A FARM SITE DEVELOPMENT METHOD: CREATING A ROADMAP TOWARDS SITE SATURATION

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ABSTRACT

Agricultural engineering applies existing knowledge to provide for humanity’s greatest need: food for survival. This article presents an opportunity to augment existing agricultural engineering practices with industrial engineering techniques, with the aim of encouraging financial control during the expansion of assets on farms. Facility planning techniques are combined with a well-known enterprise engineering technique, the transformation roadmap, to develop a Farm Site Development Method (FSDM). The purpose of the FSDM is to provide method guidance in developing a facilities master plan to evolve farm facilities in a phased approach towards a future/saturation state. The article also presents an evaluation of the FSDM, via a practical demonstration at Waterfall Farm.

OPSOMMING

Landbou-ingenieurswese gebruik bestaande kennis om aan een van die mensdom se grootste behoeftes te voldoen: voedsel vir oorlewing. Die geleentheid om bestaande landbou-ingenieurswese praktyke aan te vul met bedryfsingenieurswese tegnieke wat finansiële beheer aanmoedig tydens bate-uitbreidings op plase, word hier aangebied. Fasiliteitsbeplannings-tegnieke word gekombineer met ’n welbekende ondernemingsingenieurswese tegniek, die transformasie padkaart, met die ontwikkeling van ’n plaasterrein ontwikkelingsmetode (PTOM). Die doel van die PTOM is om metodiese leiding te bied aan die ontwikkeling van ’n meester-fasiliteitsplan ten einde die plaas se fasiliteite in fases te ontwikkel tot ’n toekomstige-/versadigingstatus. Die studie bied ook ’n evaluasie van die PTOM aan, in die vorm van ’n praktiese demonstrasie by Waterfall Farm.

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1 INTRODUCTION

The cultivation of livestock, crops, and other forms of food, also known as agriculture, is and will always be one of the essential ways of maintaining human life on earth. Burdock and Crawford [1] refer to agriculture as “humanity’s biggest industry, providing for humanity’s greatest need, which is food for survival”.

The engineering field initially made room for the practice of agricultural engineering with the introduction of mechanical tools and the use of water cans for irrigation. Agricultural engineering subsequently developed exponentially, resulting in the invention of the tractor, a manually-operated machine. Today, agricultural engineering is a discipline that combines the knowledge of mechanical engineering, scientific engineering principles, and agricultural science [2].

The agricultural sector of a country contributes significantly to the economy of that country. Dethier and Effenberger [3] note that “agriculture contributes to both income and poverty reduction in developing countries – by generating income and employment in rural areas and providing food at reasonable prices in urban areas”. The agricultural sector can, however, only contribute to the economy if arable land is available. According to Index Mundi [4], arable land can be defined as land under temporary crops, temporary meadows, land under market or kitchen gardens, and fallow lands. As of 2009, South Africa had an estimated 14,350,000 hectares of arable land [4], which amounts to 11.82 per cent of the total land area of South Africa [5, 6].

Although current literature on agricultural production practices [7] is available within the agricultural sector, there is the opportunity to apply industrial engineering techniques to encourage financial control, based on planned capital expenditures. This article applies an integrated set of existing industrial engineering techniques to an agricultural context. We suggest that a new artefact is developed, a Farm Site Development Method (FSDM), as a roadmap for incrementally transforming ‘current-state’ facilities/resources on an existing farm towards a ‘future state’ (saturation state). Although facility planning is a well-known industrial engineering focus area, facility planning primarily focuses on designing a future-state facility [8]. Another existing industrial engineering focus area, enterprise engineering, incorporates roadmaps. These consist of a list of individual ‘increments’ of implementations or initiatives according to a timeline, to show progression from the current state to a future state [9]. In applying existing facility planning practices, combined with the concept of a roadmap, we apply the design research method to develop the FSDM.

The article is presented as follows: Section 2 provides background theory about facility planning and the use of roadmaps during facilities design, concluding with the suggestion to develop a new method, the FSDM. Section 3 presents the ‘design research’ method that was used in constructing and evaluating the FSDM. Section 4 presents the constructional components of the newly-developed FSDM, while Section 5 provides a practical demonstration of the FSDM at Waterfall Farm in South Africa. In Section 6 we discuss the results of applying the FSDM in practice, and in Section 7 we conclude with opportunities for future research.

