Strategic decision support for the expansion strategy of a national breastmilk banking network

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Abstract

The South African Breastmilk Reserve (SABR) is a public benefit organisation that coordinates the equitable distribution of donor breast milk to Neo-Natal Intensive Care Units (NICUs). The donated breast milk aids in combating infections in the premature infant recipients, thereby decreasing premature infant mortality rates and saving hospitals substantial amounts in treatment costs annually.

The SABR supplies donor breast milk through its network structure consisting of the SABR head office (coordination facility), milk banks (donor breast milk collection, pasteurisation and storage facilities), corners (interim collection and storage facilities) and the NICUs.

Increased awareness of the benefits and availability of donated breast milk in the NICU has significantly increased the demand for the SABR's service over the last few years. This increase in demand necessitates the rapid expansion and evolution of the SABR's breastmilk banking network. With financial support from the Department of Science and Technology (DST), CSIR Built Environment offered its services to develop a network expansion strategy for the SABR. The focus of the expansion strategy is to decentralise the network to reduce the operational load on head office, enabling sustainable national expansion.

Strategic decision-support models were developed to aid the planning of the network structure and site selections. These models inform decisions regarding the establishment of additional corners.

1. General introduction

According to paediatricians, the inability to access breast milk in the first 14 days of a premature infant's life – particularly when below 1.8 kg of body weight – leaves them wanting for antibodies and exposed to infections and diseases (especially Necrotising Enterocolitis (NEC) – an acute inflammatory disease in the intestines) that result in hundreds of deaths annually (PAHO, n.d.). Situations that could leave premature infants wanting for breast milk include:

- Mothers in advanced stages of acquired immunodeficiency syndrome (AIDS) or TB Meningitis typically give birth prematurely and are too ill to lactate.
- Due to insufficient rooming-in facilities in the public healthcare infrastructure, mothers are sent home while their infants remain in the NICUs. This practice reduces mother-to-child contact, discouraging lactation (SABR, 2007).

The South African Breastmilk Reserve (SABR) is a public benefit organisation that coordinates the equitable distribution of safe, pasteurised donor breast milk (DBM) to premature infants in NICUs, thereby

improving their health and well-being. DBM aids in combating infections in premature infant recipients, thereby decreasing premature infant mortality rates and saving hospitals hundreds of thousands of Rands in treatment costs annually (Edmond & Rajiv, 2006). The SABR's vision is to decrease infant mortality due to NEC and mother-to-child transmission of human immunodeficiency virus (HIV), through the formation of numerous community-driven breastmilk banks and educational programmes. The demand for the SABR's service has significantly increased in the last few years due to increased awareness of the benefits and availability of DBM in the NICUs. To serve this increased demand, SABR's breastmilk banking network requires rapid expansion and evolution.

2. The current SABR supply chain and network

Breast milk is donated by lactating mothers (who have been screened and registered as donors) in plastic bottles distributed by the SABR. This as yet unpasteurised donor breast milk (UDB) can be frozen and stored at a corner or milk bank. All UDB is transferred to milk banks for pasteurisation and storage. The pasteurised donor breast milk (PDB) is delivered on demand to a NICU in the SABR network which uses it to feed premature infants that have been registered at the SABR.

Table 1 below explains the main responsibilities of the four main role players in the SABR network in the provision of its service.

Table 1: The main responsibilities of the various role players in the SABR Network

SABR	Donor		Intermediaries		Beneficiary
	In-hospital	External	Corner	Milk bank	NICU
Coordinates, manages and supports the various role players in the SABR network *(Also functions as a milk bank)*	*(Registered lactating mother)* Provides the UDB		A decentralised collection and delivery point for UDB and materials in the network (no pasteurisation facilities)	Storage and pasteurisation of UDB as well as storage of PDB	*(Registered premature infant)* Consumes the PDB

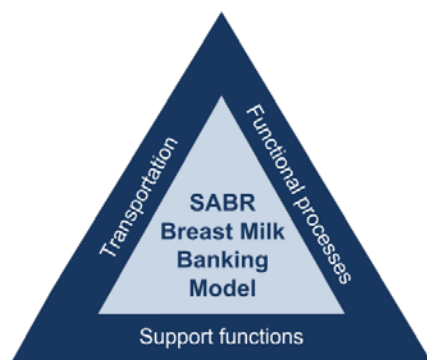The SABR breastmilk banking model consists of three components as illustrated in Figure 1 below.

