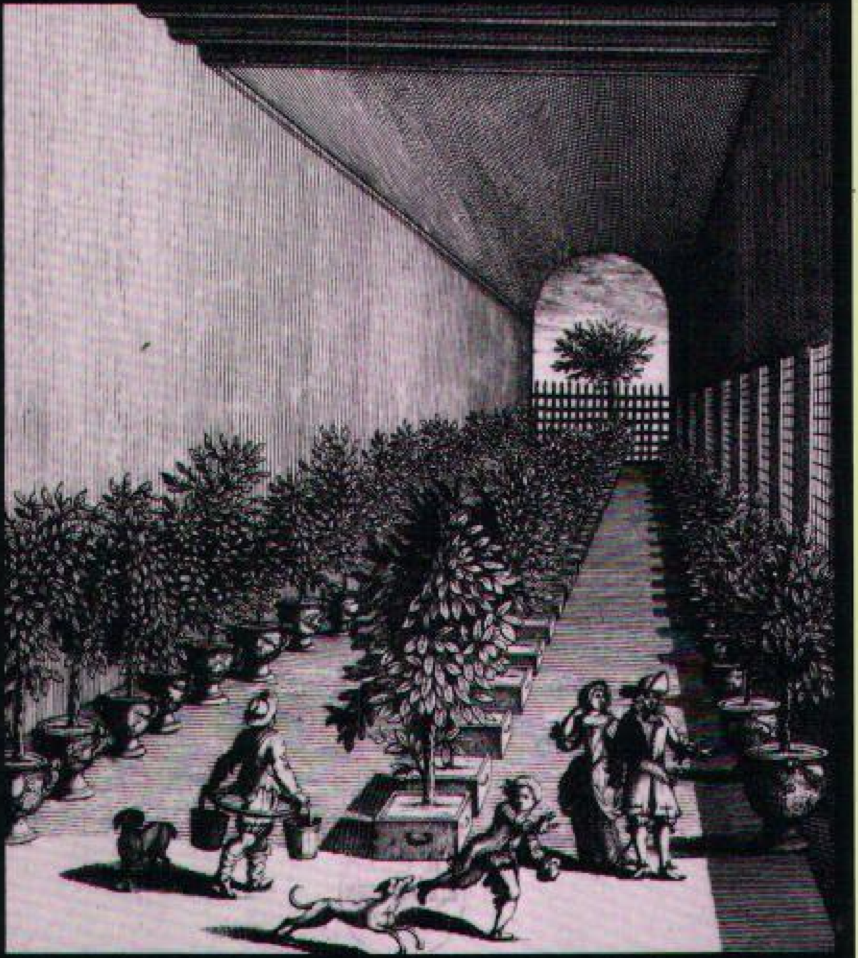
Operational Management in Pot Plant Production



K.J. Leutscher

Stellingen

1. Operationeel management gebaseerd op voortgangsbewaking en tussentijdse aanpassing van het taktisch produktieplan heeft een positief effekt op het bedrijfsresultaat in de potplantenteelt.

   Dit proefschrift

2. Bij de evaluatie van mogelijke operationele managementstrategieën voor individuele bedrijven dient niet alleen rekening te worden gehouden met te verwachten economische effekten, maar ook met specifieke persoons- en bedrijfskenmerken.

   Dit proefschrift

3. Managementondersteunende modellen dienen veeleer indirekt te worden ingezet om het leerproces van de tuinder te bevorderen, dan voor het direkt oplossen van concrete problemen op individuele bedrijven.

   Dit proefschrift

4. Modeltheoretisch onderzoek, waarbij systeemanalyse en simulatie worden ingezet om kennis uit verschillende wetenschappelijke disciplines te combineren, is een krachtig instrument om het inzicht in complexe systemen te vergroten.

   Dit proefschrift

5. Economic success is unquestionable based on intelligent foresight, but it also frequently depends on unpredictable good fortune.

   Galbraith, J.K., 1994

   The world economy since the wars; a personal view

6. De introduktie van merkprodukten biedt de Nederlandse potplantenteelt een uitstekende mogelijkheid haar positie op de Europese markt te versterken.

Koelemeijer, K., Leutscher K.J. & Stroeken J.J.G.
Branding of horticultural products: an application to pot plants
Acta Horticulturae 340 (1994): 325-332

7. Omdat teelt menselijk handelen impliceert, dient het aandachtsveld van de produktie-ecoloog zich niet te beperken tot het gedrag van planten en dieren.

8. Bij de maatschappelijke toepassing van wetenschappelijke resultaten verkregen met modellen zijn de gehanteerde uitgangspunten en aannamen tenminste zo belangrijk als de verkregen resultaten zelf.

9. Bij de calibratie van gewasgroeimodellen dient voor ogen te worden gehouden dat meetgegevens ook slechts een representatie van de werkelijkheid zijn.

10. Mondigheid van burgers wordt in het algemeen overschat als gevolg van het feit dat men weinig 'onmondige burgers' hoort.

11. Historisch besef verruimt een vooruitziende blik.

Stellingen behorende bij het proefschrift:
'Operational management in pot plant production'

K.J. Leutscher
Wageningen, 31 oktober 1995

OPERATIONAL MANAGEMENT
IN
POT PLANT PRODUCTION

(Operationeel management in de potplantenteelt)

Promotoren: Dr. ir. H. Challa
hoogleraar in de tuinbouwplantenteelt,
met bijzonder aandacht voor beschermde teelten

Dr. ir. J.A. Renkema
hoogleraar in de agrarische bedrijfseconomie

OPERATIONAL MANAGEMENT
IN
POT PLANT PRODUCTION

K.J. LEUTSCHER

Proefschrift
ter verkrijging van de graad van doctor
in de landbouw- en milieuwetenschappen
op gezag van de rector magnificus,
dr. C.M. Karssen,
in het openbaar te verdedigen
op dinsdag 31 oktober 1995
des namiddags te vier uur in de Aula
van de Landbouwuniversiteit te Wageningen.

Front page illustration: *Winter garden (i.e. orangery) of Leiden University Hortus Botanicus*

J. Commelyn , 1676

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ABSTRACT

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Operational management in pot plant production was investigated by means of system analysis and simulation. A theoretical framework for operational decision-making consisted of elaboration decisions, progress decisions, and adoption decisions. This framework was incorporated in a pot plant nursery model, which simulated the implementation of a given tactical production plan under uncertainty. In this model, crop growth as well as price formation (of the foliage plant *Schefflera arboricola* 'Compacta') were affected by randomly simulated exogenous conditions, which resulted in plant sizes and plant prices deviating from planning premises. Operational decision-making related to the adaptation of cultivation-schedules (and delivery patterns) in order to restore compatibility between plan and reality.

Regression metamodelling was applied to analyze simulations results with respect to differences in annual net farm income due to operational decision-making, tactical planning, price variability, and the grower's attitude to operational price risk. All differences could be explained by individual decision events triggered by the strategy of operational management applied in the particular simulation.

In conclusion, the applied methodology was successful in exploring the opportunities for operational management in pot plant production based on a rather normative approach and integrating theory from various scientific disciplines. Furthermore, simulation experimentation showed significant impact of operational management on the nursery's performance. Hence, the present study indicates several opportunities for beneficial support of operational management on pot plant nurseries.

Key words: operational management, simulation, decision-making under risk, pot plant production, *Schefflera arboricola*, crop growth modelling, price risk modelling, regression metamodelling.

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CONTENTS

PART I - THEORETICAL FRAMEWORK

PART II - SIMULATION MODELLING

PART III - SIMULATION EXPERIMENTS

PART IV - GENERAL DISCUSSION

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LIST OF USED SYMBOLS

Dfl.	Dutch currency ('gulden'): 1 Dfl. = 100 cts. ≈ 0.63 $

Factors of the pot plant nursery model:

E_m	Scenario of exogenous conditions as replication of system variants with $E_i \in \{E_1,..,E_{25}\}$.
P_i	Tactical production plan of system variant i with $P_i \in \{P_1,P_2,P_3\}$.
R_i	The attitude to operational price risk of system variant i with $R_i \in \{R_1,..,R_4\}$.
S_i	Strategie of operational management of system variant i with $S_i \in \{S_1,..,S_5\}$.
V_i	Price variability of system variant i with $V_i \in \{V_1,V_2,V_3\}$.

Annual output variables of the pot plant nursery model:

CIV_{im}	Annual change in inventory value of system variant i under scenario of exogenous conditions E_m (Dfl. m^{-2} $year^{-1}$).
GE_{im}	Annual organizational greenhouse area utilization efficiency of system variant i under scenario of exogenous conditions E_m.
LE_{im}	Labour utilization efficiency of system variant i under scenario of exogenous conditions E_m.
NFI_{im}	Annual net farm income of system variant i under scenario of exogenous conditions E_m (Dfl. m^{-2} $year^{-1}$).
PRP_{im}	Annual weighted price reduction percentage of system variant i under scenario of exogenous conditions E_m.
TC_{im}	Annual total costs of system variant i under scenario of exogenous conditions E_m (Dfl. m^{-2} $year^{-1}$).
TR_{im}	Annual total returns of system variant i under scenario of exogenous conditions E_m (Dfl. m^{-2} $year^{-1}$).

The crop growth model:

CVF	Conversion factor.
DAYL	Daylength (h day^{-1}).
DSR	Daily sum of global radiation (Wh m^{-2} day^{-1}).
EC	Extinction coefficient.
FLV_λ	Fraction of the total weight increase in the leaves in the developmental stage λ.
GLV	Weight increase of the leaves (g m^{-2} day^{-1}).
GPHOT	Actual gross photosynthetic rate of the canopy (g m^{-2} day^{-1}).
GPHST	Gross photosynthetic rate of a closed canopy (g m^{-2} day^{-1}).
GWT	Weight increase of the total canopy (g m^{-2} day^{-1}).
LAI	Leaf area index.
MAINT	Maintenance respiration (g m^{-2} day^{-1}).
MAXPH	Gross photosynthetic rate of a saturated and closed canopy (g m^{-2} h^{-1}).
MC	Maintenance efficiency (g g^{-1} day^{-1}).
RSC	Radiation saturation coefficient (m^2 W^{-1}).
SLA_λ	Specific leaf area in the developmental stage λ (m^2 g^{-1}).
TWT	Total dry weight (g m^{-2}).
WLV	Weight of the leaves (g m^{-2}).

Price formation model:

$\underline{d}_{mw}$	Random incidental price deviation ratio in week w of scenario E_m.
$\underline{l}_m$	Random structural price deviation ratio in scenario E_m.
$\underline{Pa}_{mw}$	Random actual price in week w of scenario E_m (Dfl. plant^{-1}).
$\underline{Pd}_h$	Random price for delivery batch h (Dfl. plant^{-1}).
Pf_w	Tactical price forecast in week w (Dfl. plant^{-1}).
Pf^{*}_{mw}	Operational price forecast in week w of scenario E_m (Dfl. plant^{-1}).
$\underline{PRR}_h$	Random price reduction ratio of delivery batch h.
PW_{bw}	Plant weight of batch b in week w (g plant^{-1}).
W^{*}	Optimal crop weight for delivery (g plant^{-1}).
W^{-}	Lower transitional crop weight for price reduction (g plant^{-1}).
W^{+}	Higher transitional crop weight for price reduction (g plant^{-1}).

Model of nursery accounting:

Ga_w	Allocated greenhouse area in week w (m^2).
Ge_w	Weekly organizational greenhouse area utilization efficiency.
Gn	Net greenhouse area (m^2).
La_w	Allocated regular labour in week w (h).
Le_w	Weekly labour utilization efficiency.
Lh_w	Extra hired labour in week w (h).
LR_h	Loss of return due to price reduction for delivery batch h (Dfl.).
Lr_w	Available regular labour in week w (h).
n_h	Number of plants of delivery batch h.
Rd_h	Return of delivery batch h (Dfl.).

Model for the evaluation of the final system state:

cC_{bS}	Current costs of batch b under strategy of operational management S_i (Dfl.).
cR_{bS}	Current returns of batch b under strategy of operational management S_i (Dfl.).
CrG_w	Average costs of reallocation for greenhouse area in week w (Dfl. m^{-2}).
fC_{bS}	Future costs of batch b under strategy of operational management S_i (Dfl.).
fR_{bS}	Future returns of batch b under strategy of operational management S_i (Dfl.).
Gar_w	Additional greenhouse area requirement in week w (m^2).
Gsl_w	Slack of available greenhouse area in week w (m^2).
Lar_w	Additional labour requirement in week w (h).
Lsl_w	Slack of available labour in week w (h).
OG_{bw}	Greenhouse area occupied by batch b in week w (m^2).
PaG_w	Price of additional greenhouse area in week w if $Gar_w > Gsl_w$ (Dfl. m^{-2}).
PaL_w	Price of additional labour in week w if $Lar_w > Lsl_w$ (Dfl. h^{-1}).
PhL	Price of hired labour (Dfl. h^{-1}).
$PVEP_{bS}$	Present value of expected profit of batch b under strategy of operational management S_i (Dfl.).
RtG_b	Return to greenhouse area for batch b (Dfl.).
ψ_{FSS}	Value of the final system state (Dfl. m^{-2}).
ψ_{ISS}	Value of the initial system state (Dfl. m^{-2}).
$\psi(i.e.p.)_{bS}$	Value inclusive of expected profit of batch b under strategy of operational management S_i (Dfl.).
$\psi(e.e.p.)_{bS}$	Value exclusive of expected profit of batch b under strategy of operational management S_i (Dfl.).

