

An extended Farm Site Development Method

AUTHORS:

Eugene Hanekom¹
Andre Liebenberg¹
Marné de Vries¹ 

AFFILIATION:

¹Department of Industrial Engineering, University of Pretoria, Pretoria, South Africa

CORRESPONDENCE TO:

Marné de Vries

EMAIL:

marne.devries@up.ac.za

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The inefficient and ineffective use of arable land in South Africa is one of the numerous challenges within its agricultural sector. Previous research has indicated that a method, the Farm Site Development Method (FSDM), could increase the effective and efficient use of arable land by providing a roadmap to the farm owner for incrementally transforming the current state facilities and resources of a farm towards a future saturation state. The FSDM was then demonstrated at a crop-producing farm and several opportunities existed to extend its utility. Here we suggest its extension for application to a livestock farm, and also include optimisation techniques, demand planning and financial planning.

Significance:

- Extension of the Farm Site Development Method, and its demonstration at a livestock farm, for facilities and financial planning within the agricultural sector.

Introduction and background

The primary agricultural sector in South Africa is growing.¹ Yet there has been a drop in GDP contribution from 7.1% in 1970 to 2.6% in 2013.² Numerous factors influence the slow growth of this sector, such as climate change³, the land reform projects of which at least 50% failed⁴, and inefficient use of arable land⁵. Previous work has already identified an opportunity to improve the efficient and effective use of arable land by introducing long-term planning techniques to the agricultural sector. A new artefact was developed, called the Farm Site Development Method (FSDM), as a roadmap for incrementally transforming the current state facilities and resources of an existing farm towards a future saturation state that is financially feasible. The FSDM was evaluated with a demonstration at a crop-producing farm.⁶

Although the FSDM was useful to a crop-growing farm, several deficiencies were identified during the demonstration of the method: (1) optimisation techniques were not used to optimise product mix, (2) demand planning was not incorporated to forecast production requirements, and (3) financial planning did not consider cash flow.⁶ In addition, drawing knowledge from the field of method engineering, we postulated that the utility of the FSDM could be further improved. The existing FSDM could also be further extended for use on other types of farms, such as livestock farms.

Background literature

Previous research combined existing techniques, i.e. facilities planning and incremental design, to the agricultural sector. Because current facilities or resources may be depleted when the farming enterprise grows, active planning is required for their replacement or extension. The FSDM was developed to evolve the farm facilities in a phased approach towards its future or saturation state.⁶

The FSDM

The FSDM comprises eight sequential steps⁶:

1. Analyse the current-state facility layout.
2. Calculate the saturation state for the farm (compile a saturation-state facility layout).
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 farm site development plan (FDP).
7. Represent phase plans graphically in support of the FDP.
8. Validate the FDP.

Each step is elaborated in more detail in Van der Merwe et al.⁶ As the FSDM could be classified as a method artefact, the field of method engineering applies and will be discussed next.

Method engineering, situational method engineering and utility criteria

Method engineering has developed within the information systems discipline as a field concerned with the construction of new methods from existing methods.⁷ One of the areas in method engineering – situational method engineering – has the objective of constructing methods which are tuned to specific situations and project types.^{8,9} Whereas a new method is constructed according to requirements, *situational method engineering* requires adaptation of a generic method according to project-specific needs.¹⁰ Because this article focuses on the extension of an existing method (the FSDM), guidelines from situational method engineering were applicable in adapting the generic FSDM for different situations, i.e. a crop-producing farm versus a livestock farm.

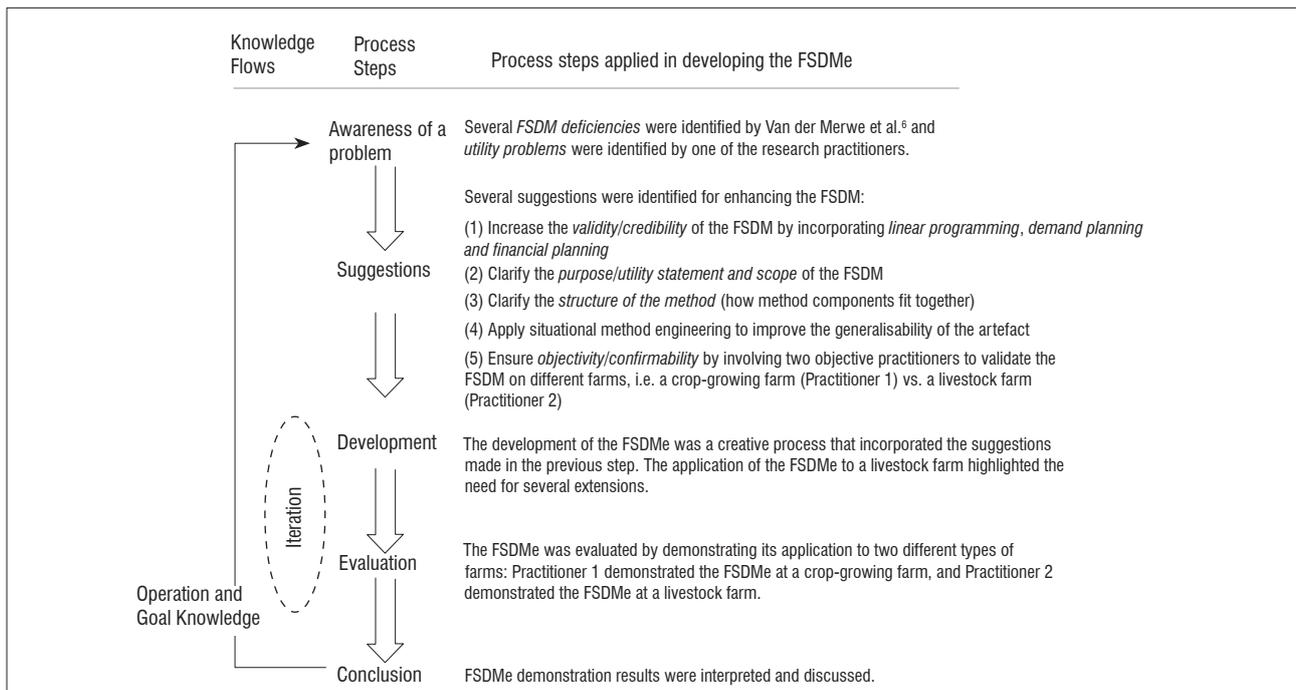


Figure 1: Applying a second design cycle for developing the extended Farm Site Development Method (FSDMe).