Figure 1: The SABR breast milk banking model

- **Functional Processes** – Core processes that directly enable the provision of breast milk to premature infants, e.g UDB expression, pasteurisation and storage, etc.
- **Transportation** – between the four main role players of three main physical flow entities:
  - **Supplies** (materials and equipment)
  - **UDB**
  - **PDB**
- **Support Functions** – the SABR's functions that assist and coordinate all role players in the network. It can be divided into:
  - **Coordination activities** – aiming to organise and manage the various role players in the network
  - **System support activities** – aiming to support and expand the SABR network

2.1 Understanding the problem

To cope with the constant pressure on the SABR network due to booming growth in the demand of its services, the SABR (and its network role players) often have to make do with a wide variety of *ad hoc* operating procedures as dictated by circumstances. This has led to a somewhat chaotic web of distribution and blurred lines of responsibility between the role players, meaning that the SABR, milk banks, corners and even donors could all undertake some functional and transportation processes without coordination. In reality, role players often leave the small staff complement at the SABR office to develop creative solutions and to perform the tasks that keep the freezers stocked and the premature infants fed.

In addition to performing some functional and almost all transport activities, the SABR is the only entity responsible for managing the entire network. This comprises the coordination and support functions which are the SABR's core function and cannot be provided by any other role player in the network.

Although the systems of the SABR have been effective until now, the current growth rate requires an expansion strategy that will enable the organisation to increase the number of in-hospital milk banks to ensure that DBM is nationally available to the public.

Two challenges currently inhibit the growth of the SABR network:

- The lack of financial and human resources required to successfully execute transport activities.
- The diverse operating procedures improvised to solve functional and transportation problems.

Thus, in developing an effective expansion strategy, two issues must be addressed:

- Firstly, operating procedures must be simplified, streamlined and standardised to ensure that each role player knows exactly what must be done and when it must be done. This standardisation is imperative if the human milk banking model is to be duplicable and sustainable.
- Secondly, an effective transportation solution must be developed to support the new standardised model.

2.2 A soft operations research classification of the problem

Ackoff's classification (Ackoff, 1974) of three different types of problems cited in Ritchley, 2003, namely i) *messes*, ii) *problems* and iii) *puzzles,* is used to determine the complexity of the SABR problem. A *mess* is a complex issue that is ill-defined. A *problem* is a well formulated issue with no single solution. And a *puzzle* is well-defined and has one specific solution that must be worked out. Using these definitions, the SABR problem is a *problem* as the issue is well-defined, and has multiple alternative solutions.

According to Flood & Keys (1984) key aspects of the problem context include the problem solvers, systems and decision makers. Once the problem context is defined, an appropriate problem-solving methodology can be developed. Flood & Jackson (1991) propose a classification framework that assists in evaluating the suitability of certain problem-solving methodologies to various problem contexts (Keys, 1991). According to Flood & Jackson (1991) the problem context can be categorised along two dimensions: *systems and participants. Simple* systems have few elements with highly organised interactions that hardly evolve over time. In contrast, *complex* systems have many elements with many interactions that are dynamic and probabilistic in nature. The *participants* dimension, which is viewed by Keys (1991) as the divergence of values and interest, is divided into *unitary, pluralist and coercive* relationships. *Unitary* implies common agreement between all stakeholders, *pluralist* refers to multiple views within a shared common goal/objective and *coercive* implies strong irreconcilable divergence of views and values. Therefore, the SABR problem context is defined as a *simple* system with *unitary* relationships.

Flood & Jackson (1991) state that operations research, systems analysis, systems engineering and systems dynamics are problem-solving tools capable of handling the *simple-unitary* problem context. Typical steps in analysing such a problem include setting objectives, developing alternatives, developing cost and resource assessments, evaluating alternatives using mathematical models and defining criteria for choosing the preferred optimal alternative. This succinctly describes the problem-solving methodology followed throughout this paper.

3. The to-be SABR supply chain and network

3.1 A simplified operational model

The most significant change to the roles and responsibilities of the role players in the new model occurs in the functional processes where the SABR will rid itself of all **functional processes**, leaving these activities to donors, milk banks and corners, so that it can focus on its core function of **planning, coordination, monitoring and support,** which concerns the establishment of new in-hospital milk banks and the coordination and regulation of the distribution of DBM through its network. As for the **transportation** responsibilities – these will be reassigned to role players or outside parties based on the chosen transportation solution.

