Agricultural Research Organization (ARO) Israel

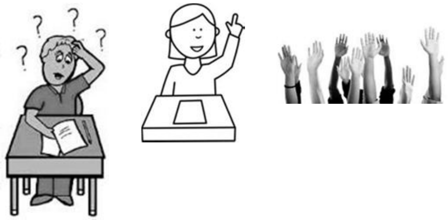
Agricultural Engineering Institution

Simulation optimization in agriculture: methodology and case studies'.

Ilan Halachmi
ARO, The Volcani Centre, Bet Dagan. Israel

EURO Summer Institute 2014
OR in Agriculture and Forest Management
Lleida, Catalonia (Spain)

Please ask during the presentation



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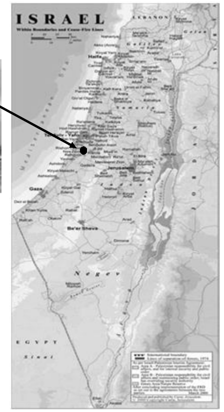


The Volcani Centre

Agricultural Research Organization (ARO)

Israel

Dr. Ilan Halachmi . Halachmi@volcani.agri.gov.il

Simulating livestock systems

- **Study the animal behaviour**
- **Simulation model building**
- **Model verification and validation**
- **RSM – Regression - Optimization**
- **Work with the model, meetings, discussions**
- **Conclusions, reporting, documentation**

Topic of this course

- **Simulation optimization– needs and theory**
  - The paradox
  - The solution
- **Case studies**
  - Milking robots
  - Aquaculture
  - Animal behavior sensors EU projects

Theory

Practical implementation

- **This lecture does not include:**
  - How to build a credible simulation model
  - Model validation
  - I assume your model is well validated

Theory

Practical implementation

Overview of a Simulation Study

- Understand the system
- Be clear about the goals
- Formulate the model representation
- Translate into modeling software
- Verify "program"
- Validate model
- Design experiments
- Make runs
- Optimization
- Analyze, get insight, document results

Advantages of (simulation) models

Study the model instead of the real system…

- **usually much easier, faster, cheaper, safer**

Can try wide-ranging ideas with the model

Simulating living animals:

- **Allows the isolation of a single parameter,**
- **Any number of repetitions, 100% repeatability**

The real power of Simulation

- **Studying complex systems where analytical methods fail**
- **Allows system variability in modeling**

Advantages of modelling

Same technology; for both fish and cow

- **Quantify the animal behaviour**
- **Build simulation model**
- **Work with the model**

The Bad News

The main limitation of simulation lies in its heuristic character:

- **simulation responses are observed only for the selected input combinations, i.e.,**
- **there is no proof of the optimality of the solution.**

The solution (1)

- :
- Given a validated model
- Design experiments DOE
- Response surface methodology (RSM)
  - **Fitting polynomial function via Multiple Regression**
- Optimization
- Simulation runs: fine tuning grid around the optimum
- Meetings in the farm, analyze, get insight, document results

The solution (2)

- the first step is to select the combination of parameters that is to be simulated in simulation experiments.
- In the simulation literature, this phase is called "design of experiment," or DOE (Banks, 1998).

Aquaculture examples

- Sde Elihu farm (2004-2005):
  - B.Sc. Shay Tabibian, M.Sc. Michal Yanay, Prof. Caspi
  - M.Sc. Simon (Prof. Zaslavski
- Sdey Troumot farm (2005):
  - B.Sc. Dana Josef,
  - B.Sc. Elik Stoleer, Prof. Edan
- Kazerin farm (2005-2006):
  - B.Sc. Maya Birenbuim,
  - B.Sc. Einav Levanoni, Prof. Edan
- Eilat (2005-2006):
  - B.Sc. Nitzan Youdan,
  - B.Sc. Itay Naous, Prof. Edan
- Ein Hamiphratz farm (2010-):
  - B.Sc. Moshe Ben soshan
  - B.Sc. Yoni Sion
- Asdod farm (2010-):
  - B.Sc. Maya Taranto.
- Hazorea Aquatics farm (2006-):
  - M.Sc. Alon Peled.
  - M.Sc. Hadas Lugasi

