be more accurate than manual casting and modification (Lemaire and Johnson 1996). This is an advantage, as information can be stored and reused for future prosthesis or monitoring of the patient's condition, which is not an option using conventional methods. It may also be possible to create a socket using simple measurements input to a specialist CAD system (Smith and Burgess 2001), choosing to allow the system to work on the embedded knowledge within, to create a socket using sample templates.

However, CAD education within prosthesis production is not progressing as rapidly as could be expected in such a computerised world. The Strathclyde programme offers only an introduction to CAD with some examples shown and its Director of Undergraduate Courses stated "*when CAD/CAM came in vogue in the late 1980s I was just finishing as an UG and we expected it to revolutionise all prosthetic practice but it did not due a variety of reasons involving cost and accuracy and time efficiency*" (Figgins 2006).

The systems required for RM will again change the required skills of the prosthetist and most importantly the prosthetic technician, potentially changing the role from a skilled craftsman to a computer based technician. RM is included in the curriculum at Strathclyde and it is considered that "*there is excellent potential and have no doubt this could change prosthetic practice*" (Figgins 2006). However, a 3D digital model is essential for RM so the CAD education will need to improve.

However, in craft-based occupations, such as prosthetics, modern working practices such as CAD are not always well received. Technology driven improvements are often viewed as an attempt by management to cut jobs (Raschke and Ford 2002). This is because much of the research and development comes from outside the profession, but it is viewed that if courses become more engineering based then prosthetics graduates will be able to contribute to the development (Raschke and Ford 2002). There also appears to be a blurring of the boundaries between prosthetist and technician role when using a CAD based system. In 'The Survey of CAD/CAM Use' (Steele 1994) it can be seen that both levels of staff seem to be performing the same function for several tasks, which may have an impact on future roles.

Methodology

This paper uses a case study methodology, which is appropriate as its content is defined by Gillham (2000), as 'a unit of human activity embedded in the real world; which can only be studied or understood in context; which exists in the here and now'. The approach encompassed the investigation of the industry from literature and external authorities, along with observation and interviews with a Prosthetist (referenced in text as (a)) and the Chief Technician (referenced in text as (b)) at a clinic in the UK providing the prosthetic services being studied.

Once the information was gathered, it became possible to analyse how the perceptions of the industry compare to the observations made at the clinic. From there, the roles in their current state were assessed in terms of specific skills and job satisfaction. An analysis of the job satisfaction was made based on the principles of the Job Characteristics Model (JCM) (Figure 1) and Job Diagnostic Survey (JDS) or Job Rating Form (JRF) introduced by Hackman and Oldham (1980).

Figure 1: Job Characteristics Model (Arnold et. al. 1991)

[Insert Figure 1 about here]

The JCM outlines five core job characteristics which can be related to the work of the technician. Having considered these factors, they can be scored using the JDS or JRF. Both contain the same questions for the two relevant sections, but the JDS is completed by an employee in the role, and the JRF by a supervisor or by an outside observer (Hackman and Oldham 1980), as is the case for this analysis. The results are then entered into the Motivating Potential Score (MPS) equation (Equation 1) also created by Hackman and Oldham, each component in the equation being scored from 1 to 7, with results ranging from 1 to 343 and scores commonly around 150 (Arnold et. al. 1991).

Equation 1: Motivating Potential Score (MPS)

[Insert Equation 1 about here]

Once the current job was evaluated, the potential roles within the RM prosthetics clinic were broken down into the skills necessary, the literature on RM was used to anticipate the potential effects that would be felt if the technology were implemented. The current and RM roles and skills were compared to estimate the changes in terms of deskilling, reskilling or upskilling as discussed in the literature.

The potential for deskilling or upskilling of the roles may impact on how the worker perceives the job and how much motivation and satisfaction is gained in performing it. With the information gained, drawing on the principles of the JCM and the MPS, the RM role is scored, and compared with the current role and normative data on comparable job roles. The information gained from the analysis was used to predict the potential implications for the prosthetist, prosthetic technician, the prosthetics industry and society.

Case Study of Prosthetics in a UK Hospital

As with many situations the 'text book' answer is not necessarily what goes on at the shop floor; an interview with a prosthetist (a) and the Chief Technician of prosthetics (b) accompanied by a tour of the department at an NHS hospital in the UK gave a more realistic picture. The team of ten qualified technicians at the case hospital are highly trained craftsmen (all of them are men), who are committed to their profession, led by a chief technician. Many are nearing retirement which may prove a problem in the years to come, but currently means they have a wealth of experience spanning several decades. The problems that occur when elderly amputees arrive with outdated prostheses are capably handled by the experienced staff. The biggest problem they may face is to recruit and train new employees.

