Warwick Innovative Manufacturing Research Centre

Key Data	
Time Period	**10 Years total** 1st October 2001-30th September 2011
Total Value of EPSRC Grant	**£16.2m total** Phase 1 £5.4m; Phase 2 £9.9m
Other Funding *(Direct leverage of additional research funding specific to IMRC)*	**£15.7m total** (97% of EPSRC funding) • Direct leverage, AWM/ERDF for facilities (£6.3m) & EPSRC Collaborative Training Accounts and Doctoral Training Grants (£996,000) • Research Councils, non-IMRC – ESRC (£437,000) • UK public sector, non-Research Council (£431,000) • UK private sector (£7.1m) • Overseas, £451,0001
Projects	94 projects funded to date
Current Staff	85 total – 41 Academic staff + 44 Post-doctoral researchers
PhD Students	53 PhDs completed to date + 26 current PhD students *(funded by IMRC grant or supervised by staff involved in IMRC)*
IMRC journal publications	103
Patents granted	13
Key Sectors of Focus	• Aerospace • Automotive • Construction • Medical
Current Research Themes/ Specialisms	• Intelligent & Eco-Friendly Vehicles • Next Generation Healthcare
Examples of key economic impacts	**1. Developing Energy Efficient Housing** – estimated annual energy bill savings of £18 million **2. Helping to safeguard the future of UK clinical research** – the estimated value of R&D in the UK pharmaceutical industry is £4.5 billion per year **3. Informing R&D in the Automotive Sector** – at Jaguar Land Rover, research outputs are being used to inform the vehicle design process, which in total is worth more than £300 million per year. **4. Cost savings to the UK aerospace sector** – estimated annual savings of £60£240 million as a result of new lean processes developed.
Key value added aspects demonstrated by the IMRC	• Encouraging multi-disciplinary working • Removing the risks associated with responsive mode funding • Providing a more strategic focus for the management and development of research • Creation of new links with industry and developing ones already in existence

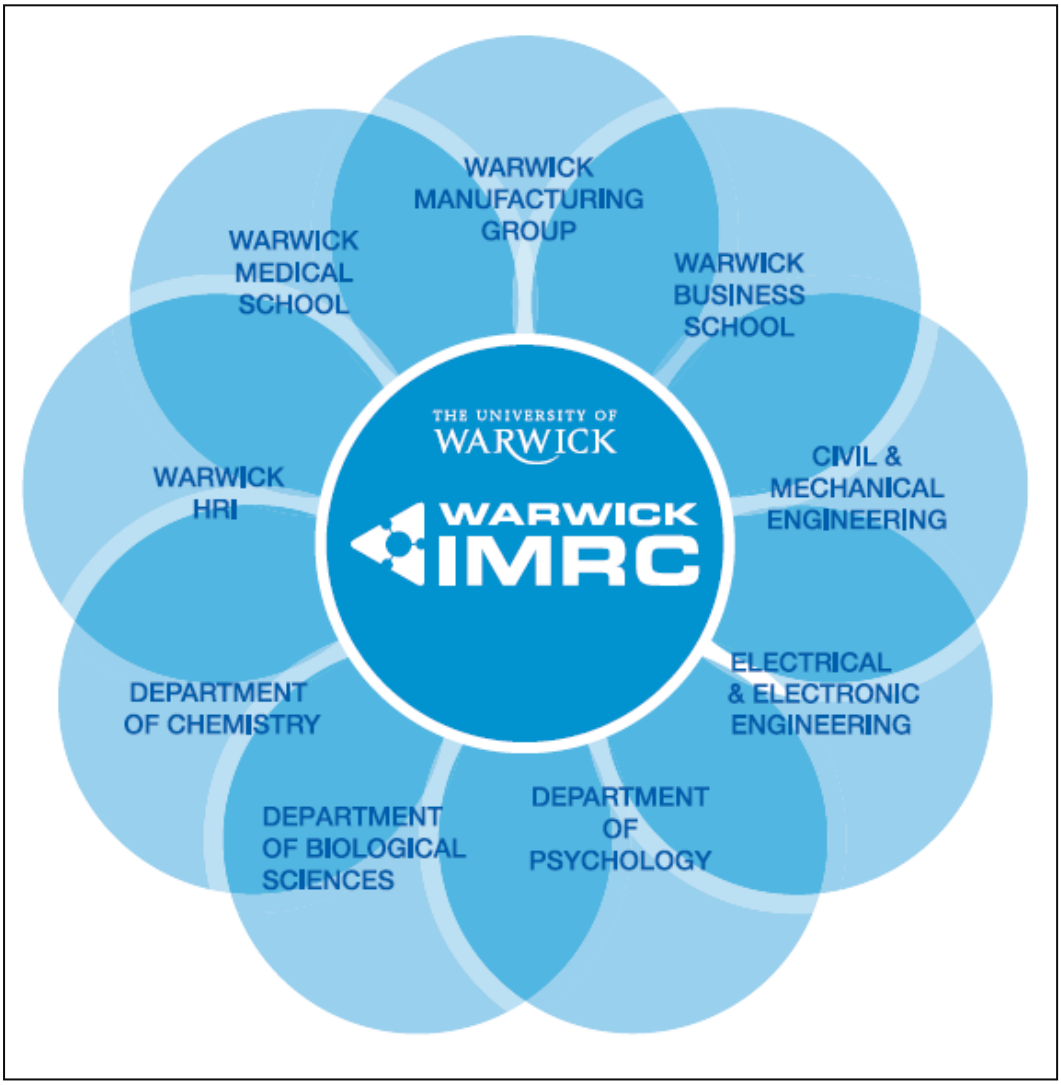
[1] Includes overseas government scholarships and self-funded doctoral students.

Overview of the Warwick IMRC

Warwick IMRC was established in October 2001 by Warwick Manufacturing Group (WMG) in partnership with a number of academics from the other Divisions of the School of Engineering and the Warwick Business School (WBS). It was set up with a broader remit than most IMRCs, focusing on the integration of engineering and management research to deliver high quality research outputs addressing the competitiveness of UK industry.

The IMRC is multi-disciplinary in its nature and the full extent of cross departmental collaboration is shown in Figure 1.

Figure 1: Warwick IMRC's Multi-Departmental Network



Source: Warwick IMRC

The Centre structure has developed over time to focus on two strategic themes:

- **Intelligent and Eco-Friendly Vehicles** – which covers the two sub-themes of Intelligent Vehicles and Eco-Friendly Vehicles.
- **Next Generation Healthcare** – covering the two sub-themes of Next Generation Healthcare Management and Next Generation Healthcare Technology.

IMRC Research Strategy

The WIMRC Phase 1 Programme (2001-2007) had six research themes:

- **Aerospace:** Concentrated on the adaptation of lean principles to the aerospace industry, creating small numbers of very high value products.
- **Automotive:** Focusing on improvements to product quality and technologies to enable the automotive sector to develop product differentiation in their market place
- **Construction:** Aiming to resolve two major issues being faced by companies in the sector. One was the management of product quality and the other was how to capture learning from one project and ensure that the same mistakes were not being repeated many times over
- **Generic:** Covering a wider range of application including research on: assessing food supply chain costs in the UK food and drink industry; and assessing knowledge management practices
- **Legacy:** There was one Legacy project, which aimed to develop technologies to deliver a maintenance-free Unmanned Air Vehicle
- **Medical:** Looking at the areas of knowledge management and the management of medical innovation.

When the centre was established in 2001, it incorporated a range of ongoing projects (14 in total) originally funded through various EPSRC programme areas. The table below provides a breakdown of Phase 1 projects and funding by research theme. It shows that the highest level of funding (£3.0 million) was awarded to Automotive projects. The five other themes in Phase 1 were allocated between £159,000 and £746,000.

Phase 1 - Theme	Number of Projects	EPSRC Funding (£)	Design	Technology	Management
Aerospace	4	£746,000	35%	-	65%
Automotive	24	£3.0m	51%	39%	11%
Construction	3	£297,000	32%	-	68%
Generic	9	£726,000	4%	48%	48%
Legacy	1	£159,000	-	100%	-
Medical	13	£395,000	30%	29%	41%

The EPSRC review at the end of Year 3 (September 2004) recognised the disjointed nature of the legacy portfolio of projects, and in moving forward asked WIMRC to develop a coherent strategy and portfolio of projects. Consultations and workshops were held with Phase 1 collaborators and other user representatives, leading to strong support for the two strategic themes of ‘Intelligent and Eco-Friendly Vehicles’ and ‘Next Generation Healthcare’.

