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Modelling & Simulation as a Strategic Tool for Decision-Making Processes: A Dairy Case Study

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Abstract. The dairy industry faces many challenges when compared to other sectors. On the supply side, due to the nature of the raw material, large inventories are not applied; during the manufacturing process, continuous production is highly sensitive to any sort of unplanned disruption; on the demand side, the market dictates the bulk powder commodity prices.
In response to the growth in competition, dairy organizations' strategy must incorporate technology into their daily processes in order to become more efficient, profitable and sustainable. To achieve desired levels of improvement, Modelling and Simulation (M&S) has been increasing in popularity in the decision-making process. Using a dairy company as a case study, this paper has highlighted the potential for M&S to be used as a powerful strategic tool for decision-making processes.

Keywords: modelling and simulation, dairy industry, decision-making processes, optimising, GAMS

Mathematics Subject Classification: 90B50, 93C95, 28A12

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1. INTRODUCTION

This paper is an expansion of a previous research manuscript presented at the DMMS 2017 Conference 2017, where a simulation model was developed to support the decision-making process in the dairy industry (Eccher and Geraghty, 2017). The object of this research has been expanded to consider all of the products produced by the industry

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partner and proposing an optimised flow of production. The model has been extended in order to consider the entire impact of additional processes on the main product.

This paper has chosen to focus on the dairy manufacturing, which differs from other sectors due to its high level of perishable products and seasonality. This sector is composed of farms, processors, retailers and distributors to reach the final consumers and faces several challenges when compared to other industrial segments mainly because of the short lead time and high degree of price competitiveness. Conversely to other commodities, dairy products require specific equipment to be processed and stored, which considerably increases the cost of the final product. Moreover, the transportation needs to be efficient in order to improve the delivery time, since milk spoils rapidly without the appropriate refrigeration. As an alternative, many companies are increasing the value-added products mix by drying processes which reduces the necessity of refrigeration and increases the life cycle.

Operating at low-level cost is essential given both uncertainties: farms on supplying the raw material and the market for the demand price. The complexity of elaborating a production plan and strictly following it relies on the product mix processed and the efficiency of their sequencing. From suppliers to final customers, several distinct levels of decisions are required.

The decision-making process is explored by (Gunasekaran, Patel and McGaughey, 2004; Özbayrak, Papadopoulou and Akgun, 2007; Tonanont, 2008; Slack, Brandon-jones and Johnston, 2013; Farahani et al., 2014; Wisner, Tan and Leong, 2017) and is divided into strategic, tactical and operational. Through this segmentation, the time horizon and investment required are defined. Moreover, metrics and measures are created and compared according to each level:

- At the strategic level, long-term decisions are made and are normally followed by Business Plan strategies such as location, strategic partnership, new products and lifecycle products, make-buy decisions, new equipment, new plant capacity, competitiveness, international partnership and organisational goals.
- At the tactical level, medium-term decisions are made and the time horizon generally covers one year. The main objective is to support the strategic level previously defined and assure that the operational level will be followed as planned. Decisions regarding planning and scheduling, inventory policies, safety stock levels, transportation route and sequence of orders are generally decided at this level. In addition, measurements and Key Performance Indicators (KPIs) are compared to achieve results.
- At the operational level, short-term decisions are made and the time horizon can be measured daily and / or weekly. Operations previously planned at the tactical level must be executed and any deviation must be reported and properly recorded to be managed in the future. Lessons learned are also reviewed to balance operations and future improvements. Daily transportation, inventory levels, production efficiency and order entries fulfilment are examples of activities executed at this level.

The promise of a modelling and simulation for decision-making processes is particularly appealing to industries where a high level of uncertainty is observed. M&S

applications can be applied to all three decision levels to improve overall processes in the dairy industry through what-if analyses.

According to (Reid and Sanders, 2012), decisions that set the direction of the entire company are broad in scope and long-term in nature. The mission, environmental scanning required to define trends, threats, opportunities and strengths are defined at strategic level and examples of strategy management tools widely used to follow the execution of activities and its consequences are: balance scorecards, SWOT and Ishikawa diagrams. Therefore, at the strategic level, capital investments benefit from simulation models in comparison to traditional static evaluation as presented in this research.

To achieve the desired profitability performance, the optimum use of resources is essential at the operational and tactical levels. Increasing capacities (external and internal) through partnerships or capital investments must be planned at the strategic level when required, and M&S provides insights to support this level of decision.