Although the BAPO (Table 1) structure recommends that technicians have or are working towards NVQ's this is not the case for the two trainees. An agreement was forged with a local college which trained existing staff but has since broken down leaving the experienced staff to in-house train all new recruits whose learning is not formally recognised. Generally trainees shadow experienced technicians until confident to be given their own quota of straightforward tasks. This can be a difficult learning environment due to the unscheduled repairs that are necessary and can mean that an experienced member of staff training a new starter has to be pulled onto an urgent case which is unsuitable for basic training. There are however, specialised training courses provided by BAPO for which a training budget exists, but this is for experienced staff to continue in professional development.

The job requires skills that perhaps would not be immediately obvious. Applicants are asked to bring samples of any craft work they have produced, this can be art based e.g. jewellery, or something more technical, to show the manual dexterity needed but also the aesthetic appreciation and talent. This is necessary as the prosthetic limb becomes part of the person and should be as aesthetically pleasing to them as possible. Otherwise, the chief technician looks for a background for new recruits in general engineering, preferably having completed an engineering apprenticeship.

At the sample hospital there is a great sense of pride in the work that emulates from the technicians; they regard their manual skills to be far superior to anything that can be created by a machine. They consider that if machines took over they would still be needed to correct and finalise, to emphasise this, the chief technician stated 'I think you can never get the machine to do what the technician does' (b).

Automation of the socket manufacture would greatly affect the technicians, as it is the really skilled part of the job, with the rest of the limb coming as 'just kits' (b) which can be assembled with little experience. It is envisaged, as technology improves and automation becomes possible, that it would be the technicians who would suffer the greatest loss of skill and number, as greater accuracy on the part of the prosthetist would lower the required iterations and decrease the sockets manufactured. Technology does impact on the patient also, as it was said that scanning and CAD can improve the results of an inexperienced prosthetist, but could reduce the skills of a highly skilled individual to a standard level (a).

The reality of the scanning/CAD method is that it currently falls short of its potential. One major advantage claimed is the repeatability of the process and the storage of information; however, this is negated by the practice that goes on in the plaster room. Rather then amend the positive stump CAD file and re-milling, the milled PU foam stumps have plaster added to them or foam shaved off, meaning that the final product is not the same as the CAD file and the file is therefore useless. A further scan of the reshaped foam could be made but this currently does not happen Also, CAD has not proliferated much beyond the younger newly trained prosthetists who feel they have nothing to lose due to their inexperience, and it may actually improve performance at this stage. It was felt that 'you can't do it as well with computers as you do it by hand' (a), and while that attitude prevails even amongst forward thinking prosthetists, CAD is unlikely to progress.

Analysis

In order to analyse the skills involved in the roles of the prosthetist and prosthetic technician, the process itself was broken down. Currently the process consists of eight steps; the tasks were assessed and coded to show what level of staff performed them. It was noted that all tasks involving the patient were carried out by the prosthetist, and so involved a different skills set. As with most roles, there were job specific skills (Figure 2), which related directly to the role, qualifications and experience, and transferable skills, which 'refer to certain personal abilities of an individual, which can be taken from one job role to another, used within any profession and at any stage in their career' (Raybould and Sheedy 2005).

The skills have been considered for the conventional casting method and scanner/CAD process and also the potential skills requirements for future RM (Figure 3). Because only part of the process is directly affected by the data acquisition and moulding phases, there are some tasks and skills that are consistent within processes. The changes in skill directly connected to the scanning and CAD equipment affect only the prosthetist. In a situation where processing takes place in-house the technician would be required to reskill to use and maintain the RM equipment. However it may be that the practice of central fabrication that exists with the scanning/CAD system for PU foam moulds will prevail within RM, due to the costs and complexities of owning and running the equipment, as found by Smith and Burgess (2001). It may also be that the technician becomes involved in the transfer of data from the hospital to the central fabrication facility but it is not necessary for him to be competent using the scanning or CAD software and it does not affect the manual process of socket manufacture. It does however take away part of the job of the technician, which could be seen as relieving him of a dirty, mundane task as proposed by Co et. al. (1998), or as a move towards the division of labour seen in other manufacturing facilities.

