Bath Innovative Design and Manufacturing Research Centre

Key Facts	
Time Period	**10 Years Total** Phase 1 (2001-2006), Phase 2 (2006-2011)
Total Value of EPSRC Grant	**£11.25m total** (Phase 1 £4m, Phase 2 £7.25m)
Other Funding *(Direct leverage of additional research funding specific to IMRC)*	**£14.4m total** of which • £4.1m[1] Research Council (non-IMRC) • £2.2m UK Public sector (non-RC) • £6.8m UK Private sector • £1.3m Overseas
Projects funded to Date	117
Current Staff	32 funded by IMRC (12 academics; 20 PDRs)
PhD Students	33 current + 25 completed to date (both phases) *(funded by IMRC grant / supervised by IMRC staff)*
IMRC journal publications	319
Patents granted	0
Key Sectors of Focus	Cross-Sectoral but with a particular focus on: Advanced Engineering, Aerospace, Automotive, Defence, Electronics, Fluid Power, Manufacturing, Marine, Medical, Mining, Packaging Machinery, Power Generation, Pharmaceutical, Rail, Renewable Energy and Sports
Current Research Themes / Specialisms	Constraint-Based Design and Optimisation (CBDO) Design Information and Knowledge (DIAK) Advanced Machining Processes and Systems (AMPS) Metrology and Assembly Systems and Technologies (MAST)
Examples of impact	• Improving industrial processes leading to increased profitability • Developing new machinery or tooling for existing machines to improve production processes and reduce cost • Reducing the amount of material used in the packaging industry leading to reduced costs and less waste sent to landfill
Examples of value added by IMRC model	• Security of funding allows research to evolve fully • Staff development • More strategic focus for research • Encourages interdisciplinary working • Are more visible and responsive to industry • Enhances international reputation • Critical mass of research • Supports both innovative blue-sky research and applied research

[1] The KIM Grand Challenge included £3.6M of additional EPSRC funding, and was led by the University of Bath. Of the £3.6M, around three-quarters was distributed across the other academic partners, and 9% to other departments at Bath.

Introduction and Overview of IdMRC

The Bath Innovative Design and Manufacture Research Centre (I*d*MRC) was established in 2001, growing out of established research strengths in machine design, design information systems and manufacturing processes and systems within Bath's Department of Mechanical Engineering. The IdMRC is unique within the UK as it researches design *and* manufacture (rather than one or the other). The centre's research programme recognises the interlinked nature of design and manufacture in modern manufacturing processes.

Centre Vision and Objectives

The Vision of the IdMRC is:

"To be an internationally leading research Centre in the synthesis of design, manufacture and product verification."

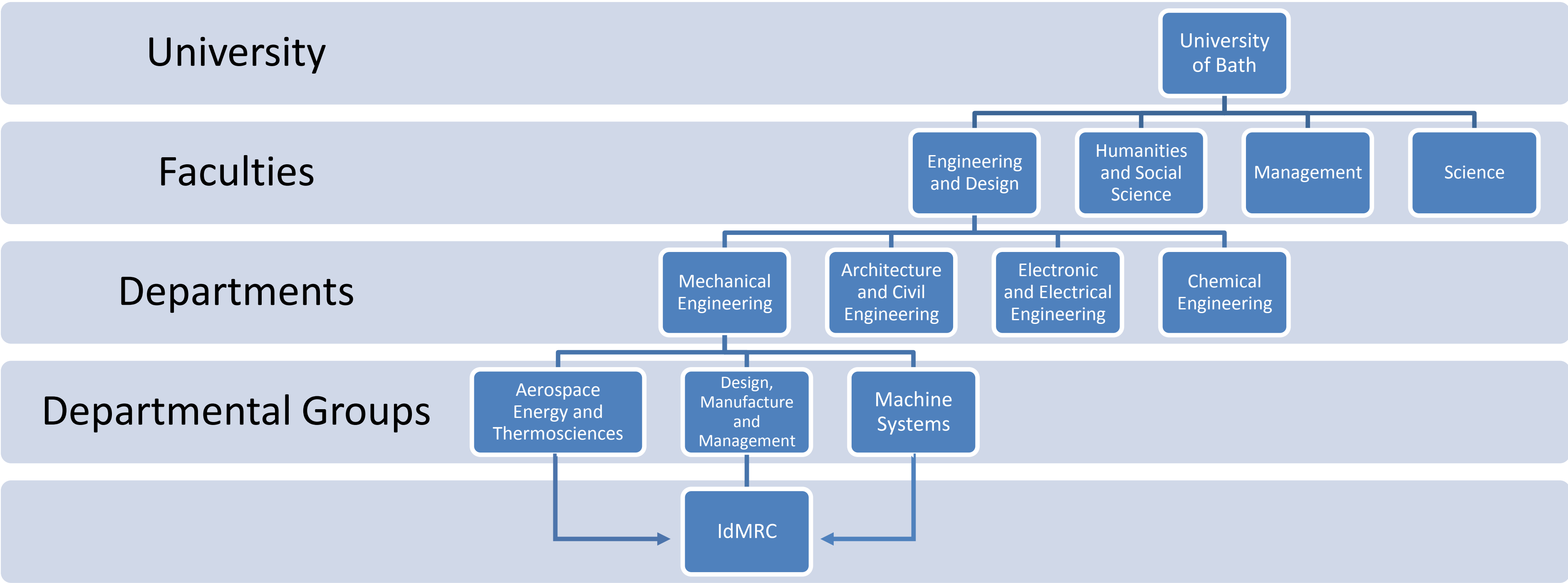
The vision will be pursued through the following objectives:

- To develop research strength in a number of key areas of manufacturing, especially large volume metrology and machining interoperability.
- To continue research into constraint modelling as a leading design space search technique.
- To develop research strength in two areas of key strategic importance: design engineering information management across the extended life-cycle and the design implications associated with the evolving new business paradigms (linked to the KIM project).
- To develop research strength in design costing and design for sustainable manufacture based on existing strengths in information and knowledge management and design for changeover.
- To continue strong industrial and international links.
- To increase funding from the European Commission and the Technology Strategy Board

Institutional Context

The IdMRC operates as a research unit within the Department of Mechanical Engineering which in turn is in the Faculty of Engineering and Design. The Faculty includes the Department of Architecture and Civil Engineering, the Department of Electronic and Electrical Engineering, and the Department of Chemical Engineering. The position of the centre within the University is illustrated below

Figure: Bath IdMRC Structure and Relationship with Bath University



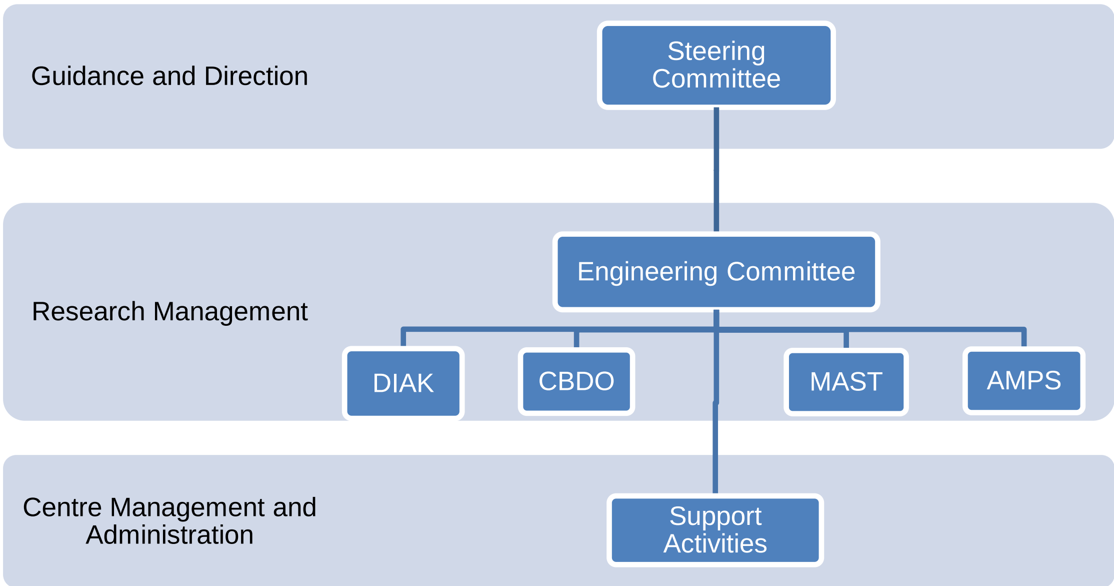
The IdMRC adds value to the University and the department through:

- Consolidating the existing design and manufacturing research strengths of the Mechanical Engineering department and helping to create a critical mass of excellence
- Enhancing the international reputation of the University
- Helping to attract leading academics in design and manufacturing research to the University
- Supporting the development of relationships with industrial partners
- Enabling collaborations with other research centres within the University from both within the Mechanical Engineering Department (e.g. Aero-Structures team and Machine Systems Groups) and in other disciplines e.g. Computer Science (through the EPSRC funded Bridging the Gap programme), School of Management (through the IMRC KIM programme) and UKOLN. The Mechanical Engineering Department adopts a strategy of forming teams from across its research groups and units in order to tackle important research issues and respond to funding opportunities.