In this research, some experiments were conducted comparing how an increase in the total profitability would be achieved if an optimised quantity of products were produced and insights for an increase in the current capacity. This analysis combines an optimisation model through a Linear Programming (LP) and M&S to demonstrate how the product mix could be improved at the tactical level and what type of capital investment would be required at the strategic level. This paper is organized as follows. Section 2 gives an overview of applications in the dairy sector using simulation tools. Section 3 describes the simulation model built in ExtendSim to support a dairy company decision-making process. Section 4 presents the statistical analysis used to validate the model. Section 5 then presents the findings and results by removing the dependency of two main production processes. Section 6 presents the conclusion and future work.

2. MODELLING AND SIMULATION APPLIED TO THE DAIRY INDUSTRY

In this section, the application of M&S to the dairy industry is be presented. The following examples of research based on modelling and simulation have contributed to clarifying the research question proposed by this case study: What is the potential of modelling and simulation to support the decision-making process? Even though several studies related to dairy and modelling and simulation processes have been found, the majority of the findings have not explored the contribution on distinct decision levels.

For example, a Discrete-Event Simulation (DES) model was developed through the Arena package to analyse the effects of each activity in the food process such as mixing of raw material throughout the final product packaging (Abed, 2008) focused on operational decisions, where several scenarios or changes in the production line were reproduced and compared in order to propose an optimum solution. A simulation and optimisation-based decision support tool was developed to evaluate the behaviour of two factories and the scheduling of a large quantity of milk suppliers combining the uncertainty in demand were explored by (Li, Zhang and Jiang, 2008). In both examples, M&S was applied to support decisions regarding planning and scheduling which are usually explored at the operational level.

The incorporation of sustainable aspects of a Dairy Supply Chain is adopted by (Sonesson and Berlin, 2003) through Life Cycle Assessment (LCA), where five approaches were explored considering the flow of material. The model considered the integration of transportation among farms, dairies, distributors, retails and households and aspects of packing, energy utilization, water and waste. In addition, the use of resources such as wood for paper production and pallets; and oil for plastic packaging production was explored. LCA was also explored by (Nutter et al., 2013) to evaluate the global warming potential related to USA milk processing. The model evaluated the GHG emission per kg of packaged milk. However, the results are not considering other products in the dairy industry such as dried commodities where the electricity required to process these products is massive.

A model based on quality-control and moral hazard was proposed by (Qiang, Yun-xian and Xian-glin, 2010) considering the quality approach of the milk's depots and processors. Effects such as additional compensation for customers, incoming inspection and independent investigation systems were evaluated in order to increase their quality to the final customers.

A centralized management optimisation model where a simulation method developed using General Algebraic Modelling System (GAMS) compared strategic decisions about centralisation and decentralisation and its impact on the dairy supply chain network was proposed by (Bei, Jie and Jian, 2006). GAMS is a high-level modelling system for mathematical programming and optimisation. It consists of a language compiler of high-performance solvers (*An Introduction to GAMS*, 2017).

The application of GAMS combined with Microsoft Excel to evaluate the cost of seasonality in Ireland was also explored by (Heinschink, Shalloo and Wallace, 2016). Due to the fact that milk production relies mainly on grass-based agriculture and the effect of extra processing capacities required during the peak season is high, a financial analysis suggested changes in supply from a seasonal to a smothered patter.

An economic approach was studied in (Guan and Philpott, 2011) describing the effects of price-demand curve contracts arranged several months in anticipation. A multistage stochastic programming model in a dairy company was conducted in this research. A payment system to compensate farmers for delivering quality goods dairy is proposed by (Fuentes et al., 2016) where a spreadsheet decision support tool was designed to calculate the profit based on suppliers' milk quality.

A model to represent the current condition between dairy companies and rural producers was conducted using System Dynamics (SD) by (Scramim and Batalha, 2003). The model proposed a reduction of cost over time through better performance in quality and quantity metrics. SD was also applied by (Reiner, Gold and Hahn, 2015) through a model to explore the effects of appropriated pricing strategy for wealth generation and health improvement at the Base of Pyramid (BoP). The research proposed insights to find the best price and decisions regarding distributions of dairy products in Bangladesh.

Optimisation process through LP models are widely applied in several manufacturing sectors namely when departments have conflictive objectives. Purchase departments, for example, sought desirable prices which normally are achieved through larger lot sizes. Reaching the lowest price could reduce the cost of raw material and consequently the total cost of production. However, costs of inventory, handling, labour and overhead are evidently increased by this excess of raw material stored. This trade-off is widely explored in the literature and provides a good example of optimisation model applications.

