Implementing a continuous Innovation Culture in a SME

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ABSTRACT

Prior to 2004 Rapid International were a small company employing 50 persons and their main output was design, manufacture and installation of bespoke concrete batching plant. The company had 11% of the market in the British Isles, but the industry as a whole had stagnated through lack of innovation, leading to increased price competition from new start-ups entering a mature craft based industry based on fabrication of relatively low technology products. It was seen that to achieve growth and profitability the company would have to change the way it did business.

Following fifteen years of grant aided research, knowledge and technology transfer collaboration with the Ulster University, Rapid International are now a high technology company focusing on manufacturing of mobile concrete batching plant and related products for worldwide export. Better management organisation and structures are in place; new continuous improvement procedures and techniques have been introduced, as has new CADCAM technology. Productivity, efficiency and product quality are improved, and costs reduced. Most importantly the company culture has changed from one focussed on production to one focussed on innovation. The initial part of the paper outlines the theoretical, engineering and business approaches and techniques that led to new strategic, tactical and product planning underpinning a seven-year programme of change to a culture of continuous innovation. The second part of the paper gives an account of product innovations under the new culture and finishes with an account of a project embracing science in innovation.

Keywords: Innovation, creativity, new product design, product development, strategy

1. INTRODUCTION

Prior to 2004 Rapid International was a small company employing 50 persons and their main output was design, manufacture and installation of concrete batching plant. The company also designed and manufactured a range of pan and planetary mixers mainly for use in concrete batching plant to their own design. The company had 11% of the market in the British Isles; however growth and profitability had stalled due to increased price competition from new entrepreneurial start-up companies. The new companies were generally formed by ex-employees of established concrete batching plant companies. The newcomers understood the mature technologies used in bespoke batching plant, and knew they could establish their own business and compete on price with the more established companies because of lower initial overheads. As a rule, customers are generally happy to purchase products with mature technology more cheaply from start-ups, as the product type has converged to a unified design architecture and generally all use standardised proprietary items, components and sub-assemblies. This means any on-going servicing, maintenance and repair can be undertaken by third parties without recourse to the OEM. Management at Rapid international recognised that to achieve growth and profitability Rapid International would have to reach a wider and higher added value market, and clearly this could not be achieved with existing operations and products. Discussions were opened between the academics at the University of Ulster with a view to establishing a relationship aimed at helping the company improve profitability and re-establish growth.

Following analysis of the existing business operations at Rapid, staged plans were generated that would see the company, with support from the University, change from a company focussed on production to one focussed on innovation. Company policy was rewritten to reflect this new vision, and the plans were translated into objectives that would see the overall aim achieved. To support the company achieve its objectives, a number of Government grant aided Knowledge Transfer Partnership (KTP) programmes were planned, which enabled knowledge and technology from the University to be embedded in the company. Where appropriate these KTP programmes were supported with Government grant aided research programmes, particularly in the area of new product innovation.

2. ACADEMIC ANALYSIS OF THE PREVAILING SITUATION IN RAPID

When the collaborative activity between the University of Ulster and Rapid International commenced in 2004, the company was an engineering based SME designing and manufacturing bespoke concrete batching plant for the building and construction industry. The academics had over thirty years of experience working with manufacturing industry and through research, knowledge and technology transfer, and had built up a reputation as innovators in the manufacturing sector of industry. Work generally focussed on helping SME's with product, process and systems innovation. Most of the academic research and experience was project related, whereby the collaborating company would require a (usually) one-off project to be completed and associated relevant, skills, techniques, processes and procedures to be embedded within the company; most projects were of two or three years duration.

This collaborative activity was to be different, the MD realised Rapid had to change if it was to grow and prosper. At that time business turnover had stagnated, costs were rising and increasing competition from entrepreneurs entering the established market for bespoke concrete batching plant was making the market predominantly price competitive. The bespoke concrete batching plant industry itself had stagnated; there were no new technological innovations in product, process or system. The academics had observed similar situations in engineering-based industry in the past. When technological innovation comes to a standstill in an engineering sector there is little by way of differentiation between competing products. To secure sales companies compete on price. Entrepreneurs familiar with the technology and the business enter the market on a low price basis, frequently without the costs inherent in a well-established company. Margins are squeezed and this further inhibits investment in new product development or innovation by the established companies.

