SYSTEMATIC DEVELOPMENT OF A

HIGH BITUMEN CONTENT EMULSION

A Thesis
presented in fulfilment of
the requirements for the degree of
Master of Technology in Product Development
at Massey University.

PHILLIP CLARK

1998

ABSTRACT

A product development approach appropriate to a medium sized civil engineering company was developed in this study. The approach was practically demonstrated to the company through the development of a high bitumen content emulsion.

Product development processes were reviewed and related to the specific company environment to develop an appropriate six stage process consisting of: Project Start, Pre-development, Laboratory Development, Mid-scale Development, Full-scale Development and Commercialisation. The high bitumen content emulsion product was taken from the Project Start stage through to the Full-scale Development stage. During each of the stages, suitable product development systems were generated to practically implement the process.

During the Project Start stage, idea capture systems were created and scoring models were developed to initiate development projects. Avenues to allow greater information collection were demonstrated to the company and a cataloguing tool was developed to assist in the organisation of a technical library useful for product development. During the Pre-development stage, marketing and technical specifications were produced to guide later development. The Laboratory Development stage had three phases: initial design, detailed design and optimisation. Experimental design was demonstrated to the company as an appropriate technique to conduct detailed design for formulated and processed products. A full factorial experimental design with four factors at two levels identified an optimum area which was further explored to produce an optimised high bitumen content emulsion at the Laboratory Development stage.

A lack of Mid-scale equipment meant scale-up was conducted on a full-scale level in this study. Two full-scale trials were run; both emulsions were stable when exiting the production mill however the emulsion was unable to tolerate conditions it encountered upon entering the spray tanker. Possible causes as to the observed instability were rapid cooling of emulsion, dilution with water, excessive shearing during circulation, incompatibility with bitumen or the formulation. All of these factors were investigated

with no conclusive results. It is recommended to further investigate the composition of bitumen used by Higgins as to its suitability for high bitumen content emulsions. A means to test emulsion application variables on a laboratory or mid-scale level are also recommended in order to investigate and solve the problems.

The tailored product development approach and supporting systems developed in this study can be used by the company in future to carry out systematic product development.

ACKNOWLEDGEMENTS

I wish to thank my supervisor John Henley-King, for his willingness to assist, guide and encourage throughout the work. I would like to express my appreciation for the voluntary input of an experienced and well respected product development mentor; Mary Earle, who provided much direction and advise to this thesis.

The research work was financially sponsored by the Graduate Research in Industry Fellowship. and Higgins Contractors Limited; I appreciate the assistance and opportunity the scheme has provided.

There are a number of other people whom I wish to thank also, whose contributions have been greatly valued.

* Higgins Group Technical Manger, John Bryant for initiating this valued learning opportunity and assisting in the management of the project.

* Higgins Product Development Technologist, Sean Bearsley for offering his valued opinion and technical advice.

* The staff of the former Consumer Technology Department including: Peter Robertson, Aruna Shekar, Rodney Adank and Tom Robertson.

* To my family, friends and flatmates; I have appreciated all your support.

* I also thank the Lord for His strength and guidance.

Finally, I would like to specially acknowledge my parents, Brian and Ruth Clark for the wisdom and input they have given over the years.

TABLE OF CONTENTS

LIST OF TABLES

Table

List Of Figures

Figure

LIST OF APPENDICES

Appendix

GLOSSARY

Aggregate	A hard inert material such as gravel, crushed rock slag or sand.
Binder	Material which secures aggregate to road surface. Comprising of bitumen, solvent, polymers or other solid material.
Break	The destabilisation of an emulsion resulting in the separation of emulsified phases (demulsification).
Chip seal	A road surface consisting of a stone chip layer held by a binding material.
Cut-back	Bitumen liquefied by blending with petroleum solvents.
Cutter	Petroleum based solvent such as kerosene, turpentine or naphtha.
Ionise	Chemical interaction leading to the formation of ions.
Hydrophilic	Water-seeking.
Hydrophobic	Water-fearing.
Slurry sealing	A pavement sealing technique in which a mixture of bitumen emulsion, fine aggregate, mineral filler and water are overlaid on an existing pavement to maintain a uniform and skid resistant surface.
Wetting	The reduction of interfacial tension.