Examples of MIP applications focused on optimising scheduling processes were found in (Doganis and Sarimveis, 2007) where an MIP was modelled to find a feasible schedule for a dairy product considering the intermediate and final stages in the production flow. Even though the model addressed issues such as short shelf-life and changeover due to the cleaning process given initial insights to this research, the solution proposed concentrates on evaluating the cost of producing a specific product and the seasonality identified in the raw material supply was not explored. A similar approach considering costs and the best production sequence was also proposed by (Alvfors, 2015) in a discrete-time scheduling lot-sizing for a dairy company where the third party packaging for finished goods storage activities were also incorporated.

Multi-objective criteria were explored in (Amorim, Günther and Almada-Lobo, 2012), although techniques have traditionally concentrated on dairy fresh end-products production and distribution planning.

Based on the literature explored, it was observed that even though each research was performed in distinct countries under diverse conditions, several manufacturers addressed similar issues providing local improvements. In addition, some researches are not totally focused on simulation models, the application of Monte Carlo simulation to introduce artificial uncertainty is observed.

Production planning strategies are concentrated on end-products, packaging area, distribution, and makespan improvements. Limited literature is focused on production flow combining efficient Cleaning-In-Place (CIP) cycles and its impact on the manufacturing process.

3. THE DAIRY CASE STUDY

In this case study, the industrial partner is an intermediate milk processor in the dairy supply chain, and the final product is further processed by several companies and processors. Most of their products are negotiated by contracts that are planned in advance. The company produces several dairy products; however, some specific products and the impact of their by-product are the main objectives of this case study. Since the information about production is confidential, the company is referred to as a Dairy Study Case (DSC) and products are referred as P1, P2, P3, P4 and P5.

The model was designed to simulate the same operation in the DSC processing which means that the milk is supplied hourly during the peak season. After processing, part of the yield is packaged, stored and further delivered.

A DES model was designed to deal with four branches of products carrying distinct production flows, strategies and processes. The first branch is a continuous process and an additional batch process occurs dividing the concentration of fat into two new products. Both products operate in a continuous process; however, due to diverse capacities and buffer tanks, the production time presents unlike results.

The third branch process P3 and after accumulating at a minimum level, a chemical reaction produces the separation of two new products. In the fourth branch, the product goes straight to the decantation process due to separation of solids from the liquid form. The concentrated solids are sent to the evaporation process to be transformed into the powder form.

Product P3 has a high added-value and is frequently disrupted by its by-product Work-In-Process (WIP). As soon as the by-product achieves a profitable level the flow is sent to the Ultra Filtration (UF) plant in order to separate solids from the liquid form. At this level, part of the product is transformed into powder and packaged for customers and part of the product becomes waste. Figure 1 illustrates the model developed in the ExtendSim package and all five branches and end-products evaluated in the DSC.

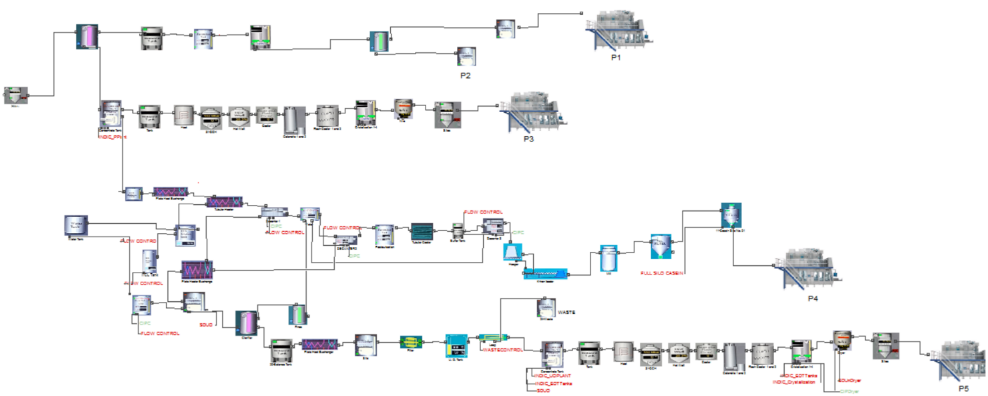

Fig. 1. *M&S developed using ExtendSim*

An initial increase in P4 production was explored owing to the fact the actual P4 supply to the market is currently below the demand, generating backlogs which are negotiated among customers and transferred to the next periods.

Some important assumptions were considered due to direct impact on the product output on the initial model:

1) The high level of WIP on P5 production flow,
2) Unplanned shutdowns caused by CIP cycles,
3) The effect of rate and flow on each process,
4) The separation process incorporated into the extended model,
5) The impact of WIP on P1, P3, P4 and P5 production flows,
6) The impact of P2 WIP on the entire process which is currently sent to be finalised by other manufacturers.

The extended version considers the entire flow of products rather than only P4 and P5 as proposed by the initial model. Moreover, the user interface was also extended to other processes as shown in Fig. 2.