The new themes were identified as presenting major research challenges that were particularly relevant to the UK. It was also recognised that the IMRC had access to existing experience and competencies that could be fostered to tackle these areas, both from within the Warwick Manufacturing Group and across the wider University.

Intelligent and Eco-Friendly Vehicles

Incorporating the two sub-themes of Intelligent Vehicles and Eco-Friendly Vehicles, the research is looking to address the increasing problems associated with congestion, safety, energy consumption and environmental impact worldwide. Much has been done to address these issues over recent years, however vehicle numbers continue to rise and this will counteract many of the gains already made. In addition, developed countries are faced with addressing issues associated with ageing populations and this includes increasing demands being placed on vehicle developers to keep people mobile and independent into their old age. These challenges are particularly relevant in the UK due to the high population density.

The aim of the research is therefore to develop vehicle borne solutions which will be available on the market within a seven to fifteen year time frame. The vehicles will use new materials, sensors and control systems to deliver safer, less polluting transport solutions in the market place.

Next Generation Healthcare

This research includes the two sub-themes of Next Generation Healthcare Management and Next Generation Healthcare Technology. The increase in life expectancy in the UK is creating increased demand on the UK health service. This, combined with the increasing range and costs of treatments available, makes it essential that the health service is as efficient as possible to ensure that the best possible treatment can be made available to all on demand.

By combining manufacturing, business and clinical academics to work in this area, the Centre is exploring not only process improvements but also decreases in harm (up to one in ten hospital admission patients suffers harm from the hospital).

The table below provides a breakdown of projects and funding by research theme. It shows that Phase 2 funding is split approximately 60:40 between the Intelligent & Eco-Friendly Vehicles and Next Generation Healthcare themes respectively.

Technology-related research accounts for two thirds of the Intelligent & Eco-Friendly Vehicles portfolio, while management-related research is more prevalent in Next Generation Healthcare.

Theme	Number of Projects (To Date)	EPSRC Funding (£) (Budget Allocation)	Design	Technology	Management
Intelligent & Eco-Friendly Vehicles	17	£5.0m	33.0%	67.0%	0%
Next Generation Healthcare	23	£3.9m	8.3%	38.0%	53.7%

IMRC Programme Management

Management of WIMRC is undertaken by an Executive Team comprising a Director, Research Manager and Administrative Officer. The Executive Team works in conjunction with the Steering Group and the Management Committee and is located in the International Manufacturing Centre of Warwick Manufacturing Group. Further detail on the management structure is provided in the table below.

	Responsibilities	When
Centre Director	Overall responsibility for the Centre and chair of the Management Committee	Ongoing
Executive Team	Implement the IMRC strategy; add value to the Steering Group deliberations on the future direction of the centre, manage the research project portfolio; grow the reputation and profile of the WIMRC 'brand' internally and externally; facilitate increased partnerships between WIMRC and target sectors, and companies and other IMRC and appropriate groups within UoW; report as required to EPSRC.	Ongoing
Steering Group	Strategic direction; Approval of project selection criteria and output measures/ metrics; Review of overall project portfolio and progress; Liaison with industrial and other collaborators; Governance on behalf of EPSRC.	Twice per year
Management Committee	Advice to the Executive Team on strategic and operational issues; involvement in the assessment and selection of major project proposals; monitoring of project progress.	Quarterly
Project Team (Project Investigator plus team)	Generation of proposals for new or evolving projects in line with the strategy; execution of projects approved by the Management Committee; reviewing progress with the Research Manager and Management Committee representatives on a six monthly basis.	Ongoing – with reviews twice per year

During the first year of Phase 2 funding, the IMRC implemented a new project proposal selection process that has broadened the range of opinions sought for a given application. The main steps are summarised below:

1. Project proposals are initially reviewed by the Research Manager against the agreed qualifying and differentiating selection criteria

2. The Executive Team then nominates two members of the Management Committee to carry out an internal assessment of the proposal and complete an assessment form

3. Following internal assessment, proposals with forecast budgets of up to £150,000 are reviewed by the Executive Team and a decision to fund, reject or invite resubmission is made.

4. Following favourable internal assessment, project proposals with forecast budgets over £150,000 are referred to a minimum of three independent external referees

5. On receipt of the external assessments the Research Manager prepares an assessment pack including all assessment reports, and the original internal assessors are asked to present the project to the full Management Committee at the next scheduled meeting and a vote is taken. This may result in approval, rejection or an invitation to resubmit taking into account the comments from the assessment process.

Economic Impact Analysis

Funding and Leverage

According to data provided by the University of Warwick for this exercise:

- A total of **£15.7 million (cash and in-kind contributions)** has been provided by partners for research at the IMRC. Thus, for every £1 provided by the IMRC, £0.97 has been contributed by other partners.
- Around £6.3 million comes from Advantage West Midlands and ERDF money.

- A further £7.1 million has been secured from the private sector. Over the period 2001 to 2011, companies such as BAE, Jaguar Land Rover, BP and Airbus are among the key collaborators for the IMRC.

Delivering Human Capital to the Labour Market

Approximately three quarters of are working in academia. Just over 20% have been recruited to work in industry. Specific examples of staff/researchers working in industry are provided below.

Approximate proportion[2] of former staff/researchers in:	
Academia	75%
Industry	21%
Government	4%

The case studies illustrate how skills have been transferred into industry through recruitment of research staff and students by partner and related companies. Human capital impacts include:

- **House building as a manufacturing process case study –** The project supported an EngD qualification and the person supported now holds a senior position at Insta Group, a company specialising in thermal insulation.
- **Sound quality in the automotive sector case study –**The project supported a PhD student undertaking research looking at "positive soundscapes". Earlier research undertaken at Warwick supported an employee of Jaguar Land Rover to undertake an EngD qualification and this employee now holds a senior position at the company and works closely with the researchers at the IMRC.

Impact Case Study Selection (detailed case studies below)

Four case studies have been selected by DTZ in conjunction with the IMRC and EPSRC to illustrate the economic impact of research funded through the Warwick IMRC as shown in the table overleaf. These case studies have been selected on the basis of the agreed shortlisting criteria, as follows:

- Demonstrates a range of types of economic impact as defined by BIS
- Offers convincing evidence of significant tangible impact
- Demonstrates the added value of the IMRC model
- Provides good coverage of the different research themes within the IMRC
- Provides good coverage of relevant sectors.

Overall, the case studies are reasonably representative of the types of work that the IMRC is engaged in, whilst focusing on examples which demonstrate significant impact and added value. The key points relating to case study selection are as follows:

- The Intelligent and Eco-Friendly Vehicles theme accounts for more than half the research undertaken as part of the Phase 2 funding programme at £5.0 million for 17 projects, while Next Generation Healthcare has received £3.9 million for 23 projects. One case study has been produced from each of themes – the clinical trials projects falls within Next Generation Healthcare, while the research with Jaguar Land Rover looking at sound quality has been one of the key research areas within Intelligent and Eco-Friendly Vehicles.

[2] These apportionments are approximate.

- More than £5.0 million of research was undertaken during the first phase of IMRC funding at Warwick and relevant case studies have also been assessed from Phase 1 in order to provide a representative view of the impacts. Two case studies have been produced – the first relating to investigating house building as manufacturing process (falling within the Construction theme of Phase 1) and the second looking at implementing lean manufacturing processes in the aerospace sector (covering the Aerospace theme from Phase 1).