Based on the structure specified by Gregor and Jones¹¹ for design theory, Offerman et al.¹⁰ consider *utility* as the primary evaluation criterion for evaluating a design theory. They define four criteria in terms of utility: (1) *validity/credibility* as the ability of a method to yield the claimed utility within the intended scope, (2) *objectivity/confirmability* as the degree to which others are able to confirm the utility statement, (3) *generalisability* as the assumption that the utility statement holds true for all possible instances within the scope, and (4) *transferability* as the postulation that the utility statement would also be partially true for out-of-scope situations. From the four criteria, Offerman et al.¹⁰ developed guiding questions for the components of a method theory, which we have applied below to identify utility deficiencies within the existing FSDM. We also evaluate the enhanced FSDM in terms of the four utility criteria of Offerman et al.¹⁰

First we introduce techniques that could be applied to extend the existing FSDM: linear programming, demand planning and financial planning.

Techniques to enhance the FSDM

Linear programming is a deterministic, optimising model that maximises or minimises a quantifiable objective. The objective could be expressed as a linear function of identified decision variables. The purpose is to optimise the objective by calculating values for the decision variables, given certain constraints. The constraints are also expressed as linear equations or linear inequalities.¹²

Demand planning deals with uncertainties within the business environment when predicting future demand of products. Time series analysis is useful if a relationship exists between the historical demand and future demand of the product, i.e. that past history of demand levels will influence the future behaviour of this demand over time.¹² Historical demand data could be used to identify the average demand for a period, a trend, seasonal elements, cyclical elements, random variation and autocorrelation. Based on the analysis, different time series forecasting techniques may be useful.¹³

Financial planning concerns the optimal use of financial resources and should be performed on two levels – a strategic level and a tactical level. Strategic planning is concerned with long-term goals in the enterprise, such as product mix and new production facilities, whereas tactical planning ensures that existing resources are exploited. The end result of financial planning is to maximise the ratio of profits to the equity capital (i.e. capital used to acquire assets) employed.¹² The financial planner

needs to estimate income and costs, differentiating between variable and fixed costs. Seal et al.¹⁴ define variable costs as a cost type that varies in direct production to the level of activity (e.g. fertiliser for crop production), whereas fixed costs remain constant regardless of the level of activity (e.g. property tax).

Research design

The research design used to extend the FSDM – design research – values the creation of novel artefacts and provides a body of knowledge to guide the researcher during different stages of a design cycle.¹⁵ Previous research applied design research to develop a new method artefact, the FSDM. During the first iteration of the design cycle, the validity/credibility of the FSDM was evaluated by applying the FSDM to a crop-producing farm named Waterfall Farm. Several recommendations were made for enhancing the FSDM.⁶ Here we apply a second design cycle, using the five-step design cycle of Vaishnavi and Kuechler¹⁶ (see Figure 1, Process Steps), to develop an extended FSDM, called FSDMe.

Referring to Figure 1, 'Awareness of a problem' entailed identification of FSDM deficiencies and utility problems, which led to several 'Suggestions' that were incorporated during a creative 'Development' process for developing the FSDMe. The FSDMe underwent 'Evaluation' by demonstrating its application to a crop-growing farm, as well as a livestock farm. As previous work already demonstrated the FSDM on a crop-growing farm,⁶ here we present the demonstration of the FSDMe only on a livestock farm. Although we present the FSDMe as a theoretical contribution in this article, we have also developed a software application, using MS Excel, which presents a user-friendly interface to the user (e.g. practitioner or farm owner) of the FSDMe. The software application is available on request.

The extended Farm Site Development Method: FSDMe

The FSDMe is a method that is used to evolve farm facilities in a phased approach towards its future or saturation state. The FSDMe comprises nine steps and the structure (as depicted in Figure 2) is as follows:

- The purpose (utility-statement), scope, prerequisites, roles and input requirements/data of the FSDMe.
- The method steps and extension points to accommodate different contexts.

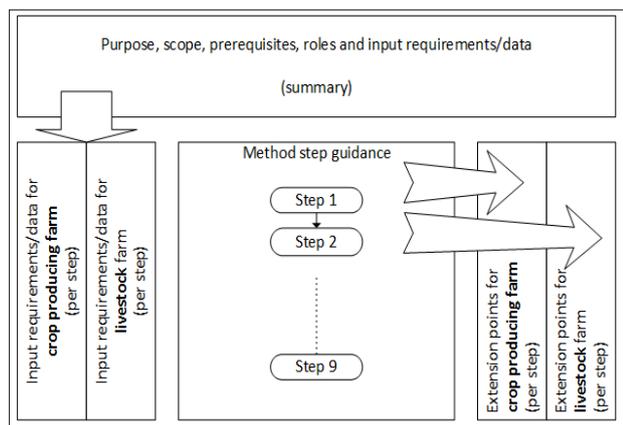


Figure 2: The extended Farm Site Development Method – FSDMe.

Purpose, scope, prerequisites, roles and input requirements/data

Purpose: The FSDMe is a strategic planning tool that facilitates production growth on an existing farm of fixed size and the incremental extension of its facilities towards the saturation state. The main output of this method is a FDP, which accommodates financial and other criteria.

