

The 50th CIRP Conference on Manufacturing Systems

Consumer Driven New Product Development in Future Re-Distributed Models of Sustainable Production and Consumption

Mohannad Jreissat^a, Svetlin Isaev^b, Mariale Moreno^b, Charalampos Makatsoris^{a,*}

^a Sustainable Manufacturing Systems Centre, Cranfield University, Bedford MK43 0AL, UK

^b Centre for Design, Cranfield University, Bedford MK43 0AL, UK

* Corresponding author. Tel.: +44-1234-758284; E-mail address: h.makatsoris@cranfield.ac.uk

Abstract

The customer as co-creator of products is a grand challenge the entire consumer products manufacturing industry is facing. The design, manufacture and delivery of mass personalised consumer products must not only meet customer preferences but must be produced economically and sustainably too. Re-Distributed Manufacturing (RDM) has the potential to disrupt the way products are designed, produced and consumed products across their entire lifecycle and will allow the creation of disruptive business models and entirely new supply chain structures. New structures of design and manufacturing can enable large reductions in resource consumption by limiting waste in a supply chain (e.g. reducing transport distances) and through addressing the flows of resources at critical times in the lifecycle of products. It can also enable reduction of R&D waste by enabling a more targeted delivery of custom products to meet specific user needs and demands in different contexts and across extended timespans of the product lifecycle. Few manufacturers have started experimenting with open innovation to address the two manufacturing challenges of: (i) the ability to identify rapidly the needs and preferences of different market segments; (ii) the ability to respond quickly and flexibly to those. This paper demonstrates a model-based methodology and information technology to engage consumers at large scales to drive new product and manufacturing process development to address these challenges. An orange beverage has been selected to show that by linking a game-like consumer facing web application and a novel computer driven flow manufacturing system, target sensory attributes obtained by consumer groups can be rapidly translated into a new formulation recipe and its manufacturing process of a beverage that meets those needs and prototyped for that consumer group to evaluate. One can then envisage future scenarios where formulated consumer products are rapidly co-created and produced serving the needs of localised markets.

© 2017 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license

(<http://creativecommons.org/licenses/by/4.0/>).

Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems

Keywords: Re-Distributed Manufacturing; Mass Customization; Product Development.

1. Introduction

Nowadays the process of designing and developing new products to meet consumer expectations is becoming a complex task. In this regard, intrinsic and extrinsic quality determinants involve in the success of New Product Development (NPD) such as globalisation, mass-individuation, the physical characteristics of product itself and environmental variables. Also, advanced technologies that deliver a variety of products should be properly adopted to become competitive tools for manufacturing companies in global markets [1] [2]. These factors (i.e. changing in consumers' lifestyle and values) as well as short product lifecycles have shifted the NPD process from a step-by-step approach to a continuous one focused on consumer values (i.e. close-loop approach) [3]. That, in turn,

requires a close collaboration between the end-users and manufacturers of formulated consumer goods to succeed consumer-driven new products or reformulated ones [1] [2] [4].

A new pattern of the sustainable manufacturing system coupled with localised production can enhance the demanding change [5] [6] [7] [8]. The ability to provide advances in process and information technologies supporting rapid responds that allow for the best consumer requirements for an individual customer to be rapidly determined will be a key part of the growth [6]. Re-Distributed Manufacturing (RDM) can reinforce this enabling the delivery of tailored, first-time-right product to consumers.

The RDM can be described as "*the ability to personalise product manufacturing at multiple scales and locations, be it at the point of consumption, sale, or within production sites that*

exploit local resources, exemplified by enhanced user participation across product design, fabrication and supply, and typically enabled by digitalisation and new production technologies” [5]. From this point, we can identify different consumer segments with the market intelligence (e.g. crowdsourcing tool for the preference market). Then, the RDM system using intensified processes with small footprint and low energy requirements can be employed to locate closer to these markets and rapidly respond to these by quickly modifying or optimising the product according to consumer needs.