Case study	BIS Impact Headings[1]	Added Value Aspects	IMRC Research Theme	Sector
House building as a manufacturing process	New business creation	Industry collaboration	Construction (Phase 1 theme)	Other (Manufacturing)
Lean manufacturing principles in the aerospace sector	Improving existing businesses (lean manufacturing principles)	Industry collaboration	Aerospace (Phase 1 theme)	Aerospace
Developing a sense of quality	Improving existing businesses	Critical mass of knowledge	Intelligent and Eco-Friendly Vehicles	Automotive
Clinical Trials	Improving existing businesses (competitiveness)	Critical mass of knowledge	Next generation healthcare	Healthcare

[1] Most projects have attracted R&D investment through industry contributions and developed human capital so these are not listed as a type of impact as they would apply to all the projects

Added Value of the IMRC Model

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

- **The IMRC structure has allowed Warwick to create new links with industry and develop ones already in existence**. This has enabled the research to become more responsive to the needs of industry, with the IMRC able to provide the resources if a particular research opportunity emerges. Good examples of responding to industry needs include the research undertaken with Westbury Homes[3] looking at house building as a manufacturing process and the sound quality research undertaken in collaboration with companies such as Jaguar Land Rover. Many of the relationships are likely to continue in the future and Jaguar is currently working with Warwick as it looks to develop hybrid vehicles, for example. By the end of February 2011 around 100 Jaguar employees will be at located Warwick Manufacturing Group engaged on this research.
- A **more strategic approach towards the management and development of research has evolved over time at the IMRC**. Responsive mode funding makes it difficult to develop a strategic research programme, given that the people involved will have no control over what is funded. Project proposals must go through a detailed selection process to ensure research fits with the aims of the IMRC in terms of targeting the right areas of focus for Intelligent & Eco Friendly Vehicles and Next Generation Healthcare themes.

[3] Westbury Homes have since been bought by Persimmon.

- The **IMRC model has removed much of the risk usually associated with responsive mode funding, which** may lead to a research area with significant potential not being able to continue until further funding is secured. This could lead to key staff leaving and relationships with industry not being developed fully. The IMRC structure has meant that promising areas of research can be developed over time, for example those in relation to sound quality in the automotive sector.
- It **has encouraged multidisciplinary working across the University**, drawing on the expertise of a number of departments at Warwick. The IMRC has also encouraged working with other institutions. To illustrate this point, the clinical trials project not only utilised expertise within Warwick Business School and the Warwick Clinical Trials Unit, it also relied on key inputs and resources from Queen Mary University London.

Consultees

The following people at the University of Warwick were consulted and reviewed a draft of the case study:

- Professor Ken Young
- Dr Nick Mallinson
- Professor Paul Jennings.

Case Study 1: House Building as a Manufacturing Process

Key Facts	
Time Period	2001-2002
IMRC Funding	£69,000
Other Funding	£32,000 (Westbury Homes) and in-kind contributions (estimate unavailable)
Collaborator(s)	Westbury Homes Limited
IMRC Research Theme	Construction (Phase 1 Theme)
Research Output	The project explored economic and practical ways of manufacturing major elements of residential housing structures within a factory based environment. The research identified the most suitable accommodation units that could be built up from factory sourced prefabricated elements and defined the optimum factory layout and manufacturing processes.
Pathway to Economic Impact	**Via collaborators –** The project led to Westbury Homes investing £13 million to set up a purpose built facility manufacturing pre-fabricated offsite construction systems, trading under the name Space4.
Actual Economic Impact	**Investment in a new company** - £13 million investment made by Westbury homes to establish the Space4 facility. **Job creation** – 90 jobs supported at the Space4 factory, contributing £5.2 million in GVA to the UK economy per year.
Potential Economic Impacts	**Energy efficiency** – on average, the energy costs for the 15,000 Space4 homes created to date will be £9 million less per year than standard block and brick housing. The value of Carbon savings attributable to the homes could potentially be as much as £900,000.
Sector Focus	Construction

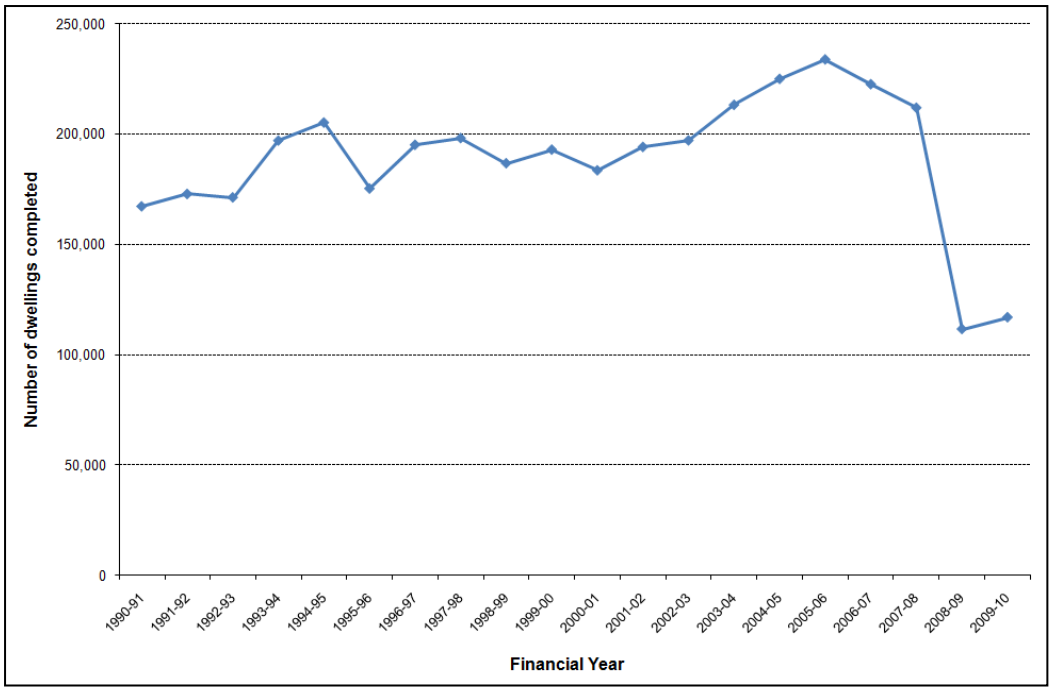
Context

Prefabricated housing has been used in the UK during periods of high demand, such as after the World Wars and during the slum clearances of the 1960s. In total about 1 million prefabricated homes were built during the 20th century, many of which were designed to be temporary. However, problems over the quality of building materials and poor workmanship led to negative public attitudes towards prefabrication[4].

Modern Methods of Construction (MMC) were developed as a new term to reflect technical improvements in prefabrication. MMC primarily involves the manufacture of homes in factories, with potential benefits such as faster construction, fewer housing defects, and reductions in energy use and waste. The majority of homes in the UK are still constructed using traditional 'brick and block' masonry. The significance of MMC has grown in recent years, particularly since housing supply has not kept pace with demand (see Figure 2).

[4] Sourced from: Postnote, number 209. Modern Methods of House Building. Published by the Parliamentary Office of Science and Technology, December 2003.

Figure 2: Housing Completions in the UK, 1990-2010



Source: DCLG

Within the last few years there has been increased use of MMC for housing, driven by a range of factors including demands for faster construction and skills shortages. While the Government has been keen to encourage the use of MMC for house building, there have been questions asked relating to its cost, the industry capacity; its environmental benefits, the quality of such housing, public acceptance and planning and building regulations. The IMRC project was developed to try and gain a better understanding of manufacturing prefabricated elements of housing and to translate the research into an industrial output.

The IMRC Project

The project built on earlier work undertaken at Warwick under the EPSRC Innovative Manufacturing Initiative and investigated how to transfer best business practice from industrial manufacturing to construction. Working in collaboration with Westbury Homes, the project included research into:

- New construction technologies
- Technology transfer from manufacture to construction
- Customer choice and service
- Product quality
- The culture change required to implement these improvements.

During the research the team considered the use of more pre-manufactured components such as steel frames or composite panels, wiring looms and plastic plumbing. The study helped to define the characteristics of a new way of building, which came to be known as the Space4 system.
The most significant output from all of the research undertaken at Warwick was for Westbury Homes to invest £13 million in a 220,000 sq. ft manufacturing plant in 2001 to manufacture a panel-based modular house building system.

High performance insulating foam is injected into each external panel using a unique patented process and external doors and windows are fitted on-line. The factory has been designed as a just-in time flow line, supported by CAD/CAM systems and configured for e-business transactions with suppliers and customers. It can produce one standard house shell per hour and has the capacity to manufacture between 5,000 and 6,000 shells per annum operating on three shifts. The actual process of constructing a Space4 property is also more efficient and reduces the overall time to build a house from 12-14 weeks to 8-10 weeks.

Figure 3: Completed Space4 Dwellings

Assessment of Economic Impact

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

- Investment in new company, job creation and contribution to the UK economy
- Developing energy efficient housing.