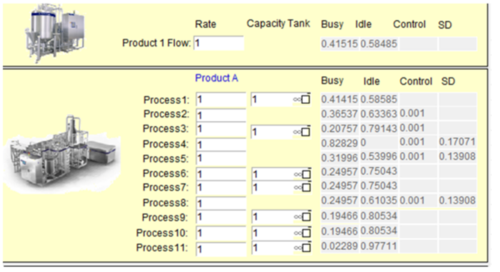

Fig. 2. *User interface*

4. MODEL VALIDATION

In this section, the validation between simulation and real process production is presented. The quantities validated were referred to as tons produced for 52 weeks. The structure of the DSC presented was statistically validated by comparing the output generated by the real production to the simulated results.

After the execution, the average of all replications of products was calculated and compared to samples from the current records. The simulation ExtendSim package provides an internal database where all the information can be stored hourly by each piece of equipment and product flow. All the results are standardized in order to preserve data confidentiality.

Through IBM SPSS, RStudio and Microsoft Excel, the volume of tons produced are recorded hourly in the dataset created by the simulation model. The results are standardized in order to preserve data confidentiality and are explored as follows.

4.1. Boxplot Whiskers

The graphs presented in Fig. 3 show the behaviour of all four products produced by the DCS. P1, P3, P4 and P5 were compared to the production and simulation results through boxplots which are a significant visual data representation of central value.

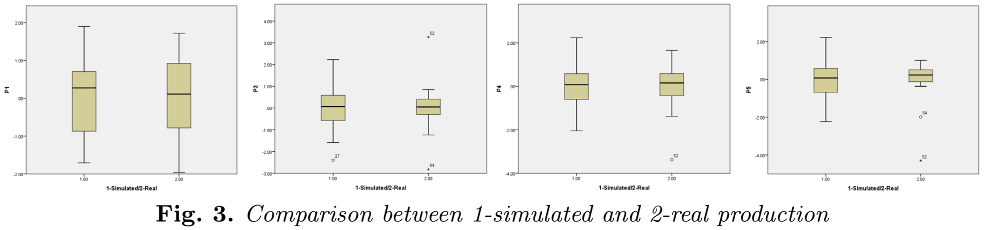

Fig. 3. *Comparison between 1-simulated and 2-real production*

Through the graphs, it is possible to observe the records or points are clustered around the simulated mean for all products and some outliers for real outputs. The discrepancy between the lowest and highest limits in both simulated and real values represent the variability not fully incorporated into the model namely for product P5.

Product P1, for example, presents a higher limit range compared to other products. In order to evaluate significant differences between measures from two independent datasets the results provided by the one-way ANOVA is explored in Section 4.2.

4.2. One-way ANOVA test

The ANOVA test was conducted to compare the two unrelated groups of variables: 1-simulated and 2-real production as presented in Fig. 4. Even though there were no significant differences between simulated and real production, some products demonstrate higher variability than others.

ANOVA

Product1

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1310.099	1	1310.099	1.020	.317
Within Groups	66804.671	52	1284.705		
Total	68114.770	53			

ANOVA

Product3

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1008.850	1	1008.850	1.858	.179
Within Groups	28239.564	52	543.069		
Total	29248.414	53			

ANOVA

Product4

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	306.173	1	306.173	1.595	.212
Within Groups	9981.245	52	191.947		
Total	10287.418	53			

ANOVA

Product5

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	19.094	1	19.094	.026	.873
Within Groups	38272.999	52	736.019		
Total	38292.093	53			

Fig. 4. *Comparison between production and simulation groups*

All measures considered the end-products: P1, P3, P4 and P5 as a final product prepared to be stored. Product P2 was not possible to compare due to the fact that is not finished by the DSC but is processed by an external dairy processor as previously mentioned.

5. EXPERIMENTAL RESULTS AND DISCUSSIONS

In the DSC, as previously explained, P5 is a by-product of P4. The increase in P4 production levels would be attainable through two methods:

– by increasing the raw material supplied maintaining the proportion at the separation process,
– by changing the proportion in the separation process.

For each 1 ton of P4 produced, approximately 1.65 tons of P5 are resulted. However, the value of P4 and P5 in the market price suggests an inverse proportion: P5 fluctuates around only 0.10 to 0.15 of P4 prices. To deal with this important trade-off, several scenarios were conducted combining reasonable strategies in order to suggest insights into what type of decision could be made and what type of results would be attained involving the three levels of decisions.

Not only is the production of P4 dependent on the current bottleneck flow, but on farmers' supply and new bottlenecks that may exist and the processing capacity of P5. In this expanded model other products such as P1 and P3 were considered in order to evaluate the level of impact on the most valuable production flow.