Figure 2: Job Specific Skills - Manual Casting

[Insert Figure 2 about here]

Figure 3: Job Specific Skills RM

[Insert Figure 3 about here]

Implications of RM introduction - the prosthetist

For the prosthetist, with the use of RM the skills change should not be as dramatic, and could be viewed as more a realignment than a loss, with potential for upskilling in some areas. The main changes that RM would bring i.e. the 3D CAD model and scanning techniques, are already used in some cases to create the CNC milled cast and would be supplemented by knowledge embedded, bespoke software such as the modification overlay method based on an individual prosthetist's style explored by Lemaire and Johnson (1996). As this becomes more commonplace the skills would increase and time spent should reduce allowing more time to see patients or complete other tasks. It is also likely that if RM fully replaces traditional methods, better software and purpose designed machines would be built, making the process and preparation stages run even more smoothly. This is already found to be the case in the hearing aid and dental-crown industries where custom CAD software and custom RM machines are manufactured for those specific applications (Hopkinson et. al. 2005). As the practical aspects of the job change, but are not removed, the underlying skills and knowledge remain relevant. It would still be necessary to recognise the load carrying areas to ensure the computer based model goes from the exact replica of the stump to the functional socket design. Research has shown that moving into computer based tasks, that have a higher mental workload, also leads to greater job satisfaction (Cook and Salvendy 1999). Initially it may be a challenge for prosthetists to learn skills totally out of their chosen speciality, but there is motivation to continue in their professional development and learn new skills while still giving the best service to patients.

The further impact of the changes mean, like all professionals, the use of computers will aid the prosthetist in parts of the job not directly connected to the socket fitting. The skills that are learned allow the prosthetist and technician to process data and communicate with the rest of the medical staff in faster more efficient ways. The sharing of on-line CAD files and prosthetic prescription options may aid in discussions with doctors and rehabilitation staff, especially as the prosthetists are not always on-site at the hospital when they are not in clinic. The obvious computerised data storage and transfer facilities would also cut down on the potential for error in the communication between prosthetist and technician which is currently done via paper based forms and files.

The current role of the prosthetist actually scores significantly higher in MPS than a general professional/technical role (see Table 3), as most factors are increased due to the type of role in the medical profession. When assessed, the role of the RM prosthetist shows little change in MPS, the reductions coming from the automated process reducing the interim input currently experienced at the plaster mould stage which would give increased feedback, not experienced when the socket is made directly from a 3D data file.

Table 3: Normative data to JRF result comparison for the prosthetist

[Insert Table 3 about here]

Implications - the prosthetic technician

The JCM analyses what makes a job fulfilling for the worker. Relating it to the role of the technician using the observations and interview information to answer the JRF questions, skills variety (SV) is currently estimated as reasonably high; in addition to the different methods used to make sockets there are the functions involved in making the casts and repair of older prostheses. Task Identity (TI) relates to the process of creating the socket attaching it to the full prosthesis and making necessary alterations; this allows the technician to complete the whole task giving a sense of achievement, which in the case of prosthetics links into the task significance (TS) by improving the life of the amputee when the job is done well. There is not a great deal of autonomy (Au) on the decisions involved as this is prescribed by the prosthetist but the workers are trusted to complete the tasks to a high standard with minimal supervision. As the tasks are primarily manual, the sockets can provide some instant feedback (Fb) on whether they are correct but the majority comes from the fitting stage of the process.

Ratings were calculated drawing on the principles of the JCM, based solely on the JRF completed by the observer, and then entered into the MPS equation. These could then be compared to the normative data produced by the authors of the models in Table 4.

If the individual factors are considered the current manual job of the technician scores well in comparison with the normative data on jobs such as machine trades and services (Hackman and Oldham 1980) which are both elements combined in the technician role.

Table 4: Normative data to JRF result comparison for the prosthetic technician

[Insert Table 4 about here]

Table 4 also shows the potential results of the JRF for an RM role; column a) represents the role with in-house RM processing, column b) when RM is outsourced. The MPS score decreases as the job becomes more automated and is very low when RM processing of the socket is outsourced. Although the new functions may provide new skills they do not meet the criteria for job satisfaction as well. The SV is cut dramatically as the only required job is to transfer files and it may be possible that the prosthetist would do this himself; it is most likely that these files will be assessed for their completeness for processing at a central facility to avoid the need to train many individuals to do a job a few can become expert in. The TI is lost as it becomes more of an assembly role and TS is removed because the technician no longer creates the part of the product that makes the amputee more active. It is likely that the job in production at the central fabrication facility will be highly skilled and rewarding one, but would probably not be performed by individuals who have been trained in prosthetics, but rather those who have an engineering and computing background.