Investment in new company, job creation and contribution to the UK economy

The research undertaken at Warwick helped lead to a £13 million investment by Westbury homes to establish the Space4 manufacturing plant in 2001. Westbury was taken over by Persimmon for £643 million in November 2005 and Space4 has continued to create homes. Moreover, approximately 90 people are currently working on site. In 2008 Gross Value Added (GVA)[5] per head in manufacturing was £58,000 in the UK. If this figure is applied to the job estimates, the contribution to GVA being made by the Space4 factory equates to £5.2 million per year.

[5]Gross value added is the difference between output and intermediate consumption for any given sector/industry. That is the difference between the value of goods and services produced and the cost of raw materials and other inputs which are used up in production.

Developing energy efficient housing

Despite the housing market crash in 2008, around 15,000 homes have been created to date by Space4, This included around 2,000 homes in 2009, equivalent to about 20% of Persimmon's total output[6].

One of the main benefits of Space4 homes is that they have good thermal insulation. During the manufacturing process, the pre-fabricated panels are injected with a special mixture of acid and resin that creates a foam to keep heat in and energy bills down.

Significantly, Persimmon has estimated that this increased energy efficiency means a reduction of 50% in heating costs compared to the average home in the UK.[7] Assuming an average energy bill of £1,200 per household, the 15,000 Space4 homes built to date will, on average, have annual energy costs of £9 million, in comparison to £18 million for 15,000 standard homes.

Using data from Code for Sustainable Homes: A Cost Review[8], a carbon saving can also be estimated:

- An average semi-detached house built to current standards will have a carbon footprint of 2,000kg of CO_2 per year
- Assuming that the Space4 homes use half the energy of a stand house, the 15,000 homes built to date will produce 15 million kg of CO_2 annually, rather than 30 million kg if built to current standards.

Taking into account the difference in CO_2 emissions of 15 million kg (15,000 tonnes), the current valuation of this by DECC would be £900,000 per year[9].

Position without IMRC Funding

When assessing the economic impact of research it is important to consider the rationale for IMCRC investment in the research. The only rationale for IMRC investment in research should be to address a market failure of some kind. In other words, there should be a reason why industry itself would not fund the research and why public intervention through the IMRC is justified[10].

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. At the outset of the research, there was no guarantee that best business practice from industrial manufacturing could be transferred across to the construction of housing.

The research undertaken which has subsequently led to the creation of the Space4 manufacturing site is benefitting all of society in terms of developing Modern Methods of Construction within the housing industry and developing new energy efficient housing which can be constructed in shorter timescales than more traditional methods.

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[6] "Today we build a house every hour". Taken from: http://business.timesonline.co.uk/tol/business/industry_sectors/construction_and_property/article7009619.ece

[7] http://www.persimmonhomes.com/offers/a-50-more-energy-efficent-and-cosier-home-12835?developmentId=2053

[8] Published by the Department for Communities and Local Government in March 2010.

[9] Assuming a carbon price of £60 – DECC (2009) Carbon Valuation in UK Policy Evaluation: a revised approach

[10] This definition remains the same for each IMRC project, therefore it is not repeated in the other case study write ups.

Consultees

The following people were consulted and reviewed a draft of the case study:

- Professor Rajat Roy, University of Warwick
- Robin Davies, Group Managing Director, Insta Group.

Case Study 2: The Management and Organisation of Clinical Trials

Key Facts	
Time Period	2007-2009
IMRC Funding	£267,000
Other Funding	£391,000 (including match funding)
Collaborator(s)	Innovation, Knowledge & Organisational Networks Research Centre (based at Warwick Business School, Queen Mary University of London, Association of the British Pharmaceutical Industry, Institute of Clinical Research, BioIndustry Association, Warwick Clinical Trials Unit, Association of British Healthcare Industries
IMRC Research Theme	Next Generation Healthcare Management
Research Output	Identification of the key social, organisational and managerial factors that influence clinical research projects with a view to improving the clinical research process and reducing the costs and risks of development.
Pathway to Economic Impact	**Via policymakers -** influencing the policy agenda for health research, and helping to safeguard one of the main contributors to the UK economy.
Actual Economic Impact	**Informing Policy -** The main impact of the research relates to informing policy and the future organisation of clinical trials in the UK. Taking this into account, the estimated impacts are potential.
Potential Economic Impacts	**Safeguarding the UK clinical trials sector** – worth an estimated £1.8 billion per year.
Sector Focus	Healthcare

Context

Clinical trials involving healthy volunteers and patients play an essential role in understanding, preventing and treating diseases, Their aim is to evaluate new medicines or a combination of medicines, as well as other types of therapies, to determine their potential benefits and safety.

The sponsor of medicines research in the UK is primarily the pharmaceutical industry, however research charities, Research Councils and the NHS also undertake medicines research. A new medicine has to demonstrate its safety, quality and efficacy through a series of rigorous clinical trials in order to obtain a licence (called a marketing authorisation) and be available to the general public. Clinical trials consist of four phases – the first three occur before a licence is granted and the last is conducted as a post-licensing phase. Pre licensing, the phases are[11]:

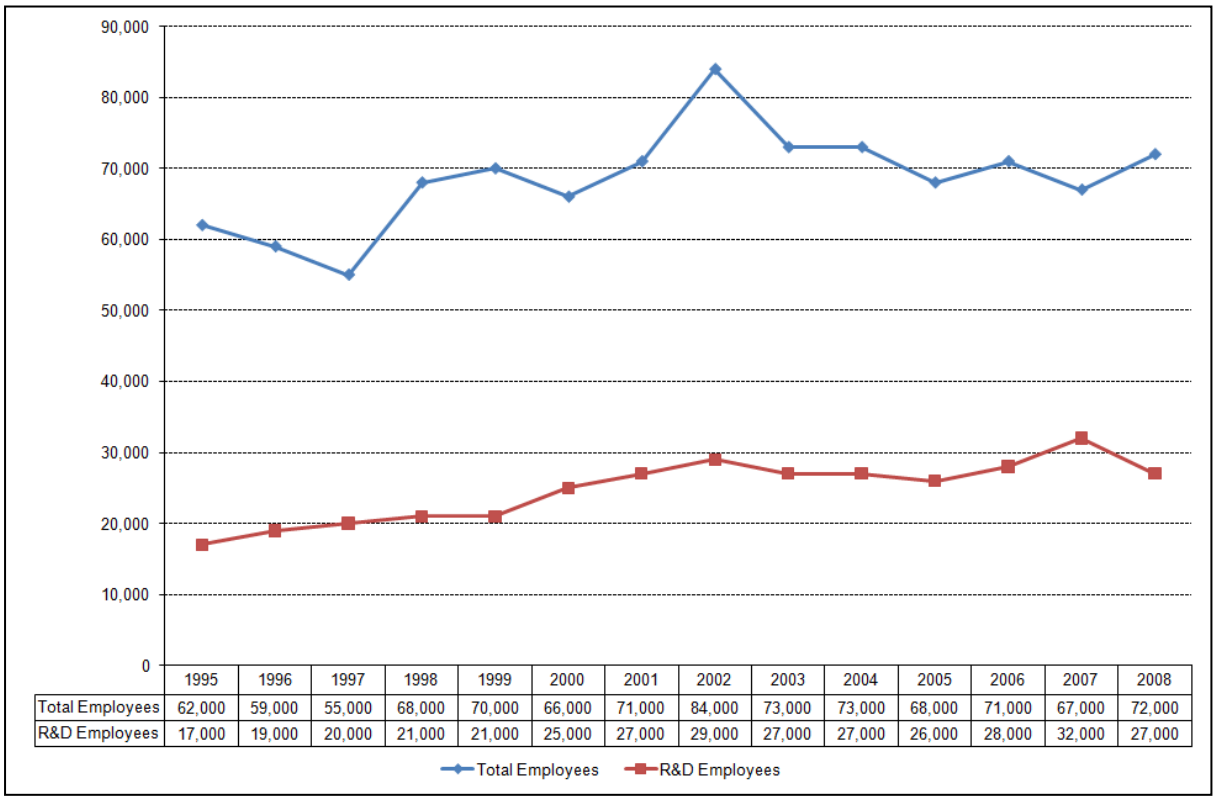
- Phase 1 – Primarily determines how a medicine works in humans, helps to predict the dosage range for the medicine and involves healthy volunteers.
- Phase 2 – Tests efficacy as well as safety among a small group of patients (100-300) with the condition for which the medicine has been developed.

