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CONCEPTUAL MODELING FOR PERISHABLE INVENTORY: A CASE STUDY IN HUMAN MILK BANKING

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ABSTRACT

The Conceptual Modeling (CM) stage of an M&S study focuses on developing an abstraction of the real world for subsequent implementation as a computer model. Several studies have acknowledged the importance of CM in the success of simulation projects. Yet, there is a lack of literature on applying CM frameworks to real-world case studies, which arguably impedes the translation of CM research into practice. In this paper, we present the development of a conceptual model, using Robinson's CM framework, for our case study investigating the perishable product of human milk within the milk banking supply chain. We present the application of the various stages of the framework, reporting on stakeholder engagement, which has allowed us to develop a shared view of the CM. The paper adds to the literature on CM in practice, providing a detailed narrative on developing a conceptual model for perishable inventory management.

1 INTRODUCTION

While much of the literature on supply chain management assumes the supply and demand, and associated parameters, to be known *a priori*, in the real world, the certainty associated with those parameters is often unknown. The volume of historical data available to the real-world decision-maker is highly variable and presents an equally variable utility for understanding the future. Additional challenges are introduced when managing perishable inventories. Fresh commodities often have a limited shelf-life and display susceptibility to physical factors, such as temperature, humidity, or light, as well as to biological processes, such as ripening that leads to physiological breakdown, or microorganism invasion. On the other hand, mechanisms like chilling or freezing can be deployed to slow down decay, maintain freshness and extend the products' shelf-life. Hence, when managing perishable goods, associated freshness, shelf-life and inventory add to the operational complexities and the need for more careful decision-making.

This study investigates a specific aspect relevant to the perishable product of human milk, namely inventory management. Human milk banking represents a process where human milk gets collected as a result of voluntary donations, processed to ensure safety and distributed to satisfy the dietary needs of premature and vulnerable infants, in circumstances where mother's own milk might not be available. The study is a collaborative undertaking with Hearts Milk Bank (HMB) (Rothamsted Institute, England), which supplies donor human milk (DHM) in England and Wales. As the system of milk banking can be viewed as a set of perishable inventories, careful management is required to minimize probabilities of stockouts as well as consideration of aspects such as shelf-life and product wastage. The following two objectives of the ongoing study are presented: (a) to investigate the behavior of the system that is likely to contribute to improved resource allocation; (b) to develop a simulation model that would allow a better understanding of costs and benefits associated with decisions about how to handle received donations of human milk. For the latter, this specifically relates to whether to treat a donated batch as a whole or employ splitting of batches of donated milk. The splitting strategies will aim to better serve stochastic demand, and the measure of effectiveness will be inventory stockout minimization.

The concept of perishability applies not only to products that have expired (such as the case with HMB), by also to those that experience declining demand due to seasonality or fashion trends or products that face obsolescence (e.g., in the case of technology products). Thus, research on perishable inventory presents an exciting opportunity for the Operations Research and Modeling & Simulation (OR/M&S) community (Staff and Mustafee 2023).

When dealing with highly complex systems with multiple layers of uncertainty, often the problems present a challenge for the application of analytical methods such as mathematical modeling. Computer-based Modeling and Simulation (M&S) is an Operations Research (OR) technique often used to model the stochasticity of the real world. As stated by Robinson (2005) such techniques *"are normally developed because a system is too complex to be represented in any other way"*. M&S provides the ability to develop "*what-if*" scenarios of an existing or a future system of interest and, through computer experimentation, to evaluate the effects of competing strategies before real-world implementation. Such experiments may also facilitate the identification of problems and bottlenecks in a safe and often more financially effective way, when compared to performing such evaluations within the real-life system itself (Pidd 2006). Examples of M&S approaches include Discrete-event Simulation (DES), Agent-based Modeling and System Dynamics. An M&S study consists of four main stages: conceptual modeling (CM), coding, experimentation, and real-world implementation of findings (Robinson 2014).

This paper presents a conceptual model as an initial step of an ongoing study of human milk banking. CM has been acknowledged as an important stage of the simulation life cycle (Kotiadis and Robinson 2008). However, the recent review by Gabriel et al. (2022) suggests that the pace of growth of CM studies lags behind that of M&S-related studies. This is in line with previous studies suggesting that CM is not researched enough, an aspect which is also pointed out by Robinson (2020). Our paper makes an original contribution to the literature on CM with a case study, which, to the best of our knowledge, is the first DES study that investigates the processes within the growing field of human milk banking.