This observation fits in with the maturity and decline stages in the product life cycle (1). An example of this kind of strategy is that of Amstrad when the company entered the PC clone market with the PC1512 in 1986. The product used mature technology but was a quarter the price of competing products at the time. It took 25% of the European market for personal computers. The difference between the Amstrad case study and that of craft-based engineering industries like Rapid, is that Amstrad were effectively opportunists entering a market where there was much technological innovation. Once the opportunity for making profit based on mature technology and low price had passed, left that market behind and entered the communications market (2, 3). The current Covid-19 outbreak has created a market for opportunist supplying the medical, nursing and care markets with Personal Protective Equipment (PPE). The need is great, the technology is mature, and the law of supply and demand allied to escalating prices has created opportunities for start-ups and new traders.

The price structure of bespoke concrete batching plant comprises the primary costs of materials, proprietary items and labour to make, assemble and install the plant, plus indirect and overhead costs. Associated key cost elements are transportation (or shipping), installation and snagging. These associated costs rise in proportion to the distance between the manufacturing base and the construction site, and more where various modes of land and sea transport must be used. The transportation, installation, commissioning and snagging costs, both actual and unforeseen, associated with distance, and the tight margins on plant in a price competitive market, meant for Rapid that their geographical market for bespoke concrete batching plant was restricted to the UK and Ireland.

Traditional economic theories look to the market as the environment in which business is conducted (4); in effect they attempt to optimise the efficiency of the economy with the objective of obtaining a marginal gain in growth. These forces are (5):

1. Adding to the labour force
2. Improving the quality of the labour
3. Adding capital (investment)
4. Improving the rate of productivity of the capital
5. Generating real cost reductions

The fifth force is vague and goes under various names although the USAID document (5) did settle on real cost reduction as the description of this element. In national terms economic growth is described as something of a mystery, and it was Arnold Harberger who first observed the limits of economic research (6). He concluded that the tremendous shift over time in a nation's total production is unaccounted for in such theories. It was Schumpeter (7) who identified that the "historic and irreversible way of doing things is innovation".

It was evident from even initial analysis of the Rapid International situation that marketing or management in relation to the traditionally identified economic forces and way of conducting business was not going to resolve anything, what was needed was a new strategy, a new way of thinking, in effect policy, strategy and tactics based on innovation. This observation agrees with that of Bellon and Wittington (8) who observed that for effective innovation to occur, strategic behaviour needs to replace management. In this context they record that changes are intentionally provoked, that forecasting replaces guesswork and that change is not only planned but is part of a continuous line, in effect they argue for continuous innovation. Schramm (9) in his discussion of successful continuous innovation and change in mature firms was perhaps more radical, as far as formal management based on bureaucratic procedures and hierarchical structure is concerned, and referencing Weber (10) suggests that entrepreneurial capitalism, driven by charismatic entrepreneurs, does not tolerate bureaucratic decision making.

3. PHASE ONE: DEVELOPING A PRODUCT STRATEGY BASED ON CONTINUOUS INNOVATION

Over several years working with multinationals in funded research, knowledge and technology transfer programmes (for example 11, 12, and 13) the academics observed the practical application of this fifth element of economics. As a general observation and analysis based on tangible evidence, the multinationals collectively (and independently) sought to implement “cost saving proposals”, and this they did under three headings (14):

- New product programmes
- Engineering change
- Reduce manufacturing costs

Now applying the need for a strategy based on continuous innovation to the three headings under which “cost saving proposals” are observed to occur in multinationals, gives an indication of the types of innovation that may be necessary in an engineering based SME. The cost saving proposals can be redefined in terms of innovation as follows:

Cost Saving Proposal	**Innovation to achieve the Cost Saving Objective**
New product programme	Radical or incremental innovation in product, process or system, brought about through scientific discovery, identification of a latent market, or (architectural) innovation through creative design
Engineering change	Technological innovation in product or process leading to (modular) innovation
Reduce manufacturing costs	Application of modern management techniques such as Kaizen, lean manufacture and 6-Sigma, possibly leading to organisational innovation

Table 1: Innovation in Relation to Cost Saving Objectives

At the commencement of the association with University of Ulster, Rapid did not meet any of the criteria in relation to cost saving proposals.

Freeman (15) identified six strategies and related these to scientific and technical and functions within the firm, a brief explanation of these strategies is:

1. Offensive: Designed to achieve technical and market leadership
2. Defensive: Being a good “second” and letting the offensive strategy-based companies make the mistakes
3. Imitative: Competing in mature markets with “cloned” products
4. Dependent: Generally, within a supply chain

5. Traditional: Based on the supply of "mature" and "ageing" products for which there continues to be a market
6. Opportunist: Respond to an opportunity based on the manufacturing capability of the company, perhaps supply of a niche market product not necessarily in the producer's line of business

Analysing Rapid International based on these criteria the category that best suited the company was "traditional". This is a category that is generally reserved for companies producing traditional artefacts in the aesthetic sense, like furniture or jewellery, and not applied to companies operating in the field of technology. However, it does sum up the offerings of businesses that do not move with the markets, they end up producing mature and ageing products and selling into a price competitive section of the market. Inevitably they go out of business through lack of investment.