2 BACKGROUND

2.1 Facility planning

“Facility planning determines how an activity’s tangible fixed assets best support achieving the activity’s objective” [8] and incorporates a systematic design process that starts at a global level and progresses through five levels of detail. Strategos [10] defines the five levels of detail that are useful in defining the design scope as: (1) global, (2) supra, (3) macro, (4) micro, and (5) sub-micro levels.

Level 1 is the global level, which locates the site in the world and consists of a space planning unit (SPU) in the form of a site. After the location of the facility is determined, Level 2 introduces site planning for the buildings or features on the site. If an existing facility is to be re-designed, this is the level where the current-state site plan is created [10]. Level 3, the macro level, focuses on the layout within the facility. Interrelationships between departments, space requirements per department, and flow analysis between departments are important components of this level [10]. The micro layout of Level 4 consists of the layout within a department or cell according to the space requirements that are defined in Level 3. Workstation configuration and motion economy are designed as part of the sub-micro layout of Level 5.

Focusing on Levels 2 and 3, Tompkins et al. [8] apply the traditional engineering design process in designing or re-designing a facility:

1. Define the problem.
- Define (re-define) the objective of the facility (products to be manufactured or services rendered, and projected volumes).
- Specify the primary and support activities to be performed (operations, equipment, personnel, and material flows).

2. Analyse the problem.
- Determine the interrelationships among all activities (work centres and departments).

3. Determine the requirements in terms of space, for all activities.
- Generate alternative facility locations.
- Generate alternative designs for the facility.

4. Evaluate the alternatives.
- Evaluate alternative facilities plans based on accepted criteria.

5. Select the preferred design.
- Select the preferred facility plan, based on the evaluation performed in the previous step.

6. Implement the design.
- Implement the facility plan.
- Maintain and adapt the facility plan.
- Redefine the objectives of the facility.

Tompkins et al. [8] provide guidance for every step of the design process. Although the engineering design process is useful in designing a future-state facility, it does not accommodate incremental design. Yet a concept that evolved within the enterprise engineering community, the ‘roadmap’, facilitates incremental development of a future-state enterprise. The next section introduces the concept of a roadmap and the possibility of applying the concept within the area of facilities planning in an agricultural context.

2.2 Using roadmaps during facilities design

Enterprise engineering is an emerging discipline that could be defined as the “body of knowledge, principles, and practices to design and enterprise” [11]. Roadmaps are key outputs of the enterprise engineering process [9], providing visual representations of the transition from the ‘as-is’ architecture to the envisioned ‘to-be’ architecture of an enterprise [12]. Useful as a tool for tactical planning and budgeting, it shows important milestones along the route and the dependencies between them. Without getting into the details, a roadmap needs to provide information for efficient decision-making towards the future state [12].

The milestones present incremental initiatives that need to consider cash flow and the impact on existing operations. Roadmaps not only accommodate required growth and change in an enterprise, but also acknowledge that existing sub-systems need to be phased out or replaced. Programme and project management practices are often applied to ensure that incremental initiatives are controlled according to budget, schedule, and other requirements.

Within the agricultural environment, current facilities or resources may be depleted, and may require active planning in their replacement or extension. When facilities need to be developed incrementally towards the future-state, roadmaps could also be used to define the milestones for facility and resource replacement or extension. However, decisions about facility and resource replacement or extension should be based on the projected demands of the agricultural products. Demand planning and forecasting techniques should therefore be added when the concept of a roadmap is used within the area of facilities planning.

In applying existing facility planning practices, combined with the concept of a roadmap, we suggested the development of a new method, the FSDM. The purpose is to advance or evolve farm facilities in a phased approach towards their future or saturation state. The next section presents the research methodology and the design research method that was used to develop the FSDM.

3 RESEARCH METHODOLOGY

According to Friedman [13], most definitions of ‘design’ share three attributes: (1) design refers to a process; (2) the design process is goal-oriented; and (3) the goal of design is solving problems, meeting needs, improving situations, or creating something new or useful. ‘Design research’ developed as a method for investigation, and has been accepted as a valuable research method within engineering disciplines [14, 15]. With recent advancements in technology and computational methods, design research also gained momentum within the discipline of information systems [16]. Gregor and Hevner [17] in particular provided practical guidance on applying design research as a research method. Although primarily aimed at information systems, their work also has “clear implications for other fields engaged in design science research (such as the computer science and engineering disciplines)” [17].