[11] Association of the British Pharmaceutical Industry: Clinical Trials – developing new medicines. Available at: http://www.abpi.org.uk/%2Fpublications%2Fbriefings%2Fclinical_brief.pdf

- Phase 3 – Involves a much larger group (1,000-5,000) of patients which will help to determine if the medicine can be considered both safe and effective.

Commercial health research brings substantial economic and social benefits, for example, the UK's pharmaceutical sector is estimated to invest approximately £11.8 million per day in R&D, more than any other industrial sector. Of the sector's total employment of 72,000 people, 27,000 of them in R&D[12]. Employment in R&D has also remained relatively stable, while the total number of employees in the pharmaceutical sector has fluctuated (see Figure 4). The Association of the British Pharmaceuticals Industry (ABPI) suggest this fluctuation is due to a decline in sales and marketing roles and pharmaceutical manufacturing in the UK. Clinical research is also central to the UK's pharmaceutical, biotechnology and medical devices industries, which combined are an essential component of the UK's economy. In total, the UK pharmaceuticals sector contributes around £18 billion per year in GVA[13].

Figure 4: Employment in the UK Pharmaceuticals Sector



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total Employees	62,000	59,000	55,000	68,000	70,000	66,000	71,000	84,000	73,000	73,000	68,000	71,000	67,000	72,000
R&D Employees	17,000	19,000	20,000	21,000	21,000	25,000	27,000	29,000	27,000	27,000	26,000	28,000	32,000	27,000

Source: ABPI

The UK has traditionally been a world leader in research to understand and treat disease. For example, the Academy of Medical Sciences[14] notes that UK scientific publications produce over 12%

[12] Association of the British Pharmaceutical Industry, 2010. "The pharmaceutical industry's contribution to the UK and beyond". Available at: http://www.abpi.org.uk/pdfs/The%20Pharmaceutical%20Industrys%20Contribution%20to%20the%20UK%20Economy%20and%20Beyond.pdf

[13] *Ibid*

[14] The Academy of Medical Sciences, January 2011 – A new pathway for the regulation and governance of health research. Available at: http://www.acmedsci.ac.uk/index.php?pid=99&puid=209

of the world's citations in both the clinical and health sciences and nearly a quarter of the world's top 100 medicines have been created in the UK.

However, the UK clinical research base is increasingly under threat from global competition and the time and cost of R&D continues to be a major challenge for the UK. In the last ten years the UK's position in health research has been under threat and its global share of research activity has fallen. The Academy of Medical Sciences has highlighted a number of trends[15], including:

- In 2002, 46% of EU products in clinical trials were being developed in the UK; by 2007 this had fallen to 24%.
- Data from the Medicines and Healthcare products Regulatory Agency show that the number of trials approved has stayed constant between 2004 and 2008, yet the UK's global market share of patients in trials has dropped from 6% to 2-3%.
- Almost half of the representatives of major pharmaceutical industries surveyed in 2008 indicated that they expected to reduce the number of clinical trials in the UK.
- Commercial and non-commercial researchers have indicated that the complexity of the regulation and governance pathway is limiting the amount of research they do.

Scientists, clinicians and industrialists have expressed growing concern about the 'translational gap' between basic scientific discovery and innovation that will benefit patients. High quality clinical research is key to closing this gap and underpins innovation and improvement in health services. The successful management and organisation of clinical research projects is important to overcoming the challenges faced by the UK clinical research base in the future.

The IMRC Project

The IMRC project was undertaken to systematically explore the challenges of organising and managing different models of clinical research. The main aim was to identify the key social, organisational and managerial factors that influence clinical research projects with a view to improving the clinical research process and reducing the costs and risks of development. The project was undertaken in two phases:

Phase 1

- A systematic literature review of previous work in this area, containing 129 articles which were generated from a review of 5,000 articles.
- 57 interviews with key stakeholders from across all areas of the industry which focused on the challenges of conducting different types of clinical research in the UK.

Phase 2

- A large scale survey generating data on the management of 247 clinical research projects conducted in the UK.

Outputs from the research were disseminated using a variety of methods, including a stakeholder workshop on the future of clinical trials in the UK held at Queen Mary University of London. A detailed

[15] The Academy of Medical Sciences, January 2011 – A new pathway for the regulation and governance of health research.

report was published in December 2009 to articulate the main findings and this highlighted that the greatest challenges affecting the management of clinical research are found around four areas, as summarised in Figure 5[16]. The report was also presented to the UK Clinical Research Collaboration (UKCRC[17]) Board and a UKCRC Sub Group. In addition, it was sent to 80 UK Clinical Trials Units, the Department of Health, regulatory authorities, UK Clinical Research Networks and all major pharmaceutical firms.

Figure 5: Main Challenges Facing Clinical research in the UK

Source: Adapted from Managing Clinical Research in the UK, December 2009

From the challenges summarised in Figure 5, retaining team expertise was identified as a critical predictor of success of trials (i.e. running to target budgets and being delivered on time), not just project management. This issue was found to be particularly acute for non-commercial trials.

Assessment of Economic Impact

Helping to safeguard the future of UK clinical research

The key impact of the research has been to highlight the many challenges associated with managing different types of clinical research projects within the UK. The subsequent report made a series of recommendations to inform the future direction of clinical research, based around the four main challenges outlined in Figure 5. Recommendations included streamlining the process for obtaining R&D approval from NHS Research Governance offices and creating a dedicated portal for UK Clinical

[16] Swan, J., Robertson, M. & Evans, S. (2009) Managing Clinical Research in the UK: Evidence on the challenges of conducting clinical research projects in the UK. December 2009.

[17] The UKCRC was established in 2004 brings together the major stakeholders that influence clinical research in the UK. One of its main objectives is to strengthen clinical research in the UK.

Research to assist less experienced clinical researchers in acquiring relevant knowledge and expertise.

The issue of supporting clinical research in the UK remains high on the political agenda and the Academy of Medical Sciences (AMS) published a report in January 2011 aimed at supporting the development of health research. The research was undertaken to try and address the problem that, *"there is evidence that UK health research activities are being seriously undermined by an overly complex regulatory and governance environment."*[18] The report sets out a new regulatory and governance pathway aimed at increasing the speed at which healthcare innovations become available to patients, whilst eliminating unnecessary bureaucracy.

To put the significance of the IMRC and AMS research into context, in the United States 40% of R&D spend is on clinical trials[19], representing around $96 billion in 2008.

According to the ABPI, UK pharmaceutical R&D spend was around £4.5 billion in 2008. Assuming a similar trend to the United States, £1.8 billion of this (40%) is being spent on clinical trials in the UK. Research such as that carried out by the IMRC is therefore hugely significant in terms of helping to safeguard the future of the clinical trials sector and the overall pharmaceutical industry in the UK.

Position without IMRC Funding

Industry would not have been prepared to pay the full cost of the research because it is unlikely that any of the outputs would ever be commercialised. Substantial in-kind support was provided via the trade/professional groups representing the sector, including the ABPI, the BioIndustry Association, the Institute of Clinical Research and the UK Clinical Research Network etc.

The main impact of the project is to help inform the future of clinical trials in the UK and the IMRC funding has helped to support the publication of a robust, independent and objective report on the many practical challenges faced by the sector. The political sensitivities around the UK as a site of clinical research excellence and confidential nature of the overall pharmaceutical industry mean that both medical research councils and the private sector are extremely unlikely to fund a study such as this.

Consultees

The following people were consulted and reviewed a draft of the case study:

- Professor Jacky Swan, University of Warwick
- Professor Maxine Robertson, Queen Mary University of London
- Professor John Powell, University of Warwick
- Professor Sallie Lamb, Warwick Clinical Trials Unit
- Dr Sarah Evans, University of Warwick.

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[18] The Academy of Medical Sciences, January 2011 – A new pathway for the regulation and governance of health research. Page 2.