5.1. Current production mix

Unlike other sectors, such as discrete assembly manufacturing where products are produced according to the combination of several components, in the dairy manufacturing environment, milk is the primary raw material and is divided according to chemical/physical reactions in order to produce several other products. The properties of the raw material influence the number of products in the first production flow and the remains can be separated according to a determined criterion by each dairy processor such as:

- Contracts: A minimum quantity must be achieved according to previously anticipated contracts,
- Market price: Products have a high fluctuation in the market price which contribute to improved financial results at specific periods throughout the year,
- Internal capacity: Bottlenecks are responsible for limiting process production quantities.

In the DSC all these criteria impact the production flow and the combination of all these elements will be explored in a multi-objective model in order to evaluate the effectiveness of the current separation process at the operational level. Initially, a linear model developed in GAMS was applied to evaluate which best products mix could lead to most profitable results.

The desired quantity is subjected by the minimum contracts, supply volumes and storage capacities which restricts the total produced. The market proportions were used instead of costs in order to maintain the confidentiality of the entire process. Event though, the prices are volatile and vary throughout the year, an average from prices from 2016 to 2019 were considered (*Prices of EU Dairy Commodities*, 2019).

The notation referring to variables and indices formulated is presented in Table 1.

Table 1. *Parameters and variables*

Variable	**Description**
i, I	Product where $1 \leqslant i \leqslant I$
MP_i	Market price per product i
TP_i	Total produced per product i
D_{min_i}	Minimum demand defined per product i
$PCap_i$	Production capacity defined by bottlenecks per product i
$SCap_i$	Storage capacity defined per product i
$TSCap$	Total storage capacity

The Market profitability ($MProf$) is calculated for all products $(1, \ldots, I)$. The market price MP_i is an external information obtained from the market while the variable TP_i is the internal volume produced measured by TONS as shown in Equation (1).

Maximise $MProf$:

$$MProf = \sum_{i=1}^{I} (MP_i \cdot TP_i) \tag{1}$$

The volume produced is limited by the minimum demand defined for product i and the maximum production capacity $PCap_i$ as shown in Equation (2). The lower limit is defined according to the minimum volume of production to satisfy the contracts. For all cases where the Demand is higher than the production capacity, variable $PCap_i$ is the assumed to be the only restriction.

$$D_(min_i) \leqslant TP_i \leqslant PCap_i \tag{2}$$

The volume produced is also limited by the storage capacity, individually by product i as show in Equation (3) and by the total storage capacity Equation (4).

$$TP_i \leqslant SCap_i \tag{3}$$

$$TP_i \leqslant TSCap \tag{4}$$

As previously described, P5 is a by-product of P4; therefore, the increase of P5 is limited by the increase in P4. This existing restriction causes a strong impact on the production and supply chain distribution processes. In order to evaluate and compare how significant these restrictions between P4–P5 and P1–P3 are an additional restriction is considered in the linear model developed according to Equation (5) where a proportion of 1.65 referred to P4–P5.

$$TP_5 \leqslant TP_4 \cdot 1.65 \tag{5}$$

The linear model developed through GAMS used to perform these restrictions is shown in Fig. 5. The special treatment to store P1 was implemented due to the fact that a distinct warehouse is required while product: P3, P4 and P5 might compete for the same space.

```
Sets
i products   / P1, P3, P4, P5 /;

Parameters
MP(i) market_price
/ P1 0.85
P3 0.57
P4 1.00
P5 0.13 /
PCap(i) production_capacity
/ P1 400
P3 190
P4 350
P5 400 /
```

Fig. 5. *GAMS – Linear model*

```
SCap(i) Storage_capacity
/ P1 500
P3 300
P4 600
P5 600 /
Dmin(i) Demand_contracts
/ P1 200
P3 120
P4 200
P5 300 / ;

Variables
TP(i) quantities produced
MProf total profitability ;

Scalar TSCap      / 800 / ;
Equations
EMProf            define objective function
demand            satisfy demand at product i
supply            observe supply limit at product i
TSP1              total stored for P1
TSTotal           total stored
propP5            proportion of P5 and P4 ;

EMProf..    MProf =e= sum(i,MP(i) * TP(i)) ;
supply(i)..   TP(i) =l= PCap(i) ;
demand(i)..   TP(i) =g= Dmin(i) ;
TSP1('P1').. TP('P1') =l= SCap('P1') ;
TSTotal.. (sum(i,TP(i)) - TP('P1')) =l= TSCap ;
propP5..    (TP('P4') * 1.65) =l= TP('P5') ;

Model mix /all/ ;

Solve mix using lp maximizing MProf ;

Display TP.l, TP.m, MProf.l ;
```