The corollary of the changes potentially brought about by RM is that the entire skills set currently used by the highly trained technician would become obsolete, with the exception only of minor adjustments after fitting and only then if the RM material chosen will allow. This represents a deskilling of the current individuals along with a dramatic decrease in the variety of tasks involved in their job, creating to them a more mundane role of computer transfer and assembler of kit parts. It is unclear if the new skills learned for CAD conversion and file validation are sufficient to counteract the skills loss, but it must be recognised that these skills are more transferable to other jobs. Also, in the modern hi-tech world this kind of role may appeal more to young people than the traditional hand skills of the current role. However, as the technology progresses and the software develops to a point where further automation is possible, a Function Allocation assessment of tasks should be considered to ensure the job roles are not negatively affected by the changes and allow the workers to keep a level of control over the process. Maintenance and problem solving for the machines may also help to reskill those who remain in the technician role where RM is taken on in-house.

Implications - The prosthetics industry

The deskilling of the socket production may cause current highly qualified, skilled staff to seek out opportunities to continue working in the manual ways and inevitably the changes in the job role and the number of tasks will allow employers to reduce numbers of staff, thus taking their abilities away from the fully accessible NHS clinics. This could cause problems for the older patients who are unwilling or potentially too adapted to the antiquated prosthesis they currently have, as the skills to repair or replace parts would be lost. The lower skilled role of technician under RM will also allow hospitals to employ cheaper staff. This may be a necessary step, as currently sockets are supplied free in an agreement between the manufacturer and the NHS but this agreement would become impossible with the increased costs to the manufacturer of RM both in terms of equipment and materials. However, it may be that RM offers a solution to the problem of recruiting new personnel into an industry declining due to a lack of craft skills, as already observed in the hearing aid industry (Masters et. al 2005).

Implications - Society

On the surface, the skills changes, especially for the prosthetics technician, appear to be deskilling or in some cases reskilling. This may in fact be the case in the developed world as technology replaces yet more manual workers, but this may also have a positive effect in the developing world. For the countries who have suffered dramatic increases in amputees due to the laying of landmines, benefit may be found from the lower skills necessary to produce a product of equal standard. If it is possible to use software and machines embedded with necessary knowledge, the time needed to train new individuals to complete the tasks could be greatly reduced, helping to alleviate the long waiting times currently experienced. Additionally, as the technology used for RM is highly automated, it can be used on a 24 hour basis with minimum supervision allowing for increased production to take place. It is considered by some that a level of automation will be what is needed to meet the needs of all the world's amputees (Smith and Burgess 2001). Further evidence that this technology can make a difference can been seen in the project 'Rapid Prototyping for Baghdad' (Vancraen 2006)

Conclusions

It has been shown that there is potential for the prosthetics profession to progress into RM techniques, but this will not be without consequences for the personnel involved.

For the prosthetist, the outlook is a positive one, increasing skills in computer related tasks that will allow them to keep pace in the medical profession and may enhance other parts of their job. The transferable skills will allow for more up to date communication methods with others involved in the treatment of amputees and the data storage will allow him to review changes in the patients' condition over years.

The technician may experience a different situation. The skills involved in the current manufacturing methods are very labour intensive and take time to master, however, with RM these can be replaced by accurate, and in future, quick production with much less training. The current role is likely to deskill from a highly skilled one to a semi-skilled or perhaps even unskilled position. RM will remove the most skilled tasks and leave a combination of data processing and assembly, which when viewed in-line with the Job Characteristics Model and Motivating Potential Score takes the position from fulfilling in most areas, to relatively unfulfilling overall. However, for the younger, computer literate generation the perception of this new position may be entirely different, and this may help to fill vacancies in a declining craft-based industry. Additionally removing the plaster processes should give the patient a cleaner and less physically disturbing experience.

It may be that RM can improve a situation where trained professionals are in relatively short supply and likely to become more so in comparison to the increasing numbers of new amputees, reducing the time in training for a technician to become productive. It may prove to be the best solution to a problem of growing proportion to the world's amputees.