Structure and Management of the IdMRC

The IdMRC operates as a research unit within the Department of Mechanical Engineering. The IdMRC reports to the Department's Research and Enterprise Committee.

An overview of the management structure of the IdMRC is shown below



The Centre Director, Professor McMahon, is responsible for the financial performance of the Centre and represents the IdMRC on external bodies.

Guidance and direction of the work of the centre is provided by the Steering Committee which has 15 external members drawn from academia and industry. The Steering Committee is chaired by Geoff McFarland from Renishaw. Its role is to provide an industrial perspective and overall guidance on the Centre's vision and development of research themes.

The Engineering Committee is made up of all academic staff within the centre. It is responsible for approving projects and their subsequent monitoring and evaluation.

Each of the four research themes are led by a Theme Director who is a member of the Centre's academic staff. The Theme Director is responsible for the development and management of the Theme's research programme.

The Centre is supported by Centre Management and Administrative staff who provide administrative, financial management, reporting, computing and laboratory support.

History of the IdMRC

The design and manufacturing centre at the University of Bath has a long history, going back to the 1990's. Before being awarded IMRC funding in 2001, EPSRC funded the Engineering Design Centre (EDC) at the University. The EDC looked to consolidate work in the areas of high-speed machinery and manufacturing systems design focusing on four work programmes:

- Design and Testing Technology
- Design Engineering
- Manufacturing Machinery and Plant
- Mechanical and Fluid Power Transmissions

Due to the success of the EDC, in 2001 the Mechanical Engineering Department (in which the EDC sat) were invited by EPSRC to bid to be a Centre of Excellence for Manufacturing Research. The centre was successful and was awarded £4m to support a five-year research programme in design, manufacture and management of processes, machines and systems.

The Centre was subsequently awarded a follow-on grant of £7.25m in 2006 for a further five year research programme on the strength of the contribution that the centre had made to UK industry and the scientific community.

IdMRC Research Strategy

The Research Strategy of the Centre is based upon the research strengths and interests of its staff and also guidance from the steering committee on the needs and requirements of industry.

During the first five years of the Centre research activities were concentrated in the three themes of:

- Manufacturing Processes and Systems
- Design Technologies
- Design Information and Knowledge

These themes covered research topics such as the development of tools, methods and theory to support improvements in engineering and manufacturing systems design, reverse engineering and information management.

From 2006, the Centre's research activities have focused on:

- **Constraint-Based Design Optimisation (CDBO)** – this research theme builds upon Bath's existing research strength in modelling constraints that arise in the design process. The theme looks to extend this knowledge to deal with systems with considerably larger numbers of degrees of freedom and to show its applicability in wider areas.
- **Design Information and Knowledge (DIAK)** – The aim of the DIAK research theme is to develop approaches to design information and knowledge management that enable rapid and

reliable access to high quality design information and knowledge over the product lifecycle. These approaches concentrate on methods for creating, managing, sustaining and exploiting the documentary records of design.

- **Advance Machining Processes and Systems (AMPS)** – covers processes and systems research with particular reference to responsive and customised manufacturing processes and systems integration – specifically interoperability and manufacturing information support systems. The theme aims to develop new manufacturing processes and innovations in system design that enable new products to be developed more rapidly, existing products to be produced with reduced lead time and mass customisation to be introduced effectively.
- **Metrology and Assembly Systems and Technologies (MAST)** – MAST is the newest research theme in the centre (introduced May 2007) and covers metrology and assembly technologies and systems and deals with their theoretical analysis, integration and optimisation within digital environments as well as their development and evaluation under laboratory and large scale technology demonstrator conditions. MAST is especially focused on complex and/or large volume and high value applications, typical of the aerospace, power generation, automotive, defence and marine industries.

These themes developed from the activity carried out in the first five-years of the centre. The emphasis of the research has shifted from manufacturing systems towards machining, digital manufacturing and metrology on the guidance of the steering group. This shift was also aided by new professorial appointments.

The future direction of the Centre is to:

- Improve inter-theme collaboration and working
- Better engage with SMEs and original equipment manufacturers in the manufacturing sector.
- Increase the level of international collaboration, particularly with researchers outside Europe
- Consolidate the research theme structure. Theme developments will include a move towards having a senior researcher in each theme, and encouragement of inter-theme projects. The central research focus of each theme will remain largely as at present, although the centre will no longer actively pursue design for changeover work, or assembly work except through the large volume metrology and assembly programme. There will be an increased emphasis on eco-design and eco-innovation.
- Build on the experience of the KIM project to create a critical mass in cost modelling and management
- Increase the research carried out at Technology Readiness Levels (TRLs) 4-6 with industrial funding and with support from other external bodies such as DEFRA, the Technology Strategy Board and the European Union. This work will be centred on collaborative industry-led programmes, with industry and other academic institutions.
- Increase collaboration with the Faculty of Engineering and Design.
- Continue strong programme of Technology Transfer through Knowledge Transfer Partnerships and dedicated courses for industry.
- Extend EngDoc activities

Since 2001, 117 research projects have been funded. The table below sets out the split of research between the Centres themes.

	Total Number of Projects	Total EPSRC Funding (£)	Categorisation of research (for definitions see below)		
			% Simulation & Design	% Adaptive technologies	% Systems & Operations
Phase 1 Themes					
Manufacturing Processes and Systems	14	1,365,000	30	60	10
Design Technologies	11	936,000	80	10	10
Design Information and Knowledge	20	1,599,000	30	10	60
Phase 2 Themes					
Constraint-Based Design and Optimisation (CBDO)	14	1,617,000	60	10	30
Design Information and Knowledge (DIAK)	28	2,278,000	50		50
Advanced Machining Processes and Systems (AMPS)	17	1,544,000	20	60	20
Metrology and Assembly Systems and Technologies (MAST)	13	1,911,000	30		70
Total	117	11,250,000	4,629,300	2,160,600	4,460,100

Project Appraisal and Review

New research projects are submitted to the Centre Director using a standard application form based on the EPSRC research funding form. Applications are supported by a six-page case for support. Proposals are reviewed and assessed by external referees, including industrial and overseas referees if appropriate. The referees assess the quality of the proposals and follow guidelines in line with EPSRC procedures to ensure that the proposal is of the same high quality expected in a standard Research Council assessment. The referees' reports are then assessed by the Engineering Committee which decides whether to accept or reject proposals, or to seek revisions. This approach ensures quality control whilst allowing decisions to be made more quickly than with usual EPSRC submissions.

All Centre staff can submit project proposals, and younger researchers are actively encouraged to. This increases the likelihood of introducing new research topics and themes into the research portfolio.

In addition to the more traditional research grant process, having IMRC funding enables the Centre to provide two other modes of funding:

- Studentships – grant applications (a shorter application form is used) for funding of studentships are reviewed by the external academic members of the steering committee. Since 2008/09 studentship grants have required external match funding from industry or research councils in order to provide the full three years of study.

- Strategic Funding – the Engineering Committee can authorise the appointment of staff to work on projects that embrace the different research themes or on activities of strategic importance to the Centre.

Project Monitoring and Evaluation

Each project produces an annual report which sets out progress of the research. This allows the project to be monitored. In addition to this monitoring activity, at each Steering Group meeting two projects from the Centre's portfolio are reviewed by the Committee.

The quality and relevance of the centre's research is enhanced by the involvement of industrial and international assessors at the design proposal stage and through overseas and industrial members on the Steering Committee.

Economic Impact Analysis

Funding and Leverage

Using data provided by the IdMRC:

- Over the two phases of the IdMRC, the Centre has received a total of £11.25m from the EPSRC IMRC programme.
- The Centre has then levered a further £14.4m from other external organisations. Thus, for every £1 provided by the IMRC programme, £1.28 has been contributed by other partners.
- Nearly half (47.2%) of the funds levered into the IdMRC come from industry and the third sector
- The IdMRC has collaborated with over 100 organisations including companies such as Airbus, Renishaw and Sandiacre Packaging Machinery.

	£ (incl cash and in-kind contributions)
Total EPSRC IMRC Funding	£11.25m
Research Councils (excluding IMRC core funding)	£4.1m
UK Public sector (excluding research councils)	£2.2m
UK Industry & Third sector	£6.8m
Overseas	£1.3m
Total	£25.65m

Human Capital

Although the commercialisation of research and its economic impact is important, academic research also adds to the human capital of the country by delivering skilled people and creating new knowledge, which in the future could have an economic impact.