Model of operational decision-making:

A_k	Set of alternatives for operational problem k.
A	General set of alternatives on the multi batch level of operational decision-making.
A^*	Set of currently optional alternatives on the multi batch level of operational decision-making.
AR_{act}	Additional requirement of limited resource c in week t of an alternative a.
EE_a	Expected economic effect of the alternative a (Dfl.).
OF_c	Objective function for limited resource of type c.
PS_{ct}	Projected slack of the limited resource c in week t according to the tactical production plan after adaptation.
RD_{ct}	Resource deficit of the limited resource c in week t after projection of the preliminary solution set on the current tactical production plan.
rE_{act}	Relevant effect of alternative a on constraint c in week t.
Sl_{ct}	Slack of the limited resource c in week t according to the current tactical production plan.
trE_{ac}	Total relevant effect of alternative a on constraint c.
Ω	Preliminary solution set with $\omega \in \{1,..,\Omega\}$.

Model for price risk attitude:

Ca	Additional costs of postponed delivery (Dfl.).
CE	Certainty equivalent (Dfl.).
nR	Net return (Dfl.).
r	Pratt-Arrow coefficient of absolute risk aversion ($Dfl.^{-1}$).
RP	Risk premium (Dfl.).
u(x)	Utility function for the quantity x.
τ	Risk tolerance (Dfl.).

Statistics:

CRN_j	Cumulative ranknumber of level j of the factor analyzed in the particular simulation experiment.
D_{ij}:	Dummy variable for system variant i representing factor level j.
$E(\underline{x})$	Expected value of random variable $\underline{x}$.
MAPE	Mean absolute percentage error.
$\max(\underline{x})$	Highest possible value of random variable $\underline{x}$.
$\min(\underline{x})$	Lowest possible value of random variable $\underline{x}$.
P	Critical probability level.
$P[Z_g]$	Probability of random event Z_g.
R^2	Coefficient of determination.
rn_{jm}	Ranknumber of level j of the factor analyzed in the particular simulation experiment and scenario of exogenous condition E_m.
β_j	Regression coefficient for factor level j.
χ	Random standard normal variable.
$\mu\{\underline{x}\}$	Mean of random variable $\underline{x}$.
$\sigma\{\underline{x}\}$	Standard error of random variable $\underline{x}$.
$\sigma^2\{\underline{x}\}$	Variance of random variable $\underline{x}$.

1

INTRODUCTION AND OVERVIEW

1.1 Introduction

This thesis deals with progress and adaptation of production plans implemented under uncertainty on pot plant nurseries. Pot plant production in Western Europe is characterized by a complex organization of labour and greenhouse area. Therefore, tactical production planning, i.e. planning before the start of the cultivation, is required. Actual conditions during implementation, however, may deviate from tactical planning premises. Hence, the progress of the implementation of a tactical production plan should be monitored and confirmed regularly. Moreover, if necessary, partial adjustment of the plan should be considered. In the present study, these decision-making activities, referred to as operational management, are analyzed in relation to nursery economics as well as cultivation aspects.

The advantage of operational management in addition to tactical planning is that the grower can respond to information which is only coming available during implementation. Hence, emerging undesired outcomes can perhaps be avoided. Moreover, the grower may take advantage of new opportunities. Thus, by adapting the tactical production plan during its implementation management performance may be improved. Besides this rather practical reason for the present study, the sequential conception of production management is also more in line with common practices in pot plant production.

Operational management in greenhouse horticulture is an uncommon subject of scientific investigation and is also hardly considered for management support. On the borderline between economics and horticulture, however, it closes the gap between long term planning and daily nursery practices. From an economic point of view both Renkema (1986) and Steffen (1989) argued in favour of more research on operational management. Moreover, with the development of crop growth models integration of economic and cultivation aspects of greenhouse horticultural production has become a challenge (Challa, 1988; Challa & Straten, 1993). Finally, rapid developments in computer science have opened new opportunities for computerized management support (Beulens, 1992; Huirne, 1990), although in (Dutch) greenhouse horticulture little has been achieved for the moment (Gollwitzer, 1991; NRLO, 1991).

Farm management

Decreasing profitability, environmental legislation and rapid changes in the marketing system have increased the urge for (farm) management of greenhouse nurseries. Farm management concerns the allocation of limited resources to a number of production activities in order to organize and operate an agricultural production enterprise in such a way as to attain the objectives of that organization (Buckett, 1988; Huirne, 1990; Kay, 1986; Makeham & Malcolm, 1993). Although as Giles & Stansfield (1990) put it *'management is management wherever it is practised'*, the distinction of farm management can be justified by the special characteristics of agricultural production. The organization of horticultural production in small-scale family enterprises leads (1) to a concentration of management in one person and (2) to a considerable influence of family social aspects on the management of the enterprise. Moreover, the typical physical and social environment in which horticultural production is imbedded (3) makes the production system rather dependent on uncertain exogenous conditions.

Because the grower in general can be regarded as an isolated manager, the context in which decisions are made is quite different from that of managers in larger company enterprises (Anthony, 1965; Anthony, 1988; Brown Andison, 1989; Framingham, 1989; Giles & Stansfield, 1990). This particular context of decision-making can be expected to affect management considerably.

The family has a great influence on the management of the farm or nursery (Boehlje & Eidman, 1984; Framingham, 1989). Recent studies on farm management styles and family lifestyles have lead to a better understanding of the relation between family and farm (Fairweather & Keating, 1994; Framingham, 1989; Olsson, 1988; Schubert Walker, 1989; Spaan & Ploeg, 1992). A simplified classification of farmers and farm management styles involves two types: (1) farmers, who regard the farm as a basis for their rural family lifestyle, and (2) farmers, who regard the farm as a source of income. Generally, these farm management styles are related to the business (and family) goals. Here, the word 'goal' is used interchangeably with the word 'objective'[1]. The distinction of these farm management styles may also serve as a handle in the discussion whether profit maximization may be regarded as the prime objective (Fairweather & Keating, 1994; Harling & Quail, 1990; Nix, 1987).

In comparison with other small-scale family operations, agricultural enterprises are surrounded by a relatively uncertain physical and social environment. Production is rather dependent on natural conditions and resources such as weather and soil. Moreover, Dutch greenhouse horticultural producers have to deal with highly fluctuating auction prices. In addition, the understanding of the managed production system is only limited. Because of these typical circumstances, growers have traditionally concentrated their management on crop growth related processes like greenhouse climate control, soil management and pest control.

Pot plant production

Differences in production characteristics between pot plants, cut flowers and vegetables impeded a general approach to greenhouse horticulture. The present study deals with pot plant production for three major reasons:

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[1] Keeney and Raiffa (1976) define objectives as indicators for the direction in which management should strive to do better and goals as clearly identifiable levels of achievement to strive toward, whereas Davis and Olson (1984) apply both terms exactly the opposite way.

1. Tactical planning research for greenhouse horticulture has been concentrated particularly on pot plant production (Annevelink, 1989; Basham & Hanan, 1983; Håkansson, 1991; Krafka *et al.*, 1989; Ludwig, 1991).

2. Because of its relatively high level of organizational complexity pot plant production was considered most challenging to analyse operational management opportunities.

3. By focusing on pot plant production the present study could be incorporated in a larger multidisciplinary research program 'Decision Support Systems in arable farming and horticulture' of Wageningen Agricultural University.

In the present study, <u>pot plant production</u> is defined as the production of plants with structural limited rooting medium, which are cultivated in greenhouses for their ornamental value, and which are traded and finally applied with pot and medium. Due to the ability to displace plants during cultivation pot plant production management is particularly focused on greenhouse area allocation (Annevelink, 1989; Basham & Hanan, 1983; Buchwald, 1987; Krafka *et al.*, 1989; Leutscher & Vogelezang, 1990). Greenhouse area can be utilized efficiently by starting cultivation at a high plant density and reducing plant density during cultivation depending on the increase of the size of the plants. High plant densities at the beginning of cultivation are not only possible because seedlings or cuttings are still small, but are also desirable for a favourable micro-climate. If, however, the size of the plants increases and plant density would not be reduced, plant growth and quality would be affected negatively. When the canopy attains full light interception, plant growth will reduce. Moreover, plant quality may be affected due to, for example, elongation of the stem and abscission of lower leaves. Therefore, the crop should be spaced to a lower plant density during cultivation.

Because of the dynamic greenhouse area requirement during their cultivation, pot plants are produced in batches. In the greenhouse various batches in different developmental stages are cultivated simultaneously. In the present study, a <u>pot plant batch</u> is defined as a lot of plants of the same species or cultivar potted at the same time and cultivated according to the same cultivation-schedule. A cultivation-schedule describes all cultivation actions that should be taken during cultivation in order to achieve the desired pot plant product. Thus, labour and greenhouse area requirements for a particular batch are defined by the cultivation-schedule. Moreover, the combination of many batches with different cultivation-schedules cultivated simultaneously leads to a complex organization in pot plant production.

1.2 Research objective and approach

The present study focuses on the operational decisions made by the grower as a manager during the implementation of a tactical production plan. Operational management is investigated within the context of an individual pot plant nursery and under the assumed presence of a tactical production plan, which is implemented under uncertain exogenous conditions. The general objective of the present study is:

> **exploration of opportunities to improve the performance of management on pot plant nurseries by operational decision-making.**

Here, the 'performance of management' refers to the degree in which management contributes to the achievement of the nursery's objectives. In this respect, profitability is a suitable criterion, although other criteria will also be taken into consideration.

The research approach in the present study involves system analysis and simulation modelling and consists of three consecutive steps:

1. Development of a conceptual framework for operational management as part of farm management and with reference to the pot plant production context.

2. Development of a model which simulates the implementation of a tactical production plan, operational decision-making, and the resulting economic nursery performance.

3. Assessment of operational management as conceived in the present study within the context of an individual pot plant nursery.

Since operational management particularly in pot plant production is a rather unfamiliar subject of study, it is necessary to conceptualize the process of operational management. Therefore, part I of the present thesis begins with a general analysis of management on pot plant nurseries (chapter 2). Farm management theory is analyzed (with special attention for decision-making under uncertainty) in order to describe the managerial context of operational decision-making. Furthermore, relevant aspects of pot plant production (in Western Europe) are discussed and important terms are clarified with definitions. Subsequently, in chapter 3, the conceptual framework for operational management in pot plant production is formulated.

In order to evaluate the formulated concept of operational management in a quantitative way experimentation one way or another is required. In chapter 4, the choice for simulation modelling is justified and general features of the simulation model, required in view of the purpose of the present study, are listed. The other chapters of part II provide a description of the simulation model. Chapter 5 outlines the simulation context. It describes the relevant features of the modelled pot plant nursery as well as the main characteristics of the formulated tactical production plans. In addition, chapter 6 describes the most important processes subject to uncertainty in pot plant production: (1) crop growth and (2) price formation. Moreover, this chapter is concluded with an assessment of the simulated uncertainty. In chapter 7, procedures for nursery organization and accounting included in the model are presented. Special attention is directed to the valuation of the final system state, since a fixed annual simulation-period is applied, whereas a pot plant producing nursery is usually a non-terminating system. Finally, chapter 8 outlines how the theoretical framework for operational management is incorporated in the model. Moreover, this chapter describes how the grower's attitude to operational price risk is taken into account in the model.

Simulation modelling enables extensive experimentation under various conditions without undesired disturbances (part III), which makes it rather suitable for exploratory objective of the present study. In chapter 9, the experimental design and the methods for the analysis of simulation results are discussed. Subsequently, the results of three simulation experiments are presented and discussed. Chapter 10 concentrates on the performance of the model, describing the effects of various strategies of operational management and various tactical production plans. Furthermore, chapter 11 concentrates on two sensitivity analyses, describing the effects of (1) various levels of price variability and (2) various levels of the grower's price risk attitude. In chapter 12, the operational management concept formulated in the present study is evaluated within the simulation context of the individual pot plant nursery. In this respect, (1) the formulated strategies of operational management are evaluated, (2) the economic impact of operational adaptations of tactical production plans is estimated, and (3) the frequency of complex operational adaptations of tactical production plans is analyzed.

Finally, the assessment of operational management as conceived in the present study is concluded with a general discussion (part IV). In chapter 13, the present research itself is evaluated. Subsequently, in chapter 14 general implications for practice as well as further research, and opportunities for computerized management support are discussed.

PART I

THEORETICAL FRAMEWORK

2

MANAGEMENT IN POT PLANT PRODUCTION

2.1 Introduction

A theoretical framework provides a basis for the relationships to be investigated and the abstractions regarded as legitimate within the problem area (Anthony, 1965; Rausser & Hochman, 1979). Before formulating such a concept, however, operational management should be placed in the context of farm management theory. Furthermore, relevant characteristics of pot plant production should be understood.

2.2 Farm management

2.2.1 Greenhouse nursery management

Traditionally, greenhouse nursery management is of a rather technical kind and relates to crop growth, greenhouse climate control, the application of current assets, and the maintenance and allocation of the capital assets (Hanan *et al.*, 1978; Langhans, 1983; Nelson, 1991). With recent developments in greenhouse horticulture, however, the grower should nowadays consider also the management of personnel (Buckett, 1988), information (Kay, 1986) and environmental aspects (Makeham & Malcolm, 1993; Olsson, 1988). Furthermore, marketing and financing are generally distinguished as special areas of management (Boehlje & Eidman, 1984; Buckett, 1988; Kay, 1986). Marketing relates to the external relations of the business, rather than to the internal business processes. Inputs for production are purchased and produced outputs are sold on the market. Traditionally, horticultural growers in the Netherlands are organized in co-operative auctions, which play an important role in the marketing of horticultural products. Nevertheless, growers decide which products when to deliver to the auction. In addition, financing concerns the acquisition and utilization of capital. Although the family provides a major input of business capital, additional capital is required for the short as well as the long term. In conclusion, greenhouse nursery management should be based on farm management theory in addition to technical horticultural knowledge.

