Institution: University of Bath

Unit of Assessment:12: Aeronautical, Mechanical, Chemical and Manufacturing Engineering

Title of case study: Improving packaging machine design and manufacture for a reduced carbon footprint

1. Summary of the impact

Packaging is vital for sales and for product protection for all process industries, with the most widely used world-wide being board and film. For example, the grocery sector alone represents about 70% of the UK packaging market, with 10 million tonnes of packaging used each year.

Packaging materials are variable, which poses significant challenges in packaging machine design. A further challenge has arisen due to environmental legislation that requires the use of thinner, lighter weight materials. There is a need to meet these challenges since the size of the world market for packaging machinery is around €20bn, of which 2% is associated with the UK. Research at Bath has helped address these challenges in a number of inter-related areas:

- **Improved performance of an existing business:** Research findings have enabled the creation of new tooling allowing lighter packaging material and reduced customer carbon footprint giving HayssenSandiacre incremental revenue in excess of $8M.
- **Improvement/changes in existing practices:** Guidelines adopted and the provision of training has allowed AstraZeneca to report a 16% improvement in overall equipment effectiveness equating to savings of £1.1M pa.
- **New business activity:** New test equipment, commercially available since 2008, and associated technical services have provided Smithers Pira and Hanatek with £200k of specialised test equipment sales.

Research has been undertaken in collaboration with industrial companies consisting mainly of SMEs, end users and research associations. Impact has been gained by embedding the results within the collaborating companies and by on-going use of the results by research associations.

2. Underpinning research

Key researchers

Dr C Berry (Research Officer 2001-2006); Dr BJ Hicks (Research Officer 1998-2001, Research Fellow 2001-2006, Senior Research Fellow 2006-2011, Reader 2011-2013); Dr J Matthews (Research Officer 2001-2010); Mr C McPherson (Research Officer 2001-2006); Professor AJ Medland (Professor 1995-2009); Professor G Mullineux (Reader 1995-2006, Professor since 2006); Mr G Neale (KT Associate, 2001-2003); and Dr D Sirkett (Research Officer 2004-2006).

Context

World packaging production for paper and board is estimated at $160bn pa, while for plastics, including film, it is at $140bn pa (Twede & Goddard, *Packaging Materials*). The size of the world market for packaging machinery is around €20bn of which 2% is associated with the UK (EUROPAMA website). Companies often design and manufacture this machinery on an evolutionary basis, so that the reasons for successful operation and the potential limitations on performance are not well understood.

Key research

There has been extensive interaction with SMEs, end users and research associations involved with packaging, processing and pharmaceutical equipment. Interest has focused on the modelling and improvement of the interaction between machines and the material and products that are processed. Carton board has distinct non-linear material properties and behaviour that may vary significantly with moisture content. When folded, it is liable to delaminate; a fundamental understanding of this process, [1], is central to the design and set-up of the manufacturing equipment. Machine design is particularly difficult because the properties of the processed material vary with ambient temperature and humidity. It is therefore necessary to understand or, at least,

bound their effects [2]. An understanding of the non-linear mechanical properties enabled the Bath researchers to be the first able to undertake realistic simulation of machine operation, including the prediction of failure [3]. This was a major contribution that enabled operating conditions for existing machines to be established for the avoidance of failure. This in turn informed the development of improved design procedures [4].

Vertical form-fill-seal (VFFS) machines are used to package products in film for almost 40% of packaged product worldwide. The key part of this is the 'forming shoulder', which takes the film from a roll, turns it back on itself to form a tube. When sealed across its width, the tube is formed into bags and product is then introduced. Although the geometry of the shoulder needs to be precisely defined to avoid damage to the film, the requirements have been poorly-understood and the industry has used various semi-empirical 'rules of thumb' to decide the form of a shoulder. The Bath research identified the five main parameters needed to determine the shoulder geometry. With this understanding, other forms of shoulder design are now possible [5]. An approach for designing shoulders for new applications has been established and incorporated in a software tool, which allows designers to create usable designs through the use of a formal methodology. More recent work has succeeded in relating the pull force needed to take film over a shoulder and in experimental determination of the factors affecting the sealing of films. The research has overcome major barriers and led to the use of thinner, lightweight packaging materials.