As for the network design, the most significant difference between the future and current setup is that there is now only one standardised way in which the flow of supplies and DBM can take place between the four main role players. In future, the SABR will only deal with the flow of materials and equipment, which it obtains from suppliers and provides to intermediaries: corners (which in turn supply to external donors) and milk banks (to in-hospital donors). The SABR will no longer be involved in the flow of DBM, which it leaves to intermediaries: corners only deal with external donors, and milk banks only with in-hospital donors. Milk banks, in turn, are the sole providers of breast milk to beneficiaries (premature infants at NICUs).

This will significantly simplify the network dynamics and will enable the implementation of a uniform, duplicable transportation solution.

3.2 Transportation options

Four transportation alternatives were developed following discussions with the SABR to aid in the expansion of the current SABR network:

- **Transportation by network players** – existing role players in the network become active transport agents
- **Independent couriers** – a paid service contract with an independent courier service to transport the DBM between network players
- **Transport partnerships** – piggy-backing on existing medical distribution networks by using outside parties which travel routinely between the role players in the SABR network, such as pathology laboratories, pharmacies or blood banks
- **In-house transport unit** – the establishment of a transportation unit within the SABR.

Before deciding on a solution, a further investigation into the implementation implications and a cost-benefit analysis is required. However, all four of these transportation alternatives require donors to drop donations off at the corners. Because the transport of UDB from external donors to corners is the most disaggregated aspect of the network distribution with the least economies of scale in the amount of product to be transported, there would be great value in minimising this distance.

4. The expansion plan

To realise its expansion goal of building a sustainable breastmilk banking infrastructure across the entire South Africa, the SABR had to develop a strategy to overcome its current lack of resources and an underdeveloped infrastructure. Thus, to be sustainable, the solution would have to be scalable and able to be operated independently by in-hospital milk banks. With this in mind, the SABR scoped a business model similar to that of typical franchising models, where the SABR remains the owner of the business concept but is not involved in the daily operation of the in-hospital milk banks. As an umbrella organisation, the SABR would establish the milk banks, set up public-private synergies, execute quality control and train the volunteer nurses and doctors involved. Consequently, the SABR network would be expanded through decentralisation, spreading the workload amongst network role players.

The focus would first be on establishing SABR corners and assigning these to existing milk banks so that the existing network can be stabilised and standardised. To grow the capacity and geographical coverage of the network this model can then be duplicated in other provinces.

5. Corner location allocation

To assist the SABR with the milk banking network expansion, a mathematical model is presented in this section. This model focuses on a specified geographical area and serves as a decision-support tool used to determine the number of additional corners required and appropriate locations to place these corners in the SABR network.

5.1 Model formulation

The mathematical model used to determine the number of corners required to maximise the coverage in a specified geographical area as well as the preferred locations to place these corners is based on the model presented by Alexandris & Giannikos (2010). Their model, the second Maximal Covering Location Problem with Spatial Objects (MCLP-SO2), attempts to maximise the total coverage of a specified number of facilities over various demand areas. This model incoporates the ability to consider not only fully covered demand areas in the formulation but also partially covered areas above a certain threshold.

To formulate the MCLP-SO2 for a breastmilk banking network, we define the following decision variables:

$$x_j = \begin{cases} 1 & \text{if a corner is located at potential location j, where } j = \{1,\ldots,J\} \\ 0 & \text{otherwise} \end{cases}$$

$$y_i = \begin{cases} 1 & \text{if donor cluster i is fully covered by at least one corner, where } i = \{1,\ldots,I\} \\ 0 & \text{otherwise} \end{cases}$$

$$v_i = \begin{cases} 1 & \text{if donor cluster i is partially covered, where } i = \{1,\ldots,I\} \\ 0 & \text{otherwise} \end{cases}$$

T   the total percentage of the geograpical area covered.