Dr. Ilan Halachmi; halachmi@volcani.agri.gov.il

Re-circulating Aquaculture Systems (RAS) – edible fish

Eilat – Ardag

Example, Sde Eliho aquaculture farm

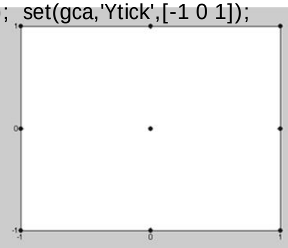
"… 448,000 possible input combinations. Using DOE, the number of simulation runs needed was set to 3,880".

Halachmi et al.,(2005) Aquaculture Engineering 32: 443–464

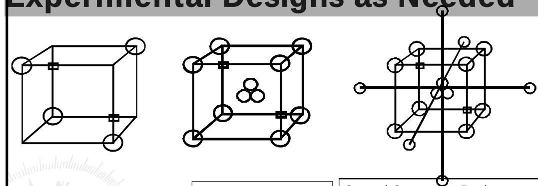
D-Optimal Designs

Matlab implementation

```
settings=cordexch(2,9,'q'),
  h=plot(settings(:,1),settings(:,2),'.');
  set(gca,'Xtick',[-1 0 1]);  set(gca,'Ytick',[-1 0 1]);
  set(h,'Markersize',20);
```



Sequential Assembly of Experimental Designs as Needed

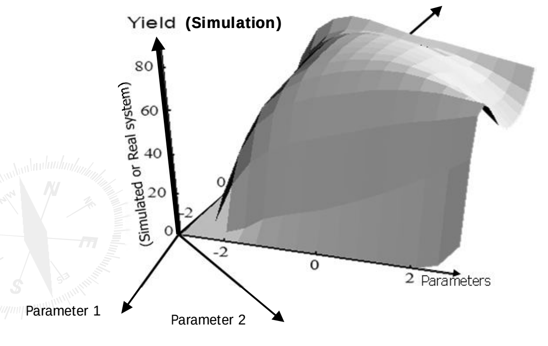


Fractional Factorial
- Linear model

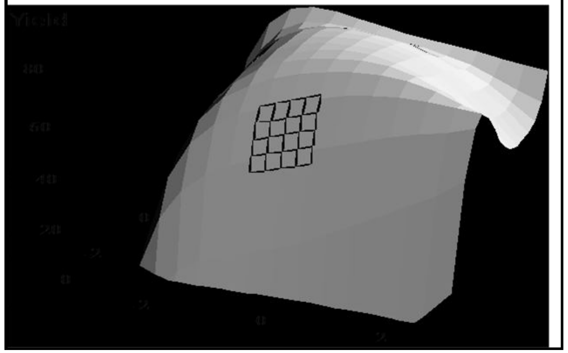
Full Factorial w/Center points
- Main effects
- Interactions
- Curvature check

Central Composite Design
- Full quadratic model

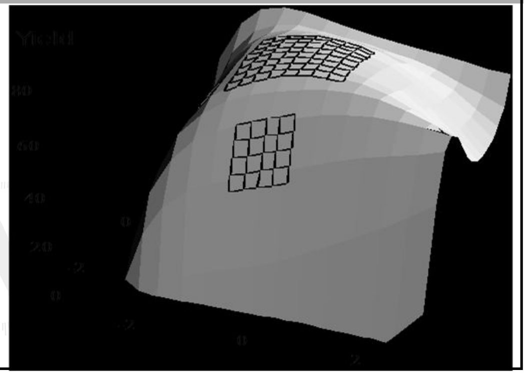
Response Surface Methodology (RSM)



