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AN APPROACH TO DEVELOPE DESIGN RULES FOR FOOD PROCESSING EQUIPMENT

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ABSTRACT
The complexity of food production stems from the diverse nature of the products. These range from large solids through to liquids and pastes. Their processing is itself also diverse: from simple assembly processes of liquids and solids through to the control of complex chemical and cooking processes. Commercial pressures mean food companies must continually reinvent and evolve their products, creating large product families. The ability to handle both the complexity of process and large variations in product format generates extreme difficulties in ensuring that the manufacturing, handling and packaging equipment can cope. This paper presents a methodology built on the understanding of the relationships between food product features and processing factors. The methodology offers the designer the possibility to redesign the processing equipment from knowing the bounds of the product features and also to reverse engineer the product from the bounds of the process. The paper also presents research findings, showing a taxonomy of food stuffs, and taxonomy of food product-process relationships. Validity relationships from this taxonomy can be used to model the product. In addition to this the limiting factors of food processing equipment are identified, these factors must be implemented in the modelling and simulation of the equipment. The methodology and its application is presented with some industrial case studies

Keywords: food product features, food processing equipment design, design constraints, design rules, variant design

1 INTRODUCTION

1.1 Product and process overview
Previous research has identified that the food processing industry maintains the highest number of product variations and makes more product changes than any other mass-producing industry [1, 2]. Many of these arise over short periods due to marketing and customer demands. Some products are stable over long periods whilst others are short lived or seasonal. The complexity of food production is further increased by the diverse nature of the products. They range from large solids through to liquids and pastes. Their processing is itself also diverse: from simple assembly processes of liquids and solids through to the control of complex chemical and cooking processes. The ability to handle both the complexity of process and large variations in product format creates extreme difficulties in ensuring that the manufacturing, handling and packaging equipment can cope.

1.2 Objective and method
The work presented in this paper has been commissioned to investigate the capability of food processing and packaging equipment to handle product variation. The goal is to create a methodology whereby the ability of existing plant to handle new variations of the product can be determined at an early development stage. Such a methodology allows the developing team to establish whether the existing plant is adequate, whether new plant needs to be created or whether slight changes in product specification or form will allow existing plant to be utilised. The approach is based upon an understanding of the food product feature characteristics together with an understanding of the equipment capabilities. The equipment investigated is limited to the actual processing and packaging

equipment employed in the food industry. Pre-processing equipment has not been considered at this stage.

- For processing operations, this includes: mechanical mixing, agglomerations, mincing/slicing, transferring, weighing and counting, cooking, and freezing
- For packaging operations this includes: cartoning, sealing and tucking, over-wrapping and bagging.

As with any design activity, a range of questions arises. For the specific problem raised in this research the following questions have been identified.

1) Food product properties:
    -Which one is important?
    -How fixed are they?
        -Do they change with season?
        -Do they change with ingredient variety?
        -Do they change with processing?
            -If so, do they recover?
2) What does the consumer want?
    -Perceived properties for example taste, texture etc
    -How constant/ measures are there?
    -How do they map onto physical properties?
3) Lots of experimental measuring work is well published
    -Lots of models proposed
            -How good is/are they?
            -How relevant is/are they?

The remainder of this paper describe how these questioned are answered, and how the answers fit into a methodology for redesigning food processing equipment to handle a variant product. Section 2 identifies the factors that relate to the food products. Section 3 discusses how the equipment is dealt with. Section 4 presents the methodology and section show the implementation of the methodology on three case studies, the paper is concluded in section 6.

2. PRODUCT CHARACTERISTICS

Each product and its preparation or assembly process demands different characteristics in order that it can be produced and handled successfully. Due to the handling and transfer processes involved, the strength and resistance to damage or movement upon a conveyor belt may need to be assessed. Many of these characteristics need to be determined and studied if the capability of the plant to handle such product is to be understood. The information is collected via experimentation using relevant testing equipment. Foodstuffs differ from most commercial manufactured products in the fact, that it is solely customer *perception* of product that matters. Customers view of quality comes from there senses, manufacturers employ taste and smell panels, to assess quality. The information obtained from equipment and product has then been used to model to effects of product variation on the processing equipment [2].