The IdMRC currently has a staff of 32 of which 12 are academics and 20 are post-doctoral researchers. These staff are funded by the IMRC grant and funds levered into the centre as noted above.

Of staff and researchers that have left the IdMRC the majority go into industry or to other academic institutions. Destinations of recent leavers have included:

Industry	Academia
PIRA International Weir, Strachan and Henshaw. Bristol Watson Wyatt, London The Prizm Game Company (spin out from IdMRC research) ABB Corporate Research, Sweden KPMG, Bristol Porsche Consultancy, Germany BAE Systems	Lecturer Strathclyde University Research Associate, University of Cambridge Research Fellow, Strathclyde University Research Fellow (Cranfield) then Senior Lecturer Coventry University Lecturer University College of Trollhättan, Sweden Lecturer Technical University of Denmark Lecturer Loughborough University

Approximate proportion of former staff/researchers in:	
Academia	42%
Industry	58%
Government	0%

The Department of Mechanical Engineering has an active programme of taught Master of Science courses. Of the eight MSc programmes offered by the department, the MSc programmes in Engineering Design and Manufacturing Modelling have been most strongly influenced by IdMRC research; however, IdMRC staff also teach students from other programmes. A total of 33 PhD students are currently studying through the IdMRC (either with IdMRC funding or being supervised by IdMRC staff). 25 PhDs have been completed to date. Ten research students have gone on to be employed by the IdMRC as research officers or research fellows.

The Centre is active in the EPSRC EngD in Systems collaborative project between the Universities of Bath and Bristol. Of the 21 students signed up to the programme, the IdMRC is involved in the supervision of five – two with Airbus, one with Halcrow and two with Rolls-Royce.

In addition to the IdMRC's postgraduate activities, undergraduate teaching is also an important part of the centre's activities. Design and manufacture is a strong feature of all of the Mechanical Engineering Department's undergraduate courses. All degree programmes are four years, with the first two years common. A Manufacturing degree option has been in place for many years, and more recently an Innovation and Engineering Design option has been introduced. Both programmes, especially in the specialist modules in third and fourth years of the courses, are strongly influenced by the research activities of the IdMRC.

IMRC status has enhanced the international reputation of the Centre and has resulted in a number of academics from overseas universities visiting the IdMRC as a visiting researcher or on secondment. Staff from the IdMRC have been seconded to other academic institutions, or in some cases to industrial partners.

Secondments to the IdMRC (originating Institution)	Secondments from the Centre
Institut Nationale Polytechnique de Grenoble Hong Kong Polytechnic University BeiHang University, Beijing University of Zagreb Ecole Polytechnique, Montreal University of Compiegne University of Toyko University of Sydney Politecnico di Torino National Kaohsiung University of Applied Sciences, Taiwan	NIST, Maryland University of Sydney Converteam Rolls Royce UKCeB SW Manufacturing Advisory Service

In addition to academic teaching, the IdMRC delivers courses to industry based on its research. In the CBDO theme, a training course for industry on Machine-Material Interactions has been produced and delivered to organisations such as Astra Zeneca. who have successfully applied the method and/or integrated it into their manufacturing improvement programmes. In DIAK, a Design for Changeover course has been produced, and CPD is also a feature of the costing work in DIAK.

Knowledge Transfer Partnerships (KTP) are a key mechanism that the IdMRC uses for knowledge transfer. KTPs are partnerships between a company and a university to work on a strategic project. There have been 23 KTP's during the life time of the Centre, with an estimated 17 of the Knowledge Transfer Associates becoming employed by the industrial partner post KTP. The University of Bath is very supportive of KTPs and the IdMRC is encouraged to use them as a key knowledge transfer mechanism. Examples of projects worked on under a KTP are:

- Continuing the work of the KIM Project (see case study 4) through a KTP with Converteam and Lancaster University to develop sustainable strategies for organising explicit knowledge to execute competitive through-life contacts over time and geographical distribution.
- Developing a theoretical means for more accurately predicting the performance of tolerance rings with the long-term aim of using simulation as the primary design tool with Saint-Gobain Performance Plastics Rencol Ltd. The research produced £200,000 in extra revenue over 5-years for SG PP Rencol and savings of up to £40,000 on future product development. The KTP associate is now employed full time by SG PP Rencol.
- Welton Packaging Ltd. - to achieve "best-in-class" in carrier bag assembly and to develop a process engineering function.
- Spriax-Sarco - to implement a modern design system to improve performance/wear of sample steam products and rollout the system and results.
- Colston Manufacturing - to design and implement a new manufacturing system in the company to improve efficiency, customer responsiveness and profitability.

In addition to facilitating knowledge transfer, KTPs allow the IdMRC to maintain and develop relationships with industrial partners. Many of the collaborators that the IdMRC work with have long term relationships with the university.

- The IdMRC also uses Knowledge Transfer Accounts (KTAs) to apply IMRC funded research into industry. The University of Bath was awarded £3.4m in 2009 for three years to fund projects that embed knowledge in external organisations. Recent KTA projects have included:
- Application of document mining and classification techniques to the extraction of information from naval service documentation, with Babcock (again building on work in the KIM project)

- Design and implementation of a prototype system that is capable of producing personalised orthotic insoles and shoe soles on demand, in a short time period (building on the research carried out in Case Study 2).

Impact Case Studies

A number of case studies have been selected to illustrate the economic impact of research funded through the IMRC. The key selection criteria for case studies were as follows:

- Demonstrate a range of types of economic / market impact as defined by BIS
- Offer convincing evidence of significant tangible impact
- Demonstrate the added value of the IMRC model
- Coverage of the different research themes within the IMRC, reflecting the level of investment in each theme

On this basis, DTZ in conjunction with EPSRC and the IMRC agreed the selection of the following case studies for economic impact analysis:

Case study	BIS Impact Headings	Added Value aspects	IMRC research theme	Sector
Knowledge and Information Management (KIM) Through-Life Grand Challenge	Improving Existing Businesses	Grand challenge project – critical mass Inter-university collaboration High level of industry engagement	DIAK	Multiple Sectors
Packaging the Future	Leverage of Inward Investment Improving Existing Businesses	Collaboration with Industry	CDBO	Food Sector Packaging
Stepping into the Future	Leverage of Inward Investment Improving Existing Businesses	Collaboration with Industry	AMPS	Health Care & Possible wider Applications
Manufacturing Systems	Improve Existing Businesses	Collaboration with Industry	MAST	Manufacturing
China on Your Desk Top	New Business Creation Improve Existing Businesses	Collaboration with over 1,000 volunteers across the world using Open Source Software	AMPS	Manufacturing

Case studies have been selected to ensure coverage of the four IdMRC research themes and the main sectors in which the centre is active. Case studies were selected on the basis of impact achieved or forecast, which has resulted in the case studies focusing on the more developed/established research areas.

Added Value of the IMRC Model and Impact Optimisation

The added value of the IMRC funding model (as illustrated through several of the economic impact case studies selected) is:

- Being an IMRC gives structure and direction to the research carried out by the centre. The centre estimate that they could probably get the same level of funding through open calls or grants but there would not be a strategic direction to the research. Traditional responses to calls are assessed individually on their own merit, they are not considered in terms of how they fit with other research at the centre. It can be difficult to allow research to develop and explore interesting findings if you have to bid for funding on a project by project basis. Greater impact will be achieved from tackling the issue as a whole rather than through one-off individual projects.
- Sustained, longer term funding gives the researchers more security and stability. This gives the centre more ability and freedom to develop individuals and ideas. The IdMRC names junior researchers as co-investigators much earlier than if they were outside of the Centre. This gives junior researchers the freedom to develop their own research identity and interests.
- Being an IMRC also gives the researchers better support functions/infrastructure, which enables the researchers to better promote themselves and their research. It also means that the researchers spend less time doing administration and responding to calls and more time doing research, which is where their strengths lie.
- It enables the university to be more responsive to the needs of industry. The research strategy of the centre is guided by the steering group which includes industrialists. In addition, if a particular research opportunity arises, it has the resources to pursue it immediately. There is no need to apply for funding and wait for the outcome. Sometimes this can make the difference in being able to pursue an exciting research opportunity with an industry partner. It also means that the research portfolio has longevity. Industry partners know that although they do not have the time and/or resources to carry out research now, if they return to the centre in 6-months time the centre will be able to help them. This helps the centre to develop longer term relationships with industry.
- By being part of a centre, industry has multiple access points to research. An industrial partner may come in to the centre through one contact, but they can then see the breadth of research that the centre carries out and can become involved in other themes. For example, many of the industrial partners on the KIM project had been involved in research with other themes previously.
- It enables greater continuity. Under responsive mode funding, there is a danger that a promising area of research cannot be continued because key staff leave (or are redeployed) before further funding is secured or subsequent proposals relating to the research are not approved. IMRC funding means that a promising area of research can be developed over a period of time and the knowledge is embedded in the Centre, not an individual. For example, the vertical form-fill and seal packaging research is the latest in a number of research projects that have been carried out on the interactions between machinery and materials in the packaging industry and RepRap was able to apply for a second grant to improve the RepRap machine.
- IMRC status enhances the reputation of the Centre and can facilitate international collaboration. IMRC status attracts the best researchers from both the UK and the rest of the world. It also helps to keep top researchers within the university. The IdMRC has hosted researchers from the US, China, Canada and France among others. In addition, IdMRC researchers have been invited to spend time in Universities overseas.
- It allows innovative, blue sky ideas to be tested. Both RepRap and the cryogenic machining projects were untested ideas. RepRap probably wouldn't have applied for funding through an open call as it needed a (relatively) small grant of £20,000 in the first instance. The time and

effort needed to respond to an open call would have been disproportionate to the amount of grant. On the other hand the cryogenic machining project needed a significant investment in machinery to test the idea, this meant that there was a high level of risk to the project which could have reduced its chances of success in a traditional call.