In the 1990's, research was undertaken to ascertain the criteria necessary for successful product development in SME's (16). This work identified that successful SME's tended to display similar characteristics:

1. Relatively high technology in product or process
2. Own brand products with high relative advantage
3. Standard product range if high in exports
4. Customised products if high in domestic sales
5. Continuous incremental product development
6. Excellent sales organisation
7. Own channels of distribution and control of channels of distribution
8. Short term (2-3 months) association with customers but good product/service wins repeat orders

Application of these criteria to Rapid fared little better. The company did meet criteria 4, customised products for the domestic market, criteria 7, own channels of distribution, and criteria 8, short term association with customers during design, manufacture, installation and commissioning of bespoke products, and 60% of customers did generate repeat orders in later years. However, they did not meet any of the other factors associated with successful SME's.

Booz, Allen and Hamilton (17) identified six categories of product that could be deemed to be new to a company. Beside each a product category a corresponding type of innovation is suggested (Table 2). (Depending on how the reader interprets innovation, the notion that each of these "new" products could be labelled as an innovation is perhaps stretching the understanding of innovation beyond acceptable boundaries).

Analysing Rapid International based on these new product criteria the company was also found wanting. Although the company would make improvements and revisions to bespoke products, this action was inevitably reaction to customer demands and not proactive.

Booze, Allen and Hamilton Product Category	Corresponding Innovation Category
New-to-the-world products	Radical innovation
New product lines	Company innovation
Additions to existing lines	Evolutionary innovation
Improvements and revisions to existing products	Incremental innovation
Repositionings	Marketing innovation
Cost reductions	Organisational innovation

Table 2: Innovation categories corresponding to Booz, Allen and Hamilton product categories

It was clear that if Rapid was to follow an innovation-based strategy, this strategy would have to embrace a feasible (new) product plan. This observation is in keeping with similar observations recorded by Tidd, Bessant and Pavitt (18), when discussing growth and performance of innovative small firms stated that they were more likely to be involved in product than process innovation.

BS7000 (1989) (19) on managing innovation gives a good account of the activities and tasks involved in managing innovation and the relationship between them. Stated simply this requires:

a) Generation of a policy document explaining and defining the business the company is in
b) A strategic or business plan generally looking at short, medium- and long-term objectives
c) A product plan that is compatible with the company policy and strategy
d) A project plan for each product clearly identifying resources, costs and timescale required
e) A resource plan that is designed to facilitate the product plan and includes people skills, facilities and equipment, externally sourced facilities and equipment, organisation
f) Financial plans to ensure investment is available as required and there is sufficient cash flow
g) Management plans to ensure organisation wide policies are implemented and functional

It had been decided that Rapid International should change from a company focussed on production to one focussed on innovation. To help draw up a company policy, the company management with the support of the academics evaluated the then current state of the business, in effect conducted a SWOT analysis. Rapid was known within the British Isles as a company who designed and manufactured quality bespoke concrete batching plant. They knew the building and construction industry very well and were very familiar with plant and equipment that produced concrete and concrete products. They knew their competitors, their strengths and weaknesses. Another asset the company had was people; the most crucial were six very well experienced engineers each with a degree in mechanical or production engineering. The skill and knowledge of the engineers meant there was a very flat management structure. This type of structure is free from unnecessary bureaucracy, fits in with the loose matrix structure generally considered the best for agile creative work, and is in agreement with the sort of structure envisaged by Weber (10), Schaum (9) and Bellon and Whittington (8). The engineering team reported directly to the

MD generally through the engineering manager. Production operatives were skilled in engineering fabrication and managed by a professionally qualified production engineer. Weaknesses were the limited product line and the inability to operate outside the British Isles.

From a policy perspective, in pursuit of a strategy based on innovation, it was decided the company should remain in the concrete business, since this is where all their knowledge and expertise lay, but they should seek to expand their business beyond the British Isles and into export markets. Applying the McKeag criteria (16) for successful SME's in Ulster, the company assessed opportunities and decided on objectives against each of the criteria.