Scope: The FSDMe has been demonstrated on a crop-producing farm as well as a livestock farm. For the crop-producing farm, the FSDMe requires choice of crop products as input, but does not aim to optimise the production mix proportions. For a livestock farm, the FSDMe similarly requires a choice of animal type as input, but also optimises the proportion of animal types. Furthermore, it is assumed that the livestock farm produces crops for the sole purpose of feeding livestock. For a livestock farm we also assume that calves and lambs are only feeding from their mother and do not need to graze. If additional feeding

is required, calves and lambs receive creep feed (a blend of maize, molasses, proteins and micro- and macro-minerals). We also assume that calves are sold once they are weaned.

Prerequisites: Decisions about crop varieties and crop production mix should have been made (based on market analyses and soil analyses) prior to using the FSDMe.

Roles: The farm owner or the practitioner will be applying the FSDMe to generate the FDP. The farm owner or practitioner should have practical knowledge of the farming industry and the farm produce. As an example, the owner or practitioner of a livestock farm needs to have skills pertaining to breeding techniques, feeding of livestock, knowledge about natural grazing and livestock diseases.

Input requirements: See Table 1.

Method steps with extension points

Step 1: Analyse the current-state facility layout

Input: Existing farm layout plans

Method step guidance: Conduct a site visit 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, use GPS coordinates to map the current-state facility layout, indicating all buildings and site features to scale.

Step 2: Calculate the arable land

Input: Total area of the farm (ha)

Method step guidance: Calculate the arable land (*a*) of the farm (in hectares) as total area less all existing facilities, production areas and road areas.

Table 1: Input requirements/data for using the extended Farm Site Development Method (FSDMe)

Inputs irrespective of production type:	
If market demand is a constraint, historical production data are required. Farmer-prioritised investment decisions (e.g. the decision to buy hail shields). Cash used for expansion (as a percentage of total profits).	
Inputs for crop production	Inputs for livestock production
Farm Existing farm layout plans Total area of the farm (in ha)	Farm Existing farm layout plans Total area of the farm (in ha) Section sizes (ha)(<i>a</i> ₁ , <i>a</i> ₂ ,... <i>a</i> _{<i>k</i>})
Produce Varieties produced and proportion (%) production for each variety Crop growth times for reaching maturity (weeks) Planting density (in units per ha) Waste or cut rate (%)	Produce Choice of animal type <i>i</i> Choice of feed crops Equivalent livestock units (in LU*) for each animal type Selected breeding technique (insemination or synchronisation or natural breeding) and number of females (<i>f</i> _{<i>i</i>}) associated with 1 male during breeding for animal type <i>i</i> Production potential (in offspring/year) of each female animal type <i>i</i>(<i>o</i> ₁ , <i>o</i> ₂ ,... <i>o</i> _{<i>i</i>}) Section yield (LU/ha/year)(<i>u</i> ₁ , <i>u</i> ₂ ,... <i>u</i> _{<i>k</i>})
Budget Variable costs (seeds, fertiliser, planting, harvesting, electricity, etc.) and associated inflation rates Fixed costs (asset depreciation, taxes, etc.) and associated inflation rates Product selling price and associated inflation rates	Budget Variable costs (animal feed, veterinary, etc.) and associated inflation rates Fixed costs (e.g. asset depreciation, taxes, etc.) and associated inflation rates Auction price of animal type <i>i</i> (when selling) and associated inflation rate Auction price of animal type <i>i</i> (when buying) and associated inflation rate Proportion of old animals that are sold for animal type <i>i</i>

*LU is a standard unit used to measure the number of animals that will be able to graze on one hectare annually. A fully grown cow of 450 kg = 1 LU

Step 3: Calculate the yield potential to generate a facility layout at saturation state

Input: Arable land (a) from previous step

Inputs – crop-producing farm:

- Varieties produced and percentage production for each variety
- Crop growth times for reaching maturity (weeks)
- Planting density (units per ha), u
- Waste or cut rate (in percentage), d

Inputs – livestock farm:

- Choice of animal type (note: production mix proportions are not required), i
- Choice of feed crops per farm section
- Equivalent livestock units (in LU) for each animal type
- Selected breeding technique (insemination or synchronisation or natural breeding) and number of females (f_i) associated with one male during breeding for animal type i
- Production potential (in offspring/year) of each female animal type i (o_1, o_2, \dots, o_i)
- Section sizes (ha) (a_1, a_2, \dots, a_k)
- Section yield (LU/ha/year) (u_1, u_2, \dots, u_k)
- Variable costs (animal feed, veterinary, etc.) and associated inflation rates
- Auction price of animal type i (when selling) and associated inflation rate
- Auction price of animal type i (when buying) and associated inflation rate

Method step guidance: The objective is to estimate the yield potential (y) of the farm at saturation state. Based on the yield potential, use a drawing tool to represent the facility layout at the saturation state.

Extension – crop-producing farm:

Yield potential on a crop-producing farm is calculated by:

$$y_c = a * u, \quad \text{Equation 1}$$

where y_c is the crop yield potential (units), a is the arable land size (ha) and u is the maximum surface utilisation, i.e. maximum number of crop units that could be grown per hectare.

The yield potential at saturation state could also be converted to potential production rate (ρ_u) in units per week and potential production rate (ρ_s) in standardised units per week.

$$\text{Therefore: } \rho_u = \frac{y}{x} (1-d), \quad \text{Equation 2}$$

where x is the average growth timeframe of all crop varieties to reach maturity (in weeks), also incorporating seasonality and growth times for different crop varieties, d is the average loss of production units (in units) before distribution and y is the yield potential (units), calculated in Equation 1.

$$\text{Expressed in standardised units: } \rho_s = \frac{\rho_u}{s}, \quad \text{Equation 3}$$

where ρ_u is the potential production rate in units per week, calculated in Equation 2, and s is the number of production units per standardised unit, where the standardised unit is a packaging unit for transporting the units (produce).