- It encourages inter-disciplinary working within the University. The IdMRC works with other groups within the Mechanical Engineering Department (e.g. Aero-Structures team and Machine Systems Groups) and with research groups from other disciplines e.g. Computer Science (through the EPSRC funded Bridging the Gap programme), School of Management (through the IMRC KIM programme) and UKOLN.

Case Study 1: Packaging the Future

Key Facts	
Time Period	September 2006 – August 2010
EPSRC Funding	£640,000 (IMRC)
Other Funding	£532,000 (DEFRA Link)
Collaborator(s)	Campden BRI HayssenSandiacre AMCOR United Biscuits (UK) Ltd
IMRC Research Theme	CDBO
Research Output	The EPSRC funded research concerned the generation of a fundamental understanding of machine-material interfaces in packaging processes. Through the DEFRA funded research, this science and understanding was used to create computer software that can design new forming shoulder tools that improve the efficiency of existing packaging processes, minimise the amount of packaging material used and enable new applications (package designs).
Pathway to Economic Impact	Via collaborators – The IdMRC worked in collaboration with machinery manufacturers, packaging material producers, end users and trade associations (Campden BRI).
Actual Economic Impact	Improving Existing Businesses • The software has already been used one of the collaborators in conjunction with a major confectionary manufacturer to design new packaging for one of its products. They were struggling to design a forming shoulder to give them the packaging they wanted. Using the IdMRC software they got the right result first time. The new design uses less packaging material. • The understanding of machine-material interaction has also been used to improve the design of the sealing mechanism. Through re-specification of the sealing jaws, a 40% reduction in sealing area has been realised leading to material savings of the order of £1m per annum for the end-user.
Potential Economic Impact	Improving Existing Businesses through: • Material reduction (cost savings) - if technology/processes are rolled out it could result in a 13% reduction in materials used which will have a resulting impact on costs • Enabling retro-fitting of new forming shoulders to existing machines, rather than having to purchase a new machine • Cost savings – the ability to create right-first-time tooling reduces development time and saves costs through a reduction in prototypes and development. • New applications – the new tools and methods allow new forms of packaging geometry to be investigated (with confidence) enabling new design of packaging to be created. Wider/Social Impact • Reducing waste sent to land fill – if technology/processes are rolled out there could be 40,000 tonnes less waste sent to landfill in the UK each year.
Sector Focus	Packaging

Context

In the light of increased awareness of the pressures on UK landfill sites and the need for more sustainable living, many industries are facing increased pressure from customers and government to reduce material consumption and the impact of the end product on the environment. Industry is therefore looking to use more environmentally friendly packaging and find ways of reducing the materials associated with its products.

The IdMRC Project

This project was specifically concerned with environmentally friendly packaging processes for vertical 'form-fill-and-seal' type packaging used for foods such as rice, pasta and crisps. The project looked to understand machine-material interactions and the design rules necessary to minimise the consumption of packaging film.

Two key areas were investigated in the research: material flow over the forming shoulder (a key tool which determines the shape of the packet) and the sealing of the material.

Building on the IdMRC's experience in constraint-based design and optimisation the research team has investigated the machine-material interaction and developed software that will design more effective shoulder forming tools. This understanding has resulted in packaging that uses less material and a more efficient process.

The research builds on previous IMRC funded research into packaging and machine-material interaction. The IdMRC have been investigating how machines and materials interact in order to design new processes and tools which would encourage the uptake of environmentally friendly packaging, reduce material usage and improve packaging processes for smaller runs of food packaging.

The IdMRC research has investigated machine-material interaction for carton board, flexibles (e.g. crisp packets) and emerging new materials.

The IdMRC research has demonstrated a new high speed environmentally-friendly packaging process that will use recycled materials and reduce the amount of plastic used and developed software that can design retrofittable forming shoulders for new packaging shapes.

Assessment of Economic Impact

The economic impact of the project can be assessed as follows:

- Reducing materials cost
- Reducing development costs
- New business through new applications
- Reducing machinery costs

Materials Cost

Vertical 'form-fill-and-seal' packaging takes a sheet of material (usually plastic film) and heat seals the edges to form the packaging. The IdMRC research has investigated the interaction between the packaging material and the packaging machine and has identified that it is possible to reduce the seal area, thus reducing the amount of material used. It is estimated that, by designing a more efficient way of sealing the packaging, the amount of material used could be reduced by 13%[2]. This will have a

[2] http://www.campden.co.uk/news/jan09.pdf

resulting impact on profitability by reducing material costs. The work with the end-users has already resulted in savings of ~£1m/annum.

Reducing Development Costs

The IdMRC software has been used by a number of machinery manufacturers to improve the design process of their tooling and in particular their forming shoulders. The use of the software enables the design of forming shoulders which are right-first-time, thereby reducing costly prototyping and development. The latter would traditionally involve trial and error testing and redesign with as many as 10 or more iterations.

New Business

The IdMRC software has already been used by a major confectionary manufacturer who could not design a forming shoulder that would produce the packaging design that they wanted. After approaching the IdMRC the new software was used to design the forming shoulder which gave the right result first time. Further, due to the complexity of the forming shoulder necessary it would be unlikely that a functioning shoulder could be produced without the use of advanced computer based tools.

Machinery Costs

One of the barriers to the design of new packaging and the use of new materials is that traditionally a new machine needs to be purchased for each packaging design. The software developed by the IdMRC for this project enables manufacturers to design a forming shoulder to produce the packaging shape they want. The forming shoulders can then be retro-fitted to existing machinery avoiding the need to purchase a complete new machine.

HayssenSandiacre (machinery manufacturer) estimated that "the main business opportunity is likely to be in the after-market sector where retrofitting newer tooling and technologies (typically £5k - £20k per machine) to existing machines will allow our customers to satisfy their ambitions without the purchase of completely new machine systems". Incorporating the IdMRC sealing and forming shoulder designs to just 3% of Hayssen Sandiacre's European machine base would provide revenue of over £1m.

Wider Impacts

In addition to the economic impacts set out above, the research also has a significant potential environmental impact. By reducing the amount of packaging material used, the research, if rolled out could reduce the amount of waste being sent to landfill. The IdMRC estimates that by using the lessons learnt from this research 39,000 tonnes of waste could be diverted from landfill per year[3]. Based on the current level of landfill tax, this would save £1.9 million in tax alone.

The research also investigated the potential of using recycled packaging materials in existing machines. Previously, industry could be loath to try new environmentally friendly materials as they could end up jamming or damaging the machinery. The Bath research has created design rules for the matching of sealing jaw design to material properties which means that the machine should not jam when a new material is used.

Pathway to Economic Impact

The main pathway to economic impact is through the collaborators. HayssenSandiacre have continued the research through their own internal funding systems to create improved machine and

[3] http://www.campden.co.uk/news/jan09.pdf

tooling designs. They have also integrated the computer based tool into their new product development process.

Campden BRI Technology is the foremost food research association in the UK. Campden BRI will transfer the knowledge from the research project to the food industry through its industry guides and publications.

The researchers at the IdMRC have also written a number of articles and conference papers to help disseminate the findings of the research:

- International Conference on Engineering Design (ICED 09) Stanford USA 2009
- ASME 2009 International Design Engineering Technical Conferences (IDETC) & Computers and Information in Engineering Conference (CIE) San Diego USA September 2009
- Co-authored Book Chapter on Mass Customization for Springer Series book (for publication mid-2010)
- Co-authored paper for journal of Concurrent Engineering Research and Application (published May 2009)
- Co-authored paper for the International Journal of Packaging Technology and Science
- Presented current work at the "Sustainable Energy & the Environment Research Showcase" - 17 September 2008 University of Bath
- Presented the work at the ACHEMA exhibition in Frankfurt Germany. ACHEMA involved almost 4,000 exhibitors from 50 countries and was held over five days from May 15th. During the five days the exhibition attracted over 200,000 visitors from almost 100 countries.