The purpose of this paper is to demonstrate a model-based methodology and information technology to engage consumers at large scales to drive new product and manufacturing process development to address these challenges. An orange beverage has been selected to show that by linking a game-like consumer facing web application and a novel computer driven flow manufacturing system, target sensory attributes obtained by consumer groups can be rapidly translated into a new formulation recipe and its manufacturing process of a beverage that meets those needs and prototyped for that consumer group to evaluate.

2. Materials and Methods

Consumer based formulation of orange-flavored beverage and its novel production process presented to test the ability of the proposed method. Fruit/vegetable flavored beverages are prominent model of emulsions in the soft drinks industry as a concentrated or diluted product. Beverages are known complex alcoholic and nonalcoholic drinks that consist of oil phase flavoring ingredients, sweeteners, coloring agents, stabilizers and their mixing conditions. During the pairing of the ingredients and production of the beverages, there are many product and process parameters that influence the taste and sensory attributes of the final formulated product [9]. As consumers' lifestyle becomes more personalized and demand has surged for a greater variety of beverage options, therefore, the industry has considerably evolved with product formulations becoming particularly targeted to the user needs. Orange-flavored beverage is selected because it is the most widely consumable and profitable drinks in the food and drinks industry. First, consumer preferences were obtained with Preference Marketplace (PM), then formulation space was used to link to deliver the resulting sensory attributes. Formulation space were developed based on number of our previous studies [10] [11] [12], that consist of identifying product and process parameters, optimization of these parameters, developing a novel flow manufacturing platform for optimum product mixing. The following sections provide more details about material and methods used.

Table 1. Description of samples

Product	Brand	Description
Product A	Commercial	orange Juice from Concentrate (50%); Water, Sugar, Vitamin C
Product B	Commercial	water, orange juice from concentrate (8%), citric acid, acidity regulator (sodium citrate), natural flavoring, preservatives (potassium sorbate, dimethyl docarbonate), antioxidant (ascorbic acid), sweeteners (acesulfame k, sucralose), stabilizer (xanthan gum), natural color (carotenes)
Product C	Commercial	water, sugar, orange juice from concentrate (12%), acidity regulator: citric acid; flavorings, antioxidant ascorbic acid
Product D	Our product based consumers	water, Arabic gum, xanthan gum and orange comminute from concentrate; citric acid, sodium benzoate; natural sweetener: maltodextrin, steviol glycosides; natural food color: beta-carotene

2.1. Samples preparation

Three samples were used from commercially available concentrated orange juices in different variants of concentrated orange level. While one manufactured orange-flavored beverage, with different amount of orange oil, was customised by consumers. The production method was different as the production in commercial products was batch wise, whereas we used a continuous manufacturing with oscillatory flow mixing technology in our samples. However, similar food grade ingredients were used (Table 1).

2.2. Preference marketplace – online consumer Interface

PM was developed using game mechanics for long-term consumer engagement as a low-cost and scalable digital crowdsourcing tool in order to collect information [13]. PM is inspired from Prediction Markets [14] and stock markets [15] in order to link new product features and concepts with contracts and to identify the most promising new product opportunities by trading those contracts. The ultimate goal of PM is to understand individual preferences from stock prices and drive the manufacturing parameters to respond user needs. Markets include figures, graphs and descriptions of product attributes as shown in Fig.1. User interface is a very important motivation factor to encourage being active participant.

First we developed the initial sensory terms for beverage products under four main groups as taste, texture, flavor and appearance. Each sensory group has a bundle of sensory descriptors. We defined individual securities as sensory descriptors that stock prices measure preferences of particular sensory attributes. Four markets were created and all stocks were mutually exclusive as shown in Table 2. Stock prices move between 0 and 100. Price of the attribute represents the percentage of user's preferences. Amazon vouchers for the top 3 players were provided to motivate participants and improve active collaboration. Markets were designed for one week trading period. Participants were invited to the online based software to create their profile.

Table 2. Sensory descriptors for PM.