2.2.2 Farm management theory

Although individual growers may all have their own way of managing the nursery, prescriptive models in farm management literature distinguish in general three main management functions: (1) planning, (2) implementation, and (3) control (Barnard & Nix, 1973; Boehlje & Eidman, 1984; Buckett, 1988; Huirne, 1990; Kay, 1986). In addition, Buckett (1988) distinguishes forecasting as a separate management function, which provides information about the uncertain environment of the enterprise for planning as well as control. In this respect, Barnard & Nix (1973) speak of compilation as the search for information in preparation for planning. Moreover, Giles & Stansfield (1990) as well as Wagner & Kuhlmann (1991) distinguish the definition of objectives (or goals) from planning. Furthermore, the management function of implementation is preceded by the decision to actually implement the plan (Giles & Stansfield, 1990; Wagner & Kuhlmann, 1991). Buckett (1988) also distinguishes recording as a separate management function, which links implementation and control. Finally, Wagner & Kuhlmann (1991) make a distinction between control and evaluation. In this respect, evaluation is executed after the implementation of the plan, whereas control is a continuous process during implementation. According to Anthony (1965), Barnard & Nix (1973), and Tricker (1976), however, control cannot properly be separated from planning. Control involves monitoring performance, diagnosing deviations from desired or expected performance, as well as planning and implementation of corrective actions (Koontz & O'Donnell, 1976; Tricker & Boland, 1982). Thus, regarding agricultural production as an ongoing activity the three main management functions make up a management cycle with implementation leading to control and new planning. Moreover, this cycle can be further specified by elaborating the main management functions to additional functions, like definition of objectives, forecasting, compilation, decision of actual implementation, recording and evaluation.

Apart from the distinction of management functions generally different levels of management are distinguished: (1) strategic management, (2) tactical management, and (3) operational management (Anthony, 1965; Anthony, 1988; Davis & Olson, 1984; Huirne, 1990; Tricker, 1976). Usually, management levels are classified by the nature of the decisions made during planning and control. Decisions may differ in aspects like planning horizon, frequency of decision-making, level of detail, and level of uncertainty (Anthony, 1988; Kay, 1986; Koontz & O'Donnell, 1976; Tricker, 1976). Anthony (1965) distinguishes strategic planning, management control and operational control. In later work of Anthony (1988) operational control is replaced by task control in order to put more emphasis on the immediate supervision of specific tasks. Other authors, like Davis & Olson (1984) and Huirne (1990) relate the levels of management particularly to planning. In this respect, strategic planning involves decisions with long term consequences such as investments in greenhouses and machinery; tactical planning involves decisions with medium term (generally one-year) consequences such as what crops when to produce during the production season; and operational planning involves decisions with short term consequences, such as whether to sell a crop now or next week. In comparison to Huirne (1990) and Davis & Olson (1984), Anthony (1965; 1988) emphasizes the importance of control including planning. In principle, however, both concepts are similar. Furthermore, the replacement of operational control by task control in Anthony (1988) corresponds with the distinction of a fourth level of management by Davis & Olson (1984): scheduling and dispatching. Moreover, other authors like Hurtubise (1984) and Lentz (1987) also distinguish a fourth level of management related to the immediate organization of the actual business processing.

In contrast, Wagner & Kuhlmann (1991) distinguish only two levels of management: structural optimization involving strategic and tactical planning, and process optimization, which relates to the implementation of strategic and tactical plans and involves operational and task management as a form of control. Ziggers (1993) applies a similar approach. The distinction of structural optimization and process optimization emphasizes the difference between management activities before and during the actual business process.

In conclusion, (farm) management concepts in literature, although perhaps appearing to be quite different, have many aspects in common. Apparent differences are particularly due to different purposes of the various concepts. Furthermore, operational management is driven and restricted by strategic and tactical plans. It concerns elaboration of higher order plans as well as control during implementation

2.3 Decision-making under uncertainty

2.3.1 Decision-making

From the prior discussion of literature it can be concluded that (farm) management involves a problem orientated decision-making activity (Giles & Stansfield, 1990; Kay, 1986). Koontz & O'Donnell (1976) prefer to use the word 'opportunity' instead of 'problem'. Other authors, like Boehlje & Eidman (1984) and Davis & Olson (1984) use the combination of 'opportunity or problem', whereas Turban (1990) applies the word 'problem' for a decision situation which may deal with trouble or with an opportunity. This last approach is also applied in the present study, since an opportunity leads to the problem of deciding whether to take advantage of the opportunity. Thus, in case of an occurring problem decision-making by the manager is initiated.

Simon (1960) formulated a classic model describing three phases of decision-making: (1) intelligence (in the military sense (Eilan, 1985)), (2) design, and (3) choice. This model has been extended with implementation (Kay, 1986; Sprague, 1989; Turban, 1990) and evaluation (Kay, 1986). Evaluation, however, is likely to overlap with the intelligence phase of a subsequent decision-making process when agricultural production is regarded as an ongoing activity. Hence, intelligence results in the definition of the current problem; design results in the decision basis[1] as formulated by Howard (1988); and choice ends up with a selected solution for the current problem, which is implemented.

In farm management literature decision-making is often regarded from a rather normative and mathematical point of view (Barnard & Nix, 1973; Boehlje & Eidman, 1984; Buckett, 1988; Kay, 1986). Decision-making, however, also in the farm management context strongly relates to human perception, attitude and cognition. Economic studies often assume rational behaviour, whereas adaptive behaviour employed in psychology, i.e. learning theories, appear to account for observed behaviour rather better (Cyert & March, 1963; Neave & Petersen, 1980; Simon, 1956). Moreover, optimizing techniques are applied to resolve so-called semi-structured problems[2] (Keen & Scott Morton, 1978), whereas the concept of bounded rationality and satisfying objectives indicates managers decide differently (Simon, 1956; Colin, 1990). Furthermore, most decision-making processes in farm management involve uncertainty. In this respect, Kahneman *et al.* (1982) show how uncertainty affects human perception and leads to judgemental biases. Moreover, Janis & Mann (1977) show how decision-making particularly under uncertainty is driven by motivational factors and can lead to psychological stress.

In conclusion, decision-making concepts to a large degree correspond with management concepts. Decision-making in an economic context can not be seen separately from psychological aspects. These psychological aspects concur with the idea of operational management as adaptive behaviour during implementation of strategic and tactical plans.

2.3.2 Risk and uncertainty

Farm management, for the most part, involves decision-making under risk or uncertainty (Barnard & Nix, 1973; Barry, 1984; Boehlje & Eidman,

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[1] Howard (1988) defines a decision basis as a set of optional alternatives, information about these alternatives, and an ordered set of preferences.

[2] Keen & Scott Morton (1978) define semi-structured problems as problems which can only partially be solved by means of formal (computerized) procedures.

1984; Castle *et al.*, 1987; Dent, 1975; Eldin & Milleville, 1989; Kay, 1986). Some authors make a theoretical distinction between risk and uncertainty. Risk refers to a situation in which all possible outcomes are known as well as their associated objective probabilities; uncertainty refers to a situation in which only a limited number of possible outcomes is known and in which objective probabilities are not available (Boehlje & Eidman, 1984; Davis & Olson, 1984; Eilan, 1985). In practice, however, the boundary between risk and uncertainty is largely a matter of degree (Barnard & Nix, 1973). Generally, the manager is able to determine the most likely and relevant possible outcomes and associate (objective or subjective) probabilities with these outcomes. Thus, decision-making under risk or uncertainty holds the middle between decision-making under deterministic conditions and decision-making under ambiguity (Eilan, 1985). Therefore, in the present study risk and uncertainty are applied interchangeably to refer to decision-making situations in which the grower has imperfect information about future events.

In principle, two types of risk can be distinguished in (farm) management: business risk and financial risk (Boehlje & Eidman, 1984; Makeham & Malcolm, 1993). Business risk involves the risk any business faces no matter how it is financed (Makeham & Malcolm, 1993). Financial risk is associated with the liquidity and solvency of the business (Boehlje & Eidman, 1984; Kay, 1986). With respect to business risk, generally a subdivision is made in production risk and price risk (Barnard & Nix, 1973; Boehlje & Eidman, 1984; Castle *et al.*, 1987; Kay, 1986). Production risk, in this respect, relates to uncontrolled and unforeseen variations of production inputs as well as production outputs.

In addition to the theoretical aspects of risk and uncertainty, the use of both words in everyday language should also be taken into consideration. Risk and uncertainty seem to emphasize different aspects of decision-making based on imperfect information. Risk is commonly associated with negative consequences, whereas uncertainty refers to a state of doubt about future events and choices. Thus, risk is generally tried to be avoided or reduced. For instance, production may be intensified resulting in a higher level of control, product diversification may be applied, insurances can be obtained, and sales can be spread or even contracted (Castle *et al.*, 1987; Kay, 1986). Uncertainty, on the other hand, generally leads to a search for more information, while maintaining flexibility towards the original problem (Castle *et al.*, 1987; Kingwell *et al.*, 1992).

In conclusion, perfect knowledge and information during strategic and tactical planning can practically never be obtained in agriculture. Hence, operational management is required as a form of adaptive behaviour in a context of bounded rationality. Therefore, the application of additional information in order to elaborate and adapt strategic and tactical plans during their implementation seems a promising area of research (Amir *et al.*, 1991; Amir *et al.*, 1993; Kingwell *et al.*, 1992).

2.4 Pot plant production

2.4.1 Cultivation in batches

Because of the special attention for greenhouse area allocation, pot plant cultivation-schedules are particularly related to actions affecting the greenhouse area occupation of a batch. Figure 2.1 shows the greenhouse area requirement and occupation resulting from the cultivation-schedule of an imaginary pot plant batch. After potting at t_0 the batch is spaced at the highest possible plant density with pots touching each other. With a constant number of plants the greenhouse area requirement of the batch gradually increases and after a while is about to exceed the occupied greenhouse area. At this moment (t_1) the batch is spaced to a lower plant density and the occupied greenhouse area increases abruptly. The new plant density after spacing allows the plants in the batch to grow further unhampered by negative effects of plant interaction. Subsequently, at t_2 the greenhouse area requirement is again about to exceed the occupied greenhouse area and the imaginary batch is spaced to a lower plant density for a second time. Theoretically, it is possible to fit the occupied greenhouse area to the greenhouse area requirement by increasing the number of spacing actions. Spacing, however, requires labour, while the effect in terms of non-occupied greenhouse area decreases with every next spacing action. On the other hand, other cultivation actions, like pinching and tying up plants, may be necessary and can be efficiently combined with spacing. Thus, to a certain extent greenhouse area can be substituted by spacing labour in pot plant production.

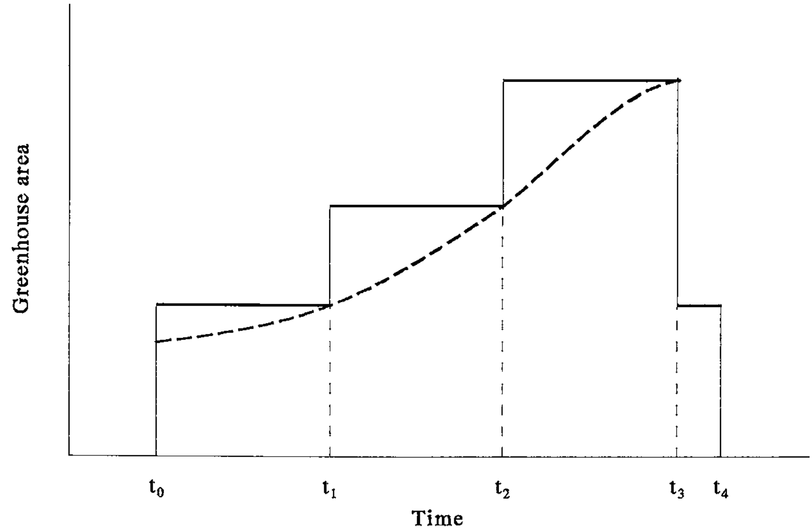

Figure 2.1 Representation of greenhouse area requirement (dotted line) and the occupied greenhouse area of an imaginary pot plant batch with potting at t_0, spacing twice at t_1 and t_2, partial delivery and re-spacing at t_3, and final delivery at t_4.

To the end of the cultivation the greenhouse area requirement of the pot plant batch may diminish as a result of delivery and shedding. Due to heterogeneity plants in a batch do not attain the required attributes for delivery simultaneously. Instead, sub-batches, i.e. delivery batches, are periodically selected from the original cultivation batch. Moreover, shedding of infected plants may also decrease the number of plants of a batch during cultivation. Hence, although the greenhouse area requirement of individual plants in the batch does not decrease, the greenhouse area requirement of the batch as a whole may decrease because of a reduction of the number of plants. The redundant greenhouse area, however, can generally not be reallocated directly, because marketable plants as well as infected plants are generally randomly distributed or clustered over the greenhouse area occupied by the particular batch. By re-spacing the remaining plants to the original plant density the occupied greenhouse area can be reduced. In figure 2.1, 60% of the plants is removed from the greenhouse at t_3. At the same time the remaining plants of the batch are re-spaced on 40% of the originally occupied greenhouse area. Due to the reduction of the number of plants the greenhouse area requirement also drops to 40% at t_3. From this moment greenhouse area requirement and greenhouse area occupation are equal, because of the asymptotic character of the greenhouse requirement curve. Finally, the remaining plants of the batch are removed from the greenhouse at t_4 and the cultivation of the batch is terminated.

The cultivation-schedule of a pot plant batch relates to cultivation and technical aspects as well as organizational and economic aspects. Moreover, it can be subdivided into cultivation-phases, which are characterized by a constant allocation[3] of greenhouse area. As follows from the presented definition of pot plant production, the purpose of cultivation is to produce plants with attributes which provide a certain ornamental and consequently monetary value. In the present study, the pot plant to be delivered at the end of the cultivation will be referred to as a product. Although standardization of product attributes is not formally elaborated yet in pot plant trading, there is to a certain extent general agreement on the product attributes which should be attained (Brons *et al.*, 1993). Hence, non-standard product attributes are expected to result in reduced prices as compared to standard product attributes. In the present study, the process of removing marketable pot plants from the greenhouse and dispatching them directly or indirectly to buying traders in return for a monetary compensation is referred to as delivery. The expressions 'selling' and 'marketing' are avoided, because they may suggest a more active role of the grower than actually necessary.