Fig. 5. (cont'd)

The solver resulted in optimum quantities limited by restrictions defined as shown in Fig. 6.

```
----     57 VARIABLE TP.L  quantities produced

P1 400.000,    P3 190.000,    P4 230.189,    P5 379.811
```

Fig. 6. *GAMS – Linear model 1 – results*

The drawback observed in the solution proposed by the GAMS model results is the existence of a dependency between P5 and P4 through the restriction defined in Equations (5) as shown in the highlighted lines. By removing this dependence, the solver resulted is limited by the storage restriction defined as shown in Fig. 7.

```
----      51 VARIABLE TP.L  quantities produced

P1 400.000,    P3 150.000,    P4 350.000,    P5 300.000
```

Fig. 7. *GAMS – Linear model 2 – P4 is not restricted to P5 – results*

It is possible to observe that P4 is produced at the maximum volumes and it is not restricted by P5 equipment capacity. Ultimately, by increasing the total storage capacity (Scalar $TSCap = 1000$), the solver increased the volumes produced for P4 and P5 as shown in Fig. 8.

```
----      51 VARIABLE TP.L  quantities produced

P1 400.000,    P3 190.000,    P4 350.000,    P5 400.000
```

Fig. 8. *GAMS – Linear model 3 – the storage capacity is increased – results*

The results suggested by GAMS models are presented in Fig. 9.

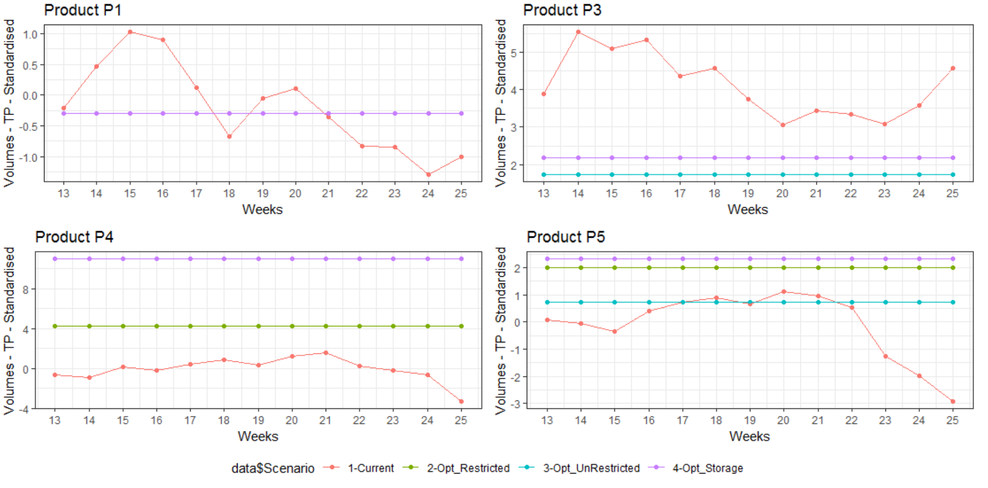

Fig. 9. *GAMS – Comparison current production an –and the optimised results*

Product P1 is not impacted owing to the nature of the production process. The volume suggested is slightly below the current production average. By decreasing P3 production and increasing P4, the impact of P5 on P4 production is visible. P3 presents similar results for both models (2-Opt_Restricted and 3-Opt_Unrestricted) suggesting the production should be decreased by more than 2 standard deviations. A slight increase in model 4-Opt_Storage is observed according to the storage improved.

The dependency between both products P4 and P5 is visible in the current volumes simulated. Weeks 22 to 25 present the same production reduction as shown in Fig. 9. The volumes (y-axis) refers as Total Produced per product i or TP_i.

The achievement of a consistent distribution process to other suppliers would be possible according to the graphs shown in Figure 9. The optimum quantities provided by the linear model suggested a change in the separation process, increasing P4 and decreasing P3 production levels. The improvement in the current profitability and storage utilisation is shown in Table 2.

Table 2. *Results provided by GAMS for each linear model*

Model	**Scenario**	**Market profitability**	**Storage utilisation min**	**Storage utilisation max**
Current Process Simulated	1	–	0.71	1.12
GAMS – Opt_ Restricted	2	0.99	1.00	1.00
GAMS – Opt_ Unrestricted	3	1.11	1.00	1.00
GAMS – Opt_ Storage	4	1.16	0.97	0.97

As shown in Table 2, even though the market profitability is the objective function defined in Equation (1), optimising the volumes produced as proposed by the first model slightly decreases the profitability when compared to the current process as observed.