2.1 Product variations findings

Investigation into the raw product that the food industry processes shows they can be categorised into five forms: liquids, pastes and slurries, particulates and solids, both rigid and soft bodied. Examples of products that fit into these categories can be seen in table 1.

Table 1 food product taxonomy

	Liquid	Paste / Slurry	Particulate	Solids	
				Rigid body	Soft body
Examples	Milk Soft drink Beverages Soups	Yogurt Fish pastes Yellow spreads Toothpaste Jams	Coffee Sauce granules Tea Cake mixes pasta	Chocolate Cookies Frozen- vegetables	Bread Cakes Meats Jelly

Table 2 shows a sample of variations which have arisen from this research has been required to investigate. It shows specific variational changes which the food industry has to cope with. In these and other examples shown, and others the research has been required to investigate, the variational changes can be divided into nine distinct categories, Increase in product size, change in packaging density, constituent change, raw product size variation, physical properties of product change, change in packaging materials, n percentage increase in product per container, and environmental factors. Column two gives a typical example of the variational change, with column three presenting the relative effect to the processing system.

Table 2 Product variation effects

Variation Description	Industrial Examples of Problem	System Effects
Increase in Product size	Change in product dimensions for over-wrapping	-Geometric -Kinematic -Dynamic -Tolerance
Change in packaging density	Two extra frozen puddings per pack	-Geometric -Kinematic -volumetric
Constituent change	-Customer product variation may force the manufacturer to expand range. The addition of noodles and croutons to dried soup range. -Flavourings used on crisp product i.e. oil or powder	-Dynamic -Geometric -Weight -Density -Tolerance
Raw product size variation	Potatoes sliced for crisps etc (raw product like potatoes shape cannot be guaranteed, only be graded to a general point)	-Kinematic -Geometric -Dynamic -shape -Tolerance
Physical properties of product change	Shifting from transferring fruit cake to a soft cream cake or pie. Softer product less resistant to higher kinematics and dynamics	-Kinematic -Dynamic
Change in packaging materials	Environmental regulations are forcing manufacturers to move towards thinner and biodegradable packaging materials	-Kinematic -Mechanical properties
n% increase in product per container	30% extra cereal in a carton.	-Geometric -Density -Weight
Environmental factors	Humidity can change the folding properties of carton skillets. Carton often stored away from product area, this can affect setting of machine.	-Kinematic -Mechanical properties
Organic product change	The physical properties of potatoes change over the picking season; this has an effect on processing equipment.	-Kinematic -Shape

2.2 Limiting factors

The results shown in table 2 are just a few examples which the food processing industry has to handle throughout the life of a product. When looking at column three, it can be seen that generic product limiting factors arise. The factors include; density, weight, geometric size, tolerance, shape and mechanical properties. Within the product processing context there is a direct linkage between geometric size, tolerance and shape, this is reflected in the diagram by the dotted line. These can be seen in the influence diagram in figure 2.

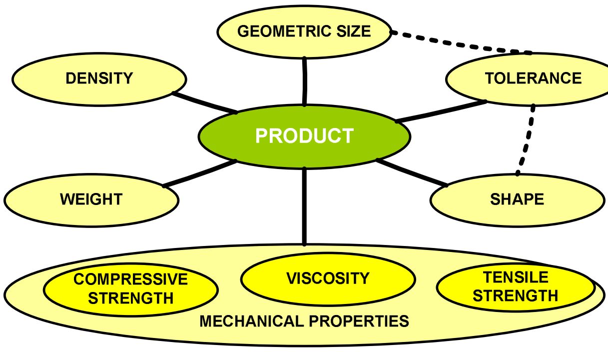


Figure 2 Product limiting factors

2.3 Food product-process relations

Table 3 shows a relationship table for incorporating the taxonomy of food stuffs from table 1 (column one) and the limiting factors identified in figure 2 (column two).