[19] http://appliedclinicaltrialsonline.findpharma.com/appliedclinicaltrials/CRO%2FSponsor/Sizing-Up-the-Clinical-Research-Market/ArticleStandard/Article/detail/660749

Case Study 3: Appropriate Product Representations for Assessment In Structured Evaluations (APPRAISE)

Key Facts	
Time Period	2008-2011
IMRC Funding	£671,000
Other Funding	£600,000 (in-kind industry contributions)
Collaborator(s)	Jaguar Land Rover, Bruel & Kjaer
IMRC Research Theme	Intelligent and Eco-Friendly Vehicles
Research Output	Consistent methods for capturing "perception-forming processes" and creation of a noise, vibration and harshness simulator
Pathway to Economic Impact	**Via Collaborators –** Jaguar Land Rover are using the noise, vibration and harshness simulator in the design process of new vehicles.
Actual Economic Impact	The impacts identified are potential.
Potential Economic Impacts	**Impact on Existing Businesses -** Jaguar Land Rover are using the noise, vibration and harshness simulator in the design process of new vehicles – part of the wider R&D process worth an estimated £378 million per year.
Sector Focus	Automotive

Context

Innovation is one of the main drivers of the automotive sector, an industry which employs 180,000 people in the UK alone[20]. At an EU level, R&D spend by members of the European Automobile Manufacturers' Association (EAMA) equated to around €28 billion in 2009[21]. Innovation will continue to account for a significant proportion of the sector's turnover as vehicle numbers continue to grow, and the drive towards creating more environmentally friendly vehicles increases.

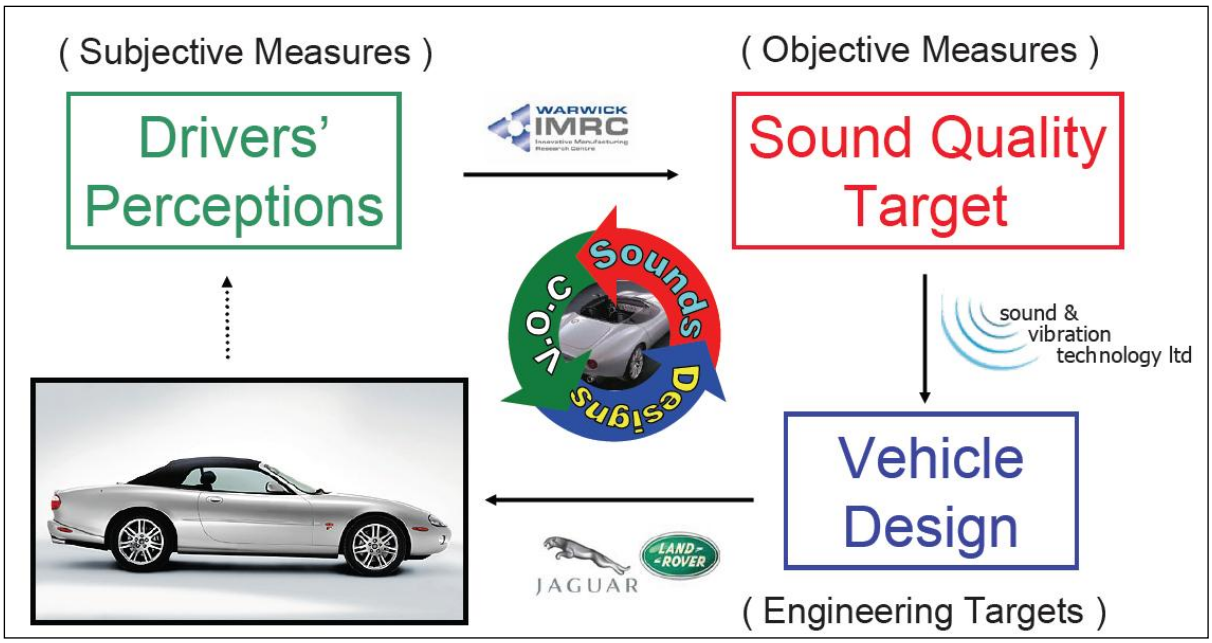
The success of the next generation of low carbon vehicles will be dependent upon objective factors including their economic viability, emission levels and overall performance. However, customer acceptance, relating to subjective and emotional responses to measures such as sound, will be critical too. That is, the vehicles developed need to be desirable to the end customer.

Figure 6 summarises the objective and subjective processes involved in evaluating customer opinions of sound quality in cars.

[20] http://www.bis.gov.uk/policies/business-sectors/automotive

[21] European Commission, 2010 – Monitoring Industrial Research: The 2010 EU Industrial R&D Investment Scoreboard.

Figure 6: Evaluating Customer Held Opinions for Enhancement of Sounds



Source: Warwick IMRC

If manufacturers are able to make decisions earlier and with more confidence during product development, this can result in vehicle designs better suited to customers. This is particularly important for sound, which is likely to be very different for the next generation of environmentally friendly vehicles being developed.

The IMRC Project

The Appropriate Product Representations for Assessment In Structured Evaluations (APPRAISE) project built on earlier IMRC-funded research called Evaluating Customer Held Opinions for Enhancement of Sounds (ECHOES) undertaken from 2003-2006. ECHOES generated knowledge and tools to allow manufacturers to predict, and account for, the subjective response of potential customers to a new product's sound. A fully interactive noise, vibration and harshness (NVH) simulator was created as part of the project, as well as a new approach to jury evaluations.

Building on the findings and outputs from ECHOES, the APPRAISE project included extensive collaboration with Jaguar Land Rover and Bruel & Kjaer, the latter being a manufacturer and supplier of sound and vibration test and measurement solutions. The objectives of the research were to:

- Develop consistent methods for capturing "perception-forming processes" in different environments (e.g. in real vehicles on-road, vehicle simulator, listening room)
- To compare "perception-forming processes" across different levels of reality
- To provide guidelines for the representation of the real world in simulated environments, understanding how simple the real world representation can be made for appropriate decision making
- To disseminate the research results and to continue scoping activity, ensuring that the research process is designed to maximise the impact of outputs.

The APPRAISE project made extensive use of the NVH simulator developed as part of ECHOES. The simulator allows real driving conditions to be generated in real-time and evaluated before the design and manufacture phases of a vehicle development programme. During an evaluation, the assessor drives a simulated vehicle through a virtual environment as if it were a real car on a real road. Whilst the assessor is driving, they hear accurate sounds, via headphones, and vibration through the seat, steering wheel and foot pedal (see Figure 7).

Figure 7: NVH Simulator at Warwick

Working closely with the industrial partners, key outputs from the project include:

- Development of a framework for subjective in-vehicle appraisals.
- Design and development of hardware and software to capture audio, video and vehicle data during in-vehicle appraisals.
- Design of post-evaluation and pre-evaluation questionnaires for subjective appraisals of vehicles.
- Design and execution of a pilot study involving multiple methodological approaches to in-vehicle appraisals. This was run with 13 expert evaluators from Jaguar appraising a Jaguar XK.
- A database of hybrid and electric vehicle sounds for interior and exterior sound assessments.

Assessment of Economic Impact

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

Informing R&D in the Automotive Sector

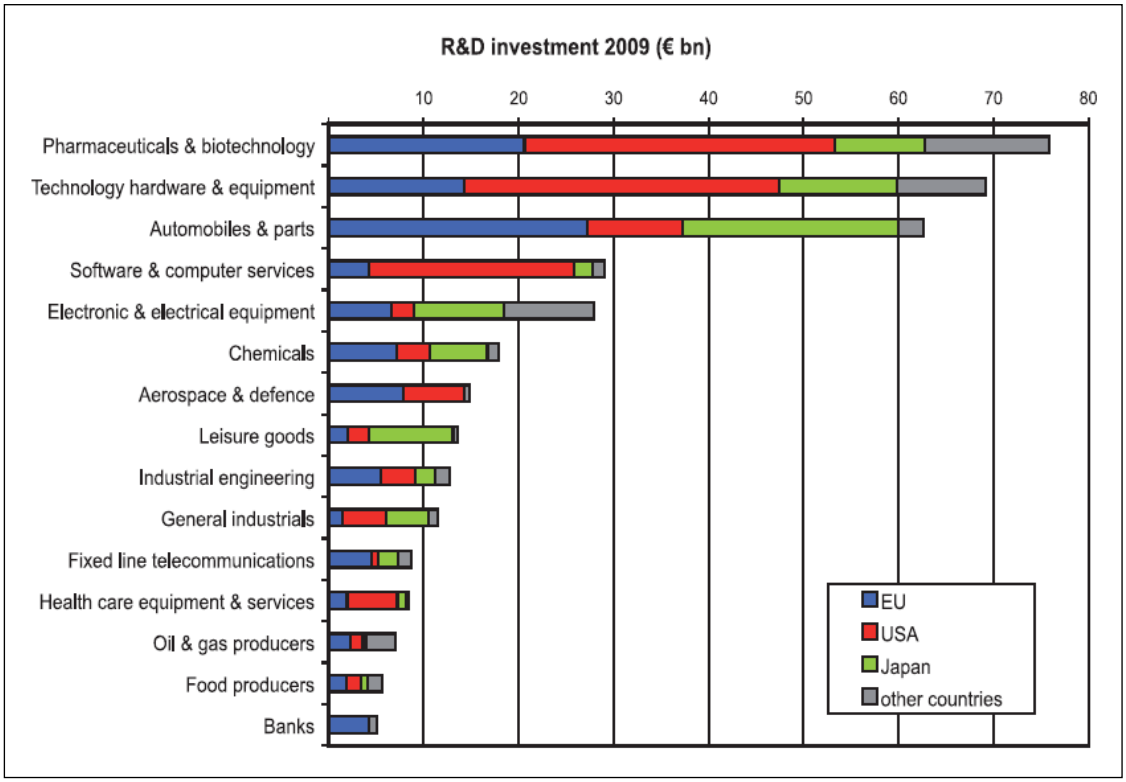
The outputs from the structured evaluations research have been taken on board by industry as part of the design process of vehicles. In particular, Bruel & Kjaer has been able to develop three commercial versions of the NVH simulator:

- **Desktop:** For use in an office or laboratory where the NVH Engineer can prepare and work with simulator models
- **On-Road:** Allowing vehicle sounds created using the Desktop simulator to be experienced in a real car whilst driving on the road
- **Full Vehicle:** Integrating the Desktop Simulator into a fixed donor vehicle to create a complete multimodal context.

Significantly, Jaguar Land Rover is now using the simulator as one of their evaluation tools during the design process of new vehicles. To put the significance of this into context:

- The automotive industry is one of the largest private investors in R&D globally, behind only pharmaceuticals & biotechnology and technology hardware & management. According to the 2010 EU R&D Industrial Scoreboard, in the EU alone the "automobiles and parts" sector invested around €28 billion on R&D (see Figure 8).

Figure 8: R&D Investment, 2009



Source: 2010 Industrial R&D Scoreboard

The ACEA has estimated that its members (including Jaguar Land Rover) spend around 5% of their turnover on R&D[22]. In 2009 the turnover of Jaguar Land Rover was approximately £7.6 billion[23]. Applying the 5% estimate from ACEA, this means that the research undertaken at the IMRC which has subsequently been utilised by Jaguar Land Rover is helping to support an R&D process worth

Position without IMRC Funding

This project enabled existing research being undertaken by the IMRC and partners such as Jaguar Land Rover to continue in a joined-up and integrated way as part of a collaborative programme. It is unlikely that industry would have been prepared to pay the full cost of the research undertaken to date because there was no guarantee that the outputs would ever be commercialised. If the IMRC funding had been unavailable, it is uncertain whether the same types of impact would have been achieved over the same time frame.

It is important to highlight the fact that the impacts arising from the project cannot be attributed solely to the APPRAISE IMRC project. Other projects undertaken at the IMRC, including ECHOES, have also played an important role in achieving the impacts discussed.

Consultees

The following people were consulted and reviewed a draft of the case study:

- Professor Paul Jennings, University of Warwick
- Dr Garry Dunne, Senior Technical Leader, Vehicle NVH – Jaguar Land Rover
- Tony Harper, Head of Research & Advanced System Engineering Advanced Product Creation – Jaguar Land Rover.

[22] http://www.acea.be/index.php/news/news_detail/automotive_sector_tops_rd_investment_scoreboard/
[23] http://www.birminghampost.net/birmingham-business/birmingham-business-news/automotive-business/2009/07/27/jaguar-land-rover-reports-losses-of-350m-65233-24250040/

Case Study 4: Lean Manufacturing in Aerospace

Key Facts	
Time Period	2002-2005
IMRC Funding	£268,000
Other Funding	In-kind (unknown)
Collaborator(s)	Universities of Bath, Cranfield and Nottingham. Private sector partners included Airbus, Rolls-Royce, BAE Systems, Westland Helicopters, Smiths Aerospace, Goodrich, Messier-Dowty, and Esterline.
IMRC Research Theme	Aerospace
Research Output	Lean tools and training aids, including: a lean enterprise self-assessment; a new product introduction (NPI) awareness game; core competence analysis; an NPI Matrix; and NPI Metrics
Pathway to Economic Impact	**Via collaborator(s) –** Dowty Propellers Repair and Overhaul applied the core competence methodology to a composite blade product.
Actual Economic Impact	**Growth in market share of existing business** – Dowty Propellers Repair and Overhaul saw growth in its share of the European aftermarket for composite propellers from 5% to 50%.
Potential Economic Impacts	**Cost savings / improving the performance of existing businesses** – The Society of British Aerospace Companies has estimated that the tools generated are contributing savings of between £60 million and £240 million per year to UK based aerospace companies
Sector Focus	Aerospace

Context

The aim of lean techniques is to make businesses more productive and competitive. The concept is based on techniques implemented by Toyota, who increased market share by improving their processes, on the shop floor and in design and development, through the application of process rigour. They identified five "lean principles" [24]:

- **Specify value:** In terms of satisfying customers' needs by providing products and/or services with desired capabilities at a competitive price and lead time
- **Identify the value stream:** Referring to the nature of activity being carried out. The value stream is the set of actions that transform a product or service
- **Make the value flow:** By reducing cycle times and batch sizes to the absolute minimum, ensuring each operation is visible, defined, and has a visible status to eliminate possible stoppages in the production process
- **Let the customer pull:** Processes or products are to be produced and delivered on-demand from the customers.
- **Pursue perfection:** Even if the other four lean principles are followed, if the mindset for pursuing perfection has not been developed across the enterprise, any improvement will only deliver a one-off benefit.

[24] Parry, G., Mills, J. & Turner, C. (2010): "Lean competence: integration of theories in operations management practice". Supply Chain Management, 15/3 pages 2016-226.

The lean approach involves the systematic elimination of all non-value-adding activities, leaving only activities that produce value. Lean methods can be applied to improve any process, including manufacturing, product development, marketing and the supply chain[25]. More significantly, many of the approaches developed originally ay Toyota can be applied to aerospace, which is one of the UK's highest value adding manufacturing sectors. According to UK Trade & Investment, the UK is home to Europe's largest aerospace industry and remains second only to the United States globally. In 2009, the sector generated turnover of around £22 billion and new orders of approximately £32 billion. Aerospace is also one of the UK's largest exporting industries, with exports accounting for 70% of the sector's total sales in 2009[26].

In 1998, the Society of British Aerospace Companies (SBAC) conducted a study into the competitiveness of the UK aerospace industry. One of the main conclusions was that in order for it to maintain its position as the world's second largest aerospace industry it needed to retain its competitive edge. As a result, the UK Lean Aerospace Initiative (UK LAI) programme was created in order to promote the best practices of lean manufacturing principles and encourage implementation of such practices in aerospace. Supported by government funding in excess of £2 million, four partner universities (Warwick, Cranfield, Bath and Nottingham) led the research, together with extensive involvement from the private sector.

The IMRC Project

The project supported by the IMRC was an extension of the original UK LAI research, with the main aim being to look at the application of lean principles to product development processes which either had not been subjected to lean analysis or where the degree to which the application of lean principles was valid but unclear. This included:

- Identifying and developing a company's core competences
- Development and continual analysis of standard New Product Introduction measures
- Investigating the impact of Enterprise Resource Planning tools
- Applying lean to the Bid and Proposal phase.

More than 40 UK aerospace companies were involved as collaborators in the research, including BAE Systems, Rolls Royce, Dowty Propellers, Lockheed Martin and Airbus.

The outcomes from the research were taken forward through the publication of over 40 reports via the Society of British Aerospace Companies Best Practice Centre. A series of UK LAI workshops were also held and it is estimated by the IMRC that these were attended by more than 1,200 industrialists and external academics.