The only product that met the requirement for relatively high technology in product or process was the own brand mixers, primarily manufactured for installation in the company's own bespoke concrete batching plant. Since all other concrete batching plant manufacturers used third party concrete mixers in their plant, it made sense to develop the own brand mixers and offer them for sale to other manufacturers of concrete batching plant but on a worldwide basis. An advantage of this strategy is that a concrete mixer can be fully tested before leaving the factory, and shipped in a container, significantly reducing transportation costs over that experienced for bespoke concrete batching plant.

A weakness was each concrete mixer was craft built, meaning there was subtle differences between mixers, even when of the same capacity. To reach the objective of standardisation, it was decided that machine jigs and assembly fixtures should be made for each component and sub-assembly, and there should be more investment in CADCAM and CNC machine tools. The range of pan and planetary mixers should be extended to cover the complete spectrum that customers were likely to need, this would mean Rapid would a one-stop-shop for all pan mixers (20) and planetary mixers (21). There should be greater commonality of components and proprietary items between products in the same range, thus gaining cost advantage from volume and minimising variety in stock. This would also facilitate shipping of spares to customers.

To meet the requirement for access to channels of distribution and control of those channels, it was decided the company should set up agents and distributors in each geographic region, and each of these regions would be served from company headquarters by is own sales person.

Looking at the Booz, Allen and Hamilton categories of new product (17), Rapid had no new innovative products. First step on addressing the issue was to conduct market research using their sales team and a marketing consultant. Using in house knowledge and understanding of the concrete business they prepared a market intelligence report, with a focus on new product opportunities. These activities identified several potential new product lines:

- Twin shaft mixers
- Mobile concrete batching plant
- Continuous mix mobile concrete batching plant
- Standard concrete batching plant

The company had observed an increasing interest in twin shaft mixers from customers, as some believed they gave a better mix when compared to pan and planetary mixers, and because they were more compact for the same output. When customers requested concrete batching plant with a twin shaft mixer, Rapid fitted a third-party mixer, so it made sense to develop their own range of twin shaft mixers (22).

Another product identified was continuous mix mobile concrete plant. The advantage of this type of plant is its continuous output, so it was ideal for large pours, such as that required when building multi-storey concrete buildings using on site shuttering. Also, with the increase in oil prices at that time, concrete was proving a cost effective and durable alternative for the substrate in new roads and it helped if the plant could move as roads were laid. The company had previously attempted to enter this market and had designed and built their own mobile plant, but it had attracted few sales. To meet the requirements for continuous mix mobile batching plant, the company decided to completely revise the existing design based on experience and current knowledge of the market. They also identified a need for a range of continuous mixing plant based on outputs from 400 cubic metres per hour upwards. In the redesign every opportunity was taken to introduce standardisation and commonality across the envisaged range. In effect they designed a base platform based on robust design principles and the principles of design for manufacture and assembly. The new plant was in effect a "trailer" that could be shipped as such to any world destination, hitched to a tractor unit at the destination port, and towed to the site (23).

To complement their continuous mix mobile concrete plant, the company identified a requirement for mobile concrete batching plant that could leave the factory fully tested and be container shipped worldwide. This plant was designed to be self-erected in a few days without the need for additional structures but could also be decommissioned and moved on to another operational base (24).

To compliment the bespoke concrete batching plant, the company decided to develop a range of standard concrete batching plant. The benefit of this plant is that it can be selected "from a catalogue"; elements built and tested in the factory, shipped in containers to the customer site, erected on a prepared base and be operational in a matter of hours (25).

Based on the Booz, Allen and Hamilton categories of new products (17), the company, with support from the University, had identified products that fitted three of their categories. The twin shaft mixer range, the range of mobile concrete batching plant, and the standard concrete batching plant range were all products new to Rapid. The additional pan and planetary mixers were additions to existing lines, and the continuous mix concrete batching plant was an improvement and revision to an existing product.

Analysis based on Freeman's strategies (15) now demonstrated Rapid was moving from the traditional category to the dependant category with regard to manufacture and sale of pan and planetary mixers, in effect they were in a supply chain whereby they competed for sales with other mixer manufacturers. Advantage here is that there are relatively few mixer manufacturers on the world market, mixers are a high added value product, and they can be easily, and cost effectively shipped to their world destination. Other products identified were to some extent in the imitative category, as competitors existed, and to some extent they were defensive as it was obvious that markets existed for these products.