Parameters included in the model formulation are as follows:

c   the minimum acceptable coverage percentage for donor clusters
N   the number of corners to be placed at potential locations
w_i the benefit of covering donor cluster i, where $i = \{1,\ldots,I\}$
α   the proportion of benefit realised when donor cluster i is partially covered

$$a_{ij} = \begin{cases} 1 & \text{if a corner at potential location j can fully cover donor cluster i, where } j = \{1,\ldots,J\} \text{ and } i = \{1,\ldots,I\} \\ 0 & \text{otherwise.} \end{cases}$$

L_i set of candidate corner locations partially covering donor cluster *i* to a percentage level of at least c, where $i = \{1,\dots,I\}$

The objective of the model is to maximise the benefit of covering donor clusters within a specified geographical area and is shown in (1). The problem may now be formulated as follows:

$$\max z = \sum_{i \in I} w_i \left(y_i + \alpha v_i \right) \tag{1}$$

Subject to:

$$\sum_{j \in J} a_{ij} x_j \geq y_i \quad \forall \quad i \in I \tag{2}$$

$$y_i + v_i \leq 1 \quad \forall \quad i \in I \tag{5}$$

$$\sum_{j \in J} x_j = N \tag{3}$$

$$x_j \in \{0,1\} \quad \forall \quad j \in J \tag{6}$$

$$\sum_{j \in L_i} x_j \geq v_i \quad \forall \quad i \in I \tag{4}$$

$$y_i, v_i \in \{0,1\} \quad \forall \quad i \in I \tag{7}$$

To ensure that a donor cluster is considered as fully covered when one or more corners that cover the donor cluster fully are placed, constraint (2) is incorporated. Constraint (3) ensures that the specified number of corners is placed in the network, whereas constraint (4) determines the number of partially covered donor clusters by each placed corner. To ensure that a donor cluster is either partially or fully covered, constraint (5) is included. Constraints (6) and (7) ensure that decision variables are binary variables.

5.2 Gauteng example

The MCLP model is applied to the Gauteng province in this section to determine where new corners should be established to serve potential donors in Gauteng. This paper focuses only on Gauteng. However, this model can also be applied to the eight other provinces in South Africa by taking a similar approach.

5.2.1 Data collection and pre-processing

The data gathering and pre-processing phase is extremely important and is divided into two main aspects:

- determining the coverage of donor clusters by potential corners, and
- determining the donor potential of the donor clusters according to demographics.

The approach adopted to determine the coverage of donor clusters by potential corners is depicted in Figure 2. For purposes of illustration a certain pharmacy group was selected as a potential partner in decentralising the SABR network using corners. All their stores within the Gauteng area were thus considered as potential corner locations.
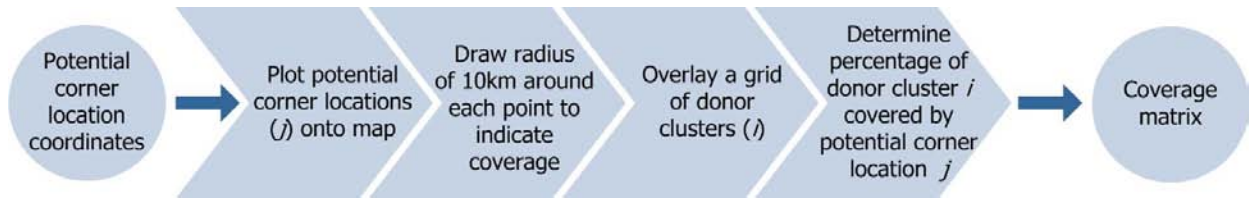
Figure 2: Determining the coverage of potential corner locations

Each potential corner location *j* is plotted onto a map of Gauteng. Because all four transportation alternatives developed during the expansion planning require donors to drop donations off at the corners, the radius of coverage of each corner depends on what is considered a convenient travel distance for donors. Therefore, a radius of 10 km was drawn around each of these potential corner locations. A grid is superimposed on the Gauteng map, each square signifying a donor cluster. For each donor cluster it is determined what percentage of the cluster is covered by each potential corner location. In this example, any donor cluster that is covered between 90% and 100% is considered as a fully covered donor cluster, whereas a donor cluster is considered partially covered when covered between 45% and 90%. Two grid sizes, 15x15 km and 20x20 km, were considered to investigate the model's sensitivity to grid size when all else is kept equal.