Design research is used to “address important unsolved problems in unique or innovative ways or solve problems in more effective or efficient ways” [17]. Knowledge contribution, when using design research, could be divided into two categories: descriptive knowledge and prescriptive knowledge. Prescriptive knowledge may be presented in the form of an artefact, such as a construct, model, method, instantiation, or design theory [17]. A ‘method’ artefact, according to Gregor and Hevner [17], is prescriptive, providing “the instructions for performing goal-driven activities”. This paper focuses on the development of a method artefact called the FSDM. According to Vaischnavi and Kuechler [18], a researcher could follow five generic steps to develop and evaluate a new artefact: (1) defining a problem or deficiency with regard to the existing knowledge base; (2) suggesting the development of an artefact to address the identified problem or deficiency; (3) developing the suggested artefact; (4) evaluating the newly developed artefact; and (5) drawing conclusions, based on the artefact evaluation results.

We applied five steps of the design cycle, as defined by Vaischnavi and Kuechler [18], to develop the FSDM:

1. Defining a problem: identifying the need to develop farm facilities incrementally towards a saturated or maximum-capacity state. As indicated in Section 2, the existing knowledge base does not address the incremental development of farm facilities towards a saturated state.
2. Suggestion: suggesting the development of a method artefact to enable incremental development of farm facilities towards a saturated state.
3. Development: developing the method artefact, called the FSDM, and applying the roadmap concept and the engineering design process adapted for facilities, as discussed in Section 2.

4. Evaluation: evaluating the FSDM by using a practical demonstration in developing a series of incremental plans, called a facility development plan (FDP), for Waterfall Farm.
5. Conclusion: discussing the demonstration results during the conclusions step.

'Circumscription' is an important process in design research, since it creates an understanding that could only be gained from the construction act. The demonstration of the FSDM at Waterfall Farm generated new knowledge or wisdom, which will be included as part of the considerations for future research to improve the FSDM.

The next section presents the constructional components of the FSDM, which were developed during the 'development' step of the design cycle.

4 THE FARM SITE DEVELOPMENT METHOD

The theoretical foundation of the new method artefact, the FSDM, is the engineering design process adapted for facilities [10] (discussed in Section 2.1) and roadmaps (defined in Section 2.2). According to Dietz [19], the development of any artefact (e.g., the FSDM) requires two development phases. The first phase entails a requirements analysis, while the second derives the constructional requirements. Since the current literature does not combine the engineering design process with the concept of roadmaps within an agricultural setting, we defined two functional requirements for the FSDM:

- The engineering design process should be adapted for facilities on farms, primarily focusing on the second and third levels of space planning.
- The concept of a roadmap should be incorporated to develop the farm site incrementally from its current state to its future saturation state.

Once functional requirements have been defined for a new artefact, Dietz [19] states that a creative process is required to derive constructional requirements for the new artefact. A creative process was followed to combine the engineering design process, adapted for the farm site facilities, with the concept of a roadmap, in devising an eight-step process:

1. Analyse the current-state facility layout (CSFL).
2. Calculate the saturation state for the farm (compile a saturation-state facility layout (SSFL)).
3. Determine the production requirements and the saturation date.
4. Identify critical resources, utilities, services, and/or structures (RUSS) and the design criteria.
5. Identify and evaluate alternatives for RUSS replacement or extension.
6. Compile a series of phase plans, called the FDP.
7. Represent phase plans graphically in support of the FDP.
8. Validate the FDP.

There are a number of prerequisites (input data) for using the FSDM:

- A market analysis and soil analysis should have been completed to finalise choices about selected crop varieties and production mix.
- A more reliable FDP could be developed if historical production data were available for demand forecasting.

Since every step in the FSDM requires decisions based on the type of farming activity, the following sections present guiding indicators for each step.

4.1 Step 1: Analyse the current-state facility layout (CSFL)

A site visit should be conducted to confirm and supplement existing layout plans, photos, GPS coordinates, and land surveys. If available, existing plans should be used to draw the current-state facility plan using an appropriate drawing program such as AutoCAD. If no existing layout plans are available, GPS coordinates should be used to map the CSFL, indicating all buildings and site features to scale.

4.2 Step 2: Calculate the saturation state for the farm

The objective of the future or saturation state calculation is to estimate the ‘maximum possible production rate’ of the farm, given the available arable land on the farm. The maximum possible production rate is calculated in three steps:

4.2.1 Calculate the maximum capacity of the farm (y)

The maximum capacity of the farm is the total available arable land, multiplied by the maximum surface use.