Since Rapid had decided to be proactive in innovation, they still wished to develop products that under Freemans strategy criteria could be considered offensive, in other words new-to-the-world products that would see Rapid achieve technical and market leadership. To help identify offensive products, the problem area was explored using the "universal" approach to product innovation allied to creativity based on user centred designs techniques. (26, 27). User centred design techniques are now seen as essential in innovation activity, and businesses not using such techniques will lose out to those who do (28). Observation, based on the technique developed to teach innovation in an academic situation identified the Rapid process of design, which was also the business process used in the company, followed the (simplified) linear sequence of events shown in figure 1.

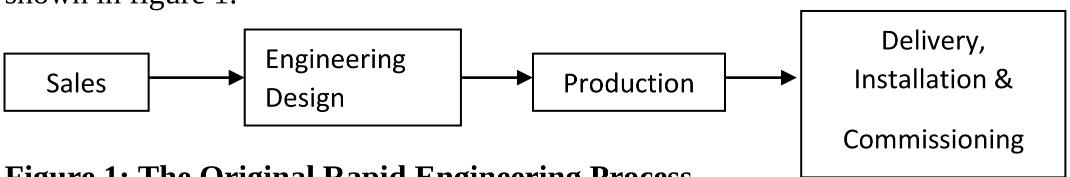

Figure 1: The Original Rapid Engineering Process

The company received invitations to tender either directly from potential customers or through sales. Engineering, based on the information received, would generate a costed proposal for the concrete batching plant. This bid would, through sales, be subject to design modification and negotiation on price. Assuming the contract was awarded, the concrete batching plant would be designed in detail, and drawings passed to production to enable product manufacture. The major proprietary items and sub-assemblies would be shipped to the customer for site installation and commissioning. In this scenario Rapid were, in a marketing sense, designing and making product for known customers.

Academics realised this system had inherent weaknesses. For example sales are not engineers or designers and do not know or understand the capabilities and limitations of technology, they are not abreast of latest scientific, technological and design developments, do not understand them, and therefore cannot be creative and innovative in product negotiations with clients (27). Designers and engineers get used to doing what they have always done because it is successful, and it is easier to give sales and customers what they want rather than trying to convince them there is something better. Production manufacture products the way they always have, operators become craftsmen and there is detail variation in product, but it works. Designers under pressure to meet deadlines leave detail to shop floor craftsmen because based on experience of similar work they know how to fill in the detail. Everything on site fits because those responsible for installation and commissioning know how the bits fit together and a centimetre here or there can be accommodated on site.

Whilst in the scenario above the potential for problems may be overstated, it is a reasonable account of how many small engineering firms operate. This type of company is largely based on craft skills, fabricating quite large one-off structures to a standard pattern. In the case of Rapid, the company would typically design and install eight to twelve bespoke concrete batching plants per year with a total annual turnover of around £4,000,000. During the growth in building and construction in UK and Ireland in the fifteen years up to 2004, the company faced increasing price competition from opportunists and entrepreneurs entering the concrete batching plant market. Lack of innovation in this type of business scenario and in the context of macroeconomics prevailing at that time is common, and in keeping with long wave cycles such as those of Schumpeter (7) and Kondratieff (29). A simplified explanation of the then economic situation based on Kondratieff long wave cycles, is that money could easily be made out of existing technology through favourable pricing and demand outstripping supply, so innovation throughout the industry was put on hold. Also, credit was cheap and easy to obtain.

This scenario had been observed by the academics in similar market and business environments and the reasons established. It is continuous innovation that keeps opportunists and entrepreneurs out of technical markets. Where there is continuous change in product and manufacturing systems design, and ongoing innovation in product and process technology, opportunists and entrepreneurs are fearful of entering that market. Although generally abreast of current knowledge and technology, they are not prepared to take a commercial risk because the business environment will have changed by the time they have made the necessary investment to enter the market. Where knowledge and technology in product, process and manufacturing systems stagnates across an industry because of lack of innovation, the technology and knowledge no longer pose a barrier. Indirect skills associated with management, administration and business techniques such as accounting and marketing, are transferable across businesses and there is rarely any significant innovation in these. Consequently, opportunists and entrepreneurs can enter a mature technical market usually based on a lower cost strategy (30) or opportunity in a niche market segment. Mature markets are usually price sensitive markets and too often the established company has let indirect costs associated with management and administration get out of proportion to direct costs, making the business less competitive.

Academic analysis of the Rapid engineering process identified several positives. Importantly the company had not fallen into the trap of letting indirect labour costs grow out of proportion to direct costs. In a technical sense all company employees had excellent knowledge of the business, and their experience allied to their professionalism particularly in engineering was a key company resource. Except for the accountant, one full time and one part time office worker, all other employees made a direct contribution to product value.