2.4.2 Production planning

On the nursery level production in batches results in a very complex organization. As pointed out, the greenhouse area allocated to individual batches varies during their cultivation. Moreover, labour and machine capacity requirements of individual batches vary also, since the application of these resources is particularly concentrated on the moments of potting,

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[3] Here, allocation of greenhouse area refers to the greenhouse area (planned to be) occupied by the batch.

(re-)spacing and delivery. In order to achieve an efficient allocation of these main resources tactical production planning was introduced in the beginning of the nineteen eighties (Bleijenberg, 1983). Because greenhouse area is generally considered the most valuable and rigid resource constraint on the pot plant nursery, tactical planning in pot plant production is particularly focused on greenhouse area allocation. Hence, a tactical production plan for a pot plant nursery is commonly presented as a greenhouse area-time diagram (figure 2.2).

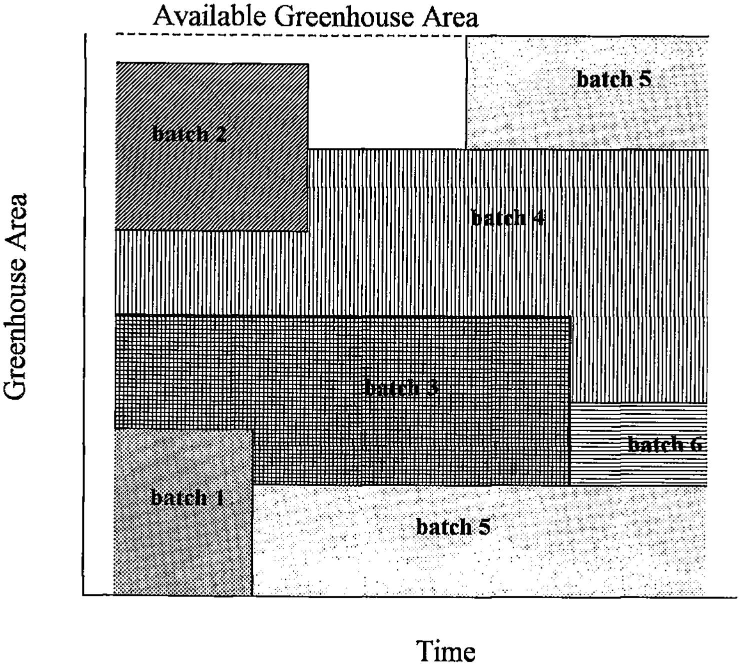

Figure 2.2 Representation of an imaginary greenhouse area-time diagram with six different batches.

The vertical axis of the greenhouse area-time diagram represents the available greenhouse area. With respect to the available greenhouse area, the grower may differentiate between compartments or benches. The horizontal axis represents the planning-period. Although tactical planning in agriculture is generally applied on an annual basis, pot plant growers may also consider shorter or longer periods. Moreover, the time slices for greenhouse area occupation should be determined. Thus, greenhouse area can be allocated for every distinguished time slice, i.e. time step during the planning-period. Before batches can be defined, however, the set of optional products should be determined. In principle, the number of pot plant products is almost infinite, but in practice it is restricted by the technical equipment of a nursery. Moreover, growers' knowledge, preferences and tradition lead in general to a limited set of optional products. Subsequently, greenhouse area can be allocated to individual batches.

Although the primary objective of tactical production planning by means of a greenhouse area-time diagram may seem an efficient greenhouse area allocation, other criteria are generally also considered implicitly or explicitly. For instance, the greenhouse area allocated to an individual batch relates to the cultivation-schedule (figure 2.1) of that particular batch and therefore to cultivation criteria. Moreover, the grower may also consider consequences of greenhouse area allocation for the demand for other resources, like labour and machine capacity. The grower will also consider the expected profit over the planning-period.

The expected profit is equal to the difference between expected returns and expected costs corrected for the difference in value between the initial and final state of the plan. Particularly in pot plant production this correction should be considered, because of its non-terminating character, i.e. at any moment young non-marketable plants are present in the greenhouse. The initial state consists of present growing batches, which are already in the greenhouse at the beginning of the planning-period. Moreover, the final state of the tactical production plan may consist also of present growing batches. These batches are planned to be continued in the post-planning-period and therefore require an evaluation beyond the applied planning-horizon. In addition, the consideration of expected profit points at the risk associated with the tactical production plan. In this respect, particularly production risk and price risk should be considered. Production risk may be due to, for instance, uncertainty with respect to the size of young plants, uncertainty related to natural radiation and the risk of plant diseases. Price risk is particularly due to the dominating role of the auction clock on the Dutch pot plant market. Hence, perceived risk of the plan may be one of the criteria the grower considers during the tactical production planning process. Furthermore, many other objectives may be involved also (Alleblas, 1987).

In conclusion, although the greenhouse area-time diagram may seem a simple management feature, it actually represents a very complex planning problem. Therefore, additional research on this subject (Gollwitzer, 1991; Hofstede, 1992; Ludwig, 1991; Ziggers, 1993) may be beneficial in practice. The present study, however, is directed to the implementation of the tactical production plan on the pot plant nursery.

2.4.3 Implementation and control of tactical production plans

In the present study, tactical production planning is regarded as an attempt to anticipate foreseen and unforeseen future events in pursuit of the satisfaction of the grower's objectives (Giles & Stansfield, 1990). The tactical production plan is not regarded as a blueprint, but merely as a general guideline for medium term future production. Because of its general character the tactical production plan requires on one hand elaboration and allows on the other hand for small-scale adaptations during its implementation. The elaboration of the tactical production plan and any adaptations relate to cultivation-schedules of individual batches. Moreover, adaptations of cultivation-schedules should be submitted to the condition that further implementation of the tactical production plan is not prohibited. Of course, the grower may also consider new tactical production planning every time adaptation of cultivation-schedules seems necessary. In the present study, however, frequent reconsideration of the tactical production plan as a whole is regarded to be inconsistent with its medium term guideline function.

For every individual batch in the tactical production plan three implementation phases can be distinguished: (1) the preparation phase, (2) the growth-and-development phase, and (3) the delivery phase. During the preparation phase the particular batch is not yet present in the greenhouse, but young plants are propagated or ordered. The main objective of the preparation phase is to start the cultivation of the batch as planned. After potting, the particular batch is placed in the greenhouse and the growth-and-development phase begins. During this second phase the grower's attention is primarily focused on the growth and development of the plants in the batch. The main objective of this phase is to enable delivery of the batch as planned. In this respect, planned deliveries refer to the standard product attributes of the cultivated pot plants, the expected cost price, and a standard delivery pattern. During the growth-and-development phase the batch is frequently monitored and unexpected events may initiate adaptation of the cultivation-schedule. At potting for instance young plants may appear to be smaller or larger than expected. Weather, in particular the amount of natural radiation, may lead to delay or advancement in growth and development. Moreover, plants may be infected by diseases or treated differently than (implicitly) assumed during tactical production planning. During the growth-and-development phase preventive action may be applied in order to enable deliveries according to plan with respect to timing, quantity, quality and cost price. In addition, curative control may be applied at the end of the growth-and-development phase leading to advancement or postponement of deliveries.

Where the transition from the preparation phase into the growth-and-development phase seems clear, the transition into the delivery phase is rather vague. A pot plant batch is definitely in the delivery phase when the first plants of the batch (are about to) attain the standard product attributes. Pot plants, however, can also be delivered before attaining standard product attributes despite possible price reduction. In the present study, the delivery phase is defined to begin on the moment the batch is spaced for the last time. Hence, the delivery phase is assumed to run parallel with the last part of the growth-and-development phase. During the delivery phase the grower decides when and how to deliver in order to, for example, maximize profit on the short term. When all plants of the batch are delivered, both the growth-and-development phase and the delivery phase end and the production of the particular batch is terminated.

For a better understanding of the delivery process further attention should be directed to the Dutch pot plant market. About 70% of all pot plants in the Netherlands are delivered through the co-operative auction organizations. These organizations provide two services: (1) price setting via the auction clock, and (2) price setting through mediation. The first service implies a passive role of the grower, i.e. the grower acts as a price acceptor. Delivery via mediation, on the other hand, requires a more active role of the grower, because prices can be set anticipating buyers' interests. Nevertheless, also in case of delivery via mediation or even direct delivery to traders pot plant growers can generally be regarded as price acceptors, because auction clock prices are generally applied as reference by traders. Still, the grower can anticipate the course of the market to a limited extent, because pot plant prices fluctuate continuously, and because once standard product attributes have been attained the delivery of in particular foliage plants can be delayed to some extent without a serious loss of quality. Thus, short term price forecasts may lead to a reconsideration of the standard delivery pattern applied in the tactical production plan and eventually to an adaptation of the tactical production plan.

In conclusion, during the implementation of the tactical production plan cultivation-schedules of individual batches are elaborated and may be adapted anticipating unexpected circumstances without undermining the guideline function of the current tactical production plan. Moreover, any adaptations of cultivation-schedules may relate to cultivation as well as to delivery.

3

THEORETICAL FRAMEWORK FOR OPERATIONAL MANAGEMENT

3.1 Introduction

The theoretical framework for operational management in this chapter is based on decision analysis as formulated by Howard (1988):

> *'... a systematic procedure for transforming opaque decision problems into transparent decision problems by a sequence of transparent steps. Opaque means 'hard to understand, solve or explain; not simple, clear or lucid'. Transparent means 'readily understood, clear, obvious'. In other words, decision analysis offers the possibility to a decision maker of replacing confusion by clear insight into a desired course of action. (...) Decision analysis is the normative practice of decision-making.'*

In the present study, such a normative approach is applied merely to enable the analysis of operational management rather than with the ambition to formulate its best practice. Therefore, according to Keeney & Raiffa (1976) the present study should preferably be referred to as prescriptive. Moreover, it should be emphasized that it is not investigated how growers actually practice operational management. Hence, the present study does not involve a positive analysis of operational decision-making as defined by Sinn (1983).

Anderson *et al.* (1977) open their book on agricultural decision analysis with:

> *'... a good risky decision does not guarantee a good outcome; rather, it is one consistent with the decision maker's belief about the risk surrounding the decision and with his preferences for the possible outcomes. A good decision is a considered choice based on a rational interpretation of the available information. Whether such a decision turns out right or wrong is partly a matter of luck and in many cases can never be determined until after the event...'*

Although this observation is in principle correct, it reflects a rather passive attitude of the decision maker during the implementation of the decision. Moreover, Anderson *et al.* (1977) seem to refer to a decision as a single instantaneous action. Crop production, however, can be viewed as a dynamic decision problem, with input decisions made sequentially in response to the state of the production system and its physical and economic environment (Antle & Hatchett, 1986; Berg, 1987; Cyert & March, 1963). In this respect, the tactical production plan of a pot plant nursery can be regarded as an initial decision with a general yet integrated view on future production and with many interdependent actions at various discrete points in time. The general character of the tactical production plan enables the grower to anticipate additional information during implementation by elaborating and adapting this initial decision. Thus, formulating tactical and operational management of pot plant production[1] as a dynamic sequential decision problem, the grower can respond to unexpected conditions and disappointing preliminary outcomes of the partially implemented tactical production plan by adaptive decision-making. This observation is essential for the present study, where operational management is analyzed in relation to adaptive decision-making with concern to the tactical production plan and in relation to control as a

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[1] Here, delivery decisions are also regarded as part of pot plant production management since they affect resource requirements in the greenhouse.

management function. Therefore, both adaptive decision-making and control are further discussed in the next section. Subsequently, elements of both concepts are applied to elaborate the theoretical framework for operational management in the pot plant production context.

3.2 Adaptive decision-making and control

3.2.1 Operational management and adaptive decision-making

In the present framework, operational management is directly related to the tactical production plan, i.e. the tactical production plan is the driving force for the nursery in operation. Hence, the number and size of all batches and their derived delivery batches are considered as given by the tactical production plan. Moreover, the business' objectives as well as the business' capital assets are considered given and unchangeable during the execution of the tactical production plan. Despite its guideline function, however, the tactical production plan enables operational management, because of the flexibility with regard to cultivation and delivery. In this respect, flexibility involves the maintenance of alternative possibilities for future actions (Attonaty & Soler, 1991). Flexibility of tactical production plans is partially due to the general character of these plans. Moreover, due to the relatively large number of relatively small batches flexibility relates also to the possibility of re-allocation of limited resources for simultaneously growing crops. Finally, flexibility can be built into tactical production plans purposely, for instance, by setting aside slack resources. Particularly in the latter case, of course, the 'costs' and 'benefits' of flexibility should be weighed against each other (Koontz & O'Donnell, 1976; Tapiero, 1988). Thus, flexibility of the tactical production plan enables adaptive decision-making without jeopardizing its guideline function.

In the present framework, operational management involves elaboration, progress and adoption decisions with respect to the given tactical production plan. Elaboration decisions relate to the cultivation-schedules of individual batches in the tactical production plan. They reduce the flexibility with respect to the particular batch, because of the interdependence of subsequent cultivation and delivery actions. Progress decisions are about whether actual performance is sufficiently in accordance with the grower's objectives. 'Sufficiently', in this respect, is measured in terms of non-violation of rejection thresholds. In case of insufficient compatibility, progress decisions are negative and continuation of the implementation of the tactical production plan is reconsidered. During such a reconsideration adoption decisions are made, which are about adoption or rejection of alternative actions (Beach & Mitchell, 1987)[2].

In the present study, the grower's objectives are assumed to be constant throughout the implementation of the tactical production plan. Moreover, it is assumed that the tactical production plan corresponds with the objectives of the grower. Thus, sufficient compatibility can be determined by comparing actual performance and tactical production plan (including the underlying assumptions about uncertain processes). In order to enable progress decision-making, rejection thresholds should be established based on the expected performance as well as on the premises of the tactical production plan.