Markets	Sensory Attributes				
Taste	Sour	Bitter		Sweet	
Flavour	Citrus	Fruity	Grapefruit	Tangerine	Tropical
Texture	Thin	Smooth	With a few particles	Pulpy	Thick
Appearance	Golden orange	Sweet orange	Bright Orange	Tropicana	Tangerine

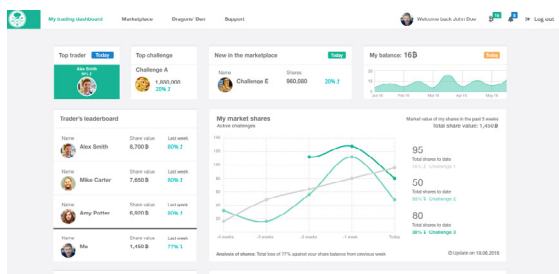


Fig. 1. P.M. Online crowdsourcing tool – user dashboard with leaderboard and trading activity for preferences.

The aim of the game was to increase the initial profit to win the game. Profit can be increased by buying and selling product attributes or investing funds for the final outcome. Players can pick a market and place an order to buy or sell sensory attributes based on their preferences with choosing the quantity of the shares. Quantity number per transaction was limited with maximum 50 to prevent manipulation and large price changes. The game was stopped in the middle of predefined trading period to review the prices of the sensory attributes. Top prices of each market were used to formulate and manufacture the orange juice products for sensory evaluation session. A sensory evaluation study was conducted to evaluate the performance of the formulated samples. After the sensory evaluation session, we asked participants to update their preferences through PM software.

2.3. Measured physical properties

Physical product properties were selected as key parameters for the formulation of beverages based on the utmost significant quality factor affecting the final product performance with regard to our previous works [10] [12]. Physical properties such as pH, viscosity, particle size distribution and colour intensity were obtained using analytical devices to build formulation design space for a target orange beverage. These devices respectively are HANNA instruments pH 211 Microprocessor (pH Meter), Brookfield digital viscometer instrument (in Mpa.sec unit), Mastersizer 3000 laser particle size analyser (in μm unit) and UV/VIS spectrometer (in nm unite).

2.4. Experimental design and statistical analysis

In the previous works [10] [16], the experimental design space was established to make and optimise the orange beverage formulation and its manufacturing processes. For this purpose, Response Surface Methodology (RSM) based on

Central composite Design (CCD) and combined with Principal Component Analysis (PCA) was used to demonstrate and test the novel flow formulation system for orange beverages. Independent variables were determined in the experimental design to formulate the orange beverage within setting limits studied, to find and optimise main and interaction effects of both formulation and process parameters on the desirable properties. Independent variables including main beverage components and process conditions were Arabic gum (w/w %), xanthan gum (w/w %), orange oil (w/w %), net flowrate (ml/min), amplitude (mm) and oscillatory frequency (Hz).

Besides the Analysis of Variance (ANOVA) outcomes, T-test technique for independent and dependent samples using SPSS, statistical package software, was utilized to compare the obtained results and validate if there is a statistically significant difference ($p < 0.05$) or no statistically significant difference ($p > 0.05$) between the mean of product properties studied of two different products.

In order to link the sensory attributes and formulation parameters, these attributes required to quantify using consumer inputs from the online PM. Then, the measured physical properties that match consumers' likings could be found in the formulation design space by projecting the target product properties. In the other words, texture resembles viscosity value; appearance represents colour intensity; mean particle size affect smell or flavor level and pH level controls the taste sense. The target properties could be found based on the clustering of physical properties as well as the manufacturer knowledge and experience in order to formulate new product or reformulate

2.5. A novel flow formulation system

A novel automated continuous formulation platform was developed to manufacture orange beverage and any formulated liquid products. It is a combination of membrane emulsification device [10] and Oscillatory Baffle Flow Reactor (OBFR) [17]. This integrated formulation system with automated computer control application and statistical experimental design method (i.e. Application programme interface) allow manufacturing companies competitive advantages to formulate or reformulate consumer products efficiently (e.g. low cost, less time and low operation pressure) with better control of product and process qualities. A prototype of the flow formulation platform is shown in Fig.2. It consists of computer driven controller, feedstock solutions, the mixing vessel consisting of the OBFR, in-line quality measurement (e.g. colour) and oscillation mechanism.