1. INTRODUCTION

Adopting a systematic approach to product development provides a company with a standard and repeatable method which enables it to more consistently create products that fulfil customer needs and generate wealth. When adopting a systematic product development approach, the approach needs to be tailored to the specific needs and environment of the company.

The goal of this study was to tailor a product development approach to a medium sized company, Higgins Contractors Limited and practically demonstrate this approach through the development of a high bitumen content emulsion product. There are therefore two aspects of development addressed throughout this study:

- The development of tailored product development systems, which make up the entire product development approach.
- The development of a high bitumen content emulsion product.

These two areas of development were intended to provide the company with a new product and an appropriately tailored product development approach which could be applied to other products in the future.

1.1 COMPANY BACKGROUND

Higgins Contractors Limited was founded in Palmerston North by Dan Higgins in 1963 as a drain laying business. Other family members joined the firm and over recent years control has been passed onto his three sons, who are directors and owners of the company. Growth of the company from drain laying has seen diversification into *aggregates**, concrete, bitumen and road construction. As a civil engineering contractor, Higgins tenders for road construction jobs offered by a variety of customers such as local bodies, Transit New Zealand and the public. When developing road construction products Higgins must not only consider these customers but also the requirements of its contractors which deliver the product and the final users of the roads.

---

* Italicised words appear in the glossary.

Three other centres of operation have been established; these are based in Wellington, Tauranga and Napier. Rapid expansion into these areas has brought the company to a crossroads over the last five years. With the company becoming quite sizeable, it is now making the transition from a family business to a corporate organisation. Establishment of a technical centre in 1996 to undertake quality testing and product development was a part of this transition. Product development at Higgins is therefore very much in its formative years, with this study contributing to the creation of product development systems. A small development staff consisting of a single product developer and a technical manager fulfil the technical development needs of the company at this point in time. A small staff means rapid implementation and adaptation of product development systems is possible as there is little bureaucracy.

Company infrastructure development is under way to establish marketing, human resources and information systems departments. The current absence of these formal departments is also a factor to be considered in the tailoring of product development systems within the company.

The road construction market is very mature and largely constrained by the allocation of government funding. Innovative products and products which provide better, lower costing solutions to customers allows for more competitive tendering within this market. Developing a systematic product development approach provides a formal means by which these more innovative and lower costing products can be created to keep the company competitive.

Environmental factors which need to be considered in creating appropriate product development systems include: company control structure, rapid growth, infrastructure development, a recently established technical department and market forces.

1.2 Product Development Procedure

Many suggested approaches to product development exist with five appropriate processes reviewed in Chapter 2: Haas, (1989); BS7000, (1989); McGrath et al., (1992); Cooper, (1993); Earle, (1997). Each of these processes have a different focus mainly due to the environment in which the systems are used and the nature of the products being produced. When tailoring a product development approach the underlying principles from the many different product development approaches need to be extracted and then applied to the specific environment at hand. Although many product development processes exist most included similar phases. Figure 1-1 illustrates common phases in a product development approach and the phases this work focused on. Research covered phases from idea capture and screening through to scale-up and product validation with particular focus on four key areas; idea capture and screening (Chapter 5), product design specification (Chapter 6), detailed design and optimisation (Chapter 7), scale-up and validation (Chapter 8). The specific product development systems created in these four areas are discussed as well as the work carried out to develop the high bitumen content emulsion.

Figure 1-1 Common Phases In Product Development

1. Strategic business planning
2. *Idea capture and screening*
3. *Information collection*
4. *Feasibility study*
5. *Product design specifications*
6. *Initial design*
7. *Detailed design and optimisation*
8. *Scale-up and validation*
9. Production and launch
10. Maintenance and disposal

Phases covered in this study.

A brief overview of the basic phases covered during the research work provides a understanding of the development path followed.