Based on the universal approach to innovation (26, 27), because they were remaining in the concrete equipment market Rapid International did have the necessary key skills, and the appropriate type of organisational structure was largely in place, although the sequential engineering process, appropriate for bespoke concrete batching plant, was not contusive to new product innovation. It was not feasible to switch the organisational and management immediately from one focussed on manufacture of bespoke concrete batching plant to one suited to innovation, as existing bespoke business would be needed to finance investment in innovation during what was perceived to be a seven-year new plan product development. With support from the academics, and grant-aided research, knowledge and technology transfer programmes; a parallel new product innovation structure was established. Within this structure business activity was led by the MD, and design, technical and engineering issues related to product development undertaken by associates employed by the university but working in the company. As additional expertise was required, staff were seconded from the existing departments. When products were designed, prototyped and tested, designs were handed over to the existing organisation for manufacture and sales. This system was copied from systems in place in Bombardier Aerospace to support concurrent engineering (31) but simplified (Figure 22).

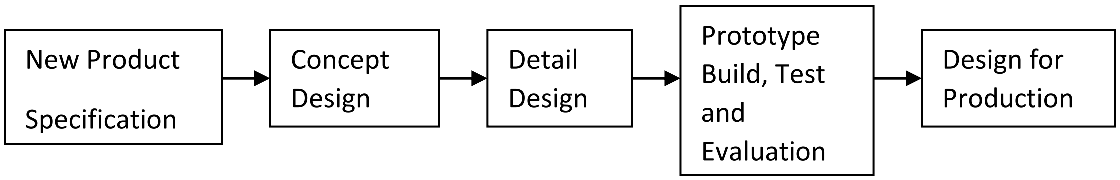

Figure 2: The Rapid New Product Development process

To help identify new to the world products user centred design techniques were employed within the parallel NPD organisation in Rapid. The primary techniques used were user research, interviews and multidisciplinary focus groups. The first breakthrough came very quickly. When users of concrete batching plant were asked in open-ended questioning, to name their biggest problem, all gave the same answer, washing the internals of the concrete mixer at the end of the working day. It generally took between one and four man-hours of work to clean the mixers in a plant, a man had to physically get inside each mixer, and another man had to remain outside to prevent use of the plant. The problems were based on cost and obvious health and safety issues. To resolve the problem further creativity techniques were employed. A power-jet based wash system was ideal and a patented product, based on having a jet-wash placed inside a mixer with the power system external, was designed and developed. The new system, known as a Rapid Jetwash System (33) system can be retrofitted to existing plant, it is fully automatic and can wash the internal of mixers in 4 minutes.

The focus group identified a further new to the world product. The largest pan mixers on the market produce 3 cubic meters of wet concrete per mix. Some claim their mixers are 4 cubic meters capacity this is dry capacity and is in fact around 3 cubic metres when wet. A concrete delivery truck has a typical capacity of 8.5 cubic meters wet slump. It was determined that if a 4.25 cubic meter wet slump pan mixer could be designed and developed, the productivity of concrete batching plant employing this type of technology (the dominant design) could be increased by 30%. This was a significant technical challenge since forces would be greater, and to benefit from cost effective modes of transport, would still need to be shipped within a container. Existing 3 cubic meter pan mixers just fitted into a container. Extensive research and development, proactive engineering analysis, and scientific testing produced a mixer that met all the constraint criteria, and with operational stresses and wear patterns lower than that of existing 3 cubic meter mixers (20).

4. A SUMMARY OF THE NEW RAPID POLICY, STRATEGY AND OUTCOMES

The key aim of the association with the University of Ulster was to improve competitiveness; the decision was made that the company should make innovation in product its key competitive weapon. Evaluation and synthesis of the findings of the academic analysis of the Rapid business led to the formation of a new company policy and strategy based on innovation, with associated objectives primarily based on new product development. It was also apparent Rapid did not have the resource to achieve all goals in a short time so a research and product plan was devised that would see the goals achieved over a seven-year period. A staff training and development plan (not reported in this paper) was formulated whereby the culture of innovation could be embedded within the company in parallel with the new product development plan. In support of the staff development plan and the new product development plan, significant investment was also made in CADCAM and information technology. New business operations, based on supply of standard concrete engineering products to (in a marketing sense) unknown customers, were also developed and embedded within the company. Rapid are now a company with continuous innovation in all aspects of its operations, but primarily in NPD, as its core policy (34). The original product plan has been achieved and new products are under development.