Extension – livestock farm:

Yield potential on a livestock farm is calculated by:

$$y_1 = \sum_{j=1}^k a_j * u_j, \quad \text{Equation 4}$$

where y_1 is the yield potential (LU per year), a is the section size (ha) (a_1, a_2, \dots, a_k) and u is the section yield (LU/ha/year) (u_1, u_2, \dots, u_k).

The yield potential could also be expressed as the number of animals of a particular type (L_i). A linear programming model is used to calculate the values for L_i to maximise profits (Z). Because not all animals are delivering offspring, a correction factor ($f_i/(f_i+1)$) reduces the income to account for the male individuals within the mix.

$$\text{Therefore: } \text{Max } Z = \sum_{i=1}^n (f_i/(f_i+1)) L_i (P_i - K_i)$$

$$i \in I = \begin{matrix} \text{Animal type 1} \\ \text{Animal type 2} \\ \text{Animal type n} \end{matrix}$$

The constants are:

- y_i = yield potential (LU per year), calculated in Equation 4
- X_i = ratio animals of type i equivalent to 1 LU, where 1 cow = 1 LU, and $i \in I$
- f_i = number of females associated with 1 male according to the breeding technique for animal type i
- P_i = the income generated from female animal type $i \in I$ in one year i.e. (selling price for animal type i) * (offspring/year o_i for animal type i)
- K_i = the cost to keep animal type $i \in I$ on the farm for one year

The variables are:

- L_i = The number of animals of type i to keep on the farm annually, where $i \in I$

Subject to:

- $\sum_{i=1}^n \frac{L_i}{X_i} \leq Y_i$ (saturation state LU may not exceed the LU capacity of the farm)
- $X_i L_i = X_j + L_{i+1} \forall i = 1, 2, 3, \dots, i-1$ (relationship of different animal types on the farm remains constant)

As L_i specifies the total number of animals of type i , the breeding technique ratio should be used to calculate $L_{i,f}$ (female animals of type i) and $L_{i,m}$ (male animals of type i):

$$L_{i,f} = (f_i/f_i+1) L_i \quad \text{Equation 5}$$

$$L_{i,m} = L_i - L_{i,f} \quad \text{Equation 6}$$

Step 4: Determine the production requirements and the saturation date based on constraints

Inputs:

- If market demand is a constraint, historical production data are required
- Farmer-prioritised investment decisions (e.g. the decision to buy hail shields)
- Cash used for expansion (in percentage of total profits)

Inputs – crop-producing farm:

- Variable costs (e.g. seeds, fertiliser, planting, harvesting, electricity) and associated inflation rates
- Fixed costs (e.g. asset depreciation, taxes) and associated inflation rates
- Product selling price and associated inflation rates

Inputs – livestock farm:

- Variable costs (feeding crops etc.) and associated inflation rates
- Fixed costs (e.g. asset depreciation, taxes, etc.) and associated inflation rates
- Auction price of animal type i (when selling) and associated inflation rate
- Auction price of animal type i (when buying) and associated inflation rate
- Percentage of old animals that are sold for animal type i

Method step guidance: Because the historical resource-acquisition decisions, existing cost structure and other investment decisions limit the cash available for production growth, this method acknowledges the need for incorporating cash flow calculations. The method is simplified by assuming that a fixed percentage of profits is used to expand production on the farm. The farmer also needs to determine if there is a demand constraint for the products. If a demand constraint exists, historical production data should be analysed to project future demand, using time series analysis. The saturation date is calculated as the date on which the saturation state is achieved, which gives an indication of the planning horizon for extending production on the farm. The projected growth of production (per product type) up to the saturation date could be demonstrated graphically.

Step 5: Identify critical RUSS and design criteria

Method step guidance: 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. Based on the needs of the farm owner, 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.

Step 6: Identify and evaluate alternatives for RUSS replacement or extension

Input: Design criteria and RUSS identified in the previous step.

Inputs – crop-producing farm:

- Potential production rate (p_s) in standardised units per week, calculated in Equation 3

Method step guidance: A number of calculations is required to identify alternative restoration initiatives and to evaluate the alternative initiatives against the design criteria identified in Step 5.

- Determine the initial RUSS sizes (see 'Extension for crop-producing farm' below).
- 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.
- 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. Because 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 the design criteria (e.g. financial and technical) lead times for constructing and/or acquiring RUSS to complete restoration before capacity depletion occurs.

Extension for crop-producing farm:

Determine the initial RUSS sizes expressed in standardised units. Calculate the RUSS capacity that is currently used, given the existing production rate.

The existing production rate, expressed in standardised units is:

$$p_s^i = \frac{p_u^i}{s}, \quad \text{Equation 7}$$

where p_u^i is the current production rate in units per week and s is the number of production units per standardised unit, where the standardised unit is a packaging unit for transporting the units (produce).

Step 7: Compile a series of phase plans: The FDP

Method step guidance: Considering the practicality of restoration activities, the practitioner needs to group the restoration dates in 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.

Step 8: Represent phase plans graphically in support of the FDP

Method step guidance: Draw each phase of the FDP sequentially, starting at the current-state facility layout and ending with a saturation-state facility layout. Although the saturation-state facility layout may resemble the initial facility layout compiled in Step 3, a revised layout may be required to reflect changes in strategy, target market, product or technology.

Step 9: Validate the FDP

Method step guidance: The purpose of this step is to evaluate the sensitivity of the FDP in terms of the quantitative assumptions that were made during the development of the restoration alternatives for the critical RUSS. During this step, the practitioner assesses the rigour of the FDP when different input parameters (e.g. cost of labour) are used or major disasters (e.g. field fires and droughts) are considered. Additional qualitative validation may also be required to ensure that the FDP is useful to management.