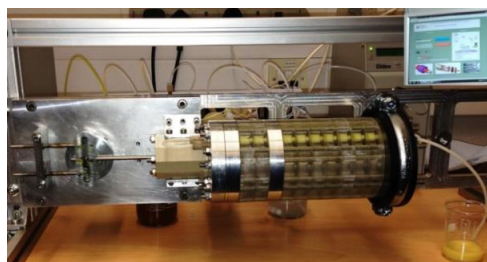


Fig. 2. A Novel Flow formulation system employed in this research [18].

This design includes three basic components that are directly controlled the overall formulation process: a tubular arrangement with a continuous production method, an oscillation process regarding the frequency and the amplitude and a net flow. These arrangements enhance greater mixing performance of ingredients in highly controllable way, in a single production passage and at a low operating pressure and shear force but in a small footprint. Also, it enables to deploy or redeploy formulation and process parameters rapidly.

2.6. Consumer panels

The aim of the sensory measurement was to establish target values of the most preferred sensory product attributes as input for the formulation system. This was done by conducting Quantitative Descriptive Analyses (QDA) with untrained consumer panel. 51 untrained consumer panels with different backgrounds such as age, gender and nationality were selected to taste and evaluate sensory properties of formulated and commercial products. The sensory attributes are appearance (i.e. colour intensity), flavor (i.e. smell), texture (i.e. smoothness), taste (i.e. acidity) and overall acceptability. These descriptors were the most familiar words to consumers. Interval based questionnaires were used for the evaluation. Assessors were asked to draw a circle based on their perceptions for the related sensory attributes on the scale range between 0 and 10 (i.e. a 10 point Likert scale).

3. Result and analysis

Data of PM, analytical physical measurements, consumer panel, experimental design and statistical analysis and the formulation design space were integrated into the consumer-driven new product development model.

3.1. Preliminary study

In the preliminary evaluation study, 51 untrained panel profiles (21 members for the product A, 17 members for the product B and 13 members for the product C) assessed orange juices sensorial attributes in order to evaluate commercially available orange juice products. The sensory attributes of a new product have the most significant effect on consumers' acceptance and ultimately their purchase decisions. Therefore, the sensory analysis plays a key role in the food evaluation and largely in the successful NPD. Sensory properties of the orange juices (product A, B and C) such as color intensity, smell, acidity, smoothness and overall acceptability are presented from different groups in Fig.3.

Orange colour and acidity in the product A were higher than the both the product B and product C due to the highest amount

of orange juice concentration as well as different ingredients such as vitamin C and citric acid. However, the overall acceptability of the product C was the highest as it had better consumer acceptance. As seen in Fig.3, aromatic flavor (smell) plays major role for overall product acceptance by consumers.

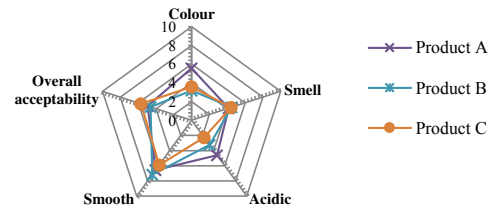


Fig. 3. Sensory profile of the three commercial juices (A, B and C).

As a result, today's commercial product (a winner product) in relation to those consumer market segments is the product C which contains 12% of orange juice from concentrate. After the sensory assessment of the three commercial orange juices, 10 consumers of the 51 untrained panels were enlisted to play a game-like consumer (online PM) and to individualize an orange drink based on beverage (product D).