However, the instability caused by the current separation process shown in Fig. 9 impacts the storage utilisation. During specific weeks, the overall storage minimum computed reaches 71% of utilisation (or 0.71) while the maximum reaches 112% (or 1.12). It is clear, that the utilisation should be limited by 100% or 1. This extra space refers to inappropriate storage used when the production process is finalised, and the designed space is compromised. Conversely, the storage utilisation below 100% presents an inefficient use of the available capacity. The volumes produced with no restriction present an increase in the Market Profitability as observed in the table.

5.2. Replicating the results using ExtendSim

The main advantage of using simulation models is the potential what-if analysis and the ability to verify changes and the possible effects when normally the real world requires a high level of complexity and inter-connected dependency. Moreover, the level of approximation from the simulation model and the real condition dictates the quality of the final results.

In this section, in order to validate the linear model developed in GAMS and the quantities returned from the solver model, a change in proportion in the separation process was implemented to test how feasible and consistent this production plan would be. Evidently, the linear model results do not present the variability required in the real process which can be reached through M&S. The simulation model considers the following parameters in the DSC:

1) Raw milk rate is defined by the flow of milk per hour;
2) Changes in the separation flow;
3) Silo capacity is one of the bottlenecks identified in the flow and it impacts on the production flow;
4) Actual bottleneck is the main restriction in the flow;
5) Concentrated silo is a binary value used to demonstrate the production flow in P4 and how it is affected by P5;
6) Level of concentrated fluid is the concentrate produced by P5 and is the main cause of disruption in P4;
7) Disruption is the quantity of hours stopped in the P4 flow due to excess of WIP.

Some level of variability is understandable due to unplanned downtimes, CIP processes and milk property. The milk property varies through the peak season. However, for the purpose of simulating and comparing results all experiments were conducted under the same environment.

In order to certify that the correlation between P4 and P5 would be reduced by investing in an alternative silo in this full simulation plant, the experiment conducted by (Eccher and Geraghty, 2017) was repeated in order to evaluate a possible increase in the P4 flow and a treatment of P5 by the industrial partner. The best 9 simulated results are shown in Table 3.

Table 3. *P4 and P5 production associated with a possible increase in Milk Rate, followed by an increase in the intermediate Silo and Actual Bottleneck capacity, the use a Concentrated Silo and the level of the concentration and total of Disruptions caused in the DSC flow. The results are standardised.*

Scenario	**P4 Volume**	**P5 Volume**	**Milk Flow Increase**	**Silo Capacity**	**Actual Bottleneck**	**Concentrated Silo**	**Level ProdC Litres**	**Disruptions**
Scenario 040	2.032	1.807	0.586	1.789	1.225	1	20,493.000	0
Scenario 101	*1.954*	*1.944*	*2.342*	–	*2.449*	*0*	–	*4*
Scenario 140	1.954	0.432	2.928	2.683	–	1	200,451.770	0
Scenario 084	1.722	0.790	1.757	0.894	2.449	1	31,798.438	0
Scenario 086	1.567	–0.104	1.757	1.789	–	1	421,313.260	0
Scenario 057	*1.386*	*1.188*	*1.171*	*0.894*	*1.225*	*0*	–	*11*
Scenario 005	*1.283*	*1.504*	–	–	*2.449*	*0*	–	*0*
Scenario 114	1.283	1.078	2.342	1.789	2.449	1	51,232.500	0
Scenario 042	1.257	1.312	0.586	1.789	2.449	1	27,165.452	0

All 39 simulation results are shown in Fig. 10 where the improved conditions are illustrated. The improvements in bottlenecks would increase both products P4 and P5 in 2 standard deviations. The first factors demonstrate the region of optimal condition where products P4 and P5 would reach best volumes.