Therefore: $y = a * u$

- The maximum available production area of the farm in m^2 (a) is calculated as the total area less all existing facilities, production areas, and road areas.
- The maximum surface use (u) is calculated by considering the minimum space requirements per production unit. If, for example, plants are the production units, the maximum surface use would be the number of plants that could be grown per square meter.

4.2.2 Calculate the maximum possible production rate (p)

The maximum possible production rate incorporates the average growth time frame per production unit and the average loss of production units before distribution:

$$p = \frac{y}{x}(1 - d)$$

- The average production unit growth timeframe (x) is calculated while incorporating seasonality and different growth times for different product types.
- The average loss of production units (d) is an allowance for an average loss of production units before distribution.

4.2.3 Express the maximum possible production rate in standardised units (p_s)

Since products are usually transported as standardised units (e.g., packaging units), the maximum possible production rate should also be expressed in terms of standardised units.

- The number of production units per standardised unit (s) should be calculated, also accommodating the ratio of product types that are distributed in the standardised unit.
- The maximum possible production rate is expressed in standardised units as follows:

$$p_s = \frac{p}{s}$$

4.2.4 Draw the saturation-state facility layout (SSFL)

An appropriate drawing tool should be used to represent the SSFL.

4.3 Step 3: Determine production requirements and the saturation date

Using historical production data, production requirements should be forecast for each product type. A graphical representation could be used to indicate expected production requirements or demand, expressed in standardised units (y axis) per calendar units (x axis). An appropriate forecasting technique should be selected, and seasonality and trends need to be incorporated.

Using the production requirement forecasts, a ‘saturation date’ should be derived – i.e., the first calendar unit during which the ‘maximum possible production rate’ ($\boldsymbol{p_s}$) is achieved. The saturation date provides an indication of the planning horizon for constructing the FDP.

4.4 Step 4: Identify critical resources, utilities, services and/or structures (RUSS) and design criteria

The specific farming industry should be considered when determining the most important RUSS required for the FDP, as well as the appropriate design criteria (e.g., financial and technical criteria) for evaluating alternatives pertaining to the RUSS.

Additional criteria may have to be incorporated from best practice frameworks such as the Global GAP (Good Agricultural Practices), Farming for the Future, the Food Technical Standard and Protocol of the British Retail Consortium (BRC), Bird Friendly standards, and Fair Trade standards.

4.5 Step 5: Identify and evaluate alternatives for RUSS replacement or extension

A number of calculations are required to identify alternative restoration initiatives and to evaluate the alternative initiatives against the design criteria that were identified in Step 4 (Section 5.4):

- Determine the initial RUSS sizes, given the existing production rate in standardised units.
- Determine the first capacity depletion date for each of the RUSS. Use the expected production requirements or demand (calculated in Step 3) to determine when the capacity of specific RUSS will be depleted for the first time.
- For each of the RUSS, use the first capacity depletion date to determine the incremental restoration initiatives for each of the RUSS. Incremental restoration initiatives specify the size and quantity of the additional RUSS, based on the standard sizes available in industry and the increase in demand. Since the restored capacity of a resource or structure may be depleted several times within the planning horizon of the FDP, several incremental restoration initiatives will be required for each of the RUSS.
- Determine the restoration dates for the incremental restoration initiatives. Consider lead times for constructing and/or acquiring RUSS to complete restoration before capacity depletion occurs.

4.6 Step 6: Compile a series of phase plans, called the Facility Development Plan (FDP)

The purpose of this step is to group, logically, the restoration dates in order to form a series of phases (from one month to a year) for the entire planning horizon of the FDP. Phase identification enables budgeting and planning for each phase ahead of time.

4.7 Step 7: Represent phase plans graphically, in support of the FDP

Draw each phase of the FDP sequentially, starting at the CSFL and ending with an SSFL. Although the SSFL may resemble the initial SSFL compiled in Step 2 (Section 5.2.4), a revised SSFL may be required to reflect changes in strategy, target market, product, or new technology.

4.8 Step 8: Validate the FDP

The purpose of this step is to validate the FDP in terms of the quantitative assumptions that were made during the development of the restoration alternatives for the critical RUSS. Additional qualitative validation may also be required to ensure that the FDP is useful to management.

The next section provides a practical demonstration of the FSDM.

5 DEMONSTRATION OF THE FARM SITE DEVELOPMENT METHOD

The FSDM was demonstrated with a project completed for Waterfall Farm [20], a start-up operation in Middelrus, near Mooiriver in KwaZulu-Natal (KZN) Province, that grows a selection of lettuce and baby leaf varieties for a single distributor in the same province.