2 CONCEPTUAL MODELING

There is no consensus on what constitutes a conceptual model, its purpose or its benefits (Robinson et al. 2015). In the 2015 *Winter Simulation Conference* panel on CM (*ibid.*), Robinson defines the conceptual model as *"a non-software specific description of the computer model"*, while Wagner's definition focuses on *"description of a real-world problem domain"*. There is an emphasis on the need for documentation of CM from Robinson. Wagner brings academic insight by emphasizing the need for the model to exhibit sufficient scope to answer the research questions. In terms of purpose and benefits, Tolk's perception focuses on the external environment, with importance given to inclusivity to future simulation users, both intended and unforeseen, clear communication and the opportunity for trust-building that CM represents.

During the tutorial on "Conceptual Modeling for DES" at the *2023 OR Society Simulation Workshop* (SW23) in Southampton, Robinson stated that at the CM stage of a simulation study, the modeler should not include *"thinking about code"* (Robinson 2023). Balci and Ormsby (2007) extend it further, stating that CM should always precede the design of a simulation model. Having the distinction between CM and design modeling serves as a mechanism to protects from programming bias and helps to de-couple CM from model implementation-related aspects (Furian et al. 2015). Despite having a seemingly dichotomous system, namely, a conceptual model and a simulation model, the former has been described as a "persistent artifact" that gets constantly redefined, irrespective of the design model's code in the later stages of modeling (Robinson 2010). Irrespective of differing viewpoints of what constitutes CM, the importance of incorporating it in the modeling life cycle is widely acknowledged.

According to Derrick and Balci (1997), a CM framework is "*an underlying structure and organization of ideas which constitute the outline and basic frame that guide a modeler in representing a system in the form of a model*". Previously published frameworks are heterogeneous in nature, with a subset displaying a high level of generalizability that aims to support modelers across a very broad scope of systems (Arbez and Brita 2007; Furian et al. 2015; Robinson 2008), whilst others are designed to capture more specific fields such as supply chains (van der Zee and van der Vorst 2005), healthcare (Kotiadis et al. 2014), and defense (Zou et al. 2016), or with applicability specifically targeted to narrow specific domains for instance physical security systems (Guru and Savory 2004) or stroke patient clinical pathways (Monks et al. 2017).

Another aspect worthwhile considering when selecting the CM framework is the complexity of the system being modeled. For instance, frameworks such as *Activity Based Conceptual modeling (ABC-mod)* by Arbez and Brita (2007), which can distinguish between structural and behavioral constructs, and *Hierarchical Control Conceptual Modeling (HCCM)* by Furian et al. (2015), which includes a centralized system logic that explicitly incorporates a control structure, are better suited for modeling complex systems.

The field of application reported in the paper (human milk banking) is widely unexplored in OR/M&S research. We used the framework presented in Robinson (2008) as it can accommodate modeling for a broad range of systems. While articles often mention the CM stage in the project life cycle, indeed, several papers also refer to the application of Robinson's framework, our analysis of a subset of the literature reveals that a detailed description of CM is often missing. This is unsurprising as papers reporting case study applications usually also cover aspects of the simulation study such as model implementation, validation and verification. This makes a detailed exposition of the CM difficult due to restrictions on article length. However, we found some examples of scholarly work that includes a more detailed description of CM/Robinson's framework, including hybrid approaches of optimization with DES, pertaining to networks of perishable florist products (de Keizer et al. 2017) and location-allocation factoring in circular economy aspects (Bal and Badurdeen 2022). For both studies, the CM framework was used to describe the DES element; however, it is unclear if the framework was also used to define the initial conceptual model at the pre-design stage of the simulation life cycle. On the other hand, the study by Yassin et al. (2020) clearly states that CM was conducted prior to developing an agent-based simulation. What transpires from those studies is that the framework appears to be utilized at least as a structured communication tool that is easy to follow and makes information readily understandable for the reader.

While the primary goal of CM is to gain a deep enough understanding of the system to facilitate the translation of a real-life situation to a computer model that aims to address specific objectives, the importance of *how* the communication is delivered is also of great importance (Lindland et al. 1994). The degree of rigor when conducting and presenting CM is considered by Gabriel et al. (2022) with the description of thirteen good practice (GP) categories that relate to aspects of syntactic, semantic, and pragmatic qualities, which stems from the close relationship of linguistic concepts and modeling which according to Lindland et al. (1994) "*is essentially making statements in some language*". Briefly, the aforementioned aspects described as *syntactic* qualities relate to close adherence of the model to language rules (modeling elements and rules that govern the relationship between them); *semantic* qualities relate to how closely statements in the model describe the real-world system; *pragmatic* qualities relate to the choice of appropriate communication to achieve the maximum level of comprehension by relevant stakeholders (Gabriel et al. 2022; Lindland et al. 1994).