Evaluation results: A practical demonstration at Bloemhoek Farm

We present a demonstration of the FSDMe at a livestock farm, which has been documented comprehensively in Hanekom¹⁷.

Input requirements/data

From Table 1 in the previous section, several inputs are required for applying the FSDMe steps. In this demonstration, we provide an interpretation of the inputs that were obtained for generating an FDP for Bloemhoek Farm in Table 2.

Applying the method steps

Applying the method step guidance given in the previous section, we demonstrate its application in this section.

Step 1: Analyse the current-state facility layout

According to Step 1, several inputs are required, which are declared in Table 2.

Method step application: The total area of the farm is divided into different feed yield sections (Figure 3). The yield capacity of each feed yield section is given in livestock unit per hectare (LU/ha) (Table 3), which is a standard unit used to measure the number of animals that would be able to graze in 1 ha annually. A fully grown cow of 450 kg is equivalent to one livestock unit. Table 3 also indicates the current crops planted in each section, as well as the demarcation of Sections 5, 6 and 7 into three grazing camps.

Table 2: Input requirements/data for using the extended Farm Site Development Method (FSDMe) at Bloemhoek Farm

Input parameter	Input value at Bloemhoek Farm
Inputs irrespective of production type	
If market demand is a constraint, historical production data are required	The market demand for meat (beef and mutton) is larger than the potential production capacity of Bloemhoek Farm. Thus, the market demand is not a constraint.
Farmer-prioritised investment decisions	The farmer did not prioritise any investment decisions.
Cash used for expansion (% of total profits)	40% of the gross profit will be allocated to growth of herds.
Farm	
Existing farm layout plans	Existing farm layouts are presented in Hanekom ¹⁷ and summarised in Figure 3 and Table 3.
Total area of the farm (in ha)	564.34 ha
Section sizes (ha) (a_1, a_2, \dots, a_k)	Summarised in Table 3.
Produce	
Choice of animal type i	The owner decided to farm with type 1 = <i>cattle</i> and type 2 = <i>sheep</i> . The rationale for this choice is that maximum utilisation of natural grazing could be achieved when rotational grazing is applied, because cattle and sheep consume different lengths of grass.
Choice of feed crops	Lucerne, maize, wheat and weeping lovegrass (<i>Eragrostis curvula</i>). The nature of the soil, the nutritive value of the crops, the yield potential and the crop production costs were the main concerns for the selected feed crops.
Equivalent livestock units (in LU) for each animal type	Cattle, weighing 450 kg = 1 LU Sheep, weighing 55 kg = 0.125 LU
Selected breeding technique (insemination or synchronisation or natural breeding) and number of females (f_i) associated with 1 male during breeding for animal type i	Cattle – natural breeding, $f_1 = 25$ Sheep – synchronisation, $f_2 = 150$
Production potential (in offspring/year) of each animal type i (o_1, o_2, \dots, o_k)	For Type 1 (cow): 0.67 For Type 2 (ewe): 1.5
Feed crop yield (LU/ha/year) (u_1, u_2, \dots, u_k)	Lucerne: 1.9 Maize and wheat: 3.1 Weeping lovegrass (<i>Eragrostis curvula</i>): 0.7 Natural grass, shrubs and bush: 0.5 Mountainous terrain: 0.4
Budget	
Variable costs (feeding crops etc.) and associated inflation rates	Annual cost per cow: R2370.74 Annual cost per ewe: R411.97
Fixed costs (e.g. asset depreciation, taxes, etc.) and associated inflation rates	The assumption was made that 40% of gross profit would be used for livestock growth, whereas the remaining 60% would be sufficient to cover fixed costs, such as taxes and asset depreciation. Future costs (feed-processing equipment, livestock-handling facilities and sheep sleeping camps) were also estimated and incorporated during cash flow calculations. Building cost inflation rate: 6.05% (Triami Media, 2014)
Auction price of animal type i (when selling) and associated inflation rate	Price per cow (old cow or weaner): R4200 Price per ewe (old ewe or weaner): R615 Inflation rate: 10%
Auction price of animal type i (when buying) and associated inflation rate	Price per cow (for breeding): R10 000 Price per ewe: R1500 Inflation rate: 10%
Proportion of old animals that are sold for animal type i	% of old cattle sold: 0.01 % of old sheep sold: 0.1

Table 3: Size, current crops and demarcation of grazing camps on Bloemhoek Farm

	Year	2014	2015	2016	2017	2018
Cattle	Number of animals	100	100	100	100	100
	Old animals sold	1	1	1	1	1
	Auction price	R4200.00	R4620.00	R5082.00	R5590.20	R6149.22
	Expenses	R2370.74	R2607.82	R2868.60	R3155.46	R3471.00
	Replacement cost	R10 000.00	R11 000.00	R12 100.00	R13 310.00	R14 641.00
	Total income	R274 433.33	R301 696.31	R331 972.63	R365 633.18	R403 281.71
	Total expenses	R237 074.25	R260 625.87	R286 780.62	R315 858.90	R348 382.27
	Increase in number of animals	1	1	1	1	1
Sheep	Number of animals	249	305	364	425	503
	Old animals sold	25	31	36	42	50
	Auction price	R615.00	R676.50	R744.15	R818.57	R900.42
	Expenses	R411.97	R453.16	R498.48	R498.48	R498.48
	Replacement cost	R1500.00	R1650.00	R1815.00	R1815.00	R1815.00
	Total income	R243 451.52	R328 410.99	R430 592.47	R552 985.71	R720 429.38
	Total expenses	R102 579.98	R138 378.25	R181 433.12	R211 822.15	R250 874.31
	Increase in number of animals	81	89	97	121	152



Figure 3: Different feed yield sections of Bloemhoek Farm – applying Step 1 of the extended Farm Site Development Method.