This paper set out to address the lack of knowledge on the potential impact RM will have on workers. Using the prosthetics industry, it has shown that there is a definite possibility that RM will cause significant changes to working practices and skills currently used, with both positive and negative outcomes. Further work on this topic is recommended to assess if the proposed effects are industry specific or may impact on any organisation wishing to implement the technology.

Acknowledgements

The authors would like to acknowledge the financial support for this work from the EU Framework 6 Project, Custom-Fit, (Project Number 507437-2). They would also like to thank all staff at the hospital who gave of their time.

References

Allied Health Professions Federation. New generations: The changing face of allied health professionals. *Department of Education*, 2004

Arnold, J., Robertson, I. and Cooper, C. *Work Psychology*. pp 309-312 1991 (Pitman Publishing, London)

BAPO. *BAPO Career Structure: proposed professional structure for prosthetics and orthotics*. British Association of Prosthetists and Orthotists, July 2004. Available online at: www.bapo.com (accessed 05 May 2006)

Borodin, A. and Gotlieb, C.C., Computers and employment. *Communications of the Association for Computing Machinery*, 1972, **15**, 695-702

Braverman, H. *Labor and Monopoly Capital: Degradation of Work in the Twentieth Century*. 1974 (Monthly Review Press, New York)

Chief Technician. Chief Prosthetic Technician– Prosthetics case study interview, 20 January 2006

Co. H.C., Patuwo, B.E. and Hu, M.Y. The human factor in advanced manufacturing technology adoption: an empirical analysis. *International Journal of Operations & Production Management*, 1998, **18,** 87-106

Cook, J.R., and Salvendy, G., Job enrichment and mental workload in computer-based work: implications for adaptive job design. *International Journal of Industrial Ergonomics*, 1999, **24**, 13-23

Deckard C.R. Method and apparatus for producing parts by selective sintering, United States Patent US4863538, September 5, 1989

Diabetes UK. *Diabetes in the UK 2004*. Diabetes UK, October 2004

Faustini, M.C. Modelling and fabrication of prosthetic sockets using Selective Laser Sintering. PhD Thesis. The University of Texas at Austin, May 2004

Figgins, E., Director of Undergraduate Courses – Questionnaire, May 2006

Freeman, D. and Wontorcik, L. Stereolithography and prosthetic test socket manufacture: A cost/benefit analysis. *Journal of Prosthetics and Orthotics*, 1998, **10,** 17-20

Gillham, W. *Case Study Research Methods*. 2000 (Continuum, London)

Gratzl, P., Prosthetic services in Sri Lanka. *Symposium on the Impact of Landmines in Sri Lanka*, March 2001

Greasley, A., *Operations Management*. p187, 2006 (John Wiley and Sons Ltd, Chichester)

Hackman, R., Oldham, G.R., *Work Redesign*. 1980 (Addison-Wesley Publishing Company, Reading, Massachusetts)

Hackman, R., Oldham, G.R. Development of the job diagnostic survey. *Journal of Applied Psychology*, 1975, **60**, 159-170

Herbert, N., Simpson, D., Spence, W.D. and Ion, W. A Preliminary investigation into the development of 3-D Printing of prosthetic sockets*. Journal of Rehabilitation Research & Development,* 2005, **42**, 141-146

Hopkinson, N., Hague, R.J.M. and Dickens, P.M. *Rapid Manufacturing – An Industrial Revolution for the Digital Age*. 2006, (John Wiley & Sons, Ltd, Chichester, West Sussex)

Horvorka, M.S., Shurr, D.G., Bozik, D.S., The concept of an entry level interdisciplinary graduate degree preparing orthotists for the new millennium Part1: History of orthotic and prosthetic education*. Journal of Prosthetics and Orthotics*, 2002, **14,** 51-58

ICRC. Mine action 2002. *ICRC* (International Committee of the Red Cross) *Special Report*, 2002

Idaszak, J.R. and Drasgow, F. A revision of the job diagnostic survey: elimination of a measurement artefact. *Journal of Applied Psychology*, 1987, **72**, 69-74

Kantowitz, B.H. and Sorkin, R.D. *Human Factors – Understanding People-system Relationships.* 1983. (John Wiley & Sons, New York)

Kapp, S, and Fergason, J., Contemporary students: learning styles and teaching strategies*. Journal of Prosthetics and Orthotics*, 2002, **14**, 71-74

Kulik, C.T., Oldham, G.R. and Langner, P.H. Measurement of job characteristics: comparison of the original and the revised Job Diagnostic Survey*. Journal of Applied Psychology*, 1988, **73,** 462-466