Table 3 Food process-product relations

FOOD PRODUCT PROCESS RELATIONS			
Type	Product properties	Relationships	Process effects
LIQUID PASTE/ SLURRY PARTICULATE SOLID -rigid body -soft body	WEIGHT DENSITY VISCOSITY GEOMETRIC SIZE TOLERANCE SHAPE STRENGTH	GEOMETRIC VOLUMETRIC KINEMATIC DYNAMIC TIMING	MACHINE COMPONENT SPEED CAPABILITY

Column three contains the validity constraints of the product. These are the key factors that affect the ability of any system to process variant product.

- *Geometric constraints*, these are indispensable for each feature, which have a standard range for specifying the value of each parameter for the shape and geometric size. Shape and geometric structure of the product is important when considering retentions for grippers and transfer guides.
- *Kinematics constraints*, these are especially important, when considering the transfer of product.
- *Dynamic constraints*, these are important consideration as the product mass increases, the forces applied will also increase.
- *Volumetric constraints*, these are very similar to geometric constraints, except that the area/ volume the product is considered important when product is retained by the manufacturing system and when product has to be put into containers and packaging.
- *Timing constraints,* the ability to move product, changes as factors such as weight and size change with the variant product.

Column four of table 3 shows the factors of the processing ability that is influenced. The research shows a distinct relationship between the food product features identified earlier, and their effects on the system. Figure 4, shows the relationship mapped into a diagram when considering an example of changes for a particulate product: gravy granular production.

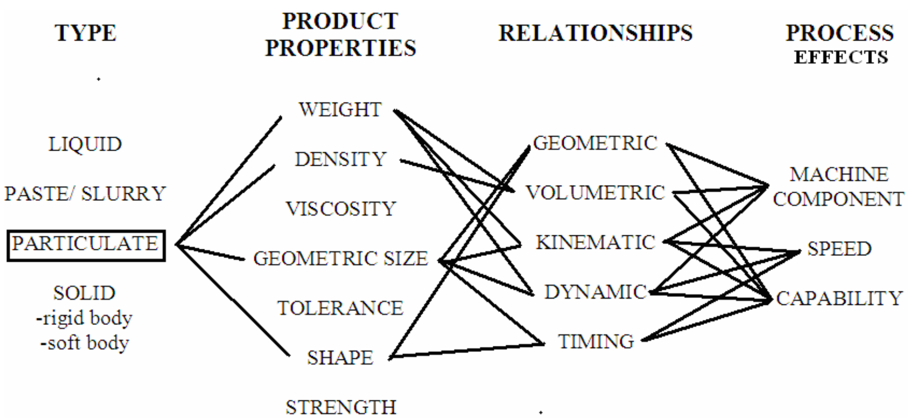


Figure 3 Particulate variation

For another example, a rigid solid, a chocolate bar in a packaging operation, the relationship diagram would look as follows. What is evident is the additional connectivity between product properties and process effect, via the relationship. There for any modelling or simulation must have the ability to investigate and monitor these factors.