The farm covers an area of 28 hectares, of which approximately eight hectares is unusable due to erosion, buildings, and livestock camps. The infrastructure is old, small, and not originally intended for the purpose for which it is currently used. Waterfall Farm's site is under-used. Additional problems include the poor layout of crop fields, and inefficient flows of humans and vehicles on-site. Moreover, no long-term planning has been conducted for the construction of the current facilities, with the consequent inability to meet any exponential increase in demand for the lettuce and baby leaf varieties in the future.

The section that follows presents the demonstration of the eight steps of the FSDM, as presented in Section 5.

5.1 Step 1: Analyse the CSFL

The first and second levels of space planning were applied for constructing a locality plan and a CSFL (using AutoCAD), which provided context regarding the farm's geographic position and highlighted problematic elements to the current-state facility.

5.2 Step 2: Calculate the saturation state for the farm

The objective of the future/saturation state calculation is to estimate the maximum possible production rate (production output per month) of the farm, given the available arable land on the farm. The maximum possible production rate was calculated in three consecutive steps, detailed in Sections 5.2.1, 5.2.2, and 5.2.3.

5.2.1 Calculate the maximum capacity of the farm (y)

Calculate the maximum available arable production area of the farm in m^2 (a).

The farm covers an area of 28 hectares, of which approximately eight hectares is unusable, resulting in 20 hectares of arable land available for crop cultivation. The area of existing crop fields was added to the 20 hectares, which resulted in:

$a = 225\ 406$ m^2 available arable production area.

Calculate the maximum number of production units that could be rendered per m^2 (u).

The production units for Waterfall Farm are the number of seedlings that can be planted per square meter. For the demonstration, three types of varieties were assigned: exotic, crisp, and baby leaf varieties. Varieties are planted at different densities; for example, crisp variety seedlings are planted in rows that are 200 mm apart, with eight seedlings per row. Furthermore, plant beds for crisp varieties are 1.5 m wide with a 0.3 m gap for irrigation pipes between each bed, and beds are approximately 100 m in length.

A proportion per variety type of the total production was calculated from historical production data to determine the relative weighting of each variety type in the total production of Waterfall Farm. This proportion presents the percentage of output that a specific lettuce category will deliver. The proportions of variety types were as follows:

- Exotic: 52%
- Crisp: 44%
- Baby-leaf: 3%

Using the proportions per variety type and the number of seedlings rendered per m^2 for each variety type, the maximum number of production units per m^2 (u) was calculated:

$u = 25.49$ seedlings per m^2.

The maximum capacity of the farm (y) could now be calculated: $y = a * u$
e.g.: $y = 225\ 406 * 25.49 = 5\ 745\ 388$ seedlings could be planted on Waterfall Farm.

5.2.2 Calculate the maximum possible production rate (p)

Determine the average production unit growth timeframe (x).

Since the average growth time differs for each variety and according to season (summer months versus winter months), the average growth time for a seedling [20] and proportions per variety type were used to calculate the average production unit growth time.

$x = 7.89$ weeks.

Determine the average loss of production units (d).

Approximately 20 per cent of the plants' leaves are lost due to handling, i.e., $d = 0.2$.
The maximum possible production rate could now be calculated: $p = \frac{y}{x}(1 - d)$.
Therefore: $p = \frac{5\ 745\ 388\ seedlings}{7.89\ weeks}(1 - 0.2)$

$p = 582\ 548$ crops per week.

Waterfall Farm operates six days a week; so the maximum daily volume is:

$p = \frac{582\ 548\ crops\ per\ week}{6\ days\ per\ week} = 97\ 091$ crops per day.

5.2.3 Express the maximum possible production rate in standardised units (p_s)

The owners of Waterfall Farm plan to use lugs to transport and sell their produce. Lugs are green, plastic, collapsible, ventilated containers with a size of 595 x 395 x 220 mm. The lug was chosen as the standardised unit for the demonstration.

Calculate the number of production units per standardised unit (s).

A weighted average number of crops per lug was calculated, incorporating the proportions per variety type and the maximum number of crops of each variety type that can fit into a lug.

$s = 15.33$ crops per lug.

Express the maximum possible production rate in standardised units: $p_s = \frac{p}{s}$.