Position without IMRC Funding

The private sector would be unlikely to invest in this type of research given the lack of information available on the certainty of a successful outcome and the possibilities of commercialising any of the research outputs.

Whilst companies in the materials and machinery supply chains have active R&D functions, this research required the co-ordination and co-operation of the main parties within the supply chain – specifically – material producers, machinery producers and end users of both materials and machinery. Given the uncertainty of success and costs involved, the private sector is unlikely to have undertaken this collaborative research without public sector intervention.

Had this research been funded by the private sector, the research outcomes would have been designed specifically for the companies involved. By involving the public sector, the research has delivered an output that is based on fundamental principles, which allows the research to be applied across industries and supply chains thus delivering much greater impact. The research also involved Campden BRI Technology who will disseminate the research findings to the food industry.

Finally, the packaging sector consists of many SMEs, due to information failures about the benefits of R&D activities or the fact that they can often benefit from other's R&D activities without investing themselves (free riding) means that they will often under-invest in R&D.

Consultees

Ben Hicks - IdMRC, Bath University

Case Study 2: Stepping into the Future

Key Facts	
Time Period	December 2006 – June 2010
EPSRC Funding	£395,000
Other Funding	£112,000
Collaborator(s)	Delcam Soletec Systems
IMRC Research Theme	AMPS
Research Output	• Design of a new process of cryogenic machining, which can be retro-fitted to a standard machining centre. • Fixture – a device that cools down the material in a consistent manner • Manufacture of over 200 insoles for medical use • Computer software • Two PhD projects
Pathway to Economic Impact	Via Collaborators – Soletec Systems and Delcam have been progressing the research
Actual Economic Impact	Limited at the moment, although 200 pairs of insoles for medical use have been manufactured with estimated value of £100,000.
Potential Economic Impact	Improving Existing Businesses – helping collaborators to win a share of the growing market for bespoke orthotics and insoles. Improving Public Services – reducing the cost of medical orthotics will deliver cost savings for the health sector (NHS)
Sector Focus	At this time – Footwear, but technology has the potential to be applied to a number of sectors.

Context

Industry is constantly looking for new ways of working with materials. When working with solid materials such as wood, metal and plastics products can be made through removing material from a block of material into the desired shape. However, this approach does not work so well with soft materials such as foams and rubbers which have a tendency to melt and distort when traditional methods are used to form a shape.

IdMRC Project

There is increasing demand for the personalised manufacture of consumer products (sometimes referred to as Mass Customisation) which has resulted in the need for affordable methods of production, particularly for soft materials. Current methods are expensive and time consuming so this research was investigating the feasibility of direct machining through cryogenics of soft materials such as rubbers, plastics and foams together with new bio-degradable materials. This research built on the Centre's experience and expertise in advanced machining processes and systems.

The IdMRC approach works by cooling soft materials to very low temperatures using liquid nitrogen. Whilst the material is this cold it becomes solid, which means that conventional machining techniques (such as milling and drilling) can be used to shape the product without the material melting and distorting.

The IdMRC research was able to design and manufacture a cryogenic machining facility for freezing soft material blocks on a standard CNC Machine. The cryogenic machining facility is a retrofittable design.

The research has initially focused on the manufacture of customised insoles for shoes; however, as the research has developed it has become clear that there are a number of applications for the technology.

Assessment of Economic Impact

The economic impact of the project can be assessed as follows:

- Product development
- Reducing the cost of producing bespoke orthotics and insoles
- Supporting innovation and product design in other sectors
- Human Capital

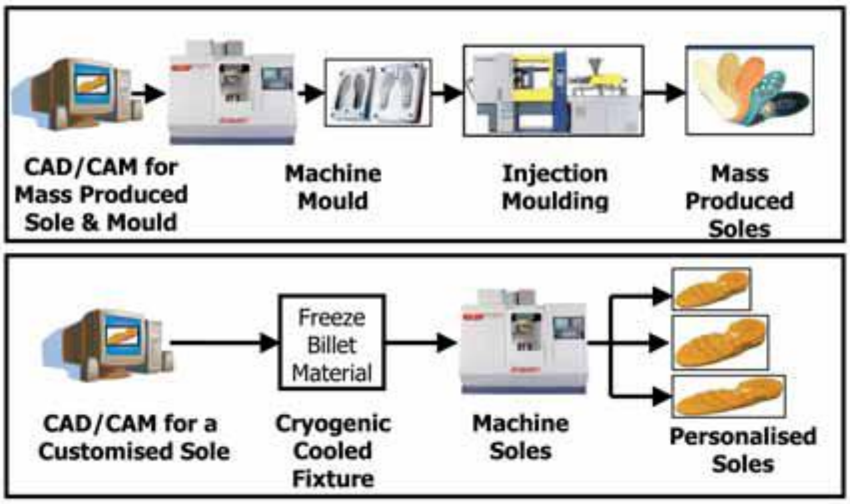
Product Development

The research project designed a new fixture for a CNC machine that cools down the soft material in a consistent manner across the whole material to allow the shape to machined within acceptable tolerances. A KTA grant has just been agreed with Renishaw to develop a commercial product based on the IMRC developed fixture. Renishaw are looking to patent the fixture within the next 20 months. It has been agreed that the IdMRC will receive royalties from the product should the patent be successful. The student who completed his PhD project on cryogenic machining will be working 1 day a week at Renishaw helping to embed the academic knowledge in industry.

Reducing the Cost of Bespoke Orthotics and Insoles

Currently, customised insoles require the production of a unique mould which can take many months of fitting to ensure the correct design and fit. This process is very time-consuming and expensive. Current bespoke insoles cost between £500 and £1,000 per pair.

Although at an early stage of development, insoles produced using the IdMRC technology are £500 per pair and take only a day to produce. The requirement for the development of moulds has been removed through the use of the latest 3-D foot scanning software developed by Delcam (a research collaborator). The research is now focusing on how the cost of production can be further reduced to increase the economic viability of the technology.



Current Process

Future Vision

Custom orthotics are used to treat medical conditions and can be ‘prescribed’ by the NHS. They are particularly used by diabetes sufferers as diabetes often results in poor circulation and can also lead to sensory difficulties where poor shoe fit, rubbing or pressure may not be noticed. Patients with diabetes are often prescribed orthotic shoe insoles to protect the foot. It is estimated that there are over 250 million people with diabetes worldwide which is forecast to rise to 450 million by 2020. There is therefore significant market potential for affordable, quickly produced bespoke insoles. The research at the IdMRC has the potential to bring significant cost savings to the NHS.

Subject to IP agreements a commercial company will be working with the IdMRC to make a device to produce insoles as part of a new project.

Supporting Innovation and Product Design in Other Sectors

This research has combined a new process (Cryogenic Machining) with new knowledge (the industrial application of cryogenic machining). The findings from the research can be applied across a number of other sectors which use soft materials to make new added-value products including personalised products such as personalised tyres for cars or motorbikes, personalised shin pads, bespoke ear pieces/headphones, customised rubber seals, bespoke packaging for high value, low volume products and soft parts used in high value equipment e.g. satellites. A number of undergraduate final year projects will investigate the feasibility of these ideas, which could become a research project should the ideas prove feasible.

Human Capital

Two PhD projects have been carried out on cryogenic manufacturing. One of the PhD students now works as a research officer within the IdMRC and will be working with Renishaw on the KTA project discussed above. In addition to the PhD studies, a number of final year and masters students have contributed to the project.

In addition, the ground-breaking nature of this research has led to the IdMRC being viewed as the experts in the field of cryogenic machining. The IdMRC have been approached by a number of industrial partners in Europe and the US who wish to partner with the IdMRC.

Pathway to Economic Impact

The main pathway to impact is through the collaborators, Soletec and Delcam. Both have taken the research further and have developed commercial products/applications in the custom shoe sole and orthotic markets.

A new company has now become involved in the research to investigate other applications for the technology. This company is fully funding the research time spent on the project.

Position without IMRC Funding

Dr Nassehi believes that “without the IMRC the concept of cryogenic machining would not have even been tested as an idea”. The project needed a fairly large grant as specialist machining was needed however, the research idea was novel research and no-one had any idea if it would work, therefore had funding been sought from traditional routes it probably would have been unsuccessful due to the high risk involved. Now that the concept has been tested and proven, further research is in a better position to seek funding through grant calls.

Industry would not have been willing to pay the full cost of research due to the innovative nature of the research. This meant that there was a lack of certainty of a successful outcome. In addition, the research primarily involved the development of a new process, which is very difficult to patent and therefore commercialise.