The benefit of covering a donor cluster (w_i) is associated with the donor potential of each cluster. Firstly the potential donor density within each municipality is determined (Figure 3).
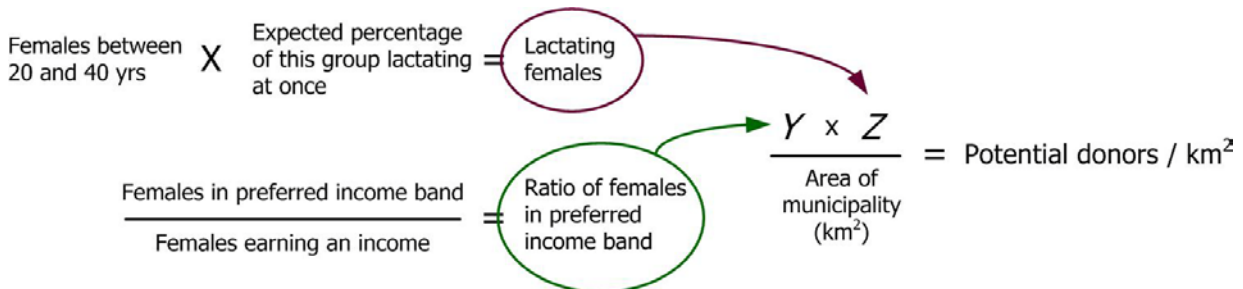

Figure 3: Determining the potential donors per square kilometre for each municipality

If a donor cluster covers only one municipality, the potential donor density of that cluster is simply that of the municipality. However, if a donor cluster covers more than one municipality (as shown in Figure 4), a proportional density must be determined. Using a scaling formula, the potential donor densities of each cluster are ranked between 0 and 10. This ranking is then the benefit of that cluster (w_i).
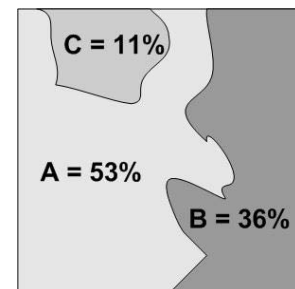
Deciding on the demographic factors to include in determining the potential donor density for each municipality is no trivial matter. Previous studies regarding breastfeeding and human milk donation provide valuable insights. However, none of the studies discussed below address the South African context specifically. Therefore, expert opinion of human milk donation in South Africa was also incorporated.

Figure 4: Donor cluster covering more than one municipality

Furthermore, the limited resources available to this project (due to the not-for-profit nature of the client, SABR) constrained the extent to which detailed data collection was possible. This constraint also had to be accounted for.

Thomaz *et al.* (2008) in their study of the human milk donation experience in Brazil, recognise that both the biological environment and social context affect a woman's motivation to donate. Their study showed that the average age for regular donors was 39.40 ± 6.28 and for first-time donors 36.69 ± 6.06. It is also clear from the study that the influence of the healthcare professional is greatly significant across all demographic groups. A higher level of education (secondary and beyond) and numerous previous pregnancies were also common among donors, but it was illustrated that even illiterate and very young donors could be motivated to donate when health professionals explained the benefits and procedures of the donation during prenatal visits. The study further suggests that awareness of the needs of the babies who will receive the milk greatly increases motivation to donate.

However, for someone to be a human milk donor, they must be willing to breastfeed in the first place. Many studies have been conducted regarding the biological factors influencing a woman's propensity to breastfeed, but psychological and societal factors can have an even more pronounced effect. In their study of psychological factors influencing breastfeeding duration, O'Brien *et al* (2009) identify five very important factors, namely a mother's priorities, faith in breastfeeding, adaptability, stress and breastfeeding self-efficacy. On the other hand, Li, *et al* (*2002*) focus their study on the public perceptions of breastfeeding constraints, arguing that social support is a critical motivator for breastfeeding. From their results it is clear that the perception that women must give up many lifestyle habits such as drinking, smoking, chocolates and favourite foods, is the greatest barrier to breastfeeding.

Statistics from the 2001 South African census were used to determine the potential donor density. Although slightly dated, this is the most accurate source of statistics at municipal level. Furthermore, it is not expected that the change in demographics over the last 9 years will have a notable effect on the final placement of corners in Gauteng. The next census will be executed during 2011. Substituting the 2001 data with the 2011 data will be a simple procedure.

It is expected that females between 20 and 40 years are most likely to be lactating, making them the demographic group of interest. Furthermore, it is taken into account that only a very small percentage of these females would be lactating at the same time. This percentage is affected by the average frequency of pregnancy, the proportion of women who breastfeed and the average duration of breastfeeding.