Step 2: Calculate the arable land

According to Step 2, several inputs are required, which are declared in Table 2.

Method step application: The arable land (a) = (total area (564.34) – existing facilities and road areas (39.05)) = 525.29 ha.

Step 3: Calculate the yield potential to generate a facility layout at saturation state

According to Step 3, several inputs are required, which are declared in Table 2.

Method step application: The yield sections are indicated in Figure 3.

Applying the extension for livestock farms:

Yield potential on a livestock farm is calculated by:

$$y_i = \sum_{j=1}^k a_j * u_j, \quad \text{Equation 4}$$

where y_i is the yield potential (LU per year), a is the section size (ha).....(a_1, a_2, \dots, a_k) (see Table 3 for values) and u is the section yield (LU/ha/year)(u_1, u_2, \dots, u_k) (see Table 3 for values).

Thus, using Equation 4, yield potential on Bloemhoek Farm, $y_i = 438.01$ LU per year.

The yield potential could also be expressed as the number of animals of a particular type (L_i). A linear programming model is used to calculate the values for L_i to maximise profits (Z). Therefore:

$$\text{Max } Z = \sum_{i=1}^n (f_i / (f_i + 1)) L_i (P_i - K_i)$$

$$i \in I = \begin{matrix} \text{Animal type 1} \\ \text{Animal type 2} \\ \text{Animal type } n \end{matrix}$$

Constants:

- y_i = yield potential (438.01 LU per year), calculated in Equation 4
- X_i = ratio animals of type i equivalent to 1 LU, where 1 cow = 1 LU, and $i \in I$
 $X_1 = 1$ (cattle)
 $X_2 = 1/8 = 0.125$ (sheep)
- f_i = number of females associated with 1 male according to the breeding technique for animal type i
 $f_1 = 25$
 $f_2 = 150$
- P_i = the income generated from female animal type $i \in I$ in one year i.e. (selling price for animal type i) * (offspring/year o_i for animal type i), in rands (ZAR)
 $P_1 = (R4200)(0.67) = R2814$
 $P_2 = (R615)(1.5) = R922.5$
- K_i = the cost to keep animal type $i \in I$ on the farm for one year. The cost calculations are based on feed and veterinary costs associated with the specific farm.
 $K_1 = 2370.74$
 $K_2 = 411.97$

Variables:

- L_i = the number of animals of type i to keep on the farm annually, where $i \in I$

Subject to:

- $\sum_{i=1}^n \frac{L_i}{X_i} \leq y_i$ (saturation state LU may not exceed the LU capacity of the farm)
- $\sum_{i=1}^n \frac{L_i}{X_i} \leq 438.01$ (substituting from Equation 4)
- $X_i L_i = X_{i+1} L_{i+1} \forall i = 1, 2, 3 \dots i-1$ (relationship of different animal types on the farm remains constant)

Solving the linear programming model renders the following results:

$$L_1 = 126 \text{ (cattle)}$$

$$L_2 = 2496 \text{ (sheep)}$$

$$Z = R215\,143 \text{ (maximum profit at saturation state)}$$

Because L_i specifies the total number of animals of type i , the breeding technique ratio should be used to calculate $L_{i,f}$ (female animals of type i) and $L_{i,m}$ (male animals of type i):

- $L_{i,f} = (f_i / (f_i + 1)) L_i \dots$ from Equation 5
 $L_{1,f} = (25/26)126 = 121$ (cows)
 $L_{2,f} = (150/151)2496 = 2479$ (ewes)
- $L_{i,m} = L_i - L_{i,f} \dots$ from Equation 6
 $L_{1,m} = 126 - 121 = 5$ (bulls)
 $L_{2,m} = 2496 - 2479 = 17$ (rams)

Step 4: Determine the production requirements and the saturation date based on constraints

According to Step 4, several inputs are required, which are declared in Table 2.

Method step application: There are two types of animals on the farm; both types will not necessarily reach their saturation dates at the same time. The growth of the number of animals on the farm will be constrained by the cash flow of the business and the percentage of profits that will be used to expand the farm. Furthermore, the annual increase in the number of cattle and sheep needs to be proportional to the shortfall when compared to the saturation-state numbers. The cattle and sheep need to reach their saturation date at the same time to optimise veld utilisation. Table 4 presents a partial cash flow budget, indicating the expenses, income, gross profit and annual increase of animal numbers when 40% of the gross profit is applied to growth of livestock numbers.

The saturation date is the date at which the saturation state is achieved, i.e. when 126 cattle and 2496 sheep are grazing at Bloemhoek Farm. As indicated in Figure 4, the saturation date is at the start of the year 2027. The saturation date is based on certain assumptions, such as normal growth and breeding. Under conditions which impede normal growth and breeding, such as drought, the saturation date will have to be re-calculated using different input values. Section 7 argues in favour of an iterative FSDMe to acknowledge dynamic changes within the enterprise context, such as climate conditions. For the purpose of this demonstration, we acknowledge different input parameters by including sensitivity analyses in Step 9. Because Bloemhoek Farm will be growing in livestock numbers, additional resources, utilities, services and structures will be required, and are calculated in the next step.

Step 5: Identify critical RUSS and design criteria

Additional capacity would be required for sheep sleeping camps, feed-processing equipment and livestock-handling facilities. The main concern or design criterion is the cost of expanding the facilities.

Hanekom¹⁷ indicated that existing sheep sleeping camps had a capacity of 3.2 ha. As calculated in Step 3, the flock of sheep will have increased to 2496 at saturation state. Because a sheep requires 0.004 ha sleeping space, the sheep sleeping camps need to increase to a total capacity of 9.98 ha (i.e. 2496×0.004).

At saturation state, the animals will rely less on natural grazing and more on additional feeding to provide adequate nutrition at different production stages. The different mixtures are also commonly referred to as 'lick', with the key ingredient being lucerne. Hanekom¹⁷ suggested mechanisation as a solution, with additional equipment to produce lucerne at Bloemhoek Farm.