Consultees

Professor Stephen Newman – University of Bath, IdMRC

Dr Aydin Nassehi – University of Bath, IdMRC

Vimal Dhokia – University of Bath, IdMRC

Case Study 3: China on Your Desktop

Key Facts	
Time Period	Phase 1 - Month 2005 – 2008 Phase 2 – September 2008 - 2011
EPSRC Funding	Phase 1 - £20,000 IMRC Grant Phase 2 - £50,000 IMRC Grant
Other Funding	£6,400 from donations via the RepRap website from individuals who support the research and through Google Advertising Income via the website Initial research (2004) received a £1,000 Nuffield Grant
Collaborator(s)	Between 1,000 – 2,000 private individuals from around the world who contribute to the development of the software through Open Source development
IMRC Research Theme	AMPS
Research Output	Two RepRap machine designs have been released "Darwin" and "Mendel" One PhD project completed, one PhD project ongoing
Pathway to Economic Impact	Spin Out Companies Via Collaborators
Actual Economic Impact	New Business Creation – 16 companies around the world have come out of the RepRap project (5 companies are UK based)
Potential Economic Impact	Revolutionising Advanced Manufacturing Delivering Advanced Manufacturing to anyone with a computer
Sector Focus	Manufacturing

Context

Rapid Prototyping production methods are where material (usually molten plastic) is deposited in layers and solidified to produce a solid, three-dimensional object. It is often thought of as 3-D printing. 3-D printers spray out thin layers of molten plastic rather than ink. As the layers of plastic solidify they build up to make objects. The IdMRC have taken this technology to develop a low-cost 3-D Replicating Rapid (RepRap) prototype machine which can produce its own parts.

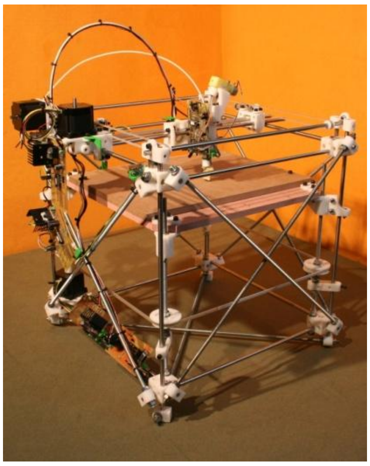
The IdMRC Project

Rapid Prototyping machines were developed in the 1980s but the cost of the machines has been very high (between £15,000 and £400,000). The IdMRC designed machine costs as little as £300 to make because it can reprint over half of the parts needed to make another version of itself. The parts that cannot be printed can be bought at hardware stores or online. Once the first machine has been made the second and all subsequent machines only cost as much as their raw materials and assembly.

All RepRap designs for parts and anything that can be made on the machine are shared and free to download under a GNU General Public Licence, so anyone with a RepRap machine can use it to make another one without the need to pay royalties.

The RepRap concept started in Bath in 2005 but its continual development relies on the input of volunteers from around the world who contribute to the open-source software.

The aim of RepRap is to produce a pure self-replicating device which provides a desk top manufacturing system for a minimal capital outlay. The system would enable the individual to manufacture many of the artifacts used in everyday life.



There are over 2,500 RepRap machines in circulation and it is estimated that over 10,000 objects have been made on RepRap machines[4].

A design-sharing website, thingiverse.com is used to upload RepRap designs so that others can copy them. There are over 1,400 designs on the website[5]. The site includes a number of designs ranging from shower curtain hooks to table-football players. RepRap owners can download the designs and add them to their machines. Once designs are added to the website the RepRap machine is almost a desktop factory producing things that you buy in shops. There are also designs for improved RepRap machine parts. In this way the RepRap machine is continually evolving and improving.

The machine is also well suited to companies looking to experiment new systems or materials. If a new material was trialled in a conventional machine and it caused damage, this would almost certainly void the warranty and result in an expensive repair bill. On a RepRap machine it is easy to print another part if something is damaged by trying experimental processes.

The RepRap project is now looking to expand the range of materials that the machine can work with as this will increase the number of products that the machine can make. The project is particularly interested in the potential for the machine to work with metal so that RepRap can build 3-D electronic circuitry, including its own electronic circuits. The more materials that RepRap can work with, the greater proportion of its own parts that it will be able to make.

In addition, the project team are also looking to make the RepRap machine as easy as possible to build, so that the technology is readily available to anyone.

Assessment of Economic Impact

The RepRap project is seen to have tremendous potential and there is great excitement at the potential that this machine has to revolutionise manufacturing as we know it. The actual economic impact of the project to date has been:

- Creation of 16 RepRap companies around the world

The potential economic impact of RepRap is:

- Delivering advanced manufacturing technology to anyone, including those in developing countries.

RepRap Spin Out Companies

There are 16 companies that Dr Bowyer is aware of that have been set up out of the RepRap project, however, due to the open nature of the project there could be more. The spin out companies are located all over the world, with five being based in the UK.

[4] De Bruijn, E (2010) On the viability of the open source development model for the design of physical objects. Lessons learnt from the RepRap project. Thesis for the degree of Master of Science

[5] ibid.

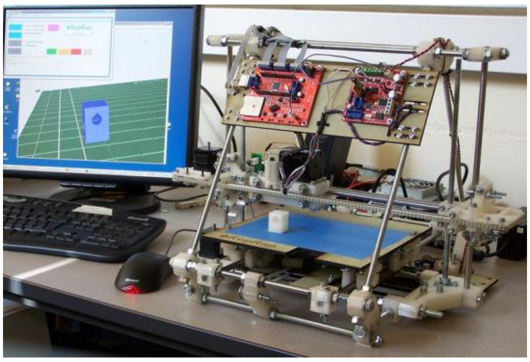
Spin out companies tend to do one of three things:

- Supply the parts that RepRap cannot make
- Supply both parts that RepRap can make and the parts that it cannot. Most companies use a RepRap machine to make the RepRap parts but some use traditional 3-D printing machines.
- Use the RepRap design as a basis to make their own 3-D printers to sell.

All RepRap companies tend to sell RepRap consumables e.g. plastic reel.

One of the RepRap spin out companies has just been bought by an established 3-D printer company[6].

Delivering Advanced Manufacturing Technology to anyone



Currently, 3-D printing tends to be used only by businesses that use the printers to produce prototype products. RepRap has produced a significantly cheaper 3-D printer which opens up the possibility of manufacturing to anyone with a computer.

The vision of Dr Adrian Bowyer, who came up with the RepRap concept, is that if RepRap takes off, it has the potential to short circuit traditional supply chains for some consumer products. Currently, due to economies of scale, it is most cost effective for factories to make the products, for these products to be distributed around the world to shops, where customers can then buy them. The RepRap vision is that someone can design the item they want, or download a design from the internet (in the same way you download music or videos) and then send that design to their RepRap machine which sits next to their computer. The RepRap machine then produces the product – thus eliminating the need for a factory or complex distribution network. RepRap has been described by Chris DiBona, Open Source Programs Manager at Google as:

"Think of RepRap as a China on your desktop"

As anyone with a RepRap machine can make another one for about £300 it is possible to envisage that RepRap has the potential to revolutionise manufacturing. Dr Bowyer ultimately wants the RepRap to be cheap enough for anyone to own, including those in developing countries.

Research carried out by one of the core RepRap team, Erik Dr Bruijn found that in the 2½ years since the first RepRap machine was released there are more RepRap machines in the world than the combined total of all of the proprietary, more expensive 3-D printers which have been available in the market for 30 years. This provides an example of the rapid adoption of RepRap.

Dr Bowyer, in an interview with the Sunday Times[7] explains the potential of RepRap to disrupt industry as we know it *"Big corporations seem necessary to us with our current model of the world, but there is nothing inevitable about them. Doubtless some will persevere. The ones that make ocean-going liners are not going to go to the wall as a result of RepRap technology. But the people who make the fittings for the ocean-going liners might."*

[6] http://www.bitsfrombytes.com/news/bits-bytes-acquired-3d-systems

[7] Rudd, M., 2011. Next, we'll print out a curly iPhone. The Sunday Times, 16 September 2011 pg 7 News Review (section 4).

Pathway to Economic Impact

Spin Out Companies – sixteen companies have come out of the project that are contributing to the UK (and other) economies.

Via Collaborators – The success of the RepRap project is dependent on individuals contributing either product designs, or improvements to the RepRap machine via the open source software. The collaborators will therefore keep the RepRap project evolving and improving.

Position without IMRC Funding

The RepRap project is very innovative, breakthrough research. Due to what the project is hoping to achieve in the long run, industry itself does not have much incentive to develop a self-replicating machine. It is therefore unlikely that this kind of research would ever have been funded by the private sector.

The people who could benefit the most from this research are those in developing countries; they do not have the resources to be able to fund research of this kind.

Had the project not received IMRC funding, Dr Bowyer believes that the project would have gone ahead but progress would have been much slower.