3.2. PM analysis

Compare to other techniques such as surveys and opinion pools, PM performs better because of its incentives and information discovery. Taste, flavor, texture and appearance were selected as the most important sensory attributes for the development of new beverage products. 10 people were participated over a week gaming period, 96 respondents were obtained for all markets. Final price of each sensory attribute defined preference of each corresponded sensory attribute as percentage. The target values for the sensory attributes formulation are the product prices that the participants have decided during PM.

Results of the taste preference market are shown in Fig.4 (a). People demanded sweet beverage before the consumer panel session. The prices of the sweet attribute were 45 Bite coins. That means 45% of the participants preferred a sweet beverage product. Sweet orange juice was formulated and prototyped. Then, we asked consumer panel to evaluate product performance. Participants reviewed their preferences in the PM after the sensory evaluation study. The prices were considerably changed after the sensory evaluation study. The price of the citrus increased to 38 bitecoins where sweet and bitter prices decreased to 32 bitecoins. That means people did not like the sweet orange juices, they decided to prefer citrus (acidic) orange juices.

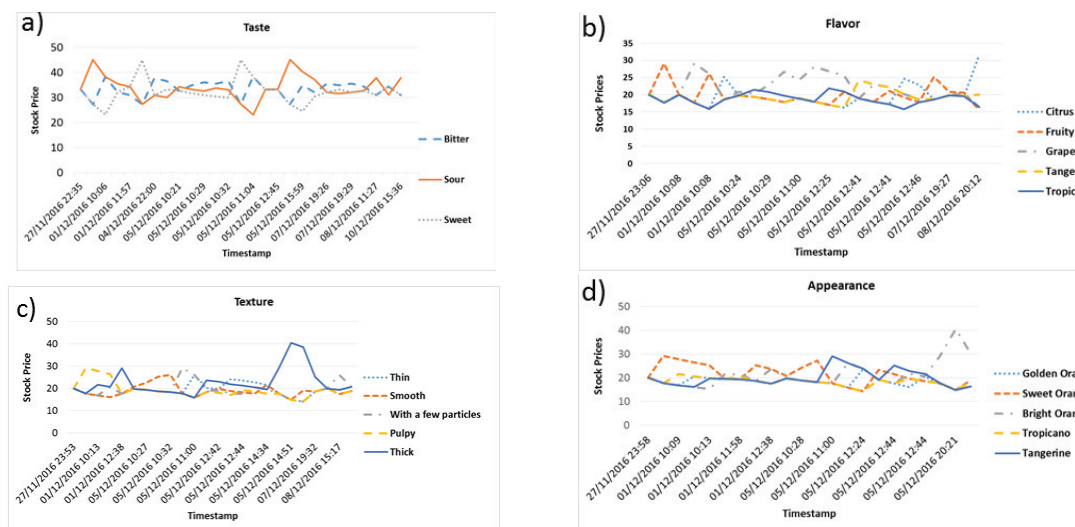


Fig.4. Preference Marketplace Results a) taste, b) flavor, c) texture and d) appearance

The most five common orange juice flavors attributes (citrus, fruity, grapefruit, tangerine and tropical) were asked participants to prioritize with PM. There was not a strong agreement on the participants for a particular flavor. All flavor stock prices were very close during one week trading period as shown in Fig.4 (b). But citrus was slightly higher than others. Before consumer panel, the price of the citrus was 24.67 bite coins, the second most popular flavors were grapefruit and tangerine with same price 20.2 bite coins. According to these market results citrus flavored orange juice was formulated and manufactured for the consumer panel session. After the consumer panel evaluation, citrus product prices increased to the 31.5 bitecoins, while other product prices decreased below 20 bitecoins.

Five different texture attributes (thin, smooth, with a few particles, pulpy and thick) were proposed to participants. At the end of the game, all prices were very similar as shown in Fig.4(c). However, before the consumer panel study, participants' agreement was for the thick beverage product with 40.50 bite coins market price and based on this market price, high viscous orange juice was formulated and manufactured for the consumer panel evaluation.