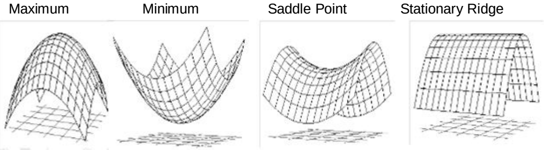
First Order Strategy



Second Order Strategy



Quadratic Models can only take certain forms



Results From First Factorial Design

Run	Factors in original units		Factors in coded units		Response
	Time (min.)	Temp. (°C)			Yield (gms)
	x_1	x_2	x_1	x_2	y
1	70	127.5	–	–	54.3
2	80	127.5	+	–	60.3
3	70	132.5	–	+	64.6
4	80	132.5	+	+	68.0
5	75	130.0	0	0	60.3
6	75	130.0	0	0	64.3
7	75	130.0	0	0	62.3

Fit the First Order Model

$$\hat{y} = 62.0 + 2.35x_1 + 4.5x_2$$

Must Use Regression to find the Predictive Equation

The Quadratic Model in Original units

$$\hat{y} = -3977 + 17.86 * time + 45.00 * temp$$
$$-0.0975 * time * temp - 0.0215 * time^2 - 0.1247 * temp^2$$

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RSM – Example II – 4th step – goal function

The yearly profit in the model is given by:

$$P = p \times T - f \times F \times \text{iBW} - f_c \times T \times f_f - o \times T - E - L - tr \times T - i - w \quad (8)$$

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RSM – Example II – step 5 - constraints

wish to maximize yearly profit (P from Eq. (8) above):

$$\max. P \quad (9)$$

subjected to the following constraints:

Stocking density in phase 1 < 55 kg m^{-3}	(Constraint 1)
Stocking density in phase 2 < 65 kg m^{-3}	(Constraint 2)
3500 < batch size < 7000	(Constraints 3 and 4)
35 g < initial body weight < 80 g	(Constraints 5 and 6)
2.4 g/day < weight gain in phase 1 < 2.9 g/day	(Constraints 7 and 8)
10 < number of small or large tanks < 14	(Constraints 9 and 10)
17 m^3 < small tank volume < 34 m^3	(Constraints 11 and 12)
34 m^3 < large tank volume < 40 m^3	(Constraints 13 and 14)

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The solution (3)

- Equation 2 is a convex function, and consequently Kuhn-Tucker conditions are necessary and sufficient for global optimality.
- Matlab solves this LP problem by a projection method, which is a variation of the well-known Simplex method (Coleman et al., 1999).

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Simulation results

Optimal Solution	Existing Situation	Parameter
160 ton	70 ton	Yearly turnover
494K $	-120K $	Yearly Profit/loss

Dr. Ilan Halachmi; halachmi@volcani.agri.gov.il

Recommendation

(valid to Sde Eliahu's RAS)

- **To split one large tank into two small tanks**
- **Size grading frequency – once per 4-5 days**
- **Size grading criteria - 450 g**
- **Batch size 3500-3800 fish, depend on the size grading criteria**

Dr. Ilan Halachmi;
halachmi@volcani.agri.gov.il

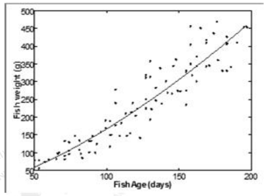
The interesting reader

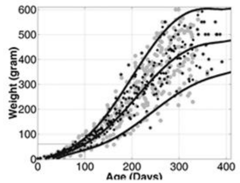
Halachmi, I. (2007) Biomass management in re-circulating aquaculture systems using queuing networks. ***Aquaculture***, 262(514-520.

Halachmi, I. (2006) Systems engineering for ornamental fish production in a recirculating aquaculture system ***Aquaculture***, 259(1-4), 300-314.