Consultees

Dr Adrian Bowyer – University of Bath, IdMRC

Case Study 4: KIM Grand Challenge

Key Facts		
Time Period	October 2005 – March 2009	
EPSRC Funding	£813,073 (to Bath)	
Other Funding	£203,760	
Collaborator(s)	**Industrial** Airbus Converteam MoD Rolls Royce UKCeB Currie & Brown Buro Happold MDBA BAE Systems Balfour Beatty KorteQ LSC Max Fordham	**Academic** Cambridge Heriot-Watt Loughborough Strathclyde UKOLN Reading Salford Imperial Lancaster Liverpool Leeds
IMRC Research Theme	DIAK	
Research Output	200 Research Papers Case studies Data sets Software/code Best Practice Guides	
Pathway to Economic Impact	Via Collaborators	
Actual Economic Impact	Improvements to existing businesses Human Capital	
Potential Economic Impact		
Sector Focus	Cross-Sectoral	

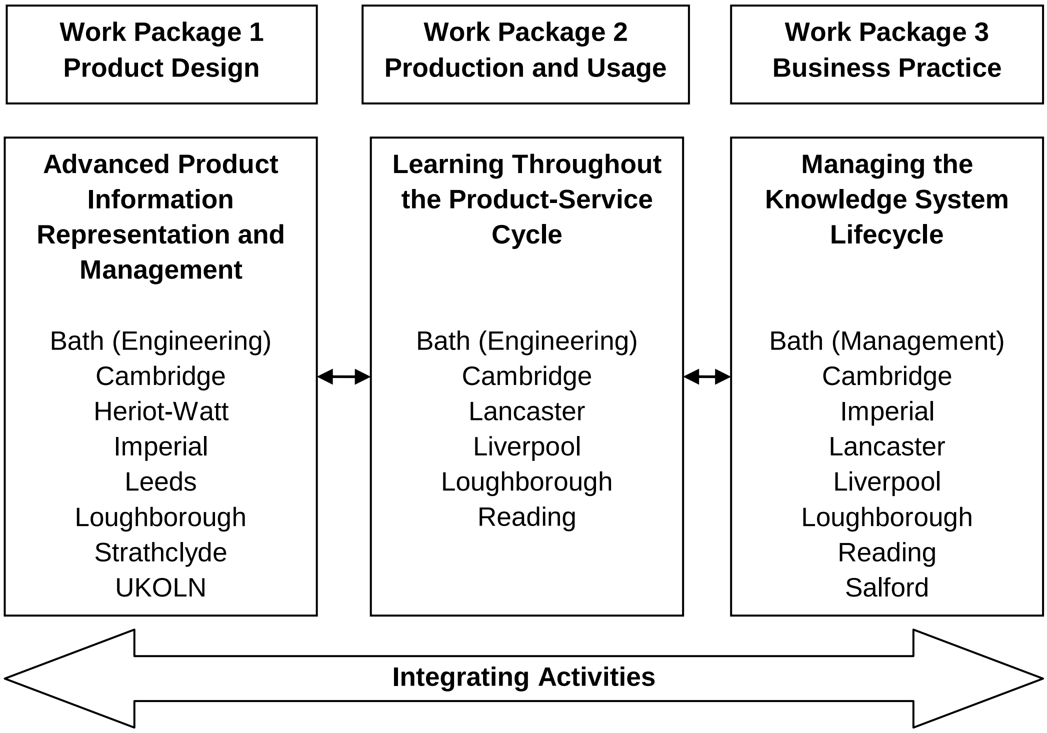
Context

The design, manufacture and operation of complex engineering products uses and generates a vast amount of data and information. When the engineering product has a long life span (e.g. 30 + years) there is a need to collect and maintain this information to facilitate high quality customer service and future product development. However, information is often stored across a number of media (e.g. note books, emails, databases, design programmes etc) and the rapidly changing nature of the information technology used to create and store the information brings further challenges for making knowledge and information available to operators, maintainers and designers over a long period of time.

The Grand Challenge Project

The KIM Project (Immortal Information and Through-Life Knowledge Management: Strategies and Tools for the Emerging Product-Service Business Paradigm) brought together eight IMRC's and five other departments from 11 different UK Universities. The project also involved significant industrial collaboration, particularly from the UK Council for Electronic Business (UKCeB) which is concerned with secure, collaborative information sharing in defence procurement. The £5.5m research programme was and jointly funded by the Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Research Council (ESRC).

The purpose of the project was to establish good practice for the design and use of information and knowledge-support systems. The project was divided into three main work packages as follows:



Work Package 1

When a product is designed a product model is produced and stored for reference in some kind of Product Lifecycle Management (PLM) system. However, the PLM system will not necessarily include informal intermediary and background information that may be contained in day-books, meeting notes and emails. The lack of storage of this informal information may cause problems later in the product lifecycle as it forms part of the engineering reasoning and documents decision-making underlying the finished design.

In addition, the rapidly changing nature of engineering software means that software can become obsolete or incompatible with later programs. As designers often revisit old designs to adapt or reuse them, these software issues can cause significant problems.

Work Package 1 considered:

- what firms should be doing to document their design processes so that design decisions and processes can be revisited over many years (what has been designed and how it was designed)
- how information can be organised and valued
- how information and lessons learnt can be fed back to the next generation of designs

A key theme running through the work package was 'how can we improve the documentation of what we do, whilst at the same time reducing the human effort involved?'

Work Package 2

When designing a product designers make certain predictions or assumptions about its construction (such as the duration and cost of production) and its eventual properties (such as its durability or fitness for purpose). In order to ensure best design, it is important that information from the construction and use of a product is fed back into the designers to inform their assumptions/predictions. Work Package 2 considered:

- how product performance information can be collected during use
- how information can be used to learn throughout a project (e.g. manufacture feeding back into design)
- how to decide what information needs to be kept, what information needs to be enhanced and what information is not required

Work Package 3

Work Package 3 concerns the flow of knowledge between people and organisations and considered:

- the best way for clients to procure product-services (such as PFIs where the client may contract with an organisation for example to build helicopters and maintain them for ~25 years)
- the human resource implications of moving to product-service type relationships
- how to improve continuity and knowledge flow throughout the service lifecycle

Bath's Role in the Grand Challenge

The IdMRC was the project lead for the KIM Project. As project lead, the IdMRC provided the planning, orchestration and integration of the research work being carried out by the project team.

In addition to leading the management of the Project, members of the DIAK theme also played a major role in Work Package 1 and Work Package 2.

Assessment of Economic Impact

The actual economic impact of the KIM project can be quantified as:

- Improving existing businesses
- Adding to the stock of human capital

Improving existing businesses

The results of KIM and subsequent work should improve the way that engineering design information is collected, stored and managed. It is estimated that engineers spend 20% of their time looking for information. If KIM can design new processes and systems that reduces the amount of time spent looking for information by just 5% this could have a significant cost saving.

Airbus reported that they have used the findings from the KIM Project to better organise and manage some of their databases. The In-Service Support department have used a facetted classification system developed by KIM researchers to organise its database, the system allows them to find information much more quickly. Similarly, recommendations made by KIM researchers with respect to Airbus' 'Lessons Learnt' database have been implemented which also allows information to be found and retrieved more quickly.

Many of the industrial and academic partners involved in the project have continued the research started in the KIM project, for example

- A KTP is on-going with Converteam and both Bath and Lancaster universities investigating sustainable strategies for organising explicit knowledge to execute competitive through-life contracts over time and geographical distance
- Rolls Royce is funding research in Cambridge on software that allows designers to record their design rationale (DR) at the time of its generation and deliberation.
- Strathclyde University is working with BAE Systems regarding the documentation of meetings
- Heriot Watt is continuing to look at how you can minimise the effort needed to properly document activity and decision making.

The KIM project and subsequent research is concerned with improving existing businesses performance through bringing about cultural change in organisations. The project overall has been a significant element in helping companies to transform their businesses from the supply of products to product-service combinations, and to systematic knowledge management approaches. Examples of project outcomes that support this transformation include improved organisation and processing of service records to extract information about incident patterns and to allow previous similar cases to be retrieved easily; improved procedures for the curation of digital records to ensure that they may be reliably revisited through life; improved contracting arrangements for PFI contracts; better and more efficient recording of design rationale; and development of communities of practice for knowledge sharing in many businesses.

It is also important to note that the research on knowledge and information management has application well beyond mechanical engineering.

Human Capital

It is believed that in the order of 14 PhD projects have been completed through the KIM project or through follow on work.

Professor McMahon estimates that at least six professorships came out of the KIM project and that six researchers gained academic posts.

In addition, industrial partners have also invested in embedding KIM researchers in their organisations. For example:

- Rolls Royce are funding a researcher at Cambridge University on the DRed project
- Converteam has funded a CASE studentship in the University of Bath
- Airbus have funded an EngDoc at the University of Bath (£50,000)
- Rolls Royce have funded a TSB project at Loughborough
- UKCeB have funded the secondment of a researcher from Bath into their organisation (£20,000)

Research activities subsequent to the KIM project have looked to embed some of the findings of the research into industry.