Livestock-handling facilities are used for several activities, such as administering medicine, animal branding and selecting animals for auctions. Existing livestock-handling facilities accommodate 105 cattle and 640 sheep. The livestock-handling facilities require a stepwise increase in capacity.

Step 6: Identify and evaluate alternatives for RUSS replacement or extension

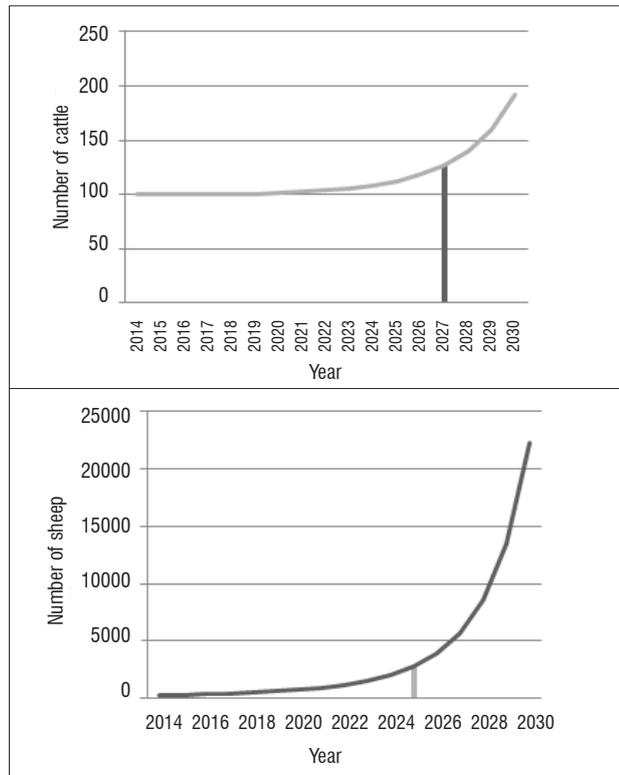
As indicated in the previous step, sheep sleeping camps, feed-processing equipment and livestock-handling facilities have to be extended.

For sheep sleeping camps, the first saturation date will occur on November 2021, as the current sleeping camp has a capacity of 807 sheep (i.e. $3.23 \text{ ha} / 0.004 \text{ ha space required per sheep}$). As indicated in Step 5, a total capacity of 9.98 ha would be required at saturation state. We propose two alternatives: (1) constructing all of the camps before November 2021 and (2) constructing camps as sleeping capacity runs out. The economic analysis indicates preference for the first alternative, as the more economical option.

Regarding feed-processing equipment, Hanekom¹⁷ suggested that the high cost and 100% utilisation of current manual labour warrants partial mechanisation. The suggested lucerne production equipment, detailed in Hanekom¹⁷ (costing R603 042), should be purchased immediately.

Table 4: Effect of animal growth choices on cash flow for Bloemhoek Farm

	Year	2014	2015	2016	2017	2018
Cattle	Number of animals	100	100	100	100	100
	Old animals sold	1	1	1	1	1
	Auction price	R4200.00	R4620.00	R5082.00	R5590.20	R6149.22
	Expenses	R2370.74	R2607.82	R2868.60	R3155.46	R3471.00
	Replacement cost	R10 000.00	R11 000.00	R12 100.00	R13 310.00	R14 641.00
	Total income	R274 433.33	R301 696.31	R331 972.63	R365 633.18	R403 281.71
	Total expenses	R237 074.25	R260 625.87	R286 780.62	R315 858.90	R348 382.27
	Increase in number of animals	1	1	1	1	1
Sheep	Number of animals	249	305	364	425	503
	Old animals sold	25	31	36	42	50
	Auction price	R615.00	R676.50	R744.15	R818.57	R900.42
	Expenses	R411.97	R453.16	R498.48	R498.48	R498.48
	Replacement cost	R1500.00	R1650.00	R1815.00	R1815.00	R1815.00
	Total income	R243 451.52	R328 410.99	R430 592.47	R552 985.71	R720 429.38
	Total expenses	R102 579.98	R138 378.25	R181 433.12	R211 822.15	R250 874.31
	Increase in number of animals	81	89	97	121	152



The vertical line indicates the saturation date.

Figure 4: Growth of livestock constrained by cash flow.

Table 5: Farm site development plan

Year	Increase in cattle	Increase in sheep	Additional facilities	Cost
2014	1	81	Feed-processing equipment (November)	R603 042
2015	1	89		
2016	1	97		
2017	1	121		
2018	1	152		
2019	2	195	Livestock-handling facilities (April)	R129 817
2020	2	255		
2021	2	340	Sleeping camps (November)	R261 360
2022	3	465		
2023	4	652		
2024	5	942		
2025	7	1405		
2026	10	2168		
2027	14	3474		

As calculated in Step 5, the existing livestock-handling facilities accommodate 105 cattle and 640 sheep. Livestock-handling facilities will be depleted in July 2022 for cattle and April 2019 for sheep. Two alternatives are suggested: (1) constructing additional units before April 2019 and (2) constructing the facilities when capacity runs out. The economic analysis indicates preference for the first alternative, based on cost.

Step 7: Compile a series of phase plans: The FDP

The suggested FDP is shown in Table 5.

Step 8: Represent phase plans graphically in support of the FDP

Hanekom¹⁷ provided a graphical saturation-state facility plan for the livestock-handling facilities, as well as the sheep sleeping camps.

Step 9: Validate the FDP

Hanekom¹⁷ automated the linear program and the resulting cash flow using MS Excel. We then used different input parameters to analyse the effect on the FDP. Examples of different scenarios include a decline in the auction price of animals, above average increases in input cost (such as labour cost and feed cost), and a sudden decline in animal numbers as a result of a lethal disease. For demonstration purposes, we demonstrate two scenarios.