Halachmi, I., Simon, Y., Guetta, R. & Hallerman, E. M. (2005) A novel computer simulation model for design and management of recirculating aquaculture systems. ***Aquacultural Engineering***, 32(3-4), 443–464.

COMPLEXITY: FISH GROWTH FUNCTIONS





$$\text{Fish body weight (gram)} = 0.175 \times \text{age}^{1.49}$$

$$\text{Fish growth rate (gram/day)} = 0.2607 \times \text{age}^{0.49}$$

Ref: Halachmi et al.,2005.

FISH GROWTH FACTORS

Y = Fish growth rate g/day
X1 = Final size
X2 = Initial size
X3 = Density, handling
X4 = Feeding, water, etc
X5 = Season
X6 = <u>Mortality ?</u>

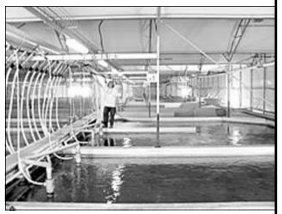
Factor cross correlation

	y	X(1)	X(2)	X(3)	X(4)	X(5)	X(6)
y	1	0.63974	0.14065	-0.59608	-0.48958	0.34183	-0.42752
X(1)	0.63974	1	0.45428	-0.60293	0.13943	0.27026	-0.31938
X(2)	0.14065	0.45428	1	-0.25719	-0.33108	0.39009	-0.23109
X(3)	-0.59608	-0.60293	-0.25719	1	0.15095	-0.46876	0.29387
X(4)	-0.48958	0.13943	-0.33108	0.15095	1	-0.3642	0.29984
X(5)	0.34183	0.27026	0.39009	-0.46876	-0.3642	1	-0.41798
X(6)	-0.42752	-0.31938	-0.23109	0.29387	0.29984	-0.41798	1

Fish growth
$$Y = 2.0403 + 0.0072985X_1 + \ldots + 0.0078129X_2 + 0.01439X_4$$

Ref: Halachmi et al.,2005.