Professor McMahon notes that in addition to research outcomes, the KIM Project also had wider impacts in that as a Grand Challenge it enabled participants to work with academics and universities that they did not previously have a relationship with. The University of Bath, has maintained relationships with the University of Cambridge, Lancaster University, Heriot-Watt University and Strathclyde University since the KIM Project. In addition, the project facilitated a sharing of contacts from partner organisations between the academic partners, for example, the project enabled Bath to develop relationships with Babcock International, Balfour Beatty and ABB through the project and Lancaster to develop relationships with Airbus and Converteam. Over 60 people were involved in the KIM project, which built up a network of relationships between academia and business.

Pathways to Economic Impact

The main pathway to impact is through the industrial collaborators. Many of the industrial partners have committed to continue the work of the KIM Project by funding research with universities involved in the project. These research studies are looking to apply the KIM research findings to real world engineering situations.

In addition to the collaborators, the KIM Project has widely publicised the results of the research. By the end of the project 54 journal papers were produced (with more produced since the end of the project). The Publications inventory shows that 220 outputs (papers, datasets, software, best practise reports) were produced through the project.

Position without IMRC Funding

Without IMRC funding a series of partial, disconnected initiatives would have taken place, but there would have been no cross-disciplinary and inter-company sharing of experiences.

Consultees

Professor Chris McMahon – University of Bath, IdMRC

Joe Cloonan - CIMPA UK (Airbus)

Steve Shephard - UKCeB

Case Study 5: Walking Worker Manufacturing Systems

Key Facts	
Time Period	April 2004 – 2007
EPSRC Funding	£130,838
Other Funding	£23,050
Collaborator(s)	Ford Renishaw Rotork Colston Engineering
IMRC Research Theme	MAST
Research Output	Design Rules and optimisation techniques for Walking Worker Manufacturing Systems Rules and techniques have been applied in two local companies
Pathway to Economic Impact	Publishing Research Knowledge Transfer Mechanisms
Actual Economic Impact	Improvements to existing businesses
Sector Focus	Manufacturing

Context

Manufacturing systems can traditionally be set up in one of two ways:

- The product stays in one place with the workers working around it. This approach tends to be used in the production of very large items such as ships and aircraft
- The product is on a moving line with the workers stationary. This approach is the principle behind modern mass production methods and was first used by Ford in the production of the Model T.

The IMRC Project

The walking worker project investigated the possibility of a manufacturing system that combined these two approaches, so that both the worker and the product are moving.

The research was looking to build on an innovative manufacturing system used by a Swedish car manufacturer which uses a process where one team is responsible for the manufacture of one car. This approach meant that if ever there was a problem with a car they could trace it back to the team that produced it thus increasing accountability and therefore quality.

Rather than having one team responsible for one product, the walking worker system looked to increase flexibility in the assembly line by having workers do a variety of tasks. Simulation tools were developed to model various configurations of walking worker lines and investigate how the line's performance can be optimised under various conditions e.g. changes in product, machine failure and production rate.

Both computer simulation and mathematical modelling have been used to analyse and design varying configurations of walking worker lines.

Through the project the drawbacks of a walking worker system were also identified, this led to further work on 'matrix' manufacturing systems which are a hybrid of U-shaped moving-worker assembly cell and the linear walking-worker assembly line. On linear walking-worker lines, the worker moves with the assembled product down the line. On a 'matrix' system, there are parallel lines, and the walking worker may change lane. This allows a faster worker (through skill/effort or a less complex product variant) to overtake a slower worker.

Assessment of Economic Impact

The economic impact of the project can be quantified as follows:

Improving the productivity and efficiency of existing businesses

The research has resulted in two walking-worker lines being installed in local companies (Rotork and Colston Engineering) with assistance and knowledge from the IdMRC project. Whilst the Colston engineering facility has since been mothballed, Rotork successfully implemented a Walking Worker line in its Bath plant. The company recognised the advantage of the system and has since implemented walking worker lines in its factory in the USA and also to the assembly of fluid power products. The Walking Worker system, along with the introduction of a Kanbam Re-order Point Control system and greater team working has enabled Rotork to be more flexible and responsive to customer demand. Rotork estimate that:

- Production lead times were reduced from 15 days to 5 days with shop floor throughput time being one day
- Capacity was increased from 30,000 to 55,000 units per year
- Production could be increased when required with only a small increase in indirect costs

Renishaw implemented a hybrid of the Walking Worker lines independently of the IdMRC project. The results were analysed and incorporated in to the matrix manufacturing project that followed the Walking Worker project.

In addition investigations were made into the potential of using walking worker systems in the Ford plant in Bridgend, South Wales. The feasibility study indicated that switching to a walking worker system could increase the system's productivity by up to 6.3%. This could be achieved without additional investment or by significantly affecting the line layout. This is a particularly good achievement given that Ford looks to optimise the design of its assembly lines pre-production. The IdMRC do not know if Ford has implemented the system within any of their plants.

Fixed assembly lines are unresponsive to changes in consumer demand. With a fixed assembly line with 100 workers, you need 100 workers whether you make 1 car or 100 cars. If demand for your product drops you can't make people redundant because they are still needed. In a walking worker system the workers are more flexible and can do a number of tasks, this gives the line more flexibility and allows the firm to reduce its staff headcount when there is less demand for its product.

Although outside the work of the IdMRC, other studies have shown that giving workers more variety and accountability increases productivity and has positive psychological benefits when compared to a fixed assembly line.

Pathways to Economic Impact

The main pathway to economic impact is through knowledge transfer of the findings. As the research investigated a process it is not patentable. However, the IdMRC has widely publicised the results of the research in academic papers and at conferences (seven journal articles, eight conferences and one book chapter).

A KTP was used to develop and implement the walking worker system in Rotork. KTPs and KTA's are likely to be used in the future to embed the knowledge in industry. A final year undergraduate student's final year project is looking at developing a walking worker line for Renishaw.

Position without IMRC Funding

Industry would have been unlikely to fund this research due to the lack of possibility of commercialising the research findings. The main impact of this research has been to develop a new manufacturing process which can be easily adopted by other firms which acts a major disincentive to investment.

If the Walking Worker project had not been funded through the IMRC it is likely that the 'science' behind the project would have happened and may have been published as a journal article, however, it would not have been as visible to industry. By going through the IMRC the project was able to get industrial partners on board and apply the findings in real world situations.

Consultees

Dr Aydin Nassehi – University of Bath, IdMRC

Appendix 1: List of IdMRC Collaborators

DEFRA
Airbus
Renishaw
Sandiacre Packaging Machinery Ltd
Achilles Group
Manor Bakeries Ltd
Vestas Blades (Technology) UK Ltd
Bendicks of Mayfair Ltd
Rolls-Royce
Bradman Lake Ltd
Field Packaging Systems
Delcam International plc
Pira International Ltd
Adiuri Systems Ltd
Galorath Affiliates Ltd
United Biscuits Ltd
Vanguard Software
Campden BRI
Marks & Spencer plc
National Physical Laboratory NPL
UK Council for Electronic Business
AMCOR Flexibles
Piedro Footwear
EADS
Image Scan Holdings
Faro UK
Marden Edwards Ltd
Balfour Beatty Plc
Rotary Precision Instruments UK Ltd
Metris
TUV Product Service Ltd
Osborne,Geoffrey,Homes Ltd
Carillion
Highways Agency
WS Atkins
NHS
ENVIRON UK Ltd
Colston Manufacturing (Engineering) Co Ltd
Processing & Packaging Machinery Association
Crown Packaging Plc
GE Aviation
WEAF - West of England Aerospace Forum
Royal College of Surgeons in Ireland
NIST (National Institute of Standards and Technology)
Soletec Ltd
GSK
Morphy Richards
Quin Systems Ltd
Crest Flexible Packaging Ltd
M-Real UK Ltd
Autologic Systems Ltd
Rotork Controls Ltd
Corus
Dyson
TRW
Lynx Technic Ltd
Arup And Ove Arup & Partners
Kohler Mira Ltd
Philips
Soltec Systems
BMT Defence Services Ltd
L S C Group Ltd
Bobst Group UK and Ireland Ltd
Japan Society for Promotion of Science
CPC Reading
KorteQ
TWI Ltd
Quanta Fluid Solutions
Hexagon Metrology Ltd
Radiodetection Ltd
Panasonic
Ardo UK Ltd
Eurostep Limited
Zepf Technologies
GKN
Vitacress Salads Ltd
Applied
British American Tobacco Co
Welton Packaging
Mayr Melnhof
Currie & Brown
Clares Merchandise Handling Equipment
Lanner Group Ltd
Cascades Paperboard UK
Hanatek Ltd
Fiskeby Board Ltd
Royal British Legion Industries
Colin Mear Engineering Ltd
Lasercomb Dies
Cooper-Avon Tyres Ltd
Securistyle Ltd
IMI Vision Ltd
Facade Hoists International
Colston Manufacturing Ltd
Eimeldingen Ltd
Ibstock Building Products Ltd
QinetiQ
ENTHEO
CC Technology
VOS