Lee-Ross, D. The reliability and rationale of Hackman and Oldham's job diagnostic survey and job characteristics model among seasonal hotel workers. *Hospitality Management*, 1998, **17**, 391-406

Lemaire, E.D. and Johnson, F., A qualitative method for comparing and evaluating manual prosthetic socket modifications. IEEE Transactions on Rehabilitation Engineering, 1996, **4** 303-309

Marx, K. *Capital*. 1967 (Everyman's Library, London) (original work published 1867)

Masters, M., Velde T. and McBagonluri F. Rapid Manufacturing in the Hearing Industry. In Hopkinson, N., Hague, R.J.M. and Dickens, P.M. *Rapid Manufacturing – An Industrial Revolution for the Digital Age*. 2006, (John Wiley & Sons, Ltd, Chichester, West Sussex)

McKnight, D.H. and Chervany, N.L. The motivating nature of the critical systems operator job: expanding the job characteristics model with relationships. *Proceedings of the ACM SIGCRP Conference, 1998, pp68-77*

Nemeth, C.P. *Human Factors Methods for Design - Making Systems Human-centred.* 2004. (CRC Press, Boca Raton, Florida)

Ng, P., Lee, P.S.V., and Goh, J.C.H. Prosthetic sockets fabrication using Rapid Prototyping technology. *Rapid Prototyping*, 2002, **8**, 53-59

Prosthetist. Prosthetist - Prosthetics case study interview, 20 January 2006

Raschke, S.U. and Ford, N. Report on key points arising from visioning process on prosthetic and orthotic education done at the British Columbia Institute of Technology. *Journal of Prosthetics and Orthotics*, 2002, **14,** 23-26

Raybould, J., and Sheedy, V., Are graduates equipped with the right skills in the employability stakes? *Industrial and Commercial Training*, 2005, **37**, 259-263

Rogers, W.E., Crawford, R.H., Beaman, J.J., Walsh, N.E., Fabrication of prosthetic sockets by Selective Laser Sintering, in *Proceedings of the Solid Freeform Fabrication Symposium*, 1991, pp 158-163

Salford University. *BSc (Hons) Prosthetics and Orthotics – Course Information*. 2006, Salford University. Available online at: www.salford.ac.uk (accessed 24 April 2006)

Smith, D.G. and Burgess, E.M. The use of CAD/CAM technology in prosthetics and orthotics – current clinical model and a view to the future. *Journal of Rehabilitation Research and Development*, 2001, **38**, 327-334

Steele, A.L. A survey of clinical CAD/CAM use. *Journal of Prosthetics and Orthotics*, 1994, **6** 42-47

Strathclyde University. *BSc (Honours) Prosthetics and Orthotics – Course Information.* National Centre for Training & Education in Prosthetics and Orthotics. 2006 Strathclyde University, Available online at: (accessed 24 April 2006)

Tay, F.E.H., Manna, M.A., and Liu, L.X., A CASD/CASM method for prosthetic socket fabrication using the FDM Technology. *Rapid Prototyping Journal*, 2002, **8**, 258-262

Thakor, M.V. and Joshi, A.W. Motivating salesperson customer orientation: insights from the job characteristics model. *Journal of Business Research*, 2005, **58**, 584-592

Vancraen, F., Limb prosthesis made with rapid prototyping for patients in Baghdad. Available online at: www.rp4baghdad.org (accessed 13 November 2006)

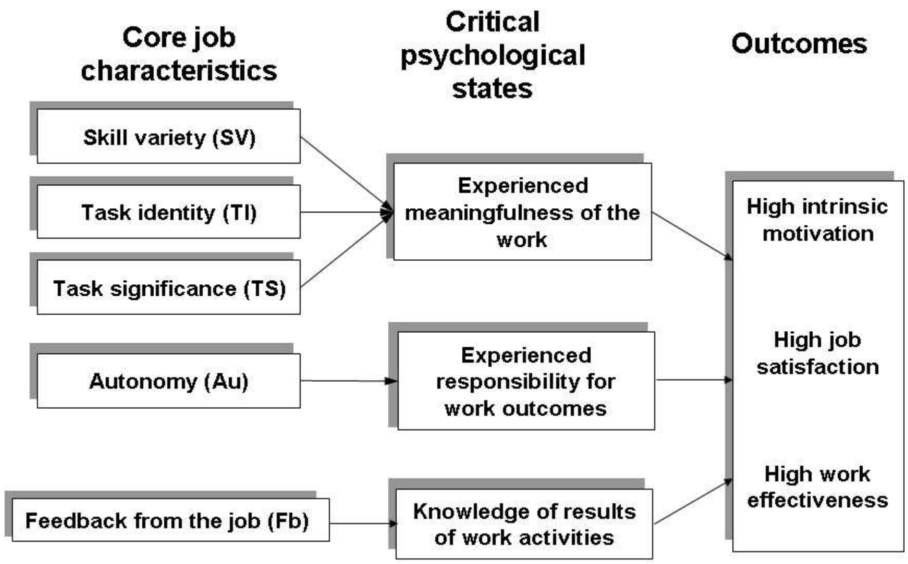
Wimpenny D.I., *Rapid Prototyping Casebook*, edited by McDonald, J.A., Ryall, C.J. and Wimpenny D.I. pp 175-203 2001 (The Cromwell Press, London)