Re-circulating Aquaculture Systems (RAS) – <u>edible fish</u>

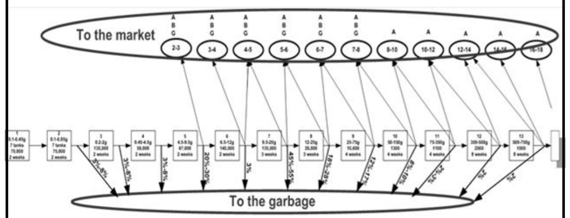


<u>One single product</u> – edible fish – 400 gram Seabream / Seabass / Grouper

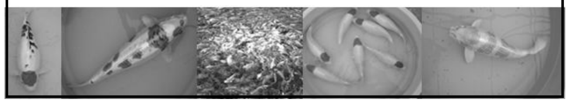
Further COMPLEXITY: Ornamental fish

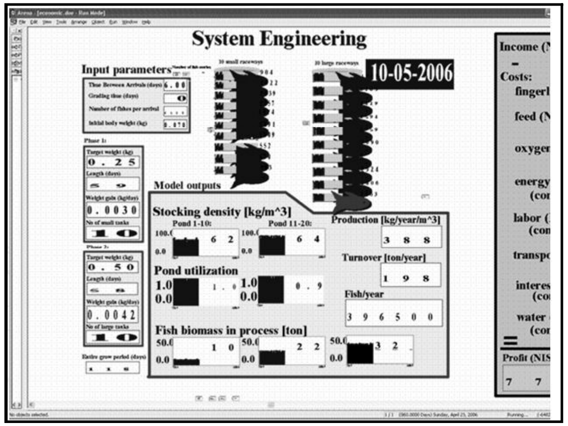
Many products from one single batch

NUMEROUS PRODUCTS

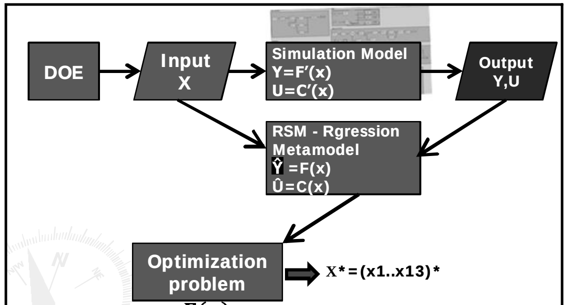


Ref: Halachmi et al.,2006





► The work of Hadas



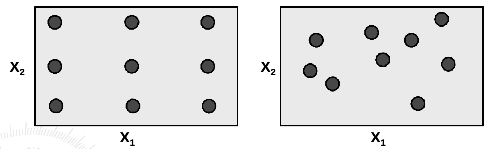
$$\max F(x)$$
$$s.t.\quad C(x) < Max\ Biomass$$

$$F(x^*) \overset{?}{=} F'(x^*)$$

Decision Variables

x(1)	Time Interval(days)	Time between batches
x(2)	Batch size\Number of fish per year	Batch size: number of fish in batch. A batch includes fish at the size of 0-2" (weight ~0.1) - input for the simulation. Number of fish per year: (365/time interval)*Batch size. Is the input for the regression, in order to reduce dependence between factors. The range is for the number of fish per year.
x(3)	Growth Rate	Factor. Value of 1 represents the current growth rate.
x(13)	Sales Factor	Factor. Value of 1 represents the current growth rate.
x(4)	Next Stage4	The percentage of fish at stage 4 that continues to the next growing stage (5). (1-next stage4) is the percentage that is going to be sale. Fish under stage 4 are not for sale.
x(5)	Next Stage5	The percentage of fish at stage 5 that continues to the next growing stage (6).
x(6)	Next Stage6	The percentage of fish at stage 6 that continues to the next growing stage (7).
x(7)	Next Stage7	The percentage of fish at stage 7 that continues to the next growing stage (8).
x(8)	Next Stage8	The percentage of fish at stage 8 that continues to the next growing stage (9).
x(9)	Next Stage9	The percentage of fish at stage 9 that continues to the next growing stage (10).

DOE Method



Classic

2^k, 2^{k-1}

Space-filling

simple random assignment, uniformly distributed in the variables range.

The Optimization Problem

► **The Goal: maximum annual profit**

$$\text{Max } F(x)$$
$$s.t.$$
$$14 \le x_1 \le 71$$
$$1M \le x_2 \le 5M$$
$$1 \le x_3 \le 2$$
$$1 \le x_{13} \le 4$$
$$0.001 \le x_4, \ldots, x_{12} \le 0.9$$
$$C(x) \le 28.75$$

$$F(x) = \beta_0 + \sum_{i=1}^{13} \beta_i x_i + \sum_{i=1}^{13} \sum_{i \neq i'} \beta_{ii'} x_i x_{i'} + \sum_{i=1}^{13} \beta_{ii} x_i^2$$

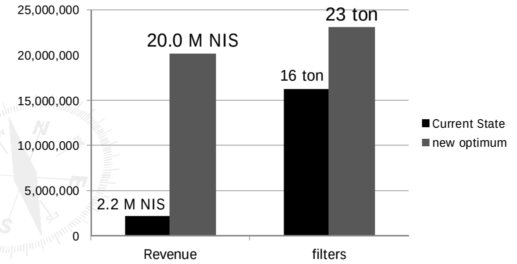
$$C(x) = \alpha_0 + \sum_{i=1}^{13} \alpha_i x_i + \sum_{i=1}^{13} \sum_{i \neq i'} \alpha_{ii'} x_i x_{i'} + \sum_{i=1}^{13} \alpha_{ii} x_i^2$$

Results

	All	Met filter constraints
# of scenarios	25,530	1417
R^2	0.652	0.852
Explanatory Variables	8	11
G′(X*)	30.26 M	20.8 M
Simulation (X*)	9.8 M	19.8
The gap: (RSM-Simulation)	21 M NIS	1 M NIS