If none of the rejection thresholds is violated, the implementation of the initial decision can be proceeded with elaboration of the tactical production plan. If, however, one or more rejection thresholds are violated, further action in terms of adaptive decision-making is required. The urge to restore the compatibility between the initial decision and the actual situation may lead to one or more adoption decisions (Beach & Mitchell, 1987). These adoption decisions may involve taking immediate corrective action with regard to the actual situation, adaptation of cultivation-schedules in the tactical production plan, or complete new tactical planning (Beach & Mitchell, 1987; Brossier *et al.*, 1991).

Adoption decisions with respect to the tactical production plan may be divided into two categories. Firstly, on the operational level adoption decisions involve small-scale adaptations of individual cultivation-schedules, which do not prohibit further implementation of the current tactical production plan. Secondly, on the tactical level adoption decisions involve new tactical production planning resulting in a completely new initial decision for further operation of the business. Moreover, adoption

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[2] The concept of 'progress decisions' and 'adoption decisions' is based on the 'Image'-theory formulated by Beach & Mitchell (1987). In this respect, a semantic caution seems necessary: **adoption** decisions are made to restore compatibility between plan and reality, whereas cultivation-schedule **adaptations** are one way of doing so.

decisions of the second category may go beyond the tactical production plan and lead to strategic change of for instance objectives or capital assets. Obviously, such changes require also new tactical production planning. In the present study, however, the possibility of new tactical production planning during the implementation of the current tactical production plan is disregarded. As pointed out, the business' or grower's objectives as well as the business' capital assets are assumed to remain unchanged during the complete implementation of the tactical production plan. Moreover, the present study is focused on management behaviour towards incidental disturbances, rather than the process of learning about structural differences between the expected and actual behaviour of the production system.

Although adoption decision-making may seem to open opportunities to improve management performance during implementation, it should be noticed that adoption decisions are also made under uncertainty. Moreover, there may be no possibilities to improve the current performance or to benefit from apparent opportunities. Even when improvement of performance is possible, there may seem not enough time to make adoption decisions and to actually take corrective action. These aspects of adaptive decision-making may lead to stress and consequently maladaptive behaviour (Janis & Mann, 1977). The 'Conflict-theory' model of Janis & Mann (1977) describes unconflicted adherence as the behaviour which follows from a positive progress decision. Moreover, adoptions are made without decision conflict if the consequences of change are perceived as not risky. Of course, subjective and contingency aspects affect perception and acceptance of risk (Slovic *et al.*, 1982). If change is perceived risky, the urge to find more acceptable solutions will increase. This search process leads to stress if there is little hope to find such solutions or if time seems insufficient to find them. Conversely, if a better solution in an uncertain situation is thought possible and there is time, a vigilant process of thorough search, appraisal and contingency planning can be expected. According to Janis & Mann (1977):

> *'... when a person displays the pattern of vigilance he is most likely to discover and select a successful optimizing solution to resolve the decisional conflict.'*

In addition, Beach & Mitchell (1987) make a distinction between situations with a single candidate for adoption, and situations with multiple candidates for adoption. According to their 'Image' theory in the latter case the evaluation criterion will not be sufficient restoration of compatibility, but 'profitability', which they regard as conceptually similar to expected utility. Moreover, in particular adoption decisions events with multiple candidates relate to the procedural models of decision-making formulated by for instance Simon (1960) and Howard (1988). Furthermore, in such situations normative planning principles may be applicable, like for instance the principle of contribution to objectives (Koontz & O'Donnell, 1976), the principle of the limiting factor (Koontz & O'Donnell, 1976), and the principle of opportunity loss (Dannenbring & Starr, 1981). Also, adoption decisions may concern 'profitability' of multiple objectives. Hence, the principle of dominance (Keeney & Raiffa, 1976, Neufville, 1990) may be relevant as well as the application of lexicographical ordering, indifference curves and value functions (Huylenbroeck & Lippens, 1992; Keeney & Raiffa, 1976; Neufville, 1990; Sinn, 1983).

3.2.2 Operational management and control

Anthony (1965) originally used the term 'operational control' in his management concept, because operational management, for the most part, consists of control. In addition, Voich *et al.* (1975) distinguish planning in the preoperating period, operational control during the operation, and managerial and financial control in the postoperating period. In this respect, operational control relates especially to the implementation of the planning decisions made during the preoperating period. Managerial and financial control, on the other hand, relate to learning behaviour, i.e. improvement of knowledge for the planning of the next operation. Some authors, like Boehlje & Eidman (1984), and MacRae (1986), refer to managerial and financial control as 'feedback control'. In general, feedback refers to a loop from the output to the input (Pidd, 1992). In case of managerial and financial control, feedback refers to the use of output of a terminated operation as input for the planning of a next operation. Feedback, however, may also be applied to improve the performance of the current operation. Therefore, both operational control, and managerial and financial control may involve feedback. Furthermore, planning in the preoperating period can not be properly separated from control. In the preoperating period the grower may eliminate potential disturbances or may try to avoid their possible consequences (Dalton, 1982). Where often these activities are viewed as part of the planning process, they may also be regarded as part of the process of control over the future operation. In this respect, Rausser & Hochman (1979) distinguish three types of control: (1) deterministic, (2) stochastic and (3) adaptive. For both deterministic and stochastic[3] control the process by which information is generated along with learning processes is not recognized, i.e. feedback is absent. Adaptive control, according to Rausser & Hochman (1979), implies the process of applying additional information in a sequential decision problem in order to make subsequent decisions. Moreover, Tricker (1976) relates adaptive control to the process of taking corrective action, either to bring the operation into line or to change the plan, in case divergencies from the plan are identified. Thus, adaptive control implies feedback during the operation.

In addition, the absence or presence of feedback relates to the distinction between open-loop and closed-loop controls (Berg, 1987; Boehlje & Eidman, 1984; Palm, 1986; Pidd, 1992; Rausser & Hochman, 1979). Open-loop controls involve a fixed sequence of actions over the complete operating period, where information which is coming available during the operating period is disregarded. In contrast, closed-loop controls can be regarded as rules that relate each subsequent decision to be made to the latest information available. Rausser & Hochman (1979), however, regard open-loop and closed-loop controls as extremes with several types of intermediate feedback controls in between. These intermediate types of feedback controls have in common that at some point during the operation information about uncertain processes is updated and applied to possibly adapt the planned course of actions still to be executed.

The application of the term 'control' may lead to confusion, since it is used in many respects and in many domains. According to Palm (1986):

> *'... control refers to the process of deliberately influencing the behavior of an object in order to produce some desired result'*

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[3] In the terminology of Rausser & Hochman (1979) stochastic control formulations expand the specification requirements of deterministic control frameworks by the inclusion of the inherent uncertainties.

This general description covers many different views on control. The particular object of control is often regarded as a system, i.e. for instance a machine, a living being or an organization. Moreover, it should be emphasized that one can only speak of control if the controller can purposely affect the behaviour of the system to some extent (Sterman, 1989). In this respect, the purpose of control may be either the initially expected behaviour of the system or the objectives the controller tries to achieve by means of the particular system. In fact, control is often applied to maintain a desired value (like a setpoint in engineering or a standard in management) in the presence of disturbances (Palm, 1986; Voich *et al.*, 1975). In many cases, however, the desired result from the system's behaviour is not the planned course of actions nor a certain value, but a more general objective like for instance maximization of profit. Therefore, actual performance should be compared with potential performance under the actual conditions and operational expectations. This implies monitoring of the operation as well as external influences as an ongoing activity. Moreover, if the possibility of new tactical planning is disregarded (as in the present study), the potential performance is of course restricted by the fact of a given plan. In conclusion, control as an activity of operational management consists of:

1. The ongoing monitoring of uncertain processes, i.e. the operation itself and its external influences.

2. The identification of necessities as well as opportunities for adaptive decision-making.

3. The choice of corrective actions with regard to the actual operation or the tactical plan.

With respect to monitoring, Rausser & Hochman (1979) emphasize the active accumulation of information during the operation. Usually, recording is applied to structure the process of information gathering. According to Koontz & O'Donnell (1976), recording may relate to physical performance, costs and returns, program standards, finances, intangible standards, and verifiable goals. For operational management control, costs and returns as well as non-monetary measures are regarded as most suitable (Antle & Hatchett, 1986; Barnard & Nix, 1973; Koontz & O'Donnell, 1976; Levallois & Pellerin, 1989; Tricker, 1976). Operational management control generally relates to clearly identifiable production units (Boehlje & Eidman, 1984; Levallois & Pellerin, 1989). In addition, recording may not only lead to outcome feedback, but also to action feedback (Sterman, 1989), i.e. lead to corrective intervention in the plan particularly with respect to planned actions which have not yet been executed.

Because in the present framework operational management is associated with the implementation of the tactical production plan, monitoring and identification of divergencies relate particularly to actions executed according to the tactical production plan. In fact, the virtual system, which exists besides the real system as a conception of reality in the grower's head, on paper, or in a computerized system, consists of two parts: (1) the recorded behaviour of the real system in its environment, and (2) the planned and expected behaviour of the real system and its environment. Hence, monitoring as part of operational control involves the comparison of both subsystems. Corrective action is required to restore compatibility, if the divergence between both subsystems is no longer acceptable. In case of discrepancies between (1) tactical forecasts and expectations and (2) operational forecasts and expectations, preventive actions may be taken. Preventive actions are based on knowledge of the system and intend to compensate for disturbances before actual deviations between desired and actual behaviour of the system occur (Dalton, 1982). Curative actions may be taken if actual deviations occur. In literature, preventive control is also referred to as preliminary control (Boehlje & Eidman, 1984; MacRae, 1986) and feedforward control (Koontz & O'Donnell, 1976). Moreover, curative control is also referred to as concurrent control (Boehlje & Eidman, 1984; MacRae, 1986).

3.3 The pot plant production context

3.3.1 Implementation of the tactical production plan

In the present framework for operational management in pot plant production the tactical production plan is regarded as the initial solution of a dynamic and sequential decision problem. Moreover, the tactical production plan is applied as an integrated guideline for the cultivation and delivery of individual batches. Since the present study focuses on operational management, the possibility of new tactical production planning is disregarded in the framework.

Operational management involves elaboration, progress and adoption decisions as to control the implementation of the tactical production plan. The implementation of the tactical production plan is spread over small time steps, which make up the total tactical planning period. At the beginning of every time step during implementation, a sequential pattern of operational management actions and decisions is initiated (figure 3.1). The first operational management action is monitoring of the actual situation, which results from the implementation of the tactical production plan so far. Because crop growth and price formation are the major sources of uncertainty in pot plant production, these processes should particularly be subject of monitoring. Whereas, the tactical production plan is based on expected patterns of crop growth and on tactical price forecasts, actual patterns of crop growth as well as actual prices and operational price forecasts may deviate from these premises.

Crop growth and price records as well as operational price forecasts may provide useful feedback during the implementation of the tactical production plan. Crop growth records, of course, relate to individual batches as every pot plant batch is treated individually. Moreover, price records and operational price forecasts relate to products, since pot plant products are regarded as the marketable result of cultivation. Thus, monetary as well as non-monetary, and internal as well as external variables are monitored.

In the present framework, crop growth deviations are assumed to increase gradually during the cultivation. Moreover, early crop growth deviations may be compensated during continued cultivation without changing the cultivation-schedule. Furthermore, pot plant price formation is quite uncertain until delivery. Therefore in the present framework, monitoring is related to crop growth and price formation of batches in the delivery phase. Hence, operational management in the present framework is neither an open-loop nor a closed-loop control, but rather an intermediate feedback control as formulated by Rausser & Hochman (1979).

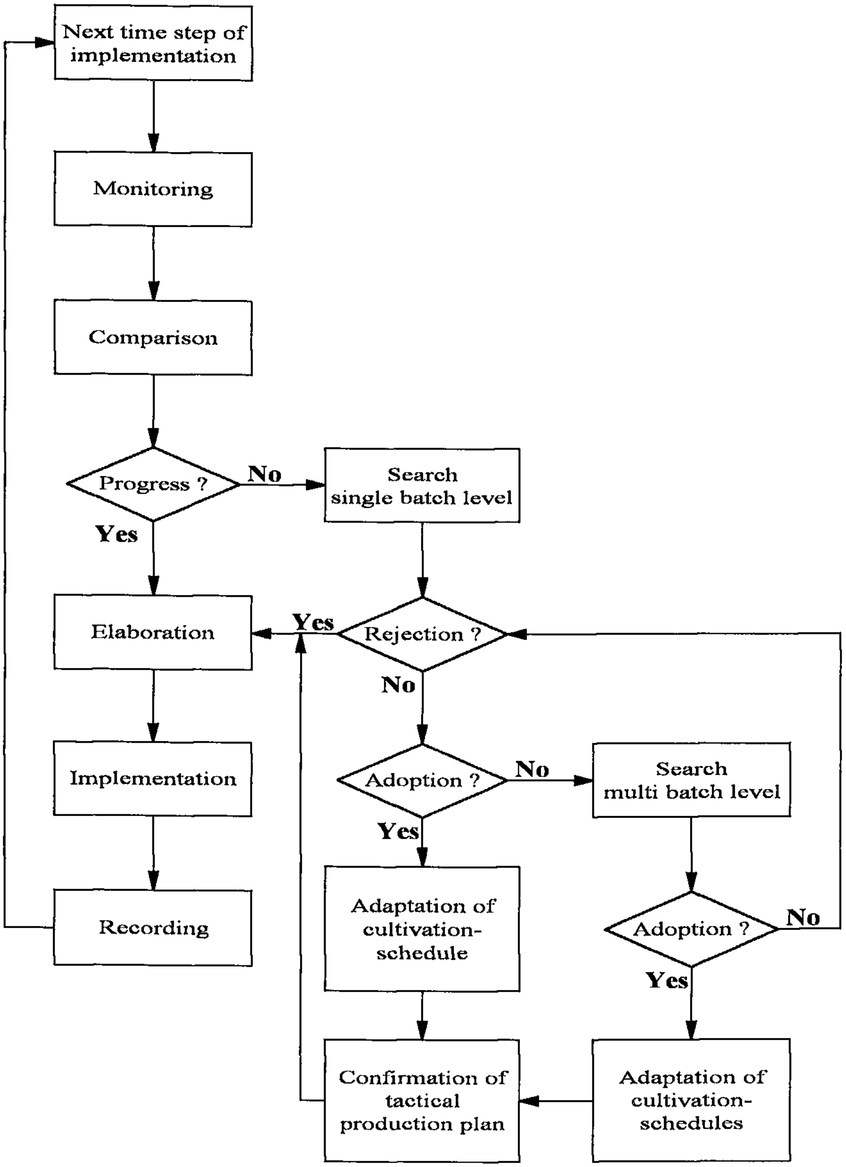

Figure 3.1 Representation of the theoretical framework for operational management in pot plant production applied in the present study.