Key Role	Elements of Competence
1. Service Delivery	Developing data capture (casting / tracing) and rectification skills. Developing knowledge of frequently prescribed componentry.
4. Communication & Relationship Skills	Works as part of the multi-disciplinary team. Developing a good rapport with colleagues and patients.
5. Management	Shows an awareness of good time management
7. Analytical and Judgemental Skills	Judgements involving complex facts or situations, which require the analysis, interpretation and comparison of a range of options.
8. Planning and Organisational Skills	Planning and organisation of straightforward tasks, activities or programmes, some of which may be ongoing.
9. Physical Skills	The post requires highly developed physical skills, where accuracy is important, but there is no specific requirement for speed. This level of skill may be required for manipulation of fine tools or materials.
18. Mental Effort	There is a frequent requirement for intense concentration
19. Emotional Effort	Occasional exposure to distressing or emotional circumstances.

BAPO Proposed Career Structure - Graduate Prosthetist
254x190mm (96 x 96 DPI)

Level 8 - Consultant Practitioner	A very high level of clinical expertise & or responsibility for planning of services. There is specific DH guidance on the criteria that must be met before consultant roles can be set up
Level 7 - Advanced Practitioner	Must have developed a very high standard of skills and theoretical knowledge, the holder must be empowered to make high level clinical decisions and often manages own caseload
Level 6 - Senior/Specialist Practitioner	Has a higher degree of autonomy and responsibility than practitioners in the clinical environment
Level 5 - Practitioner	Normally, registered practitioners in their first & second post registration jobs
Level 4 - Assistant Practitioner	Normally studying for foundation degree, BTEC Higher, HND or professional degree some of their remit would be to deliver protocol based clinical care that had previously been the remit of registered professionals, under the direction and supervision of a registered practitioner
Level 3 - Senior Healthcare Assistants/Technicians	A higher level of responsibility than support worker, probably studying for or have attained NVQ level 3
Level 2 - Healthcare Assistants/Technicians	Probably studying for or attained NVQ 2
Level 1 - Entry Level Trainee	Requires no previous knowledge or experience of healthcare

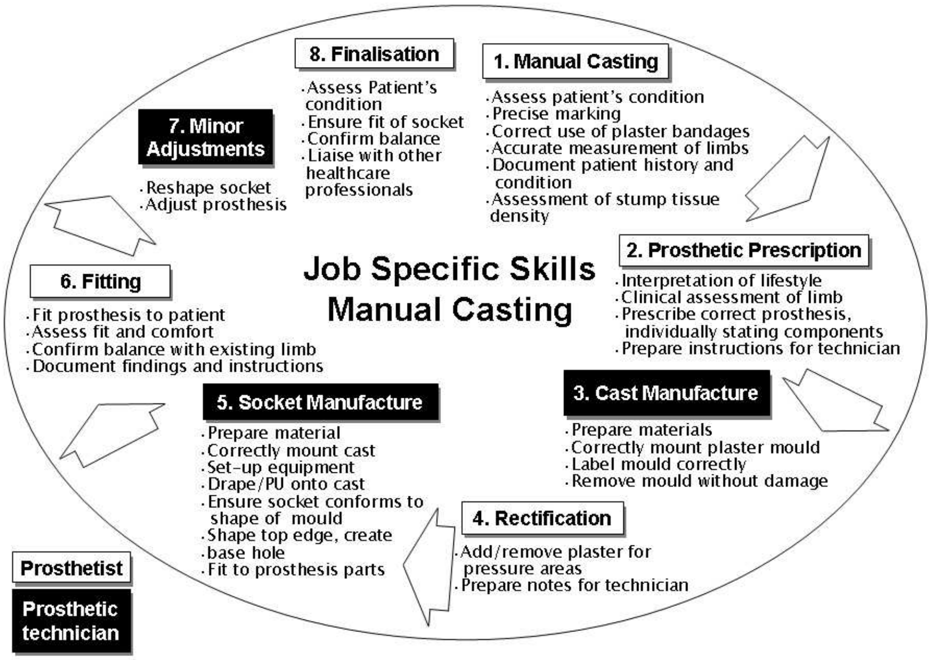
BAPO Career Structure for Prosthetists and Prosthetic Technicians
254x190mm (96 x 96 DPI)