Therefore: $p_s = \frac{97091\ crops\ per\ day}{15.33\ crops\ per\ lug}$

$p_s = 6\ 330$ lugs per day can be harvested.

A year has 365 days, of which 313 are workdays (i.e., 365 days – 52 Sundays) and the average number of days per month is 26.08 days (i.e., $313\ days \div 12\ months$). The total number of lugs per month that can be harvested was calculated as follows:

$p_s = 6\ 330\ lugs\ per\ day * 26.08\ days = 165\ 125$ lugs per month can be harvested.

Waterfall Farm could thus render a maximum of 165,125 lugs per month at a saturated capacity.

5.2.4 Draw the SSFL

The site saturation facility plan for Waterfall Farm was drawn using AutoCAD.

5.3 Step 3: Determine the production requirements and the saturation date

The forecast per variety type for Waterfall Farm for the next ten years was based on an estimated growth of 30 per cent per annum, which was validated as a realistic and reachable assumption for Waterfall Farm. The lug was chosen as a standardised unit for the forecasting calculation.

Using the actual production data from 2013, the production data included the seasonality and trends of the lettuce and baby leaf varieties. Applying a 30 per cent annual growth rate, the forecast was completed per variety type for the next ten years (from 2014 to 2023), graphically represented in Figure 1. The saturation date, depicted in Figure 1, is the first calendar unit (November 2021) during which the maximum possible production rate ($\boldsymbol{p_s}$) of 165,125 lugs per month, as calculated in Section 6.2.3, is achieved.

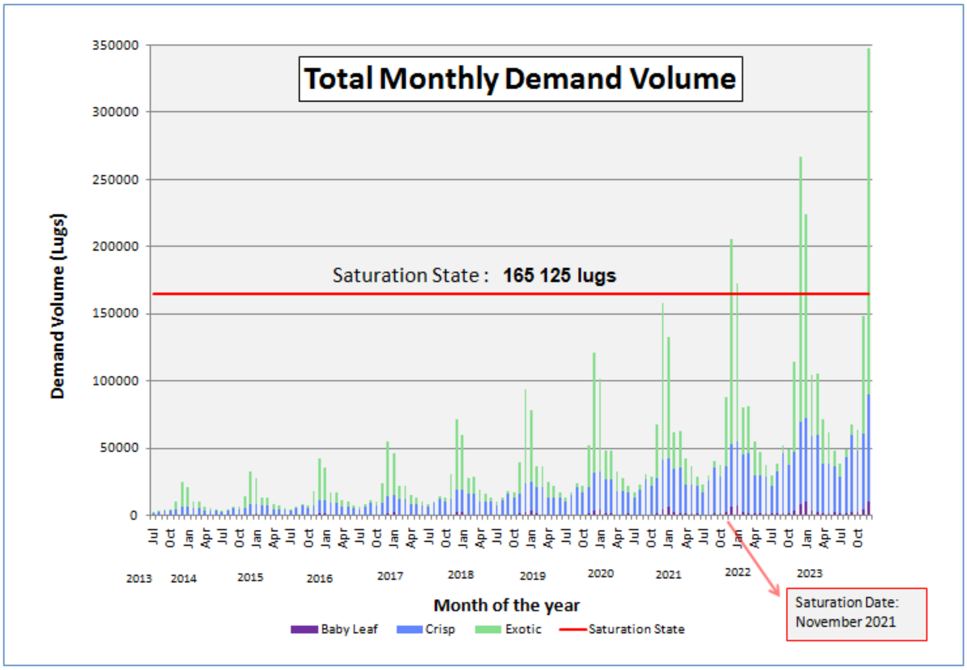


Figure 1: Total monthly demand volume per month: July 2013 to December 2023

The estimated saturation date indicates a planning horizon of about eight years (July 2014 to November 2021) for the FDP.

5.4 Step 4: Identify critical RUSS and design criteria

Five critical resources and structures were identified to be developed in the FDP for Waterfall Farm. The five resources and structures are: (1) support activity facilities, (2) cold rooms, (3) refrigerated trucks, (4) the loading area, and (5) the crop fields and roads. The primary design criteria used for selecting the appropriate alternative initiatives for each critical resource or structure were ‘financial feasibility’ and ‘technical factors’. In addition, the restoration initiatives had to be realistic, minimise idle capacity and optimise the use of space of the RUSS, and satisfy the demand without disrupting production.