The optimal solution

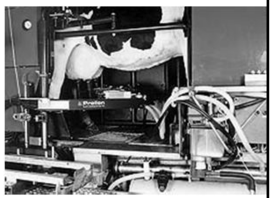
The 5 years revenue in the recommended policy is multiplied by ~10



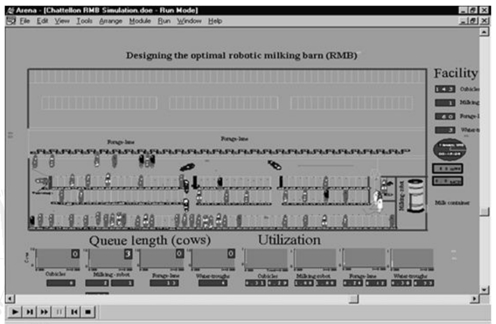
Cows examples

- **Robotic milking**
- **A mega dairy in India**
- **Automatic Lameness detection**
- **Body condition scoring**

Robotic milking



Milking Robots



Milking Robots

3. Halachmi I., Metz J.H.M., Maltz E., Dijkhuizen A.A., and Speelman L. (2000). Designing the optimal robotic barn, Part 1: **quantifying facility usage**, . Journal of Agricultural Engineering Research, 2000. 76: p. 37-49.

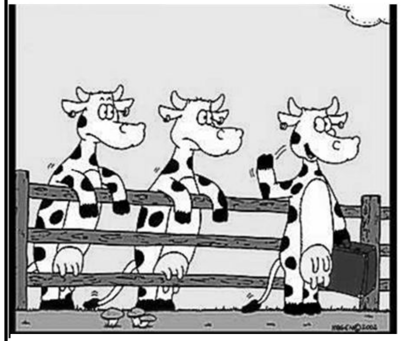
4. Halachmi I. (2000). Designing the optimal robotic barn, Part 2: **Behaviour-based simulation**. Journal of Agricultural Engineering Research, 2000. 77(1): p. 67-79.

8. Halachmi et al. 2002. **Optimal** Facility Allocation in a Robotic Milking Barn The Transactions of the ASAE 45(5): 1539-1546,

5 Halachmi I., Adan I.J.B.F., van der Wal J., Heesterbeek J.A.P., and van Beek P. (2000). The design of robotic dairy barns using **closed queuing networks**. European Journal of Operational Research 124(3): p. 437-446

7 Halachmi I., Dzidic A., Metz J.H.M., Speelman L., Dijkhuizen A.A., Kleijnen J.P.C. (2001). **Validation** of simulation model for robotic milking barn design: case study. European Journal of Operational Research, 134(3): p. 677-688.

13 Halachmi I. (2004). Designing the Automatic Milking Farm in a Hot Climate. Journal of Dairy Science, 2004. 87(3): p. 764-775. **8 Application in the farms**



So long losers !
I'm off to India to live like a Goddess…

A mega dairy in India – introduction & summery

- Economic and environmental pressures are guiding intensive milk production to large farms located in the Far East.
- The design and management of large-scale dairy farms require OR tools.
- A combined model:
  - queuing-network, robust 6σ design,
  - simulation and optimization

  was developed
- Design criteria were:
  - 10,000 cows in milking,
  - intensive farming with maximized animal welfare,
  - year-round indoors, no grazing, open cowsheds, dry manure bedding, no cubicle housing, maximizing cow resting time and worker convenience.

    All design criteria were met.
- We modeled eight farming aspects: cow traffic, milking parlors, vet treatment, manure handling, cow cooling, feed-center operation, workers' transportation and a problematic junction, and their interrelations.