The key achievements of the collaborative research, knowledge and technology transfer activity between the University of Ulster and Rapid International over the first seven years can be summarised as:

- Rapid International are a company focused on innovation
- In-house R & D is in place and there is ongoing collaboration with the University of Ulster
- Rapid produce a range of standard high added value products for world-wide export
- Patents and intellectual property rights are used to protect new designs
- The company use creativity approaches and techniques to help identify new product and market opportunities, and established investment in continuous product and process innovation as their key strategy.
- Rapid work closely with lead customers in developing their new products
- All products embrace the principles of design for manufacture and assembly rules and there is significant component commonality between products
- Rapid invested in fully integrated CADCAM and IT systems
- The company launched the world’s first fully automated system for cleaning the internals of commercial pan and planetary mixers, eliminating health and safety hazards and enabling a one-hour manual task to be completed in 4 minutes
- Rapid launched the world’s first 4.25 m^3 wet slump mixer enabling productivity of concrete batching plant to be improved by 30%

5. PHASE TWO: INRODUCING A SCIENTIFIC APPROACH TO INNOVATION

Following the seven-year period of collaboration between the Ulster University and Rapid International from 2004 to 2011, when the culture changed from one focussed on production to one focussed on innovation, Rapid International continued to innovate. In addition to their range of pan mixers, planetary mixers and twin shaft mixers, and the innovative Rapidjet wash system, they developed and produced a comprehensive range of mixing plant with three subdivisions, mobile, transportable and static.

The mobile division was expanded to include three versions of their continuous Rapidmix plant, the Rapidmix 400, the Rapidmix 600 and the Rapidmix 1000 (24), the three being differentiated by the amount of concrete each could produce per hour. The Company introduced a revolutionary tracked Transmix concrete plant (25) which is self-propelled and can move around building and construction sites as required, it can produce 250m^3 of concrete per hour.

Transportable concrete plant as the name suggests, behaves like a static plant when erected. However, this type of plant takes but a few hours to erect and dismantle, meaning it can be moved to another building or construction site when required. There are two versions of the transportable plant, the Transbatch Mobile Mixing Plant (36) and the Rapidbatch Mobile Concrete Batching Plant (37).

Static batching plant (38) which is not designed to be moved from site to site. The Static Standard Batching Plant is of modular construction, each element can fit into a standard forty-foot (12 meter) container and be cost effectively shipped to any site worldwide. Because each element is built and tested before dispatch there are minimal snagging problems faced with this type of plant. Rapid still manufacture bespoke batching plant (39) on demand to client specification, in a manner like their original production focussed business. This is now a quality plant for discerning customers and is not designed to compete on price.

Except for the occasional need to get laboratory work undertaken there was no research or product development work undertaken between Ulster University and Rapid International between 2011 and 2016. In 2016 the Company approached the University in relation to an environmental opportunity, based on the requirement to design and develop a concrete reclaimer. There was history behind the project in that Rapid International had worked with the University to develop probably the world's first concrete reclaimer in the 1980's. The plant received much acclaim in the media and at trade shows and was also on a UK national television programme called "Tomorrows World". The product was not a great commercial success, although the Company did retain it on their list of products there were few sales. The primary reason for lack of sales was that in the period through to the second decade of the twenty first century the environment was not an important issue in the building and construction industries.

More recently the attitude of clients to the building and construction companies was changing about the environment, and increasingly companies were being asked to demonstrate their environmental credentials as part of tendering for contracts. One such aspect under scrutiny is disposal of waste material, surplus concrete being one element of critical concern, another is use (and reuse) of water, and another is pollution caused by transportation to and from building and construction sites. This change in attitude led to Rapid customers enquiring about supply of a concrete reclaimer, so they in turn could demonstrate to their clients that they were taking the environmental issues seriously. There was a problem from Rapid's perspective, the 30-year-old design could not meet the concrete reprocessing requirements of many customers, and it used a lot of water in the separation process. Clearly a more creative solution was required.

In early discussions with potential clients an outline specification for the new reclaimer was identified:

- Reprocess $1m^3$ of wet slump concrete per minute
- Use minimal water
- Be capable of accepting concrete from both low and high ejection vehicles
- Reclaimed material should be capable of reuse
- Comply with legislation on air, water and noise pollution
- Comply with health and safety legislation

During preliminary discussions with the academics it was suggested that Rapid International would need take a more scientific approach to the problem of concrete reclamation if the objectives were to be reached. Research by the academics identified that there had been relatively little scientific work undertaken in relation to concrete reclamation and concrete mixing. The outcome of the dialogue was a proposal for a project embracing a multi-disciplinary, industry-academia, interdepartmental partnership aimed at developing an innovative, highly efficient and sustainability-focused mobile concrete reclaiming equipment.