The results of the research have been encapsulated into a guide and a workbook, [6], intended for industrial professionals in the packaging sector to help them assess and improve their packaging operations. The research began in 2001 and is still on-going.

3. References to the research (* references that best indicate quality)

1*. BJ Hicks, C Berry, G Mullineux, CJ McPherson and AJ Medland. An energy-based approach for modelling the behaviour of packaging material during processing, 2004, Proceedings IMechE, Part C, Journal of Mechanical Engineering Science, **218**, 105-118. DOI: 10.1243/095440604322786983

2*. C Berry, BJ Hicks, CJ McPherson, AJ Medland and G Mullineux. Impact of environmental conditions on the performance of carton board skillets, 2005, Packaging Technology and Science, **18**, 225-241. DOI: 10.1243/095440604322786983

3*. DM Sirkett, BJ Hicks, C Berry, G Mullineux and AJ Medland. Simulating the behaviour of folded cartons during complex packing operations, 2006, Proceedings IMechE, Part C, Journal of Mechanical Engineering Science, **220**, 1797-1811. DOI: 10.1243/0954406jmes109

4. G Neale, G Mullineux, J Matthews and AJ Medland. Case study: constraint-based improvement of an over-wrapping machine, 2009, Proceedings IMechE, Part B, Journal of Engineering Manufacture, **223**, 207-216. DOI: 10.1243/09544054JEM1189

5. CJ McPherson, G Mullineux, C Berry, BJ Hicks and AJ Medland. The performance envelope of forming shoulders and implications for design and manufacture, 2004, Proceedings IMechE, Part B, Journal of Engineering Manufacture, **218**, 925-934. DOI: 10.1243/0954405041485993

6. BJ Hicks and J Matthews, *Understanding Machine-Material Interaction: A Practitioner's Guide* (ISBN 0-86197-152-3) and *An Illustrated Workbook* (ISBN 0-86197-153-1), University of Bath, 2009. (Can be supplied by HEI on request)

4. Details of the impact

The **context** of the Bath research is concisely stated by the Chief Executive of PPMA [A], prior to the assessment period, who indicates that the consideration of climate change, packaging waste legislation and economics leads to the conclusion that the use of thinner packaging materials is advantageous, particularly if achieved without a significant reduction in packaging machine performance.

The **impact** achieved has been in a number of inter-related areas.

Modelling of machine-material interaction: The Bath research has generated new computer-based models to represent the complex interaction between machines and materials during processing. This helps to reduce the volume of packaging and to make use of new lighter and more environmentally friendly materials. The significance is illustrated on the website of Smithers Pira [B]:

> '*The tools and methods created by the research team have enabled the optimum material properties to be established for particular processes, the re-engineering of packaging design, the redesign of tooling and matching of tooling to new and emerging materials, and the determination of robust machine settings (less sensitive to material variation). It has been shown that the ability to represent machine-material interaction enables reasoning about material, machinery and product within a single approach, and bridges the link between the three key supply chains: materials, machinery and consumer good manufacturers. The latter of these is critical for consumer goods manufacturers to meet the ever-increasing legislative requirements* [European packaging and packaging waste directive 2004/12/EC of 11 February 2004 amending 94/62/EC11, 2004].'

Improved performance of an existing business: The research on the VFFS process has been undertaken in conjunction with HayssenSandiacre, a global manufacturer of flexible packaging systems. Its Technology Director states of the Bath research findings [C]:

> '*Our customers are continually requiring us to handle thinner, lighter-weight, recycled and bio-based packaging materials ... to comply with the new packaging waste legislation ... We believe that this research has helped us to develop improved techniques for creating forming set tooling that better enables the creation of right-first-time-tooling ... and significantly contributes to reducing our customers carbon footprint. The main business improvement resulting from successful completion of this research has been our ability to offer forming set tooling which creates package styles that were previously difficult or not commercially viable.This work has significantly contributed to the sales of a large number of machine systems, with approximate total revenues of $8M.*'

The research on forming shoulders has put its design on a much firmer foundation. This has led to the creation of a design methodology that has been incorporated into a design tool called FORMIT. As part of the collaboration, HayssenSandiacre has used the tool to define 'non-symmetric shoulders', which was not previously possible. This has enabled the company to move to a **new business activity** with the design and manufacture of machines, for example, new 'quad-pack' designs for Cadburys. The Technology Director states further [C]:

> '*We are delighted to have been involved with these projects and the provision of machinery, equipment, manufacturing capabilities and engineering time as part of our industrial contribution has been a very good investment for HayssenSandiacre.*'

Improvement/changes in existing practices: The findings relating to machine-material interaction have been presented as a workbook [6] that provides a general methodology for understanding machine-material interaction and the realisation of targeted and sustainable benefits. They may be practice, process or design led. This publication includes detailed industrial case studies, worksheets and templates. In particular, AstraZeneca has successfully used the methodology within the UK to **improve its processes**. Early in the assessment period (2008), the Manufacturing Engineering for UK Operations stated that [D]:

> '*... the AstraZeneca packaging department at the Macclesfield site has been working with the University of Bath to introduce their methodology for understanding Machine-Material Interaction (MMI) and to deliver training courses for our manufacturing teams in Macclesfield. The methodology has now been incorporated into our manufacturing operational excellence programme and along with Reliability Centred Maintenance (RCM) forms a fundamental component of our programme. Our Operational Excellence programme has already resulted in a 16% improvement in Overall Equipment Effectiveness (OEE) for one packaging line. The*

significance of this is underlined by the fact that a 1% improvement in OEE is worth an estimated £70,000 to the business each year.'

New business activity: Based on the research into the deformation and delamination of carton board, an item of equipment for testing the crease resistance of carton board was created as a **new product**, in conjunction with Smithers Pira (formerly Pira International) and Hanatek. It is used to assess material properties in order to determine the settings for good running of packaging machinery. This specialised equipment is now commercially available (via Rhopoint Instruments) [E] and is used by Smithers Pira as part of its commercial testing:

'*Other developments to come out of this research collaboration with the University of Bath is a new item of industry specific testing equipment ... This equipment is now commercially available and in use worldwide (costing in the region of £10,000 with approximately 20-25 units sold).*'

Collaboration with research and trade associations: Where possible, research is undertaken in collaboration with research and trade associations, in particular, with Smithers Pira, the Processing and Packaging Machinery Association (PPMA), and Campden BRI. This collaboration ensures access to the research outcomes by members of these associations, thus ensuring that real problems are investigated [F] and facilitating dissemination of the results of research. PPMA indicates [G]:

'*In terms of direct benefit for PPMA members, one of the most successful research projects has been the 'Impact' research project led by the University of Bath which modelled the behaviour of carton board and flexible films in packaging machinery.*'

This has allowed the offering of **new and improved services**, particularly with respect to Smithers Pira, which currently employs around 80 people in the UK and provides testing and consultancy services to the paper board, printing and packaging industries. It has enabled Smithers Pira [B] to produce guidelines providing new protocols relating to the properties, storage and processing of folding cartons. It has provided this information to its member base of 200 companies worldwide through a web resource on its website and through presentations at trade conferences (e.g. IAPRI, International association of packaging research institutes). The Senior Scientist of Smithers Pira states [F]:

'*Experience from the collaboration with the University of Bath has improved our techniques for investigating complex, challenging problems, where standard tests are either not available or inappropriate. The experience gained enables Smithers Pira to 'win' a greater proportion of high-value and value-added customer enquiries which would have historically been lost or turned away.*'

5. Sources to corroborate the impact

A. PPMA Machinery Update, Issue 1, Volume XVIII, Jan/Feb 2007 (editorial, page 3, also page 6), www.machineryupdate.co.uk/pdf/mu/MU_2007_January.pdf.

B. https://www.smitherspira.com/testing/research-collaborations.aspx.

C. Corroborative statement from Technology Director, HayssenSandiacre, 13 June 2013.

D. Corroborative statement from Manufacturing Engineer UK Operations, AstraZeneca, 19 September 2008.

E. http://www.hanatekinstruments.com/Carton-Force-Analyser.html.

F. Corroborative statement from Senior Scientist, Smithers Pira, 27 June 2013.

G. PPMA Technical Services, www.ppma.co.uk/about/pdf/PPMA Technical Services.pdf.