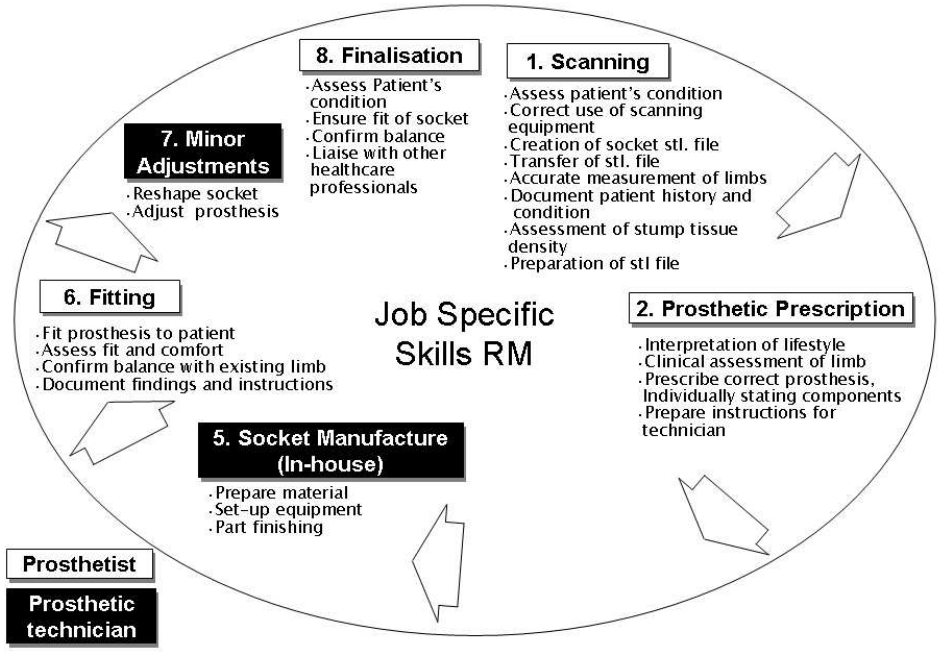
Job Characteristics Model
254x190mm (96 x 96 DPI)

$$MPS = \frac{SV + TI + TS}{3} \times Au \times Fb$$

Motivating Potential Score (MPS)
254x190mm (96 x 96 DPI)



Job Specific Skills - Manual Casting
254x190mm (96 x 96 DPI)



Job Specific Skills - Rapid Manufacturing
254x190mm (96 x 96 DPI)

	Professional /Technical	Prosthetist	
Variable	$\bar{X}$	**Current**	**RM**
Skills Variety (SV)	5.4	6.3	6.0
Task Identity (TI)	5.1	5.0	5.0
Task Significance (TS)	5.6	6.7	6.7
Autonomy (Au)	5.1	6.0	6.0
Feedback (Fb)	5.8	6.0	5.7
MPS	154	216	202

Normative Data to JRF Result Comparison for the Prosthetist
254x190mm (96 x 96 DPI)

	Machine Trades	Service	Prosthetic Technician		
Variable	$\bar{X}$	$\bar{X}$	**JRF current**	**RM role (JRF) a**	**b**
Skill Variety (SV)	5.1	5.0	5.7	4.7	3.7
Task Identity (TI)	4.9	4.7	7.0	6.3	2.3
Task Significance (TS)	5.6	5.7	7.0	6.7	4.3
Autonomy (Au)	4.9	5.0	4.7	3.3	3.3
Feedback from job (Fb)	4.9	5.1	4.7	3.7	3.7
MPS	136	152	145	72	42

Normative Data to JRF Result Comparison for the Prosthetic Technican
254x190mm (96 x 96 DPI)