Five different shades of orange colour (from dark to light) were asked for the participants to invest their preferred beverage colour as shown in Fig.4 (d). Bright orange colour was the most required orange colour shade with 40.40 bite coins market price before consumer panel session. The required color option was formulated with natural food coloring ingredients beta-carotene and we asked participants to evaluate it again. The bright orange price was decreased to 29.9 bitecoins at the end of the game but it was still the most preferred shade of the orange colour.

3.3. Large scale beverage product customization

According to the PM's information, the sensory properties of the product D were identified and linked to its physicochemical properties such as pH level, viscosity, colour and mean particle size. Then product D was formulated according to these manufacturing processes conditions: 4.00 mm oscillatory amplitude, 2.5 Hz oscillatory frequency and 8.60 ml/min net flowrate. The formulation design space was generated with regard to limits of the experimental parameters studied (i.e. product and process parameters), for more detail refer our previous paper [10, 11, 14].

3.4. Sensory evaluation by consumer panels

The assessment of the product D were performed using five sensory descriptors such as colour, smell, acidity, smoothness and overall acceptability. Consumer requirements were a lighter colour, more citrus and higher acidic juice without changing the smoothness. According to those requirements Product E was reformulated in order to deliver consumer needs. That, in turn, requires significantly altering the physical properties of the product D which had orange comminute from concentrate (8 w/w%) as follows: smaller mean particle size (4.18 μm), smaller pH (4.80), lighter colour (574.92 nm) and keeping viscosity value at the similar level (14.90mPa.sec). Consumer panel were tested the performance of the formulated product E. The assessment results were positive compared to product D as shown in Fig.5.

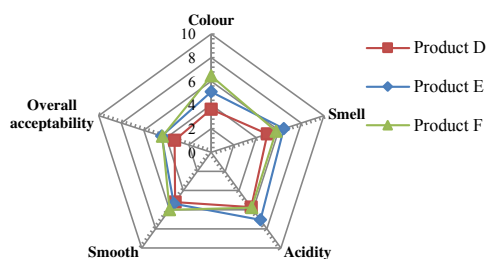


Fig. 5. sensory profiles for manufactured orange juices based on consumers

Alternatively, the consumers' desire ready to consume orange juice with similar acidity and smoothness levels to the product E but less citrus and darker juice. In this condition, reformulated Product, named *sample F*, was produced to test and evaluate promptly by the same consumers. The product F which has orange comminute from concentrate (4.73 w/w %); had these physical features: larger mean particle size (7.22 μm), 5.07 pH level, 16.80 mPa.sec of the viscosity value and 577.50 nm of the colour value. The overall acceptance of the product F was determined in the similar level of the product E. In fact, the reformulated product E had the best overall consumers' acceptance among both products (D and F).

4. Conclusion

In this paper, we presented a novel methodology for the creation and design of new beverages. Our methodology comprises of a digital crowdsourcing tool to elucidate preferences from consumers. Then using a model based approach, that our methodology encompasses, these preferences were translated into actionable instructions to drive an automated continuous formulation system to produce the beverage rapidly, for tasting and evaluation. With this approach, we demonstrated a closed loop beverage design method allowing the consumers to co-create the products they wish to consume alongside a New Product Development team. On evaluating our approach with actual consumers, we found that that a preference marketplace is a flexible, scalable and viable crowdsourcing tool for this purpose. They found the platform better and more engaging than surveys and questionnaires due to the game-like features of the approach and those we implemented. On the manufacturing side, our formulation platform has been able to rapidly respond to consumer preferences by preparing the formulation of the beverage that corresponded to those, and at the same time determine a scalable manufacturing process for large scale production of the product. The combination of small footprint, modular design and low energy requirements of the apparatus, makes it an enabler for localized, redistributed manufacture of food products, that is inclusive to the needs of consumers in local markets. In the future we will investigate deployment and business models of our methodology for redistributed, inclusive manufacture of food products that scale according to the needs in terms of quantity, variety and quality of localized markets.