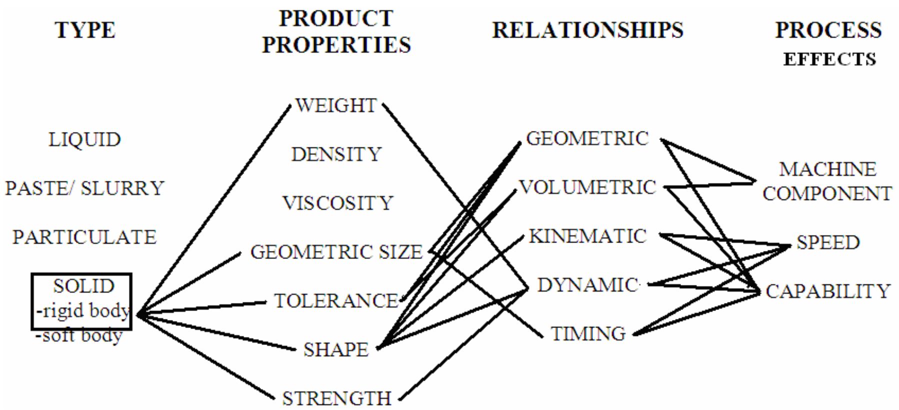


Figure 4 Rigid body product variation

3. EQUIPMENT CAPABILITY

For the assessment of product variables on equipment, the critical factor is the identification and formalization of the functional requirements for the design, with respect ok the inherent capabilities of the existing design. With the requirements specified, the constraints imposed by the existing equipment and that of the variant product can be formalized for the design problem. There are two types of models that have been extensively used in the modelling manufacturing systems: prescriptive and descriptive. Prescriptive models are generally employed to construct decisions on that system. Descriptive models are generally employed for performance evaluation of the manufacturing system. These models can be sub-categorized into analytical and simulation models. The following section highlights techniques for physical form modelling for food equipment.

3.1 Form modelling and simulation of physical system

Modelling and simulation analysis are well established techniques, for the analysing the potential effects of complex manufacturing changes, without companies committing resources, such as manpower and processing line time. As noted by [2], the specific manufacturing process employed in the food industry, initially require continuous event modelling approach and then later with a discrete event approach. One approach that has been employed to access the design capability of food process equipment using the identified bounds of the manufacturing system is “Limits modelling”. [10] The developed approach employs a parametric model of the system defined within a constraint-modelling environment. The information to produce the model is generated from machine drawings (if available), manual measurements and high speed video. The high speed video is also used to validate that the model represents reality. Failure modes for the model are derived from testing of the product to be manufactured and by a consensus of the designer and manufacturer. Parametric variation is employed is 'disturb' the geometry of the mechanism, and the model is then actuated. Constraint monitoring is employed to check if the model violates any of the applied constraint (failure modes). The successful configuration returned, from functioning instances are used to produce the functional matrix. The values from this matrix can then be visually represented to produce the performance envelope for the equipment. Interrogation of these representations, allows the engineer to see if a variant product can be produced using the modelled equipment. When simulating and modelling the processing equipment with methods such as that presented in [11], what has become evident is that there is a group of six generic limiting factors that have to be handled with any modelling approach. These are shown in the lightly shaded regions of figure 5.

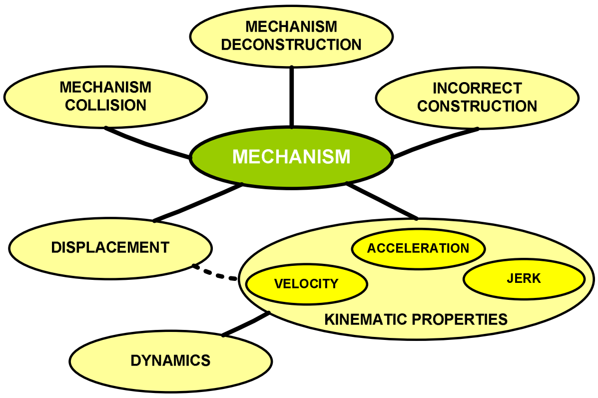


Figure 5 Mechanism limiting factors

An explanation of these limiting factors is given in Table 4 below. Missing from the table is the "Incorrect construction" factor. This is specific to modelling approaches that use rule based strategies for their modelling and simulation. As models are constrained to assembly and satisfy the given rules. The outputted assembly may not be the same as the object being modelled. An example of this is commonly seen with the four bar mechanism, the mechanism can assembly in an inverse manner even though as far as the modeller is concerned the constraints are met.