3 HEARTS MILK BANK CASE STUDY

The Hearts Milk Bank, launched in 2017, is the only independent milk bank in the UK. The primary purpose of the HMB is to ensure equitable, assured access to pasteurized screened DHM for the care of preterm and otherwise vulnerable infants cared for in hospitals. The HMB now provides DHM to over 50 UK National Health Service (NHS) Trusts (operated using the cost recovery purchasing model). Due to the fact that the hospital DHM allocation is a patient-tailored decision, that falls under the clinical ambit, the current understanding of numbers of infants benefiting from provision is limited. Additionally, through fundraising, grant funding and academic evaluation studies, DHM provision has been extended to families facing lactation challenges, embedded within a comprehensive program of lactation support, and to assess whether the wider availability of DHM (not restricted to hospital) would be clinically useful (Griffin et al. 2022). Currently, only around 50 families a year can receive DHM on the NHS, outside of the neonatal intensive care unit setting. Hearts Milk Bank provides DHM to over 200 families, free at the point of care, and has supported over 550 families outside of the hospital setting across the UK and Ireland since 2018. In 2019, HMB was merged into a newly founded charity- the Human Milk Foundation.

4 CONCEPTUAL MODELING FOR SIMULATION OF HEARTS MILK BANK

This section will present the reader with a description of the CM for the HMB study. The CM framework developed by Robinson consists of five broad steps, namely *"understanding the problem situation, determining the modeling and general project objectives, identifying the model outputs, identify the model inputs, and determining the model content"* (Robinson, 2008) (Figure 1). Instead of presenting a linear path, they are designed to be used in an iterative manner. Additionally, our work recognizes the good practices (GP) for CM development reported by Gabriel et al. (2022). The 13 GPs are summarized in Table 1.

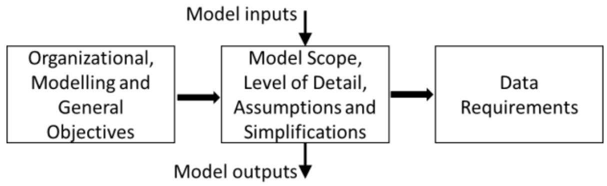

Figure 1: Conceptual modeling framework based on Robinson (2008).

Table 1: CM Good Practice Categories as described by Gabriel et al. (2022).

Category number	**Name:**	**Relates to:**
GP1	Audience's knowledge	Selection of mutually understandable language
GP2	Application	Matching CM language with the application
GP3	Textual and visual language	Selection of visual and textual CM language
GP4	Translation from the conceptual model to the computer model	Language choice to allow ease of conceptual model translation into a computer model
GP5	Client and the project team	Engagement of client in CM
GP6	From the simplest to the most complex details	Directionality of model development
GP7	Review	Continual verification throughout the CM process, including verification of syntactic qualities, validity and understanding of the model by the audience
GP8	Language rules	Adoption of rules as specified by chosen CM language
GP9	Level of detail	Choosing the correct level of detail to address project aims
GP10	Visual pollution	Preventing visual pollution to obtain uncluttered diagrams
GP11	Simplifications and assumptions	Stating simplifications and assumptions explicitly
GP12	Integrated conceptual modeling	Development of conceptual model with external data in a visually accessible way
GP13	Neutral conceptual model	CM independent of the computer modeling software

The conceptual model was co-developed with the co-founder of HMB (a co-author of this paper). Considering the iterative nature of CM development and as our study is an ongoing exercise, the authors may further clarify and refine the conceptual model presented here in subsequent work.