3.3.2 Progress decisions

The monitored variables are compared to the premises of the tactical production plan. In a pre-post comparison, actual crop growth is compared to planned crop growth for each batch in the delivery phase. With respect to price formation, actual prices and operational price forecasts are applied to compare direct deliveries to postponed deliveries for each batch in the delivery phase. These comparisons provide the basis for progress decisions with respect to every present batch (figure 3.1). Hence, four types of operational problems, which associate with the objectives of the implementation phases 'growth and development' and 'delivery', may preclude a positive progress decision for a particular batch (table 3.1).

Table 3.1 Description of the four types of operational problems which lead to negative progress decisions in the present study.

Type	Operational problem
I	A batch with advanced crop growth has attained standard products attributes earlier than planned in the tactical production plan.
II	A batch with delayed crop growth has not yet attained standard product attributes, although planned to be delivered at the instant in the tactical production plan.
III	A batch, which is in the tactical production plan planned to be delivered later, is based on operational price forecasts considered to be more profitable if immediately delivered.
IV	A batch, which is in the tactical production plan planned to be delivered at the instant, is based on operational price forecasts considered to be more profitable if deliveries are postponed until the next time step of implementation.

Progress decisions are made under uncertainty, since they also relate to expected performance in the near future (Galligan *et al.*, 1991; Yu *et al.*, 1994). For crop growth this relates to standard product attributes, which should be attained or maintained. With respect to price formation, uncertainty is still considerable on the short term. Furthermore, the cause of operational problems should be analyzed before making operational adoption decisions, because a structural cause of discrepancies between tactical production plan and actual behaviour of the system may give reason for new tactical production planning. Because the possibility of new tactical production planning is disregarded, however, all discrepancies are assumed to be incidental in the present framework.

If all progress decisions are positive, the operational management procedure proceeds with the elaboration (figure 3.1). In case of one or more negative progress decisions, however, adoption decisions on the single batch level are considered. These adoption decisions relate to adaptation of the delivery pattern as part of the cultivation-schedule of batches with operational problems. Adaptations are assumed to relate to entire batches or their pre-declared delivery batches[4] . Thus, with regard to crop growth, curative corrective actions could involve advancement or postponement of all initially planned delivery batches of the particular batch. Moreover, with regard to price formation, preventive corrective actions could involve advancement or postponement of individual delivery batches as compared to the tactical production plan. In fact, the planning of deliveries, also on the operational level, is a dynamic sequential decision problem. In the present framework, however, operational price forecasts are assumed to be available only for the subsequent time step because of strong short term price fluctuations. Hence, operational delivery decisions are regarded as static decision problems, which are solved based on operational price forecasts.

3.3.3 Adoption decisions

For any batch with an operational problem operational management search on the single batch level is applied (figure 3.1) to find one or more

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[4] Branching of batches other than to delivery batches is disregarded, because this would interfere with the guideline function of the tactical production plan.

candidate cultivation-schedules for the particular batch with an alternative delivery pattern. In case of more than one candidate, the most favourable one is selected. This candidate for adoption can either be rejected or adopted. Of course, if no candidate for adoption is found, no positive adoption decision can be made. Moreover, if the candidate is considered inferior to the current cultivation-schedule, the adoption decision is also negative, i.e. the candidate for adoption is rejected (figure 3.1). Even, if the candidate is preferred to the present cultivation-schedule but jeopardizes the feasibility of the tactical production plan, the adoption decision on the single batch level is negative. In the latter case, however, the candidate is not rejected definitely. In spite of infeasibility, it is projected on the current tactical production plan as alternative for the present cultivation-schedule.

Feasibility of the tactical production plan is attempted to be restored on the multi batch level. In this respect, infeasibility is due to a violation of greenhouse area or labour constraints. Thus, the objective of operational management search on the multi batch level is to find a combination of adapted cultivation-schedules of batches (not only the batch with the particular operational problem) that restores the violation of these constraints. Because, greenhouse area is regarded as most valuable and rigid resource constraint in pot plant production, greenhouse area and labour are applied as attributes of the objective on the multi batch level in the particular lexicographical order. Furthermore, adaptations of cultivation-schedules of batches on the multi batch level relate not only to the delivery pattern, but also to additional respacing, and planned moments of potting and spacing. These types of cultivation-schedule adaptations lead to reallocation of greenhouse area and labour and may in this way contribute to the restoration of feasibility of the tactical production plan.

In conclusion, adoption decisions on the single batch level and on the multi batch level may lead to adaptation of the cultivation-schedule of one or more batches without jeopardizing the feasibility of the tactical production plan. These adaptations are incorporated in the current tactical production plan. However, because the number of batches and the number of plants per batch remain unchanged, the guideline function of the plan remains unaffected by adoption decisions. Adoption decisions may also be negative on the single batch as well as the multi batch level despite negative progress decisions. In these cases, the tactical production plan remains unchanged and perceived negative consequences of deviations in crop growth and price formation are inevitably accepted. Thus, after confirmation the (adapted) tactical production plan is elaborated and implemented for the current time step of implementation. In addition, recording of consequences of implementation may provide feedback for operational management in the next time step (figure 3.1).

3.4 Implementation of the theoretical framework

After formulating the theoretical framework for operational management in pot plant production, the prerequisites for its implementation can be listed. A tactical production plan should be formulated, because of its assumed driving force function for the nursery in operation. This plan should be comparable with records of crop growth and price expectation. Hence, progress decisions can be made based on the operational problems defined in the present chapter. Furthermore, procedures to generate adoption alternatives on the single batch level as well as on the multi batch level should be formulated. Finally, procedures and criteria for adoption decision-making should be established.

Procedures and options for progress decision-making as well as adoption decision-making are elaborated in chapter 8. In that chapter, special attention is directed to the restoration of feasibility of the tactical production plan on the multi batch level. Due to its complexity the search for a solution of operational problems on the multi batch level may easily result in maladaptive decision-making as described by Janis & Mann (1977). Therefore, a heuristic search procedure is developed based on the concepts of Simon (1960) and Howard (1988) and applied in case favourable candidates can not be adopted right away. A heuristic search procedure is a set of logically developed rules, which is repeated iteratively until a satisfactory, not necessarily optimal, solution is found (Dannenbring & Starr, 1981; Turban, 1990). Heuristic search is applied in the present study, because the objective of the secondary problem is feasibility of the tactical production plan and not so much profitability. Thus, operational management search on the multi batch level may lead to an alternative allocation of greenhouse area and labour, and may enable adoption of the alternative for the particular problem batch.

PART II

SIMULATION MODELLING

4

RESEARCH METHODOLOGY

4.1 Introduction

The primary purpose of modelling the theoretical framework was to show the response of economic and organizational features of a pot plant nursery in operation to alternative strategies of operational management, with the intention behind of proposing useful concepts for improvement of pot plant nursery profitability. Naylor (1971) describes three alternative research approaches for such a purpose, which at least in theory could be applied in the present study: (1) controlled experiments with actual enterprises, (2) ex post experiments based on cross-section data over time, and (3) system analysis and modelling.

Controlled experiments, as for example Jofre-Giraudo *et al.* (1990) conducted, were considered impractical in the present study. It would hardly be possible to assure consistent practice of operational management in separate groups of nurseries. Moreover, it would be difficult (if not unethical) to persuade growers to apply strategies of operational management that were regarded improper or rather risky beforehand. Finally, such experiments in economic research are generally complicated by the limited control over intervening variables, which often leads to nonrandom sampling and distorted results.

Ex post experiments could be conducted based on the availability of cross-section data over time of individual nurseries. Verstegen *et al.* (1993), for example, examined farm results before and after implementation of computerized management information systems. In the present study, however, this approach could not be applied, because operational management on pot plant nurseries was not expected to change demonstrably and abruptly at some point in time.

A third option, although not mentioned by Naylor (1971), was the so-called laboratory experiment, where real growers should solve virtual operational management problems (Cats-Baril & Huber, 1987). Although setting variables, such as available time, undivided attention and motivation, could invalidate the results of such an approach, it would have opened opportunities to conduct rather controlled experiments with real growers involved. Such laboratory experiments, however, were considered to be more appropriate for institutional decision problems as defined by Rausser & Hochman (1979), i.e. decisions about for instance investments or initial tactical production planning. Because the present study focused on the dynamic process of adaptive decision-making, the use of laboratory experiments was also rejected. In fact, system analysis and modelling techniques were applied to investigate the impact of operational management on the economic results of pot plant nurseries.

4.2 Simulation

Simulation was applied in the present study for experimentation purposes, because of the dynamic and complex character of the studied system and the uncertain character of exogenous conditions. As formulated by de Wit (1982):

> *'A system is a limited part of reality that contains interrelated elements, a model is a simplified representation of a system and simulation may be defined as the art of building mathematical models and the survey of their properties in reference to those of the system.'*

Simulation enabled the analysis of sequential decision-making and its consequences in response to variable environmental conditions, as a kind of experimentation with a virtual enterprise (Chatelin & Poussin, 1991; Csáki, 1985). Analytical optimization techniques, such as linear programming and dynamic programming, were not applied because the purpose of the investigation was not to optimize, but to analyze the expected transient effect of various strategies of operational management. Furthermore, at the start of the present study simulation was believed to give maximum flexibility for adaptive decision-making with respect to the further course of the multi disciplinary study itself. Thus, simulation was applied as in similar studies such as, for example, Lentz (1987), Papy *et al.* (1988), Stafford Smith & Foran (1992), Walker & Helmers (1984), and Werthwein (1986).

In preparation of the development of the pot plant nursery simulation model the system, i.e. the pot plant nursery in operation, and its environment were analyzed on the basis of Dent & Blackie (1979), Naylor (1971), Ward & Mellor (1985), Yourdon (1989), and Zeigler (1984). The system boundary and relevant exogenous variables were identified.

The pot plant nursery system involves all ongoing production processes and their management over an extended period of time. Moreover, production processes are driven by the tactical production plan, the strategy of operational management, and uncontrollable exogenous conditions (figure 4.1). After interruption of the system's operation and a valuation of the final system state the performance of the nursery over the reviewed period (w=1 to W) can be determined.

Figure 4.1 was applied as basis for the context of the present pot plant nursery model. Of course, also the endogenous processes of the studied system had to be modelled. According to Rausser & Hochman (1979) a system which involves decision-making processes (as in the present study) consists of five most relevant elements: (1) a decision-maker, (2) an objective function, (3) instrument variables, (4) a structure for information generation, and (5) constraints such as the initial system state and state-transformation functions. Basic processes, such as crop growth, price formation and accounting, were modelled in accordance with generally accepted theory and definitions as far as possible. The modelling of operational management, however, basically involved the paradigm described in the theoretical framework.

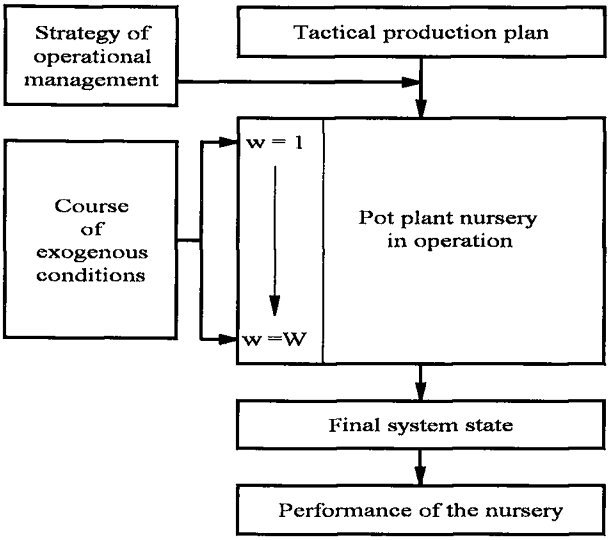

Figure 4.1 The pot plant nursery in operation driven by the tactical production plan, the strategy of operational management and uncontrollable exogenous conditions.

Validation of the model was a tricky exercise like in most simulation studies (Balci & Sargent, 1984; Bratley *et al.*, 1987; Dalton, 1982; Dannenbring & Starr, 1981; Dent, 1975; Fosset *et al.*, 1991; Gass, 1983; Kleijnen & Groenendaal, 1992; McCarl, 1984; Naylor & Finger, 1967; Naylor & Vernon, 1969; Pidd, 1992; Turban, 1990). In the present study, however, the pot plant nursery model was composed of specific models for more or less independent processes within the system. This approach is often applied and enables validation of these individual models independently (Dent, 1975; Naylor & Vernon, 1969; Seuster, 1982; Werthwein, 1986). Validity of individual models, however, did not guarantee validity of the pot plant nursery model as a whole. In the present study, the latter is discussed after simulation experimentation and in relation to the discussed conclusions of the whole research.