Table 4 Model limiting factors

Limiting factor	Description
Element collision	Clash interaction between elements of equipment
Mechanism deconstruction	Motion cause elements of equipment to pull apart
Displacement	To much or insufficient movement of element to translate required motion
Kinematics Velocity Acceleration Jerk	 -Low or high velocities can cause timing problems -Excessive acceleration and jerk cause vibration -Lack of accuracy and advanced wear
Dynamics	Effects of forces on the motion, increase in speed and product load can cause vibrations, increased wear and lack of accuracy

4. PROPOSED METHODOLOGY

The major factor that has been identified in this research is that although there is a vast amount of research on food product properties and some published research on food processing equipment, there a void in work that combines the use of both for the handling of variant products. Following is a proposed approach to handle such a problem. The flowchart figure 5 shows the proposed methodology performed in this paper. What is immediately identifiable is that it is a concurrent procedural process that identifies the key characteristics of both product and process. Once established their relative bounds and limits are identified, these are then used to produce specified models of product and process. With these models established, the effects of product variation can be optimized to find a either a best product or process solution. It is then used to answer the questions:

- Can a given process deal with the food variation?
- Can a given process variant deal with existing food?
- Can an optimal arrangement be found?

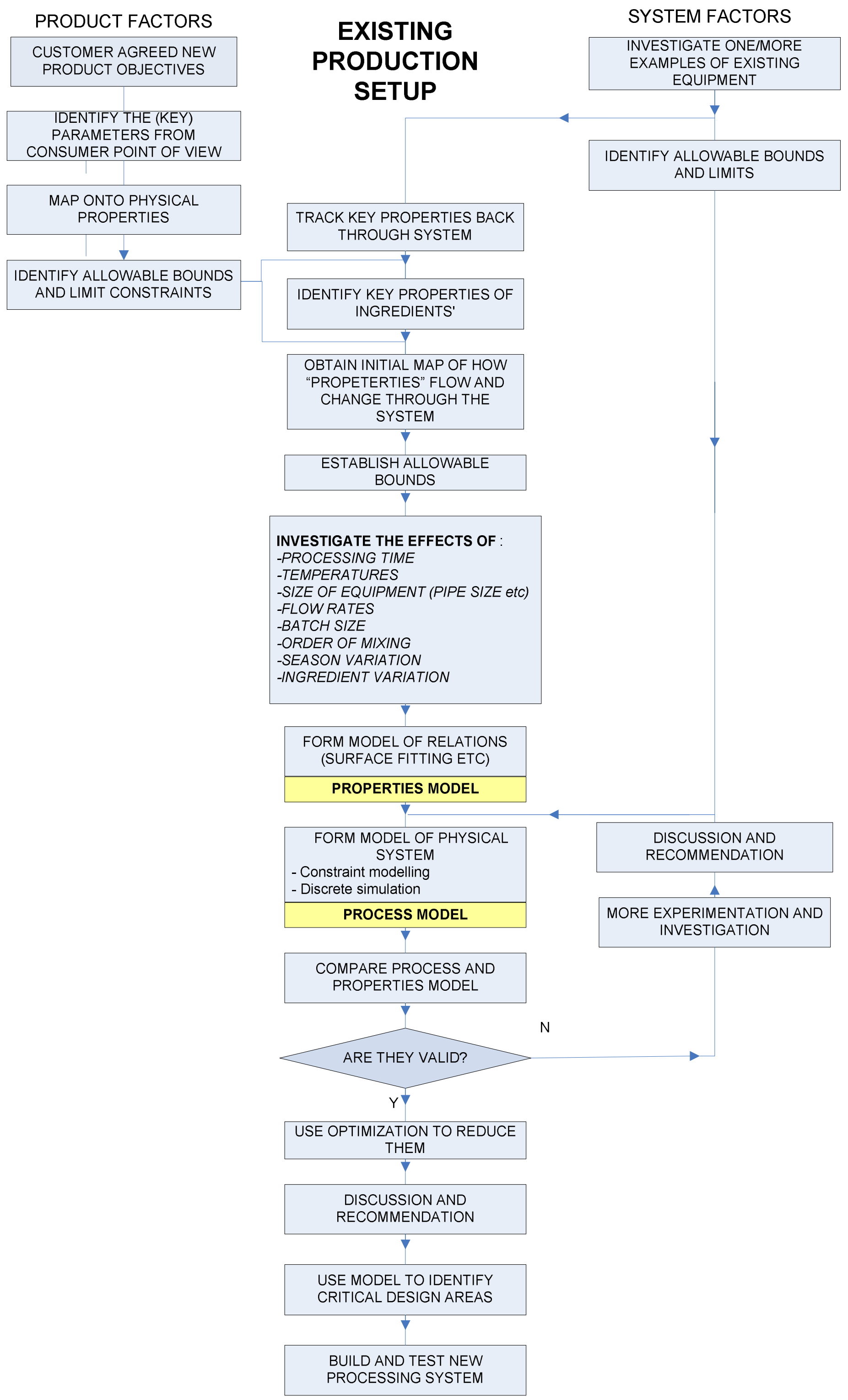


Figure 6 Methodology flowchart

5 CASE STUDIES

The methodology has been implemented on three different case studies, two from food packaging, and one from processing. The case studies show how the identification of system bounds can be employed to model the effects of product variation, and the finding of a solution which will accept this variation.

5.1 Carton erection