Due to length constraints, this article only demonstrates the design of one critical structure: the cold rooms. Cold rooms are required when Waterfall Farm increases its production volume, since harvested lettuce and baby leaf varieties need to be stored overnight and transported in the early morning.

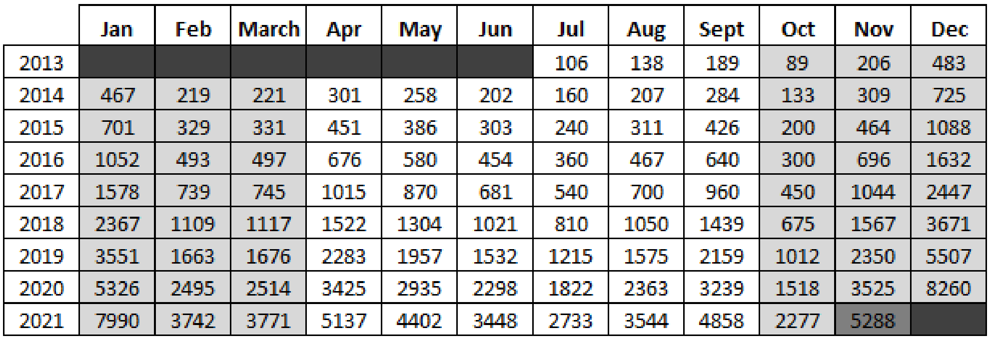
5.5 Step 5: Identify and evaluate alternatives for RUSS replacement or extension

Following the steps defined in Section 5.5, the alternative initiatives for cold rooms were identified as follows:

5.5.1 Determine the initial RUSS sizes, given the existing production rate in standardised units.

Using the forecast calculated in Section 6.3, a daily demand volume in lugs was calculated. The cold room space was designed for February, March, October, and November only. December and January were excluded, since their peak demands are significantly higher than those of other months, and their inclusion would result in cold room idle space for the rest of a year. The months from April to September were also excluded from the calculation, since the maximum number of lugs should be refrigerated, given the demand. Table 1 presents the forecasted demand volume in cold room storage space required, expressed in lugs per month.

Table 1: Cold room storage space requirements, in lugs per month



	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2013							106	138	189	89	206	483
2014	467	219	221	301	258	202	160	207	284	133	309	725
2015	701	329	331	451	386	303	240	311	426	200	464	1088
2016	1052	493	497	676	580	454	360	467	640	300	696	1632
2017	1578	739	745	1015	870	681	540	700	960	450	1044	2447
2018	2367	1109	1117	1522	1304	1021	810	1050	1439	675	1567	3671
2019	3551	1663	1676	2283	1957	1532	1215	1575	2159	1012	2350	5507
2020	5326	2495	2514	3425	2935	2298	1822	2363	3239	1518	3525	8260
2021	7990	3742	3771	5137	4402	3448	2733	3544	4858	2277	5288	

Applying the financial feasibility criterion (as stipulated in Section 6.4), loose-standing cold rooms were chosen for Waterfall Farm because they are less expensive than insulated panels, which require additional construction, planning, and customisation. A manufacturer of loose standing cold rooms was selected to demonstrate the cold room development plan. For the standard cold room specifications available from the manufacturer, the optimum number of lugs that can be fitted was calculated [20]. As an example, a cold room with a volume of 5.63 m^3 could fit 54 lugs.

5.5.2 Determine the first capacity depletion date for each of the RUSS.

Since no cold rooms have been installed at Waterfall Farm before, and no other form of refrigeration exists on the farm, the first capacity depletion date was October 2013.

5.5.3 Determine incremental restoration sizes and quantities based on the standard industry resource and structure sizes.

The cold room development consists of purchasing more cold rooms when the capacity is depleted. Cold rooms would not be sold and replaced with larger ones. Applying the design criterion (as stipulated in Section 6.4) of optimal use of the cold room space available at a time, at most two years' demand volume was applied to restore cold room capacity. Larger cold room sizes will thus be required as demand volume grows exponentially.

5.5.4 For each of the RUSS, use the first capacity depletion date to determine incremental restoration initiatives for each of the RUSS.

The cold room alternatives were identified from October 2013. Incremental restoration initiatives were proposed with depletion dates of October 2013, November 2015, November 2017, November 2019, and November 2021. Applying the financial feasibility criterion (as stipulated in Section 6.4), various alternative cold room acquisition options were considered, which are detailed in [20]. Costs and net present values were calculated using the inflation rate of June 2013. Using the lowest total cost (i.e., R299,252), five incremental restoration initiatives were identified, acquiring five cold rooms of various sizes over the eight-year planning horizon of the FDP.