Project Aim

Design a mega dairy

- ► 10,000 cows in milking
- ► Three rotary milking parlors
- ► Two veterinary hospitals
- ► One animal-feed center
- ► Cow-manure handling & biogas production
- ► Cow cooling centers
- ► Calves, heifers, replacement
- ► Workers' traffic and facilities

A mega dairy subsystems

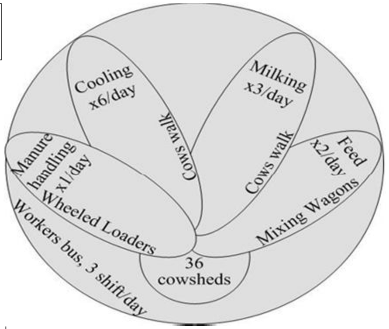
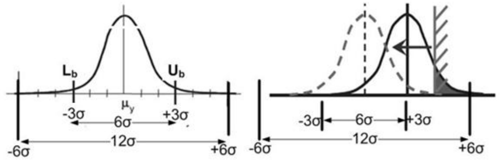


Figure 1. The mega dairy's five traffic circles

Design tool 1. Robust 6σ design

The under-study farm milks 290*12*3*365*3 = 11,431,800 milkings per a year.



standard deviation	Percent variation (%)	Missed milkings per year (no sigma shift)	Missed milkings per year (1.5σ shift)
±1σ	68.26	3628453	7975966
±3σ	99.73	<u>30865</u>	<u>763678</u>
±4σ	99.99	720	70877
±5σ	99.9999	6.5	2664
±6σ	99.999999	0.02	<u>39</u>

Design tool 2. closed queuing network

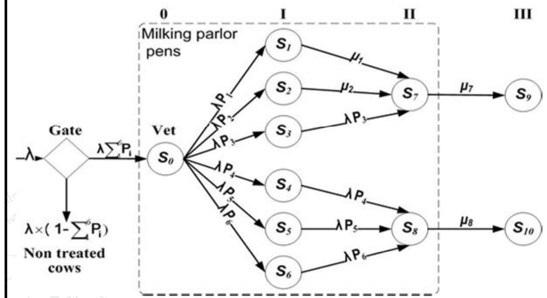
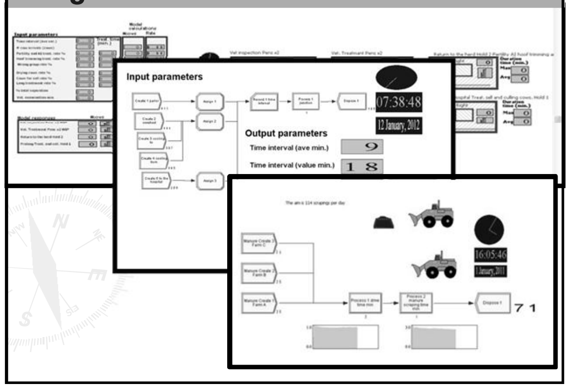


Figure 6. The flow of the cows throughout the treatments at the parlor's pens

Design tool 3. Simulation model



Model Validation

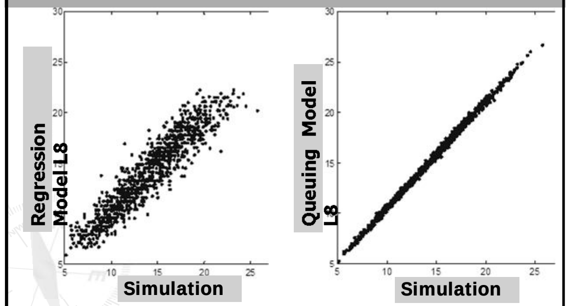


Figure 7. Validation – queuing vs. regression models.