The first example describes how finding the bounds of a product a packaging carton dictate the redesign of the equipment. Crash erection machines are used in the packaging industry to produce carton boxes. The machine is loaded with a stack of pre-cut and pre-creased board nets. In each cycle, one net is transferred from the stack and placed over the opening of a die. A plunger then carries the carton through a die section. This has the effect of folding up the walls of the box thus erecting the carton. A model of such a machine is shown Figure 5a. It is driven by a single motor. The effect of the reciprocating action of the plunger is that it impacts the board at its maximum speed. Thus the output of the machine is limited by the mechanical product features of the carton in particular its ability to sustain the impact without exhibiting damage such as tearing or delamination.

A constraint modelling environment [11] was employed to produce a form model of the physical system (cf. Figure 5a, 5b) an additional link was added to the design with one end constrained to move along a linear track. To achieve this, the lengths of the links were allowed to vary along with the offset position of the joint (with respect to the original link) with a view to reducing the peak velocity. As noted in section 3 figure 4, the kinematics of the equipment been proven to be a limiting factors. With models established it is now simple to evaluate other variant cartons.

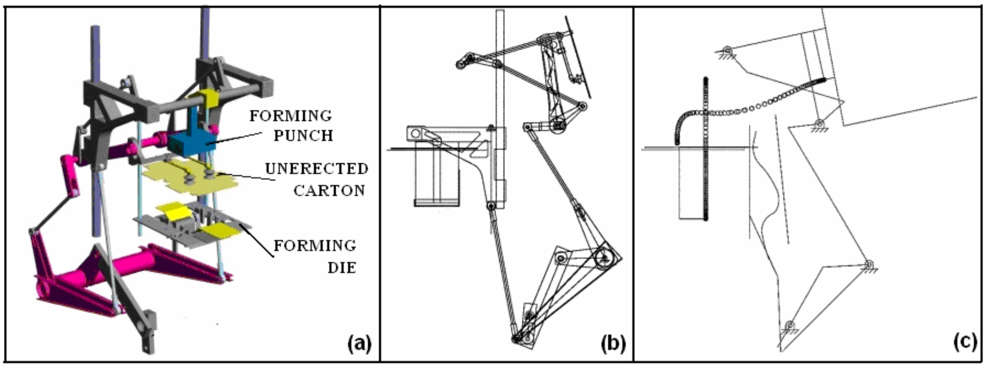


Figure 6 Investigation of modification to a crash erector system

With the product bounds established, this became an example of speed control, where the desired speed is not prescribed but a range of values is given. It was found however that when the speed was reduced substantially, the shape of the cam track was unacceptable because of considerations of pressure angle. The inclusion of constraints relating to the cam laws meant that only a 10% reduction in impact velocity could be achieved. Figure 7 below shows the relationship identified earlier in the paper remain true. They identify to the designer which validity constraints must be dealt with and the effects on the processing system