Acknowledgements

This work has been fully funded by the UK Engineering and Physical Sciences Research Council (EPSRC) primarily by grant with number EP/K014234/2 with a supplement from grant with number EP/M017567/1. The authors fully acknowledge and wish to thank EPSRC for the financial support.

References

- [1] A. Linnemann, M. Benner, R. Verkerk and M. A. V. Boekel, "Consumer-driven food product development," *Trends in Food Science and Technology*, vol. 17, pp. 184-190, 2006.
- [2] A. Kutin, V. Dolgov and M. Sedykh, "Information links between product lifecycles and production system management in designing of digital manufacturing," *Procedia CIRP*, vol. 41, pp. 423-426, 2016.
- [3] A. Costa, M. Dekker and W. Jongen, "An overview of means-end theory: potential applications in consumer-oriented food product design," *Trends in Food Science and Technology*, vol. 15, pp. 403-415, 2004.
- [4] P. Tsimiklis, F. Ceschin, S. F. Qin, S. Green, J. Song, T. Rodden, S. Baurley and C. Makatsoris, "A consumer-centric open innovation framework for food and packaging manufacturing," *International Journal of Knowledge and Systems Science*, vol. 6, no. 3, pp. 52-69, 2015.
- [5] J. S. Srari, M. Kumar, G. Graham, W. Phillips, J. Toozee, S. Ford, P. Beecher, B. Raj, M. Gregory, M. K. Tiwari, B. Ravi, A. Neely, R. Shankar, F. Charnley and A. Tiwari, "Distributed manufacturing: scope, challenges and opportunities," *International Journal of Production Research*, vol. 54, no. 23, pp. 523-69, 2016.
- [6] J. S. Srari, T. S. Harrington and M. K. Tiwari, "Characteristics of redistributed manufacturing systems: a competitive study of emerging industry supply networks," *International Journal of Production Research*, vol. 54, pp. 6936-6955, 2016.
- [7] D. T. Matt, E. Rauch and P. Dallasega, "Trends towards distributed manufacturing systems and modern forms for their design," *Procedia CIRP*, vol. 33, pp. 185-190, 2015.
- [8] P. Tsimiklis and C. Makatsoris, "An open innovation framework for collaborative food product design & manufacturing," *Journal of Innovation Management*, vol. 3, no. 4, pp. 134-163, 2015.
- [9] D. T. Piorkowski and D. J. McClements, "Beverage emulsions: recent developments in formulation, production and applications," *Food Hydrocolloids*, vol. 42, pp. 5-41, 2014.
- [10] M. Jreissat, "Novel flow system for the concurrent product and process design of emulsion-based formulations," *PhD Thesis in Brunel University*, London, UK, 2016.
- [11] S. Isaev, M. Jreissat, C. Wagner and C. Makatsoris, "Linking human and machine - towards consumer-driven automated manufacturing," in *IEEE International Conference on Fuzzy Systems (FUZZ-IEEE)*, Vancouver, 2016.
- [12] S. Isaev, M. Jreissat and C. Makatsoris, "Formulated food product and manufacturing process design with a novel continuous flow reactor," in *International conference on manufacturing research (ICMR)*, Bath, 2015.
- [13] E. Dahan, A. Soukhoroukova and M. Spann, "New product development 2.0: Preference markets," *Journal of product innovation management*, vol. 27, pp. 937-954, 2010.
- [14] J. Wolfers and E. Zitzewitz, "Prediction Markets," *Journal of economic perspectives*, vol. 18, no. 2, pp. 107-126, 2004.
- [15] M. Spann and B. Skiera, "Internet-based virtual stock markets for business forecastin," *Management science*, vol. 49, no. 10, pp. 1310-1326, 2003.
- [16] M. Jreissat and C. Makatsoris, "A novel knowledge-based framework for predictive food design," in *International Iseki Food Conference*, Athens, 2014.
- [17] C. Makatsoris, L. Paramonov and R. Alsharif, "A modular flow reactor". GB/Middlesex Patent WO 2013/050764 A1, 11 April 2013.