Scenario 1: The auction price dramatically increases as a result of El Niño, which causes a drought. Typical unit auction prices quoted in February 2016 for cattle were R6000 (instead of R4200) and for sheep R1050 (instead of R615). The result of this scenario is shown in Table 6. The optimal quantities for cattle (405) and sheep (264) at saturation state are very different to the optimal quantities calculated in Step 3. Thus the FSDMe should not be based on volatile prices, i.e. stable price trends should be used.

Table 6: Scenario 1: Auction prices increase dramatically

Higher auction prices as input		Optimal quantities	
Cattle	R6000	L_1 (Cattle at saturation state)	405
Sheep	R1050	L_2 (Sheep at saturation state)	264
		Z (Maximum profit)	R706 021.13

Scenario 2: Above average additional costs are used, e.g. additional costs for cattle are R1000 (instead of R515) and for sheep R300 (instead of R180). The result of this scenario is shown in Table 7. Higher additional costs do not have an impact on the optimal quantities for cattle (126) and sheep (2496), as the same optimal values were obtained in Step 3. Because of higher input costs, the maximum profits are lower than those obtained in Step 3, as expected. In addition, a qualitative validation was performed, using a questionnaire to validate the usefulness of the FSDMe to the farm owner.

Table 7: Scenario 2: Above average additional costs are used

Higher additional costs as input		Optimal quantities	
Cattle	R1000	L_1 (Cattle at saturation state)	126
Sheep	R300	L_2 (Sheep at saturation state)	2496
		Z (Maximum profit)	R116 591.65

Discussion

In this article, we have suggested the extension of an existing method – the FSDM – towards an FSDMe. We have presented the FSDMe, which was adapted and extended to address several utility deficiencies, which are now discussed. The *validity/credibility* was improved by extending the

FSDMe for livestock farms and incorporating optimisation techniques, demand planning and financial planning. Even though we incorporated demand planning theoretically, our demonstration at Bloemhoek Farm assumed that demand exceeded supply. Additional demonstrations of the FSDMe, in which demand is constrained, would further increase the *validity/credibility* of the FSDMe. In addition, the *purpose/utility* statement and scope of the FSDM was clarified by defining the purpose, scope, prerequisites, input requirements and roles. The new FSDMe provides clarity on the structure of the method, separating the initial input variables from the method guidance. The *generalisability* of the method was improved through the distinction between the generic and extension components, as illustrated on crop and livestock farms. The *objectivity/confirmability* of the method was improved by involving two objective participants as practitioners, demonstrating the FSDMe for different types of farms.

The two demonstrations partially confirmed the utility of the FSDMe, as a component could not be demonstrated if its method condition did not occur. As an example, Step 4 requires a time series analysis to project future demand *if* market demand is a constraint; because market demand for produce was not a constraint for the two demonstration farms, the time series analysis component could not be validated.

The FSDMe demonstration on the livestock farm acknowledged the heterogeneous nature of the arable land, different feeding habits of animal types and grazing sequence to ensure optimal utilisation of plant material. The FSDMe demonstration on the crop-producing farm acknowledged intervention decisions of the farm owner (e.g. the decision to buy hail shields), which constrains the solution space for developing the FDP.

Conclusions

We have addressed several utility deficiencies of an existing method (the FSDM), extending its *utility* in terms of its validity, its purpose statement and scope, its generalisability and confirmability. In terms of its *purpose*, the extended FSDMe is a strategic planning tool that facilitates production growth on an existing farm of fixed size and incremental extension of its facilities towards the saturation state. The *scope* of the FSDMe includes crop-producing farms as well as livestock farms. For the crop-producing farm, the FSDMe requires choice of crop products as input, but does not aim to optimise the production mix proportions. For the livestock farm, the FSDMe similarly requires a choice of animal type as input, but also optimises the proportion of animal types. Furthermore, it is assumed that the livestock farm produces crops for the sole purpose of feeding livestock. As indicated by the FSDMe, the practitioner or farm owner needs to have some practical knowledge of the farming industry and the farm produce prior to using the FSDMe. Several input values regarding the particular farm, produce and budget are required prior to applying the FSDMe.

The two distinct demonstrations of the FSDMe for a crop-producing farm and a livestock farm validated the utility of the FSDMe. For demonstration purposes, only the livestock farm was included as an example. Feedback from the research participants indicated several extension opportunities for future work. Currently the FSDMe does not question decisions regarding farming produce (i.e. crop varieties, crop production mix and animal types). Because the initial business model may not be optimal, the FSDMe could be extended to re-visit and guide business model decisions regarding markets, produce, partners and resources. One of the assumptions of the FSDMe, when applied to a livestock farm, is that calves and lambs do not graze and are sold once they are weaned. Yet, if the price of crops (e.g. maize) is very low, some farmers rather use a percentage of their crops as rounding feed for calves and lambs. A possible extension of the FSDMe is to incorporate the rounding feed as an input, which will affect the saturation state. Other constraints that need to be considered include crop rotation, land rehabilitation practices and legislative constraints. The FSDMe could also be converted to an iterative method to acknowledge dynamic changes within the enterprise context, such as labour strikes and climate conditions, as well as disasters, such as veld fires and droughts.

Design science research acknowledges that additional research cycles will increase the rigour of the artefact, i.e. the FSDMe, as well as the utility of the accompanying software application that provides a user-friendly interface to the user of the FSDMe.

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Authors' contributions

E.H. was a co-designer of the FSDMe and applied the FSDMe to a livestock farm. A.L. was one of the initial designers of the FSDMe, critically evaluated the extensions to the original method, and contributed towards the development of the FSDMe. M.d.V. coordinated the project and ensured that the participants adhered to Offerman et al.'s¹⁰ guidelines for good method design.

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