Income is used as a proxy variable to account for stress, education level and other lifestyle factors. Females in the lowest income band are assumed to have lower levels of education and very little access to healthcare facilities and education. Consequently, this band of females is excluded as potential donors. Females that earn a comparatively large income are assumed to have high-stress, full-time employment. The higher stress levels and decrease in lifestyle adaptability resulting from such employment also preclude such females from human milk donation. Females in higher income bands are thus also excluded.

5.2.2 Results

The model is solved exactly using LINGO 10.0 (LINDO Systems Inc., 2006) optimisation software. This is followed by a sensitivity analysis to investigate the impact of increasing the number of corners to be allocated as well as the impact of varying grid sizes on the final result. The results for the two grid sizes are depicted in Figure 5.

The results indicate that as the number of corners increases, the total donor benefit increases at a decreasing rate, until a point is reached where no additional benefit is realised when increasing the number of corners to be allocated.

Even though that particular point can be seen as the best possible solution in terms of total donor benefit, the decision maker should decide at what point the additional benefit, realised by placing another corner,

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does not justify the cost of the additional corner.

From Figure 5 it is clear that there is a significant difference between the results of the two different grid sizes. The blocks in the larger grid have a bigger area, resulting in fewer donor clusters being fully covered by the same radius than in the smaller grid. The number of partially covered donor clusters also decreases significantly when increasing grid sizes for the same corner covering radius. Consequently, more donor clusters are disregarded in the model with bigger grids as the coverage of more blocks falls below the partial coverage threshold.
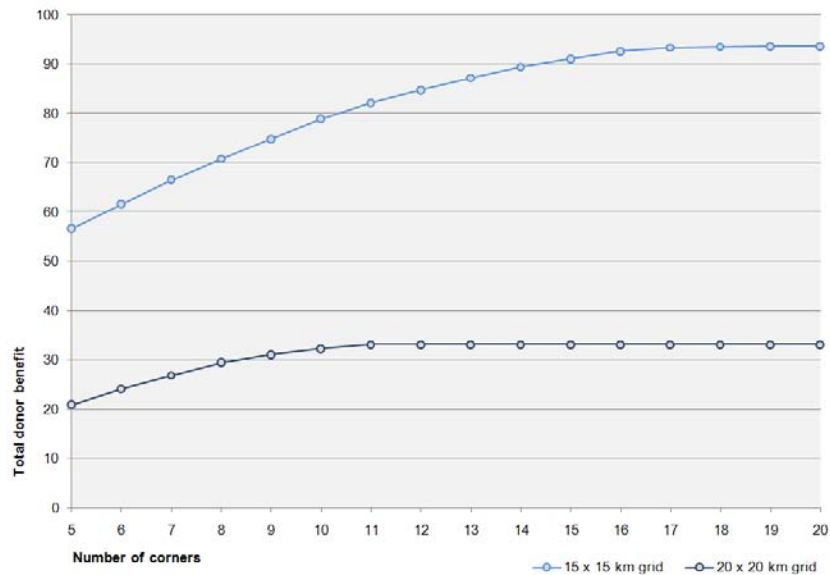

Figure 5: Total donor benefit realised by different number of corners for two grid sizes

To illustrate the difference in results obtained for the two grid sizes, the model was solved for both grid sizes, and the number of corners to be allocated was specified as 14, since at that point Figure 5 shows a tapering-down in the benefit gradient for both grid-size lines. The map in Figure 6(a) depicts all the potential corner locations, while (b) indicates the chosen location for 14 corners on the 15x15 km grid and (c) the chosen locations for 14 corners on the 20x20 km grid.
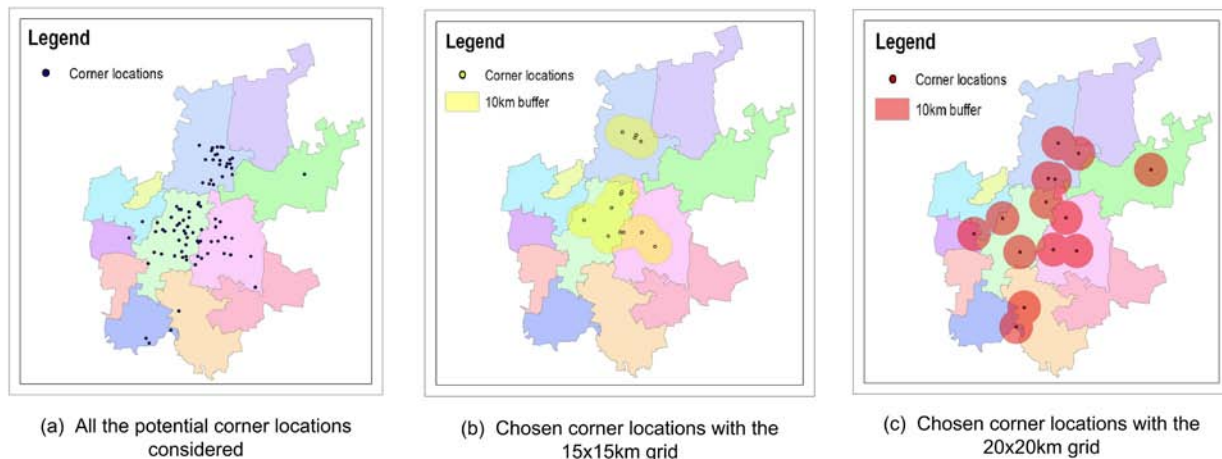