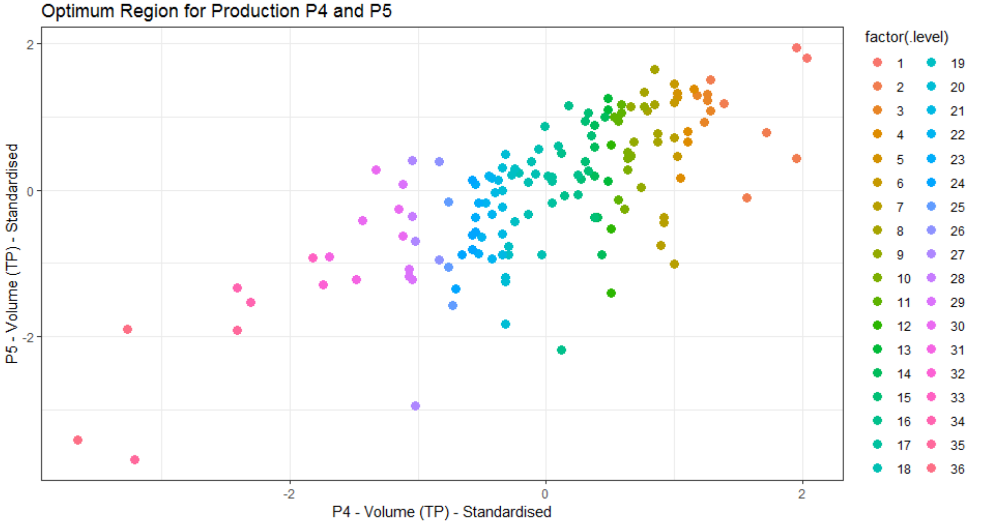

Fig. 10. *Best scenarios by improving bottlenecks around products P4 and P5 – 36 scenarios*

5.3. Discussion regarding optimum mix in dairy manufacturing

The initial experiments in the DSC were conducted considering two branches of products. The interaction of the other products in the total production mix, followed by storage capacity required in the warehouse was not properly explored by (Eccher and Geraghty, 2017). Moreover, the unpredictability caused by fulfilment contracts had to be considered at this phase in order to guarantee reasonable results.

Some special attention for seasonality in this environment may not represent the exact production for each period proposed by a smoothed production. For this reason, the peak season was selected and represented by weeks 13 to 25.

The main challenge in the Dairy sector, especially in high volumes of commodities, is the reduced time required to process the WIP compared to assembly lines where the intermediate products can be stored longer. The main objective is to avoid disruptions in any branch of production flow.

Capital investments are required if a long-term decision of increasing or balance capacity towards product P4 is desirable as proved that the dependency of P5 capacity, compromises the P4 production performance. Such an increase in the capacity of a spray dryer for P5, also providing an available time to dry P2 which was not explored in this research because it is transported in liquid form to different dairy plants.

Capital investment to process P5 in order to remove the restriction in the P4 production and process P2 is required and proved to enhance the overall performance metrics.

To support the decision-making process in the DSC, some strategies were evaluated in the current process by:

- Evaluating the entire production flow by calculating an optimum production mix according to the production capacity, market price, minimum level of contracts and storage capacity,
- Exploring the dependence of P5 over P4 and how this correlation heavily affects the financial results and storage utilisation,
- The volume required to increase the flow by investing in an extra silo to storage the concentrated product in order to send this intermediate product to an external industrial partner.

6. CONCLUSION AND FUTURE WORK

This article explores the benefits of using simulation in order to evaluate the effects of system changes in the overall production processes. The main objectives are to present the particularities involved in the Dairy sector where it differs from other sectors due to the high level of perishability and evaluates the potential of modelling and simulation to support the decision-making process.

In this research an extension from a previous DES model was developed to represent the real process in this DSC to support decision-making processes through different levels of decision: An analysis of the tactical/operational improvement evaluating the current ratio of production was performed followed by removing the dependency of an important added-value product and its by-product.

The simulated results revealed bottlenecks at several stages of the production and an unstable production process as demonstrated by the current process scenario where each week has distinct outcomes. The changes proposed at the operational and tactical levels are the first step to understand the real limitation of the current system and the changes proposed such as remove the restriction between products P4 and P5 by sending the extra concentration or increase the bottleneck are decisions evaluated at the strategic level.

Processes such as milk reception, for example, where the separation of the milk occurs daily in order to produce different branches of products was considered. The simulation model was built to operate all processes at the operation level in order to provide strategic insights to satisfy the customer's demand.

At the strategic level, capital investment to process P5, and thus eliminating the dependency of both P4 and P5 production, is required and proved an increase in overall performance metrics.

The potential for M&S for decision-making processes was explored. One-layer of the dairy supply chain was considered to test the model and the scenarios created and some changes in the current process were suggested. Through the model developed, every improvement throughout the current flow, new bottlenecks will undoubtedly appear such as pipes, pumps, and balance tanks, for example, and new financial assessments will be required for the usage of what-if analysis to find a reasonable solution in the short, medium and long term. This is the natural behaviour of any continuous improvement process.

The expansion to a multi-echelon and the relationship among other processors combined with costs and financial analysis would improve the model. Additionally, waste is an important aspect in all the dairy processors and highly restricts the capacity of process flow due to the legal requirement. Investment in a waste plant was not considered in this research due to its complexity and the deviation of the subject proposed. However, it can be supported by modelling and simulation to the decision-making process as a future work since its capacity restricts the current flow during peak season.

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