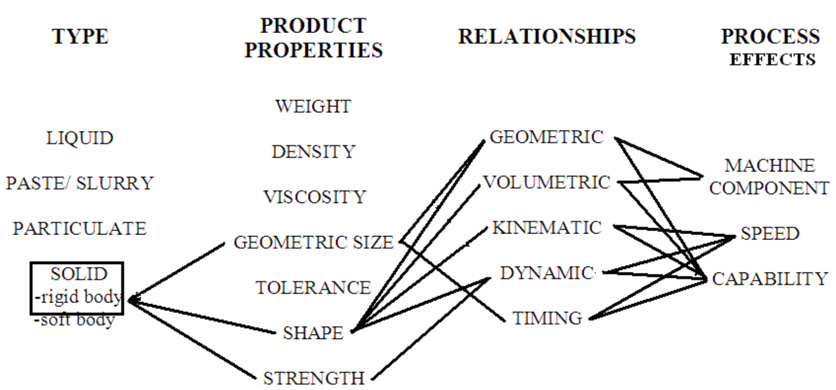
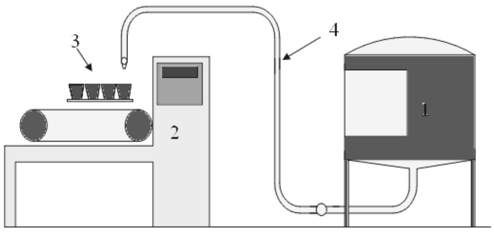


Figure 7 Relationships for example

5.2 Yogurt processing

The following example describes how finding the bounds of the product (yogurt), dictates the redesign of the equipment. The variation in yogurt stems from the consistency and the addition of flavouring and fruits pulps. Yogurt is a non-Newtonian material and is thixotropic so that work performed on it, it shear thins. While there is some recovery (over a period of time), the aim is often to try to minimise the amount of processing that is done upon the product. The amount of work required to pump and mix depends upon the temperature.

There is a trade-off between the ease of processing (and reduction in damage) and the need to keep the temperature low in the interests of fixing the reaction and storing the product. One option is to undertake the processing at room temperature and only cool the product in the pots after filling. An alternative is to cool in the pipe as the product is being moved into the filling station.



1. Holding flask 2. Packing machine
3. Yogurt pots 4. Feed piping

Figure 8 Yogurt feeding process

Given the conflicting requirements, a constraint-based modelling methodology was well suited to looking for an optimal design of production system. The main difficulty is that the properties of yoghurt do not seem to be well understood. A number of rheological models have been proposed [5] for various food stuffs. These include the Herschel-Bulkley model [6], the power law [7], and Cross's model [8]. While these have all been used to model yoghurt, they lack any involvement of time and temperature which are essential given the nature of the product. To cope with this, a model has been proposed [9]. The methodology was employed to investigate both product and process. Although the yogurt producer would prefer to reduce costs of the pumping rigs by reducing pipe size, the optimisation process showed detrimental effects to the product. It was also shown in this process that the pressures required to pump the yogurt could not reach the required value until relatively large pipe radius was used. This example shows how the bounds of the product fix the optimal configuration of the process.