4.1 Understanding the Problem Situation

According to Robinson's framework, the modeling process needs to commence by understanding the problem situation enabling the modeler to develop a sufficient imitation of the real world. This stage is recognized to be heavily reliant on the domain experts' knowledge and ability to convey that information to the modeler. This modeler-client relationship is also the first element of GP proposed by Gabriel et al. (2022) (*GP1*: *Audience's knowledge*). It is delivered through mutually comprehensible language and is defined to be the key element for avoiding ambiguity and misunderstandings. *Choosing* an appropriate language suggests *a priori* definition of terms, which could be particularly challenging if the stakeholders are from different domains. This can be alleviated by having a partner involved throughout the CM stage, enabling the development of trust between the modelers and the stakeholders (Harper et al. 2021). Over time, this leads to better understanding among the stakeholders and the language used converges, and a high level of comprehension is thus achieved. As well as being related to *GP1*, this discussion, together with shared ownership of research (e.g., through co-authorship and shared presentations), also contributes to the fulfilment of *GP5: Client and the project team* and *GP7: Review* (Table 1).

Common shortcomings of modeling studies include a lack of explicit description of the interaction between modeler and system expert (Jahangirian et al. 2010; Staff and Mustafee 2023) including at the CM stages (Gabriel et al. 2022). In this paper, to provide clarity in this regard, in the following sections, we present the description of how the modeler and the problem owner understand the problem domain in HMB. The modeler's understanding of the process flow has been informed through informal interviews with HMB's directors and employees and through observation of processes in a video form (organizational training materials) and from in-person site visits.

4.1.1 Production-Inventory Map

The product flow within the HMB can be broadly decomposed into four stages (as shown in Figure 2):

1) Upon the arrival of a donation in the form of frozen milk, the batch weight and the age of the oldest sub-element are recorded. It then gets stored frozen in the ingress inventory.
2) A batch gets defrosted, pooled, spit into bottles and pasteurized, (also, two small samples of pre- and post-pasteurized milk are sent for microbiological testing).
3) Milk then gets re-frozen in the mid-inventory freezer where it awaits microbiological test results, and once in the clear, the bottles are bagged into batches and transferred to the egress inventory.
4) Milk remains in the egress inventory until dispatch.

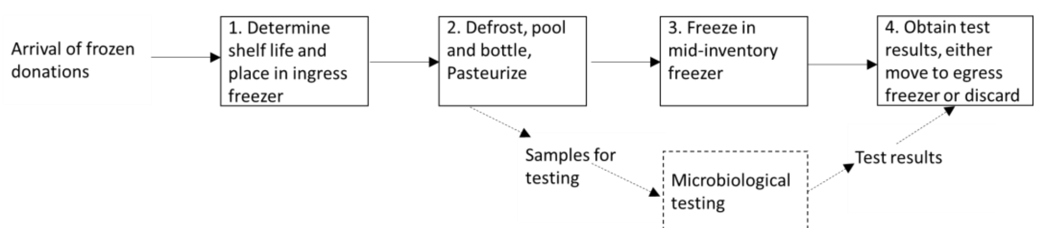

Figure 2: Product flow within the Milk Bank.

The pool of donors is limited to lactating individuals willing to share their milk. This contributes to the stochastic nature of supply. Freshly expressed milk is perishable with a limited shelf-life of three to five days. However, its shelf-life is routinely extended by freezing, with a maximum three-month shelf-life until it needs to undergo the pasteurization process at the HMB, and with a total storage time of up to six months "from expression to use". The aging of the product starts from the point of leaving the human body. For many lactating individuals, expressing milk constitutes an unsupervised process undertaken mainly at home. Thus, the act of donation is not simultaneous in time with the collection process. After milk is expressed, it is frozen and accumulated over time, only to make an aggregate donation at a deferred point in time. Thus, at the point of collection, each batch constitutes an accumulation of discrete frozen samples that are differentiated in size and heterogeneous in age. This is believed to be a unique and previously unresearched feature of the supply side of milk banking. For example, in the widely researched field of blood banking, donor samples are uniform in size, with donation and collection times coinciding, leading to a homogeneous age profile for donated blood for each donation. These features of human milk banking are of particular importance when considering the specific problem, namely the potential batch-splitting of received donations to optimize aspects of HMB inventory management.

4.1.2 Organizational, Modeling and General Objectives

Having clarity in modeling objectives is important as this is likely to affect all the stages of the modeling life cycle and is a determinant of a project's success. Robinson (2008) recommends developing a deeper understanding of the objectives of the organization, as only then are the modeling objectives likely to become meaningful and useful in achieving the organizational aims. The modeling objectives to be addressed could be perceived as a subset of the wider organizational objectives. Beyond those, general objectives that are concerned with the project’s technical aspects should also be defined as early as possible.