1.2.1 Idea Capture and Screening

The product development process is initiated by ideas. For the best set of ideas to be developed into profitable products the ideas first need to be systematically collected, screened and prioritised. Idea collection systems are usually simple to use, able to capture the essence of the potential opportunity and be widely adopted across the company.

Such idea collection methods include suggestion boxes, idea collection sheets, brain storming sessions and idea contests (Cooper, 1993).

Ideas screening needs to be unbiased so as to correctly identify the best allocation of resources to maximise the benefits to the company. Screening needs to be based on set criteria to assess both accurately and consistently all key areas of project viability. Scoring models, decision trees and profile modelling are a few suggested screening methods (Balachandra, 1989; Hass, 1989). Regular reviews of new and old ideas are carried out to ensure that the best set of projects are being developed at any one time.

Key product development system areas in the idea collection and screening phase include a good documentation system, regular reviews and an appropriate screening method.

1.2.2 Information Collection

A product developer uses research skills to collect information from numerous sources to carry out more informed product development; generally resulting in lower costs, shorter development time and better performing products. Increasing the ability to research and gather information enables the product developer to carry out product development more effectively. The information gathered during here will be the basis on which many later decisions will be made; the feasibility and design specification stage relying heavily on the information gathered during this phase to determine project viability and set development direction. The technical knowledge built up through research will also guide design decisions. Product development systems required in this phase include, a means of cataloguing past research, an efficient means of accessing new information and the ability to remain up-to-date. These systems provide the means to carry out research based product development.

1.2.3 Feasibility Study

A feasibility study quantitatively establishes project viability. Three key areas of feasibility are investigated; these are market, technical and financial feasibility. Demonstrated viability in these areas will justify further allocation of resources. Market feasibility is the key to on-going product success. A study conducted by Cooper (1993) marketing specification and a technical specification (Cross et al., 1992). Both specifications begin by researching and prioritising customer requirements to ascertain what is wanted from the product. The technical specification translates the customer requirements into quantifiable metrics. The metrics describe in a technical sense the desired product characteristics which can be measured and tested. Target levels for the metrics are set, based on competitive product analysis. To obtain a product advantage a number of these metric levels should exceed competitors' levels. The sum of these metrics accurately describes in a technical sense the product the customer requires.

The marketing specification contains more of the qualitative factors related to the product including:

- Target market and users.
- Benefits of product use.
- Positioning of the product within the company's range and within the market.
- Initial marketing and promotional strategies.

The two specifications fully describe why the product is to be developed, who the product is aimed at and what is to be achieved during development. The process by which these design specifications were developed specifically for Higgins is discussed in Chapter 6.

1.2.5 Initial Design

Having established clear design direction through the design specification initial design can begin. Initial design is an exploratory phase of design where an understanding of important product variables is gained and many concepts are investigated. The scope of work is purposefully kept broad to avoid potential solutions being eliminated too early (O'Hare, 1993). Initial prototypes are screened against criteria set out in the design specification to identify a concept which possesses the greatest potential for further development.

1.2.6 Detailed Design and Optimisation

Detailed design takes the most promising concept identified during initial design and systematically explores the many design possibilities within this concept; out of the numerous design possibilities a preferred design is identified. The method in which detailed design is carried out will vary greatly depending on the nature of the product; formulated products such as the high bitumen content emulsion require a different approach to manufactured and consumer goods. Formulated products require investigation into both the mixture components and the processing conditions, as different combinations of these variables will produce different products. Formulated products may use mixture design, experimental design or central composite design experiments to carry out detailed design (Montgomery, 1985; Barnes; 1997). A detailed design method suitable to Higgins products is outlined in Chapter 4.

Through the systematic design process a complete understanding of the product is gained and a preferred design is identified. The preferred design is further optimised to arrive at a final design. The final prototype design is validated through scale-up.

1.2.7 Scale-up and Validation

The aim of scale-up and validation is to take the final prototype design and prove its performance in a situation more representative of final production and application. Scale-up errors can occur when moving from small prototype designs to full production, this is due to differences in processing and product behaviour. By making incremental scale-up steps the risk and cost of potential failure is reduced while more accurate predictions can be made about full scale production and costs.