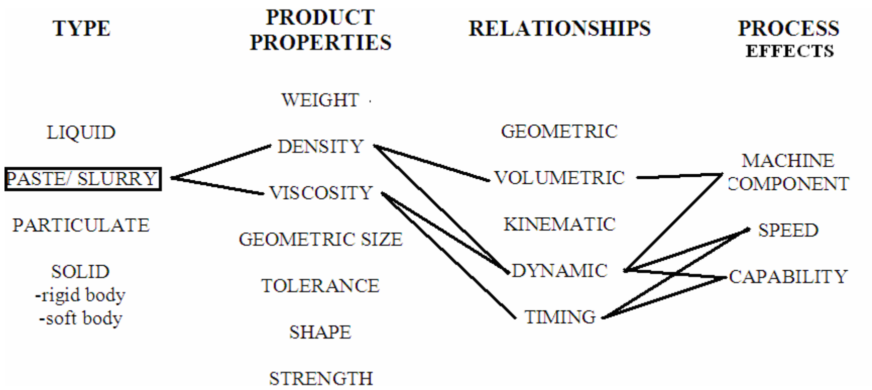


Figure 9 Relationships for examples

Figure 9 shows that the relationship identified earlier remain true. They identify to the designer which validity constraints must be dealt with and the effects on the processing system

5.3 Skillet erection

The following example describes how finding the bounds of the process. In this case a packaging system dictates the redesign of the product. A common method of creating cartons is to use a skillet. A skillet is a partially folded carton, which takes the form of a flattened parallelogram (cf. figure 11). Such packaging styles are used to box a whole variety of foodstuffs. Often the carton may have a window so the buyer can see the product, adding additional complexity into the processing. One method of erecting a skillet is by use of an epi-cyclic mechanism. The skillet is collected from a stack and the parallelogram is open by forcing it against a fixed backstop. This process and the subsequent product packing operations are critically dependent upon the successful opening of the skillet. Obtaining reliable and repeatable opening is therefore particularly important, but it can be a complicated and time-consuming task when new carton sizes or materials need to be accommodated. However, it is often not always clear what properties need to be changed and what the effects might be in terms of production capabilities and cost.

In this case a finite element model was constructed of the process and key machine-material interactions was constructed. This included the complex interactions between the skillet, backstop and moving lug, and considered the deformation of the skillet due to aerodynamic effects. The latter of these depends upon production speed, pack size and pack material. In addition to these factors, it is also particularly important to represent the inherently nonlinear properties of creased carton board during processing As a consequence of this, user defined elements were created within a finite element (FE) model of the skillet to represent the creased regions of carton board. The underlying rules for these models are generated using the results of experimental testing. In order to investigate the effects of changes in tooling configurations, various modelling episodes were conducted to evaluate the effect of changes and define the performance envelope of the tooling. These enabled the identification of the limiting configurations which result in process failure. Repeating the modelling process for different pack sizes enable the optimum tooling configurations to be determined.

Following the methodology, modelling both product and process, the manufacturer can now knows the limitation of the product. The structure of the carton and configuration of window are set by the optimal process properties. The manufacturer also knows the optimal setup of the machine including vacuum cup positions and running settings. Although the relationship diagram is not shown, it has the same relationship connections as that in Figure 7, which is to be expected.

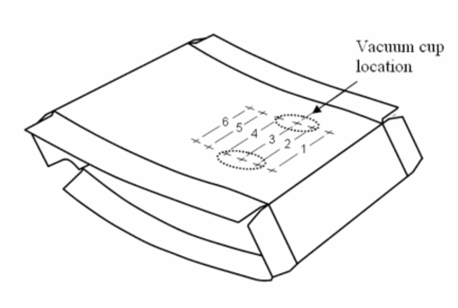


Figure 11 Skillet pack erection

6. CONCLUSION

This paper contributes a methodology, which offers the designer of food industry related products, the ability to:

- to redesign the processing equipment from knowing the bounds of the product features
- to reverse engineer the product from the bounds of the process.
- to optimize the two options above

The paper also presents research findings, showing a taxonomy of food stuffs, and taxonomy of food product-process relationships. Validity relationships from this taxonomy can be used to model the product. In addition to this the limiting factors of food processing equipment are identified, these factors must be implemented in the modelling and simulation of the equipment. The application of the methodology is presented with some industrial case studies, showing the development of product using process limitations and the development of process from knowing the food process feature bounds

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