For our case study, the main organizational objective is to maximize access to screened DHM for premature and vulnerable infants (Table 2). HMB’s engagement with our research team has helped identify possible ways to improve efficiencies in their inventory and production procedures. Given the stochastic demand and high importance of meeting hospital demand at near 100%, and supply that relies on limited voluntary donations, there is a strong case for understanding whether there could be ways to minimize the stockout risk. A simulation-based study provides an environment where “*what if*” scenarios can be tested prior to real system implementations. For this case study, experimentation within the real system could jeopardize the provision of DHM to vulnerable infants, and therefore experimentation within the simulation domain is preferred. Beyond the aforementioned stakeholder’s objective, while gaining a deeper understanding of the milk bank system and engaging in model conceptualization, five general objectives were realized (Table 2). Our work intends to understand what are the benefits/drawbacks that result from possible batch splitting and the subsequent cost arising from the required changes in milk bank operations.

Table 2: Aims and Objectives of the HMB study.

Organizational Aim:
- To maximize the access of DHM to premature infants

Modeling Objective
- To determine the cost-benefit analysis of donation batch splitting, which extends the shelf-life of fraction of the finished product, thereby reducing waste.

General Project Objectives:
- Time scale: by the end of 2023
- Flexibility: to be considered for further development
- Simulation run speed: not a priority
- Visual display: not a priority, however having a 2D visualization could be useful when sharing the model with wider industry stakeholders in the future
- Ease-of-Use: not a priority, but with some consideration

In terms of general project objectives, the recommended aspects to be considered might include timescale, model flexibility (including its future reuse), simulation run speed, visual display, and ease of use. While being enthusiastic about understanding the system behavior and identifying where improvements to the system could be introduced, the stakeholders have not been overly focused on the timeline, as currently limited government funding is unlikely to translate into immediate operational implementation. The model outcomes are more intended for strategic future planning and preparedness for new provision policy implementation. We agreed that the model, relevant data, and experiments should be ready by the end of 2023. Therefore, unlike many models that are needed to be developed under time constraints, this project benefits from having scope for more careful consideration of the level of accuracy. In terms of flexibility, we envisage further development of our model to allow an understanding of different aspects of milk bank operations. Also, while it was discussed that the model is primarily aimed to be used by a modeler and results to be communicated to the stakeholders, when selecting a simulation software in the later stage, the possibility of having a 2D animation for communication and sharing the concepts with a wider set of stakeholders, could be beneficial. Additionally, we acknowledge that healthcare decision-makers may prefer models implemented as a spreadsheet. Hence, we will attempt to incorporate an interface for data entry and outputs in Excel as it is likely to present a more inclusive user-friendly outlook.

4.2 Model Inputs and Outputs

Model outputs and inputs constitute other elements that need to be identified at the early stage of CM. Input factors are model data/parameters that, through alteration over different experiments and simulation runs, aim to achieve the modeling objectives. The well-chosen outputs will become instrumental if modeling objectives were met; if not, they should guide the understanding of why this is the case. Table 3 summarizes the inputs and outputs related to this case study.

Table 3: Inputs and Outputs.

Model Input-
- Batch Handling Process predominantly related to Batch Splitting
- Donor milk supply and demand-related parameters (statistical model parameters)

Model Output-
- Order fulfilment rate
- Shelf-life characteristics of dispatched batches

Model Output to support the establishment of a possible scenario when aims were not met-
- Shelf-life distribution profile within egress inventory

4.3 Model Scope, Level of Detail, Assumptions and Simplifications

4.3.1 Model Scope and Level of Detail

When deciding whether to include features, a modeler may be tempted to include more features, assuming that a better model is the one which is more realistic (Koivisto 2017). Instead, the elements to be included and their level of detail should be evaluated through the prism of possible usefulness in the model's validity, credibility, utility and feasibility (Robinson 2008).

For the purpose of this modeling work, the boundaries of the model are rather unambiguous, as they include the milk unit flow from entry as a donated batch, through the manufacturing process to the dispatch of externally placed orders. Within those boundaries, the components that contribute to the process that is being investigated are commonly divided into four groups. Those include Entities, Activities, Queues and Resources; they display different characteristics and influence the system's behavior differently. A brief description of components is presented in Table 4, alongside the identified milk bank components.

Table 4: Component inclusion.