Gaining the most benefit from conducting scale-up and field trials involves thorough planning of trials, clear communication with the many involved parties and accurate data collection. Good planning results in greater control of the many tasks involved in scale-up, while communicating with the many involved parties assists in producing the product designed. Data collected during validation is used to confirm specifications, correlate laboratory scale work with full manufacture and to indicate product launch or re-design. Appropriate product development systems facilitate the execution of these key activities.

1.3 APPLICATION TO BITUMEN EMULSIONS

The product development procedure outlined was demonstrated in a practical way within the company using the development of a high bitumen content emulsion.

1.3.1 Background

Bitumen emulsions containing water are used in the road construction industry to improve the materials flow properties, once emulsified the bitumen behaves more like water than viscous bitumen. The traditional means of altering bitumen's flow properties is to add solvents such as kerosene at around 3-8%, this is called *"cutback"* bitumen. The bitumen/kerosene mixture is then applied to the road with a sprayer at temperatures around 140°C; this technique is called "hot cutback spray sealing".

Emulsified bitumen is also used in spray sealing and has the advantages of lower spraying temperatures of around 85 °C and less kerosene. Once applied to the road, water in the emulsion evaporates leaving a bituminous layer similar to standard cutback bitumen. This sealing technique is called "emulsion spray sealing". Stone chips or *aggregate* are then spread over the bitumen to produce a *chip-seal*. The development of a bitumen emulsion for use in spray sealing to produce chip-seals is the area of interest to the project.

1.3.2 High Bitumen Content Emulsions

Standard bitumen emulsions contain from 55%-65% bitumen; the remainder being water, solvent, emulsifier and acid. This relatively low proportion of bitumen has limited the application of bitumen emulsions in standard chip sealing. By increasing the percentage of bitumen in the emulsion a number of these limitations are overcome:

- Lower transportation costs due to less water cartage.
- Greater application efficiency.
- Larger sized chips can be used as greater *binder* depths can be achieved.
- Reduced cure times.
- Greater productivity.
- Potential reduction of environmental impact and energy consumption.

Difficulties however arise when increasing bitumen content, including:

- Exponential increase in viscosity causing difficulties with handling and spraying.
- An emulsion which rapidly *breaks*.
- Short storage life.
- Potential inversion from an 'oil in water' emulsion to a 'water in oil' emulsion.

A number of ways have been developed to increase bitumen content to 75%-80% and overcome these problems (Duval and Beranger, 1989; Holleran, Booth and Maccarrone, 1993; Marchal, 1995). These methods along with basic bitumen science and technology are reviewed in Chapter 3. Based on this research and the design work conducted, this study attempted to develop a high bitumen content emulsion for production and application by Higgins for New Zealand conditions.

The development of the high bitumen content emulsion followed the systematic product development process developed. Information was gathered to gain an understanding of the science and technology of the industry and to establish project feasibility. Customer research was undertaken to formulate a design specification which would guide the design phases. Scale-up field trials were conducted using the finalised laboratory formulation in an attempt to demonstrate final product performance.

1.4 Project Aims and Objectives

1.4.1 Project Aim

The aim of the project was to develop, within a specific company environment, an appropriate product development approach with supporting systems. The approach would be used to develop a high bitumen content emulsion for use in spray sealing applications.

1.4.2 Objectives

- Understand science & technology related to high bitumen emulsion production.
- Develop performance criteria relevant to New Zealand conditions.
- Produce an optimum product which meets performance criteria.

- Conduct large scale field trials.
- Correlate laboratory development with field performance.
- Provide a tailored product development approach applicable to current and future projects.
- Develop product development systems for the various stages within the entire approach.

1.4.3 Constraints

1.4.3.1 Product constraints

- Achieve a bitumen content of 75% or greater.
- Meet relevant industry specifications and standards.
- Not infringe patent laws.
- Product performance be acceptable to the customer, contractor and user.

1.4.3.2 Processing constraints

- Prototypes to be produced on Higgins laboratory size colloid mill.
- Optimum formulation to be produced using existing production plant and technology.
- Commercially available raw materials to be used.