4.3 Main features of the model

4.3.1 General features

The pot plant nursery simulation model had to enable the simulation of various strategies of operational management under uncertain exogenous conditions. Additionally, it had to be possible to combine these strategies with various tactical production plans, since tactical production management and operational production management are strongly interdependent. Tactical production plans, however, strongly depend on the characteristics of the nursery for which they are developed. Moreover, operational management also relates to particular characteristics of the nursery. Therefore, aspects like crop growth, price formation and resource constraints had to be specified. In the present study, an imaginary pot plant nursery was formulated, which is considered representative for Dutch nurseries producing foliage plants. Moreover, some characteristics of the pot plant nursery in operation were varied by means of three different tactical production plans. The description of the simulated pot plant nursery was based on available data and consultation of some pot plant growers.

In order to provoke operational problems during the simulated implementation of the tactical production plan random exogenous variables had to affect crop growth and price formation. Hence, crop growth and price formation as well as management processes had to be simulated discontinuously. In the present study, each simulation run involved a period of one year with 52 time steps of one week for all processes except for crop growth. For crop growth the time step was one day in order to improve the performance of the crop growth model.

The main purpose of the crop growth model was to simulate realistic crop growth deviations for individual batches. In this respect, the incorporation of various pot plant products in the model was not regarded to be essential. Therefore, the crop growth model was specified for only one product, i.e. *Schefflera arboricola* 'Compacta' in a 13 cm diameter pot and with a height of 60 cm. Furthermore, because operational corrective actions had to be possible, crop growth had to be simulated dynamically. Finally, the crop growth model had to relate to product attributes (which affect price formation), and heterogeneity (which is the reason for multiple deliveries per batch). Thus, the crop growth model had to enable the simulation of the partially controlled cultivation of individual batches eventually resulting in several deliveries with a particular price per plant in return.

The price formation model had to simulate random prices based on a long-range average seasonal pattern (which was also applied to establish tactical price forecasts), and the product attributes of the delivered pot plants. Moreover, the price formation model had to enable the simulation of operational price forecasts, as to represent the reduction of uncertainty on the short term. Furthermore, it was assumed that the supply of the simulated nursery on the market had no effect on price formation, i.e. the reasonable assumption of perfect competition among pot plant growers was applied in the present study.

The operational management process, as presented in figure 3.1, was applied as skeleton of the present pot plant nursery simulation model. State transformation equations were applied to simulate the economic and organizational consequences of simulated crop growth and price formation. In this respect, available 'Information Models' for pot plant nurseries (Beers, 1985) and greenhouse nurseries (Selman *et al.*, 1987) were particularly useful. Furthermore, at the beginning of each time step a model of progress and adoption decision-making, which enabled the application of various strategies of operational management, was triggered. This model simulated monitoring of crop growth and price formation, and possible adoption of alternative cultivation-schedules for individual batches in the tactical production plan.

4.3.2 Strategies of operational management

In the present study, five strategies of operational management were defined (table 4.1). The *passive* strategy (S_1) involved no operational management whatsoever, i.e. involved an open-loop control as described in subsection 3.2.2. This strategy corresponds rather well with the attitude towards operational management of people developing computerized systems for the support of tactical production planning in the nineteen seventies and nineteen eighties (Krijgsman & Achter, 1973). Moreover, this particular open-loop strategy of operational management was applied as a reference because in subsequent strategies the scope of operational management is broadened gradually. Thus, under the *passive* strategy all cultivation-schedules are implemented exactly according to the initial tactical production plan. Consequently, the delivery of batches with advanced or delayed crop growth leads to price reductions due to non-standard product attributes.

Table 4.1 Specification of the applied strategies of operational management.

Strategy	Monitored processes	Short term profitability as objective	Fixed delivery moments per week
passive (S_1)	none	no	yes
product quality (S_2)	crop growth	no	yes
profitability (S_3)	crop growth	yes	yes
flexible delivery (S_4)	crop growth	yes	no
active marketing (S_5)	crop growth & price formation	yes	no

Under the second strategy of operational management, the *product quality* strategy (S_2), price reductions are tried to be avoided by adapting cultivation-schedules. Hence, under this strategy the objective of operational management is to deliver pot plants with standard product attributes as much as possible. In this respect, short term profitability is disregarded. In fact, the definition of this strategy was based on the idea that tactical production planning should assure profitability and that continued deliveries of pot plants with standard product attributes would be profitable on the long term notwithstanding short term losses. Conversely, a third strategy of operational management was defined based on the operational objective of short term profitability. Under this *profitability* strategy (S_3) cultivation-schedules are only adapted to crop growth deviations if such adaptations are expected to be profitable on the short term. Moreover, both strategies of operational management S_2 and S_3 involve the monitoring and correction of crop growth deviations only. Hence, these strategies of operational management represent a rather passive marketing attitude, which corresponds with selling via the auction clock system.

Under the strategies of operational management S_1, S_2 and S_3 pot plants were assumed to be always monitored, treated and delivered at fixed moments during every week based on the premises of the tactical production plan. Hence, particularly in the summer period batches could grow that fast, that at the fixed delivery moment in one week standard product attributes were not yet attained, whereas in the next week these batches were already 'beyond' standard product attributes. Consequently, these batches resulted under these strategies always in price reduction, although at some moment between both fixed delivery moments these batches complied with standard product attributes. This feature was considered not realistic particularly with respect to a more market orientated attitude. Therefore, under the *flexible delivery* strategy (S_4) the assumption of fixed delivery moments was dropped. Besides, the *flexible delivery* strategy (S_4) is identical to the *profitability* strategy (S_3).

After the transition to flexible delivery moments, the last strategy of operational management, the *active marketing* strategy (S_5), was defined. This strategy of operational management involves the adaptation of cultivation-schedules due to crop growth deviations as well as the adaptation of cultivation-schedules due to discrepancies between tactical price forecasts, on the one hand, and actual prices and operational price forecasts on the other hand. So, this strategy corresponds with selling via a mediation service, where the grower can respond to price offers. Moreover, short term profitability and flexible delivery moments are also included in this final strategy of operational management.

Because of the formulation of strategies of operational management, consistent operational decision-making could be assured and simulated without the interaction of actual growers. This lead to the advantage of very controlled, extended and efficient experimentation. On the other hand, however, the incorporation of a normative model of the grower's behaviour limited the possibilities for the analysis of the interaction between the effectiveness of operational management and the characteristics of the grower. In this respect, particularly the assessment of operational price forecasts was expected to be affected by grower's characteristics. Therefore, the attitude to operational price risk was modelled based on expected utility theory.

4.3.3 Tactical production plans

The tactical production plan was regarded as the driving force and the means of co-ordination in the pot plant nursery simulation model. The initial tactical production plan determined the initial system state. Moreover, all operational adoption decisions were incorporated in the tactical production plan. As a result, the initial tactical production plan could be adjusted during its implementation as a result of adopting alternative cultivation-schedules for included batches. In this respect, adoption decisions could only be made if the feasibility of the tactical production plan was not jeopardized. This condition was applied in order to assure the full completion of every simulation run.

The simulation of all cultivation and delivery actions was triggered by the tactical production plan, which can be regarded as elaboration decision-making as part of operational management. In the present study, all planned actions were assumed to be executed exactly. Thus, the tactical production plan had a major influence on the simulations. Therefore, three tactical production plans were applied in the present study (table 4.2). All three tactical production plans were based on the same description of the imaginary nursery and average exogenous conditions with regard to crop growth and price formation. Moreover, all three tactical production plans were developed as annually cycling plans by means of linear programming as often applied in pot plant production (Annevelink, 1989; Annevelink, 1992; Basham & Hanan, 1983; Håkansson, 1983; Krafka *et al.*, 1989; Saedt, 1982).

The first tactical production plan (P_1) was the *reference* plan. This tactical production plan was developed by applying standard technological coefficients and a profitability objective function in the linear programming model. In addition, the second tactical production plan, the *extra slack* plan (P_2), was based on the same linear programming model, except for the length of the standard cultivation-schedules. In fact, for every optional batch the standard cultivation-schedule was extended with one week. Thus, the *extra slack* plan (P_2) represented a situation, in which the grower purposely builds additional flexibility into the plan. In this respect, the purpose was to allocate sufficient greenhouse area to every individual batch in order to deliver all batches with standard products attributes despite any crop growth delays.

Table 4.2 Specification of the applied tactical production plans.

Plan	Projected length of the cultivation-period	Interest rate on operating capital
reference (P_1)	standard	standard
extra slack (P_2)	extended	standard
cash flow (P_3)	standard	high

Finally, a third tactical production plan was developed. Although in the present study the financial situation of the modelled nursery was disregarded, operational management was believed to be affected by the cash flow situation. For this reason the third tactical production plan, the *cash flow* plan (P_3), was based on the standard linear programming model except for the interest rate on operating capital. It was assumed liquidity problems lead to higher interest rates as a consequence of a negative cash account.

4.3.4 Exogenous conditions

Every simulation with the present pot plant nursery model is influenced by a given course of exogenous conditions. Because the purpose of the present study was to analyze implementation of tactical production plans under uncertainty, these exogenous conditions were simulated randomly prior to any simulation-experimenting with the pot plant nursery model. In fact, 25 independent scenarios of exogenous conditions related to crop growth and price formation were established and stored.

Each scenario of exogenous conditions (E_m) consists of a course of stochastic variables which affect the simulation of either crop growth or price formation in the pot plant nursery model. The time horizon of these scenarios equals the run length of the pot plant nursery model, i.e. one year. Hence, a set of 25 scenarios of exogenous conditions could be applied to replicate individual combinations of strategy of operational management and tactical production plan under various uncertain conditions. In fact, the same 25 scenarios were applied in all simulation-experiments in the present study in order to assure all investigated system variants experienced the same uncertain exogenous events.

4.3.5 The model's output

The present pot plant nursery model was modelled to provide two types of results: (1) economic and organizational output variables, and (2) decision events. Economic and organizational output variables indicate the performance of the simulated nursery over the simulation-period. Since this period was fixed on one year, these variables involve annual results. Moreover, monetary annual results are expressed per square meter of gross greenhouse area in order to eliminate the effect of scale. Furthermore, since the pot plant nursery is a nonterminating system with transient behaviour, the change in value between the initial system state and final system state has to be included in the analysis. Besides the annual economic and organizational output variables, the present pot plant nursery model was also modelled to provide information about individual decision events, which occurred during every simulation. Analysis of these decision events in relation to the economic performance was expected to lead to better understanding of operational management in pot plant production.

5

SIMULATION CONTEXT

5.1 Description of the nursery's characteristics

The present pot plant nursery model was specified for a greenhouse compartment of 75 by 51.2 meters, i.e. 3840 m^2 gross greenhouse area. In this greenhouse, 64 production area units of 46.8 m^2 are installed, which results in a net greenhouse area of 2995.2 m^2 and consequently in a technical greenhouse area utilization efficiency of 78%. Furthermore, in this greenhouse only one pot plant product is produced, i.e. *Schefflera arboricola* 'Compacta' in a 13 cm pot and with a height of 60 cm (figure 5.1). Despite this single product, the organizational complexity of the simulated greenhouse is realistic. New batches can be potted every week of the year, which leads to the typical situation in pot plant production greenhouses of various batches in different stages of development present at the same time. Besides benches with plants on it, the modelled greenhouse includes also personnel. Two full-time employees are available for all necessary crop operations[1]. In the present pot plant nursery model a distinction is made between (1) crop handling operations, like potting, spacing and delivering, and (2) crop maintenance operations,

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[1] The number of employees was based on the expected labour requirement for the cultivation of the specified pot plant product in the specified greenhouse compartment.

like watering, fertilization and crop protection. Moreover, crop handling operations can also be executed by temporary labour, which can be hired in addition to the available permanent labour up to 200 hours per week. Furthermore, crop operations are not limited by machine capacity in the modelled greenhouse. Operating assets which are applied during crop handling operations are specifically applied for the particular batch. In contrast, operating assets which are applied during crop maintenance operations are generally applied for all present batches in the greenhouse.

Figure 5.1 The modelled pot plant product: *Schefflera arboricola* 'Compacta'.

Although just one greenhouse compartment was modelled instead of a complete pot plant nursery, an average Dutch organization of general depreciable assets is assumed. Moreover, associated costs are expressed per m^2 gross greenhouse area. Each of the 64 production area units in the greenhouse compartment can be allocated to only one batch at the time. As pointed out, all batches relate to the same pot plant product. *Schefflera arboricola* 'Compacta' was chosen, because of its suitability for the present study and the availability of relevant data. It is a foliage pot plant with strong apical dominance (which prohibits branching) and without any storage organs (Anonymous, 1991; Vliet, 1986). In The Netherlands this pot plant product is cultivated around the year. Information about crop growth and price formation of this product was obtained from growers, auctions and the Research Station for Floriculture in Aalsmeer (The Netherlands). This information enabled determination of standard cultivation-schedules[2] for batches potted every next week during the year (figure 5.2) as well as tactical price forecasts (figure 5.3).

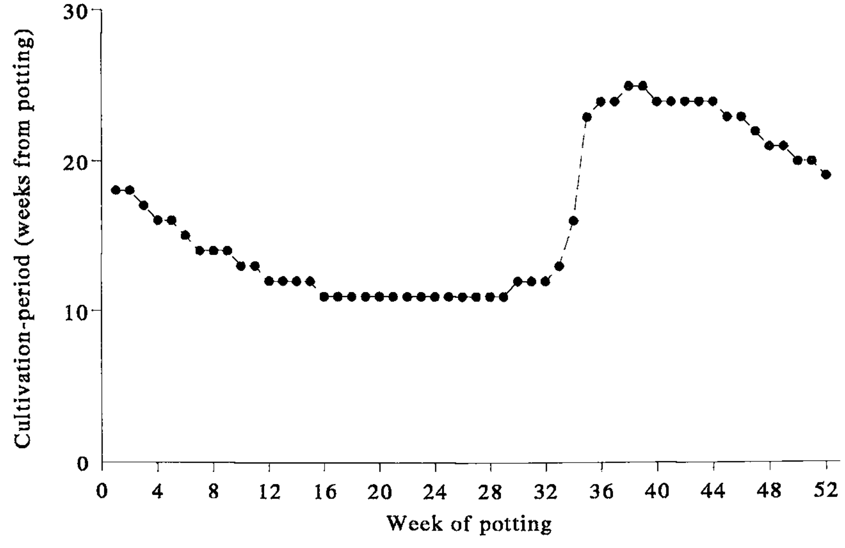

Figure 5.2 Cultivation-periods of optional standard cultivation-schedules of *Schefflera arboricola* 'Compacta' in the present study.