Component	**Milk Bank Component**	**Inclusion**
Entities Physical or information components with defined characteristics that pass through the system (e.g., patients, phone calls, food units etc.). They undergo *Activities*, compete for potentially limited *Resources*, and can form the *Queues* when needed.	Milk Units Bags Jugs Pasteurization bottles	Included Excluded Excluded Excluded
Activities Actions to the *Entities* that refers to the state transition.	Batch Handling Process Defrosting, Pooling and Bottling Testing Pasteurization Refreezing and Batching Moving to egress freezer	Included Included Included Included Included Included
Queues Aggregation of *Entities* which await *Activities*.	Ingress Freezer Mid-inventory Freezer Egress Freezer	Included Included Included
Resources Human or equipment that is required for *Activities* to get completed and allow *Entities* to progress through the system.	External Microbiology testing facilities On-site equipment (e.g., pasteurizers, freezers) Human resources	Excluded Depends Excluded

For the *entities* being considered, we are only focusing in our study on the milk units, as we assume that other entities, such as bags, jugs, pasteurization bottles are available in surplus. Hence those are stated to be excluded. When considering the milk units, important aspects to include will constitute arrival patterns, quantities, and their attributes related to characteristics of age.

Moving on to consider the *activities*, the Batch Handling Process (which starts subsequent to the arrival of donations at the HMB) is a key experimental aspect we plan to investigate. Unlike in countries such as the US, where milk from multiple donors is pooled to achieve a prescribed nutritional content, in the UK (the context of our case study) the term pooling refers to combining milk from a *single* donor. Currently, a batch that arrives from a single donor is assigned the earliest harvest date when calculating the expiry date, pooled and hence treated as a whole. After pooling, it gets split into bottles and sampled for microbiological testing, the whole pool having the same expiry date. We are proposing to assess how splitting the donation, which will result in an integer number of sub-batches, changes the profile of the remaining shelf-life at the dispatch point (an illustration is presented in Figure 3). Defrosting (removing frozen donations from the ingress freezer to defrost over time), refreezing and batching (placing pasteurized bottles in one-liter batches in a mid-inventory freezer) and moving to egress freezer, while included, are treated deterministically with a constant time spent at each activity. Also, a deterministic processing time is attached to the pooling, bottling, and pasteurization; however, this varies as it is a function of bottle size and number. Finally, testing is an activity, which after taking samples, is carried out externally. The timing of this activity represents a round-trip until reception of microbiological results. All resources identified within the boundaries of the Milk Bank, except for pasteurizers, are assumed to be always present and/or are used in standardized way. Hence they are excluded from the conceptual model.

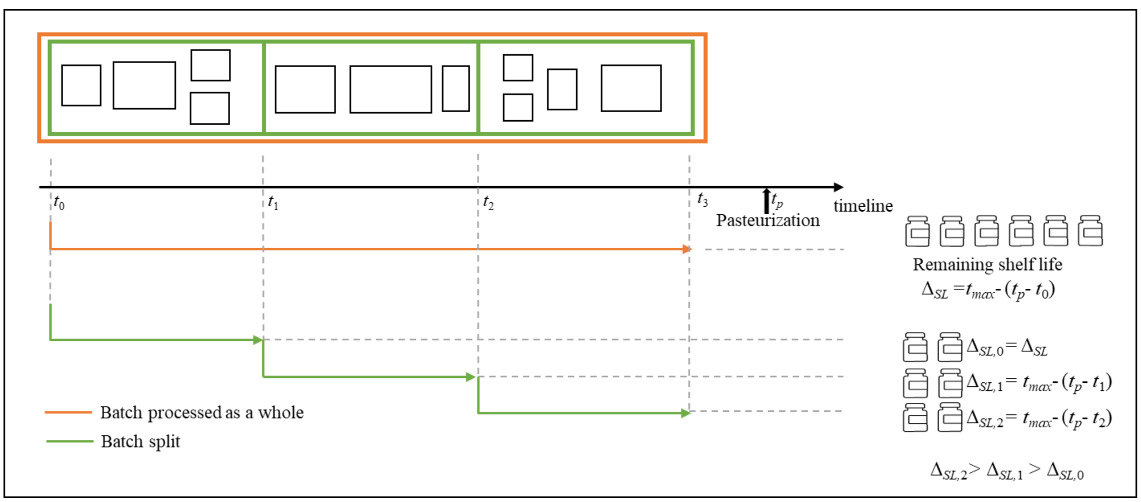

Figure 3: Batch splitting. The black-bordered rectangles represent samples of milk collected over time, frozen and accumulated prior to donation. Sizes and frequencies indicate the variation of harvest that is likely to affect volume (represented by the area of the rectangle) and frequency (number of harvests per time interval). The orange border indicates the post-donation processing (inc. pooling and pasteurization) between t_0 and t_3 as a whole, resulting in a single expiry date. Conversely, green boxes represent the splitting process. In this example, as splitting happened three ways (between t_0 and t_1, t_1 and t_2 and t_2 and t_3), the three sub-batches result in three discrete smaller finished products with differing shelf-lives.