Assessment of Economic Impact

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

- Implementing lean processes and defining "core competence"
- Cost savings to the UK aerospace sector

[25] Adapted from: http://www.bath.ac.uk/management/aerospace/leanxeur/
[26] http://www.ukti.gov.uk/export/sectors/advancedengineering/aerospace.html

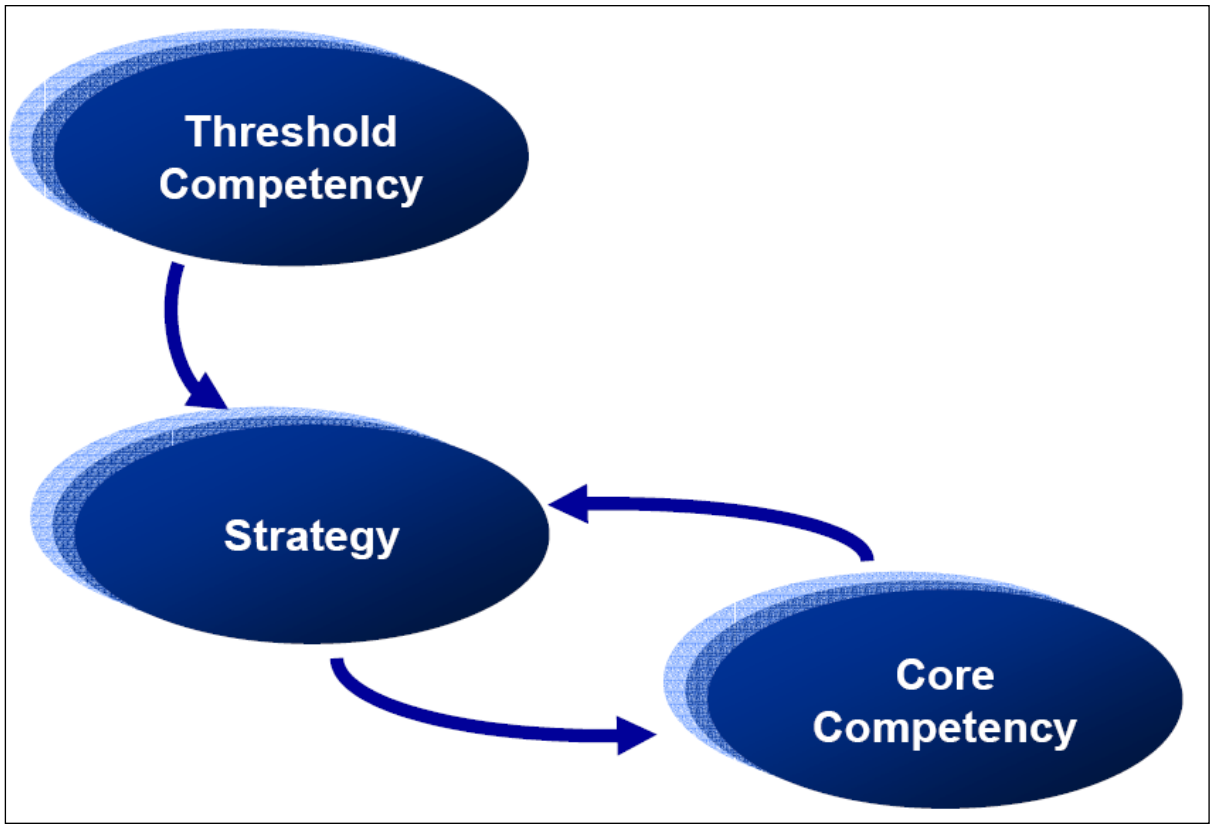
Implementing lean processes and defining "core competence"

Firms have core competencies or skills that they must defend at all costs if they are to survive and prosper in a competitive market. For example, IBM effectively outsourced two of its core competencies (writing software to Microsoft and microchip technology to Intel) and concentrated instead on what it believed to be its core competence, producing hardware. However, the aerospace sector did not have a commonly agreed definition about what constituted a core competence. One of the main outputs from the IMRC project was therefore an agreed definition of the term:

"…Core Competence is a skill/asset/technology that underpins the growth of the business and differentiates the business from its current and future competitors…"

A further key finding of the research was that competence and strategy need to be considered simultaneously. Strategies may identify development needs in core competence, while core competences need to be exploited when planning strategy. This leads to the virtuous circle where competence and strategy drive each other towards continuous improvement (see Figure 10).

Figure 10: Interaction between competency and strategy



Source: UK LAI Working Party and Warwick Manufacturing Group

Having developed a definition of core competence, a methodology for lean implementation, drawing upon core competence theories was developed. The method comprised four tools

- **Market analysis –** Defining the market place and company performance
- **The visible value stream –** Identifying the elements used to deliver products or services to market, identifying value adding activity and flow

- **Customer value analysis –** Achieved by obtaining an objective understanding of the customer base and its needs

- **Financial modelling –** Using a value based management approach to identify where value is created and to financially quantify it

The methodology was applied to a single case study company, Dowty Propellers, and the impacts were observed over a number of years. The company produces and services propellers and systems for military and civil aviation. A subsidiary of this business, Dowty Propeller Repair and Overhaul (DPRO), offers full in-house repair and overhaul capabilities for both metal and composite bladed propeller systems. The core competence methodology was trialled at DRPO for composite bladed systems and the following actions were undertaken by the UK LAI team:

- Customer interviewing was carried out to identify value

- The UK LAI team mapped processes and captured skills and capabilities within DRPO – which included developing a skills matrix of employees

- An assessment of the global market for composite bladed propeller systems and DRPO's competitors

- Detailed cost modelling to reduce overheads and identify profit drivers linked to product streams

The research undertaken at DRPO provided the company with a better understanding of their core competence and the risks to be considered in their future strategy. For example, after mapping processes/skills within the company and assessing the global market, eleven areas of process improvement became apparent and actions were proposed – including additional training for staff where necessary.

In supporting DRPO to understand core competence, the company was able to gain a better appreciation of how customers perceive value and more easily handle costs and revenues. The key outcome was to provide greater confidence in decisions for future growth, which in turn could lead to increased market share and profitability.

In Spring 2009 a post case review was carried out with the DPRO senior management team and those involved with the implementation of the proposed actions in order to explore the impacts and outcomes.

Significantly, analysis showed that DRPO's share of the European aftermarket for composite bladed propellers grew from 5% to 50% in the 12 months following the end of the intervention. As noted by DPRO management:

". . . That growth came following the intervention. There were some other factors around our desire to expand in this market, but this formed the core of our strategy . . . the findings from this linked into what the strategy becomes . . ."[27]

While not entirely attributable to the UK LAI work, DPRO's market share continued to increase after the case study and reached more than 80%.

[27] Taken from: Parry, G., Mills, J. & Turner, C. (2010): "Lean competence: integration of theories in operations management practice". Supply Chain Management, 15/3 pages 2016-226.

Cost savings to the UK aerospace sector

At a wider level, the estimated savings from the UK LAI work are significant. It is possible to analyse these from two perspectives:

- Firstly, from a delivery viewpoint in relation to the benefits achieved from the various workshops runs, company visits case studies etc. Taking into account similar interventions across the automotive supply chain, the benefits of these initiatives have been estimated by the Society of British Aerospace Companies to be around £11.3 million per year.

- Secondly, by looking at the impact the new lean processes have made in terms of helping aerospace become a self sufficient industry. This includes quantifying the impact of applying new methods of lean manufacturing and the value stream mapping discussed as part of the Dowty case study, for example. Based on a 5% performance improvement, SBAC has estimated that the attributable benefits to UK aerospace companies could be worth between £60 million and £240 million per year.

Consultation with BAE Systems on initiatives undertaken separately to those developed by the IMRC confirmed benefits of this order due to the better understanding of lean principles and the opportunity for sharing best practice in a rigorous and structured way.

Position without IMRC Funding

The UK LAI project provided the opportunity for existing lean manufacturing research to continue, with collaborative working with industry an integral part of this. It is unlikely that the private sector would have been prepared to pay the full cost of the research undertaken because there was no guarantee of success and that any outputs would be commercialised. While similar outputs may have been achieved in the absence of IMRC funding, it is uncertain whether the same types of impact would have been achieved over the same time frame.

Consultees

The following people were consulted and reviewed a draft of the case study:

- Mike James-Moore, University of Warwick
- Dr John Garside, University of Warwick
- Phil Astley, Head of System Design – BAE Systems
- Dr Celine Martin, University of Warwick.