Design tool 4. Optimization

A deterministic design problem:		A probabilistic design problem:	
Minimizes:	$F(\mu_y(X))$	Minimizes:	$F(\mu_y(X), \sigma_y(X))$
subject to:	$gi(\mu_y(X)) \le 0$	subject to:	$gi(\mu_y(X), \sigma_y(X)) \le 0$
$X_L \le \mu_X \le X_U$.		$X_L + n\sigma X \le \mu X \le X_U - n\sigma X$	

$\mu_y - n\sigma_y \ge$ Lower specification limit

$\mu_y + n\sigma_y \le$ Upper specification limit

n=6

The complexity

- several facilities making up a large farm
- mutual interaction
- numerous animal-related parameters
- number of multidisciplinary fields.

Systems engineering

- Regular design – each facility separately
- Static design (Excel) and simulation
- **- no proof of optimum solution**

Design all components as one single system

- animal friendly
- environment friendly
- convenient for humans
- economically feasible
- **Social aspects - local community**
- sustainability

Simulation & Optimization

A mega dairy subsystems

Seven simulation models were built:

- Milking parlor cow flow (model 1)
- In-parlor treatment cow flow (model 2)
- Cow traffic to the milking parlor and cooling sheds (model 3)
- Junction flow near the milking parlor (model 4)
- Manure scraping (flow?) (model 5)
- Feed-distribution flow (model 6)
- Worker traffic flow (model 7)

A mega dairy as a one single system

In this project, the model comprises

- ▸ **Optimization - maximizing capacity of each facility**
- ▸ **Queuing network links all the facilities into one single system**
- ▸ **Reliability – Quality over Time**
- ▸ **Robust (6 sigma) design**

A mega dairy in India - results

Farming area 1. Milking parlor

Based on the model, the decision were:

- ►80-stalls rotary parlor
- ►Rotary speed 7.5 sec / cow

A mega dairy in India - results

Farming area 2. Cow treatment

Based on the model, the decision were:

- ► **102 stalls for fast treatments in the parlor after milking: fertility, hooves, lameness, drying**
- ► **Other treatments – send the cow to the hospital**
- ► **Queue length :**

"I tried looking through rose-colored glasses, but that just made it worse."

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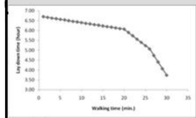
Farming area 3. Cow traffic

Based on the model, the decision were:

- ► **the walking time to and from the parlor should not exceed 20 min**
- ► **Otherwise the natural lying time is suppressed**
- ► **Cow's Time-Budget**
- ► **Walking distance and lane width were design**



The influence of walking time on the availability of lie down time during one 8-h shift with milking

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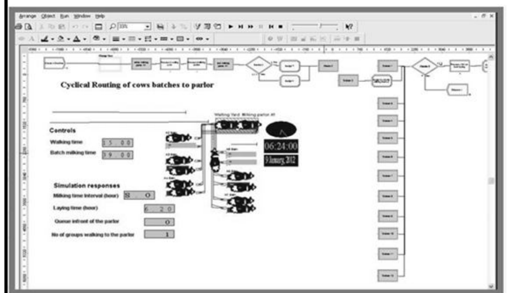
Farming area 3. Cow traffic



Cow traffic simulation program objects and user interface; the influence of walking time on the availability of cow reclining time

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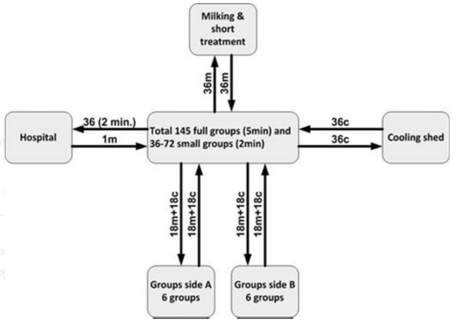
Farming area 3. The Junction



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Farming area 3. The Junction

Model suggests:

- ► **Junction crossing time**
- ► **10 min. or less from the parlor**
- ► **5 min. or less from the cooling shed.**
- ► **Otherwise – the successive group is being delayed**
- ► **Consequently, a 80m buffer was designed and the junction was relocated accordingly.**