For the deterministic activities mentioned above, how much time per unit is required for processing needs to be established. Regarding resources and queues, the number of equipment resources of pasteurizers and their maximum capacity and run times will be factored in. As far as queues in the system are concerned, we omit aspects such as quantity, capacity and possible breakdown. The aspect of the queue that gets considered is the prioritization rule of *First Expires First Out (FEFO)* for pragmatic reasons of waste reduction. The description of the current subsection directly coincides with the *GP9: Level of detail*, and as the model proposed is relatively simple, we believe the presented level of detail is appropriate.

4.3.2 Identifying assumptions and simplifications

In the process of abstracting the real world and constructing a conceptual model, clarifying the incorporated assumptions and simplifications is a meaningful step. Some assumptions might lead to natural simplifications, e.g., while a staff member is off sick there is always someone else to step in (assumption), hence human resources are excluded (model simplification); or the supply chains of bottles are highly reliable (assumption), hence they are always available (model simplification). As highlighted by Gabriel (*GP11: Simplifications and assumptions*), the simplifications and assumptions stated in publications rarely provide sufficient detail to identify whether those were realized during CM. In our proposal, this ambiguity is absent as all assumptions and simplifications are described, as listed in Table 5.

Table 5: Model simplifications.

Model Simplification
• The time associated with manual labour is represented as the mean of observed processes. • The milk discards occur as a result of failed microbiological test, residual fractional bottles, and expired units; no other type of spillage occurs.

4.4 Data Requirements

The final element of Robinson's framework for CM involves the identification of data that the modeler would require to execute and validate the model. As stated, this is "*fairly straightforward*" (Robinson 2008) as major work that serves as a basis for this step has already been done when defining the level of detail. Doing this at an early stage, rather than after the conceptual model has been developed, is likely to lead to a realization of what data might have been routinely collected and hence available, and what data is yet to be collected. For the latter, assessing feasibility and timescales might lead to a realization that the design of the conceptual model might need altering. Table 6 presents the data requirements for our case study.

Table 6: Data requirements.

Data Requirement
• Pasteurizer: capacity, cycle time • Operational timings • Batch donations: frequency, volumes, distribution of time characteristics • Discard rate: frequency of microbiological testing failure • Hospital orders: frequency, quantities

As HMB is highly committed to data collection in order to engage in continuous process improvement, historical data related to supply and demand is carefully collected. However, batches donated have so far only been considered as a collective, and investigations relating to volumes and temporal dimensions at more granular level within each batch are yet to be conducted. Additionally, process observation with timed recordings of each stage of the process will be conducted by the modeler in due course.

4.5 Visual Modeling of Conceptual Model

The initial CM stage of the project was performed independently of simulation software. However, as more aspects became understood, the decision was reached that the Discrete-Event Simulation (DES) is likely to be a modeling technique appropriate to fulfil the modeling objectives of the study. This is a useful insight when deciding the appropriate visual language for the CM, which will likely facilitate ease of future coding. The choice of visual language was guided by *GP4: Translation from the conceptual model to the computer model*, with the selection of *Integration Definition for Process Modeling (IDEF) SIM* as a visual diagram language. Figure 4 presents the IDEF SIM graphical representation of the conceptual model.

Regarding some of the other GPs, as we provide both textual and visual descriptions, we believe we have fulfilled *GP3: Textual and visual language*. Regarding *GP8: Language's rules* (whether the syntax of IDEF SIM was applied correctly) and *GP10: Visual pollution,* this is left for the reader to evaluate instead of the authors claiming to follow the GPs in those areas.