The project was submitted to Innovate UK for funding via a 24-month Knowledge Transfer Partnership. The project united a diverse team, with industry expertise in mechanical design and fabrication, and academic experience in both product and process innovation and construction materials technology (UU), as well as graduate-level experience in mechanical engineering. While the project's core strategic aim was to develop innovative mobile recycling equipment, another underpinning goal was to strengthen Rapid's focus on customer technical demands, R&D and innovation in order to deliver new business streams and, ultimately, increased profitability.

Throughout the KTP, Rapid International ensured all aspects the desired product specification were met, and the constituent parts of the separated concrete were suitable for beneficial re-use. The cost and environmental benefits of this project proved to be significant and in direct alignment with the UN's key Sustainable Development Goals – issues reinforced as internationally topical at the World Economic Forum earlier this year (40). Concrete is the world's most ubiquitous construction material, with around 25 billion tonnes manufactured globally each year. This equates to around 6.4 million truck loads a day or 3.8 tonnes per person in the world each year. In terms of wastage, around 5% of all in situ concrete is unused on site. If un-used or landfilled, this comes at a significant environmental cost, as each of the 4.65 billion tonnes of cement manufacturing globally each year carries a greenhouse gas-emissions price tag of approximately 0.9 tonnes of CO2e. As such, technologies to efficiently reclaim unused concrete are highly relevant on statutory, economic, social and sustainability grounds.

Despite possessing excellence in mechanical design and fabrication, Rapid International were lacking the required expertise in production/process innovation and fundamental concrete technology required to meet the target. All aims were achieved through investigative research, laboratory research, use of proof of principle models designed and manufactured using rapid prototyping for evaluation, and finally embedding elements of the design into other products for full scale physical testing and performance qualification.

The partnership delivered enhanced performance to the existing (Mark 2) concrete reclaimer. During the project enquiries were made for two reclaimers, one from New Zealand and another from Australia. Rapid realised that the new (Mark 3) reclaimer could not be developed and delivered within the client's timescale. However key elements of the new reclamer were sufficiently advanced to permit their incorporation into the tried and tested Mark 2 reclaimer (which became the Mark 2A), and this modified reclaimer would meet the performance requirement of the customers. The two Mark2A reclaimers were manufactured, installed and commissioned within the timescale of the KTP, two more for other customers are, at the time of writing are being manufactured.

As alluded to earlier. Rapid International would design and construct quality bespoke concrete batching plant to customer requirements. During the reclaimer project Rapid had a timely approach from the nuclear industry in relation to their need for custom designed concrete batching plant to meet strict criteria. In addition to meeting strict concrete quality standards, a key criterion was that everything that would go into the plant must be used including water and nothing could come out. A key element of the new concrete reclaimer was that all materials including water could subsequently be used in the manufacture of product, thereby eliminating environmental impact from waste. The water system for the new reclaimer was sufficiently developed for incorporation into the design of the bespoke concrete batching plant. To date two have been delivered and commissioned and two others are being manufactured.

The new concrete reclamation plant, which was a key objective of the partnership, has been designed and is under manufacturing development. Some elements have been tested in the University; some innovative features have been incorporated into other advanced company products being developed in parallel (see above regarding bespoke concrete batching plant for the nuclear industry).

A new rapid prototype machine was purchased as part of the research and development programme, and engineering design staff within Rapid International have been trained in use of the new rapid prototype system. It is now primarily used for making proof of principle models of new product designs for test and evaluation. The staff, who are increasingly innovation conscious, are on the lookout for new ideas, and as can be seen from the diffusion of several new reclamation plant ideas into the development of other new and improved product lines. The concrete reclamation project has improved the innovation capability of the Company.

Use has been made of university staff and laboratory resources to develop scale materials used in the test and evaluation of proof of principle concepts, and in the evaluation of flocculants. The laboratory staff and academic staff have gained experience in leading edge new product innovation, and the science that underpins those ideas.

The concrete reclamation project for the first time made use of the materials science underpinning the production of concrete products. This project also had a profound impact within Ulster University's School of the Built Environment by kick-starting a number of educational/research initiatives.

The research and development collaboration between Rapid International and the Ulster University is continuing. Upcoming projects are looking more closely at the materials science of concrete mixing, the chemical science of mixing and the mechanical science of mixing. It is expected from these projects that even more environmentally friendly outcomes will arise. These will be in terms of the reduced environmental impact of concrete production and the reduced environmental impact of the new concrete products.

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