(a) All the potential corner locations considered

(b) Chosen corner locations with the 15x15km grid

(c) Chosen corner locations with the 20x20km grid

Figure 6: Comparison between potential and chosen locations in Gauteng for different grid sizes

When considering the chosen corner locations and their potential coverage, it can be ascertained that, when allocating 14 new corners, the total corner coverage of Gauteng for the 20x20 km grid is larger than the total coverage of the smaller grid, even though the total benefit determined by the model is significantly lower, for reasons previously explained. The greater size of the 20x20 km donor clusters results in less benefit to be gained in the densely populated municipalities such as the City of Johannesburg, the City of Tshwane and Ekurhuleni. The model thus places corners towards the less

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densely populated periphery of the province to realise further benefit. In the case of Gauteng, smaller grid sizes ensure greater coverage in densely populated areas, whereas the larger grid sizes tend to spread the coverage across the province. The decision maker would have to decide which is more suitable. It is possible that the model's sensitivity to grid sizes is accentuated by the non-uniform distribution of population and income in Gauteng.

6. Way forward

Much refinement is needed before expanding the MCLP-SO2 model to determine corner allocations in the rest of South Africa. Firstly, the data used to determine the model parameters can be honed by using the 2011 Census statistics and using statistics at electoral ward level, instead of municipal level. Secondly, the crude way in which potential donors are currently determined can be improved through an extensive study into the demographic characteristics of South African breastmilk donors. Lastly, through interaction with the SABR and pharmacy groups that could become potential corner partners, the potential corner locations can be updated to reflect the current situation at the SABR. Decision makers need to determine how much refinement is sufficient bearing in mind the costs of such an exercise, as well as the increase in model complexity and possible loss of user-friendliness.

Apart from refining the MCLP-SO2 model, there are various other aspects of the network planning problem that must still be addressed. The most urgent is the selection of the optimal transportation alternative. Thereafter, decisions regarding strategic milk bank establishment, inventory planning and capacity planning can be made. Once the network planning is complete, a detailed implementation plan is required to guide the roll-out of the network.

The problem-solving approach followed throughout this paper, and particularly the implementation of the MCLP-SO2, can be used to address similar network planning problems in other not-for-profit operations where supply must be gathered in small quantities from geographically dispersed donors. Two examples are the collection of donations during disaster relief efforts and food banking.

7. Conclusion

The work undertaken aimed to aid the SABR in their mission of decreasing infant mortality by providing premature infants across the entire South Africa with safe, pasteurised breast milk. In order to service an increasing demand for DBM, an expansion strategy was required that would overcome its current lack of resources and an underdeveloped infrastructure. Thus the SABR scoped a franchise-based business model whereby it remains the owner of the business concept but is not involved in the daily operation of the in-hospital milk banks. Consequently, the SABR network would be decentralised, spreading the workload amongst network role players and reducing the operational load on the SABR, enabling sustainable national expansion.

The first step in this strategy was to improve the SABR network design by standardising the way in which supplies and DBM flows between the four main role players, thus simplifying network dynamics and enabling implementation of a uniform and duplicable transportation solution. Four options for a transportation model were scoped – all of which relied on the establishment of additional SABR corners and assigning these to existing milk banks, before scaling the solution towards new territory. Thus, a mathematical model was developed to aid the planning of the network structure by informing decisions on the number of additional corners required and appropriate corner site selections.

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