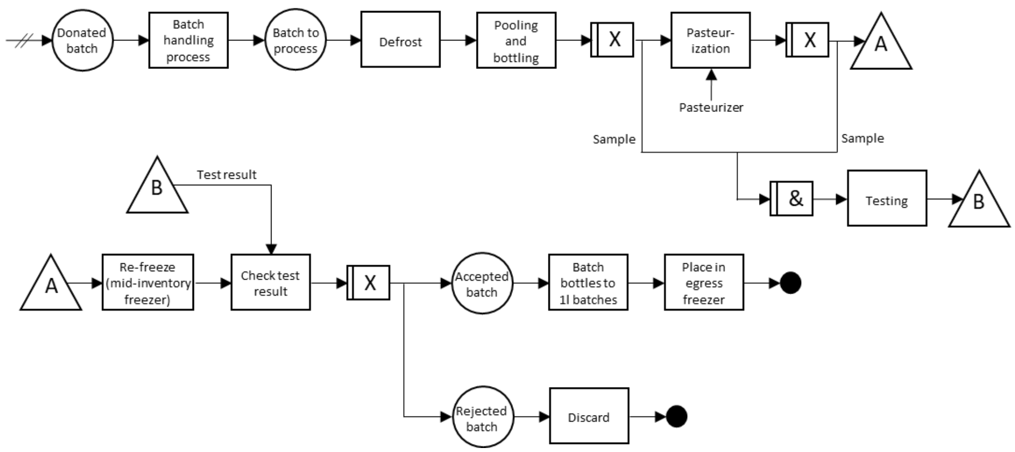

Figure 4: Graphical representation of the conceptual model.

5 DISCUSSION AND CONCLUSIONS

Three attainment levels for the articulation of the problem description from expert to modeler have been suggested, starting from a clearly understood and expressed situation, to the expert being convinced of their knowledge but with that not actually being the case, to finally a neither well understood nor expressed situation (Robinson 2008). While these three possible scenarios are plausible with, as stated in the aforementioned article, many customers displaying the characteristics of the middle level category, we suggest steering away from such assessments of the expert. Rather, we encourage perceiving the modeling undertaking as a willingness to learn, that in an ideal situation would work bidirectionally. Learning from the domain expert and making explicit cause and effect, even in situations where this was not realized by an expert a priori to modeling, is likely to benefit the system both in real life and in the simulation paradigm.

Conceptual model validity refers to the ability to develop a simulation model based on the CM to address the particular problem being considered (Robinson 2008). At the current stage, our conceptual model's validity heavily hinges on the modeler's subjective perception that she believes it is possible to develop a computer model based on the specified features and in the required timescales. Only in future stages when code gets developed will a "beyond opinion" validation process be facilitated. Additionally, as the problem-owner at this stage perceives the conceptual model to be credible, the long-standing modeler-organization relationship is a likely catalyst for developing a tool that will become useful to support organizational decision-making in future. If further refinements to the CM are required, the already-demonstrated mutual efforts to reach a deep level of understanding and openness within the stakeholder team suggests that this would be readily achieved.

Perishable inventory management of goods requires careful consideration to minimize waste. Towards this, our conceptual model of a human milk bank aims to explore batch-splitting strategies to exploit the heterogeneous properties of the incoming donation batches. This is a potential strategy to minimize waste and stockouts and better serve stochastic demand. The conceptual model explicitly defines the important elements required to address these aims. Through articulating the application of Robinson's CM framework (2008) to our milk banking case study, the paper adds to the literature on the practice of CM and informs readers who wish to undertake future CM studies related to perishable inventory management.

As suggested by Keshtkar et al. (2020) "a fundamental principle is modeling and conceptualization should be focused on a problem instead of a system and guided by a clear purpose and objectives", hence for the presented modeling aim of determining the cost-benefit analysis of donation batch splitting, extending CM beyond the assumed DES paradigm is likely to be unwarranted. However, for future research we intend to explore other avenues. With a broad aim of improving human milk provision to premature and vulnerable infants, beyond addressing other operational aims that could be facilitated through DES modeling, a more holistic outlook is likely to be shared in future publications. Given the scarcity of quantitative data in the human milk banking industry, conceptualization through Qualitative System Dynamics might be considered an appropriate tool to facilitate drawing a causal loops mental inference of a system's behavior (Kunc 2017). This could provide insights for strategic-level decision makers, in areas such as network expansion or stock movements among such networks of milk banks. Furthermore, despite benefits of hybrid simulations highlighted by Mustafee et al. (2017), this is currently not being considered in this study. However, we would like to draw attention to the fact that moving beyond a single simulation paradigm could aid future objectives. Utilizing novel CM frameworks, such as those recently proposed by Jones et al. (2022), is likely to benefit the research in hybrid simulation. Finally, irrespective of whether a single simulation technique or a hybrid paradigm is employed, researchers are encouraged to share conceptual models with the wider community. This is likely to provide useful insights of this essential stage of the modeling life cycle of future modeling projects.

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