5.5.5 Determine restoration dates for incremental restoration initiatives.

Restoration dates allow for preparation, construction lead time, or planning for the RUSS. The cold room's restoration dates are the same as the depletion dates because no preparation is required.

This demonstration only included one of the five critical RUSS (i.e. cold rooms). However, another critical resource, crop fields, requires a two-month preparation period preceding the depletion date for seedlings to be planted, grown, and harvested. Details of the calculation of restoration dates for the five critical RUSS are available in [20] and are summarised in Table 2.

Table 2: Restoration dates summary

Five Critical RUSS	Restoration Dates
Support Activity Facilities	Jul 2013
Cold Rooms	Oct 2013, Nov 2015, Nov 2017, Nov 2019, Nov 2021
Refrigerated Trucks	Jul 2013, Nov 2018, Nov 2019, Nov 2021
Loading Area	Jul 2013, Oct 2019
Crop Fields and Roads	Oct 2013, Oct 2014, Oct 2015, Oct 2016, Oct 2017, Oct 2018, Oct 2019, Oct 2020

5.6 Step 6: Compile a series of phase plans, called the FDP

The restoration dates of the resources and structures, summarised in Table 2, were grouped together to form the phases of the FDP. The FDP consisted of nine phases over the eight-year planning horizon of the FDP. The phases are detailed in [20].

5.7 Step 7: Represent phase plans graphically, in support of the FDP

Each phase was represented graphically using AutoCAD, and only showed the visible changes to the site, the newly-prepared crop fields, and the expanded or demolished facilities. The cold rooms would, for instance, be installed within the existing loading area, together with the refrigeration trucks.

5.8 Step 8: Validate the FDP

Sensitivity-and-scenario analysis was used to investigate how sensitive the FDP is to change. Changes may be the result of demand variation, inflation increases, or increases in the costs of the RUSS. Scenarios were identified to test the assumptions that were made during the development of the FDP. These assumptions were about the quantitative factors that could influence the decision between alternative options for restoration initiatives for each of the RUSS.

6 DISCUSSION

Using design research as a research method, we suggested and developed the FSDM, which provides method guidance in developing a facilities master plan to evolve farm facilities in a phased approach towards a future or saturation state. We concluded with an evaluation of the FSDM by using a practical demonstration at Waterfall Farm.

Although the demonstration validated the FSDM and rendered an FDP that was well-accepted by management, a more reliable FDP could be rendered if existing assumptions were challenged further. The assumption about the 30 per cent annual demand growth could be replaced, for example, with more realistic demand forecasts if historic production data were available. In addition, the 20 per cent loss of plant leaves was not questioned or challenged, but taken as a fixed loss. Improvement events could also have been suggested in order to reduce production loss.

The act of demonstrating the FSDM (also called circumscription) also led to the identification of additional requirements for enhancing the FSDM in future. Possible enhancements include the following:

- Currently, the FSDM assumes that a market analysis and soil analysis have been completed to inform choices about crop varieties and production mix. The FSDM could be extended to incorporate market analyses and soil analyses to optimise crop mix.
- The current FSDM focuses on level 2 (supra) and level 3 (macro) of space planning. The FSDM could be extended to include level 4 (micro).
- Step 3 (i.e., determine production requirements and the saturation date) could be extended by incorporating forecasting or demand planning techniques.
- Step 6 (i.e., compile a series of phase plans, called the FDP) also needs to consider cash flow and budget cycles to determine realistic phases.
- Step 8 (i.e., validate the FDP) could be extended to incorporate verification – for example, ensuring that the FSP complies with initial requirements or design criteria.
- The current FSDM does not consider the impact of technology on the saturation state and the restoration phases. In the agricultural industry, many advances have been made to reduce the length of the growth cycles. In warehousing and logistics, high density storage uses a third dimension, height, to accomplish significant gains in the use of space.

7 CONCLUSIONS AND FUTURE WORK

The FSDM was demonstrated for a specific farm that grows lettuce and baby leaf varieties. Since the process of circumscription already indicated additional requirements to improve the FSDM, it is suggested that the FSDM be extended during a second cycle of design research. The extended FSDM could then be demonstrated on a similar crop-growing farm to validate the extensions. Furthermore, the FSDM should be validated for different types of farms (e.g., livestock or forestry) to confirm its broader application across different farm types.

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