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[2] The seasonal effect on the length of the cultivation-period will be discussed in chapter 6.

Data on standard labour requirements and cost levels of various assets are based on the consultation of growers and available statistics (Achter, 1975; IKC, 1987-1992; LEI, 1990-1992). In the present pot plant nursery model, separate standard labour requirements are applied for all individual crop handling operations, whereas for crop maintenance operations one overall average standard is applied (table 5.1). Crop maintenance operations could be generalized, because in the present study operational problems are assumed not to be due to crop growth limiting factors like water and nutrients, or crop growth reducing factors like pests and diseases.

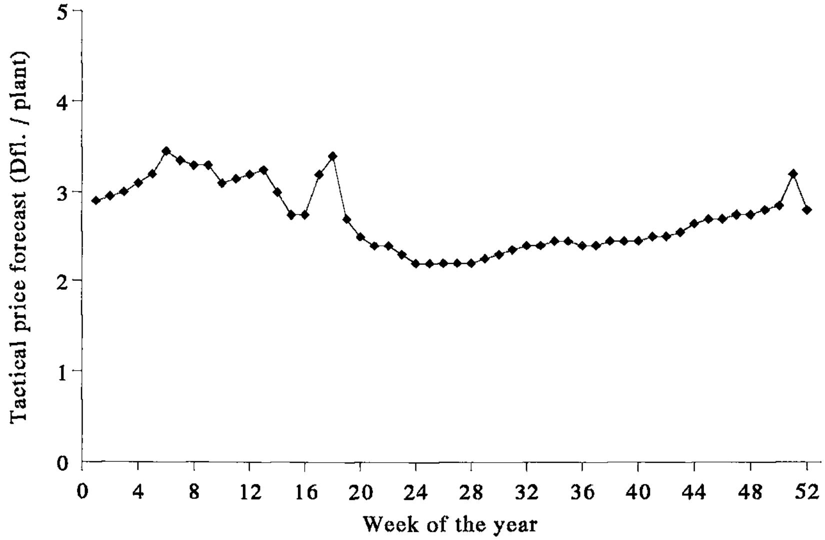

Figure 5.3 Tactical price forecasts of *Schefflera arboricola* 'Compacta' in the present study.

The foundation for costs accounting in the present pot plant nursery model is presented in table 5.2. Costs can be classified by three principles: (1) fixed versus variable costs (Boehlje and Eidman, 1984), (2) constant costs versus costs which fluctuate in the present study, and (3) generalized versus attributed costs in the present study. In the present pot plant nursery model, all fixed costs as well as all costs for generalized operating assets (of fertilization, watering and crop protection) are constant. Hence, all other costs fluctuate per simulation run. With respect to attributed operating assets, costs are subdivided in (1) starting costs[3], (2) delivery costs and (3) interest on operating capital. At the beginning of every cultivation starting costs are attributed on the basis of the number of plants per batch. Similarly, delivery costs are calculated at the end of each cultivation. Delivery costs, however, are only partially (packing and transportation) related to the number of plants. In fact, auction costs are calculated separately as a fixed percentage of returns. Furthermore, the interest on operating capital is also determined per batch in the present pot plant nursery model. The standard interest rate equalled 6%, whereas the high interest rate applied under the *cash flow* plan (P_3) equalled 10%. Finally, costs for additionally hired labour are based on a fixed price per hour. These costs are not attributed to individual batches, because of the possibility of substituting regular labour.

Table 5.1 Labour requirements (per 1000 plants) for crop operations in the pot plant nursery model.

Crop handling operations	
Potting	3.0 hours
Spacing	1.5 hours
Delivering	6.0 hours
Crop maintenance operations	
Average per week	0.5 hours

Thus, all nursery costs could be simulated in the present pot plant nursery model. Total costs were expected to fluctuate considerably per applied tactical production plan, because the tactical production plan determines the number of plants cultivated during each simulation. Furthermore, the varied rate of interest on operating capital in the *cash flow* plan (P_3) was also expected to affect total nursery costs. In addition, total costs were

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[3] Starting costs relate to operating assets immediately applied at the beginning of cultivation, like cuttings, pots and potting medium.

expected to vary somewhat with the applied scenario of exogenous conditions and strategy of operational management, because of varying conditions and operational decision-making. The interest on operating capital was expected to be affected by varying cultivation-periods and varying returns of the first delivery batches. Delivery costs were expected to increase proportionally with returns of delivery. Moreover, costs of extra hired labour were expected to be affected by operational decision-making.

Table 5.2 Basic information with respect to cost accounting in the present pot plant nursery model.

Constant costs		
Land and depreciable assets	24.45	Dfl. m^{-2} gross greenhouse area $year^{-1}$
Regular labour	50000.00	Dfl. $year^{-1}$ $employee^{-1}$
Heating energy	10.50	Dfl. m^{-2} gross greenhouse area $year^{-1}$
Other generalized operating assets	1.50	Dfl. m^{-2} net greenhouse area $year^{-1}$
Fluctuating costs		
Starting costs	108.60	Dfl. per 100 plants
Delivery costs (exclusive of auction commission)	19.50	Dfl. per 100 plants
Auction commission	6%	of returns
Extra hired labour	25.00	Dfl. $hour^{-1}$
Interest on operating capital	6% or 10%	depending on applied tactical production plan

5.2 Applied tactical production plans

As pointed out in subsection 4.3.3 three tactical production plans were formulated: (1) the *reference* plan (P_1), (2) the *extra slack* plan (P_2), and (3) the *cash flow* plan (P_3). Table 5.3 shows the main characteristics of these tactical production plans. While the number of batches is almost constant for all tactical production plans, the average size of the batches varies from 8625 to 9568 plants per batch. Moreover, table 5.3 shows the expected resource utilization efficiencies for greenhouse area and labour[4] on an annual basis. The labour utilization efficiency increases with the number of potted plants, whereas for the organizational greenhouse area utilization efficiency this relation seems absent. The latter, however, is due to the extension of cultivation-schedules in the *extra slack* plan (P_2).

In addition to table 5.3, figures 5.4, 5.5 and 5.6 present the dynamic patterns of potting operations and allocation of greenhouse area and labour of all three tactical production plans P_1, P_2 and P_3. In these figures, the expected utilization efficiencies for greenhouse area and labour are presented on a weekly basis. All three figures (plans) show similar dynamics in potting pattern and in the resulting allocation of greenhouse area and labour. Moreover, crop characteristics as well as tactical price forecasts seem to have a considerable impact on all three potting patterns. Comparison of figures 5.2 and 5.3 with figures 5.4, 5.5 and 5.6 leads to the conclusion that in winter fewer batches (and plants) are potted, because of longer cultivation-periods. In fact, when crops grow slowly, the difference between batches potted in two consecutive weeks is only small, while the planning process becomes more complex with every new batch. Furthermore, in all three tactical production plans a large batch is potted around New Year. This particular batch is meant to be delivered in week 17 and 18, when prices are expected to be high due to Mother's Day. In the *extra slack* plan (P_2) this batch is potted early, because of the extended cultivation-schedules. Delivery of this relatively large batch in week 17 and 18 results in a strong reduction of the expected weekly organizational greenhouse area utilization efficiency, because the greenhouse area which

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[4] The **organizational greenhouse area utilization efficiency** equals the allocated area over a particular period as percentage of the available area, whereas the **labour utilization efficiency** equals the amount of allocated labour as percentage of the sum of available permanent labour and extra hired labour.

is consequently becoming available is not directly allocated to other batches.

Table 5.3 Presentation of the organizational features (on an annual basis) and the economic features (Dfl. m^{-2} $year^{-1}$) of the three tactical production plans applied in the present study.

	P_1	P_2	P_3
Organizational features			
Number of batches	28	28	27
Number of potted plants	249,912	241,488	258,336
Average number of plants per batch	8925	8625	9568
Expected organizational greenhouse area utilization efficiency (%)	89.30	89.78	91.44
Expected labour utilization efficiency (%)	96.96	97.12	98.22
Economic features			
Fixed costs	62.16	62.16	62.16
Expected variable cost	104.85	100.48	109.63
Expected total cost	167.01	162.64	171.79
Expected total returns	178.00	168.73	182.73
Expected net farm income	10.99	6.09	10.94

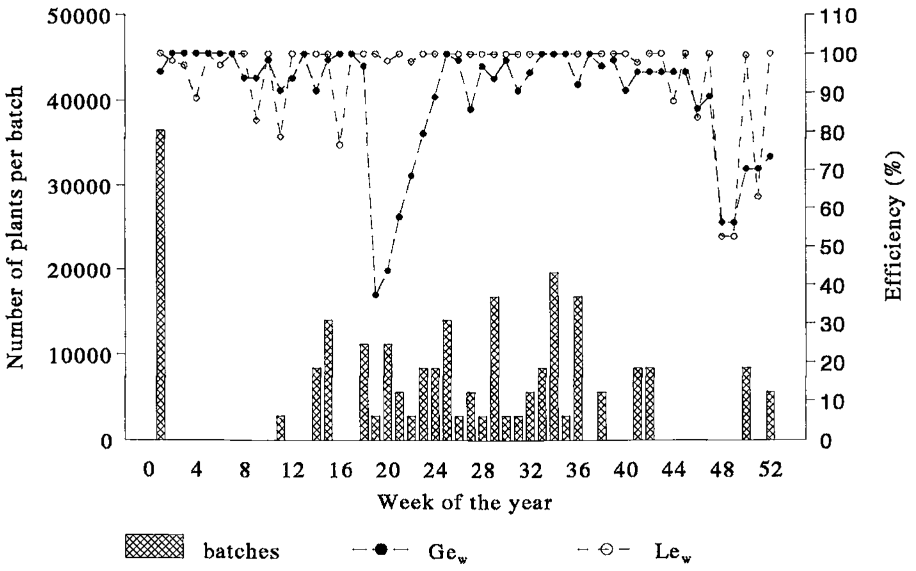

Figure 5.4 The number of plants per batch and the expected weekly utilization efficiencies of greenhouse area (Ge$_w$) and labour (Le$_w$) for the *reference* plan (P_1).

Finally, tactical production plans P_1 and P_3 show only small differences in potting pattern and utilization efficiencies of greenhouse area and labour. Both tactical production plans were nevertheless applied in the present study because of the different rate of interest on operating capital, which was expected to affect operational decision-making. Table 5.3 presents also the expected annual economic results for the modelled greenhouse. With exception of the constant cost all economic variables represent expected values since all three tactical production plans are founded on expected conditions. Furthermore, the expected net farm income is equal to the difference between expected total returns and expected total costs, i.e. the final system state is expected to be identical to the initial system state.

The expected net farm income for all three tactical production plans is rather high compared to actual average net farm incomes in Dutch pot plant production in recent years (LEI, 1990-1992). The expected net farm incomes presented in table 5.3, however, result from optimizing tactical production planning under the assumption of perfect information. Hence, average net farm incomes resulting from simulation under uncertain exogenous conditions can be expected to be lower. Moreover, annual statistics involve average figures, where considerable differences between individual nurseries and products are common. Finally, the applied pattern of tactical price forecasts (figure 5.3) was based on price statistics over many years, collected in 1989 when pot plant production was still quite profitable, whereas in recent years pot plant prices have been reduced considerably. Hence, the average pot plant price level applied in the present study is rather high compared to actual prices in 1992 and 1993. Such differences, however, should be considered inevitable when investigating the effect of uncertain processes.

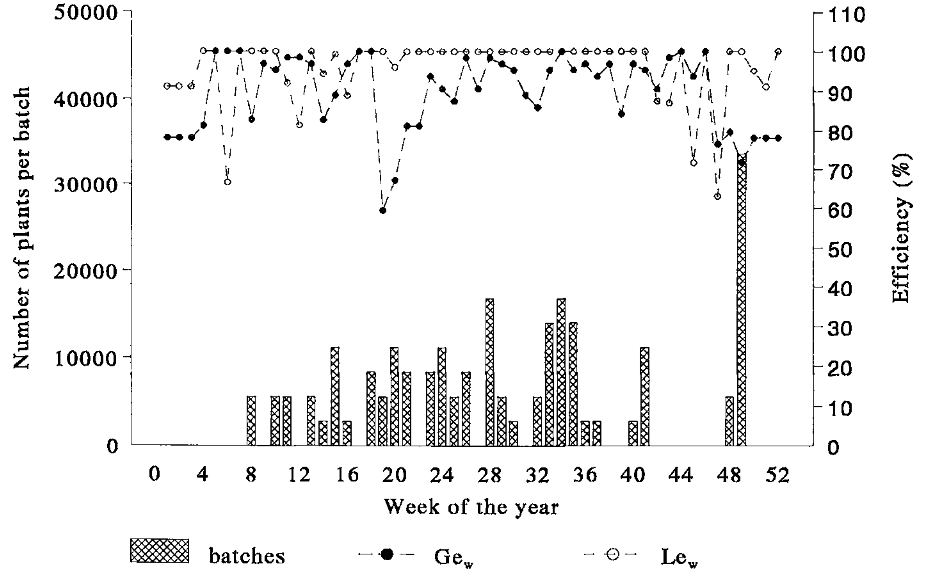

Figure 5.5 The number of plants per batch and the expected weekly utilization efficiencies of greenhouse area (Ge_w) and labour (Le_w) for the *extra slack* plan (P_2).

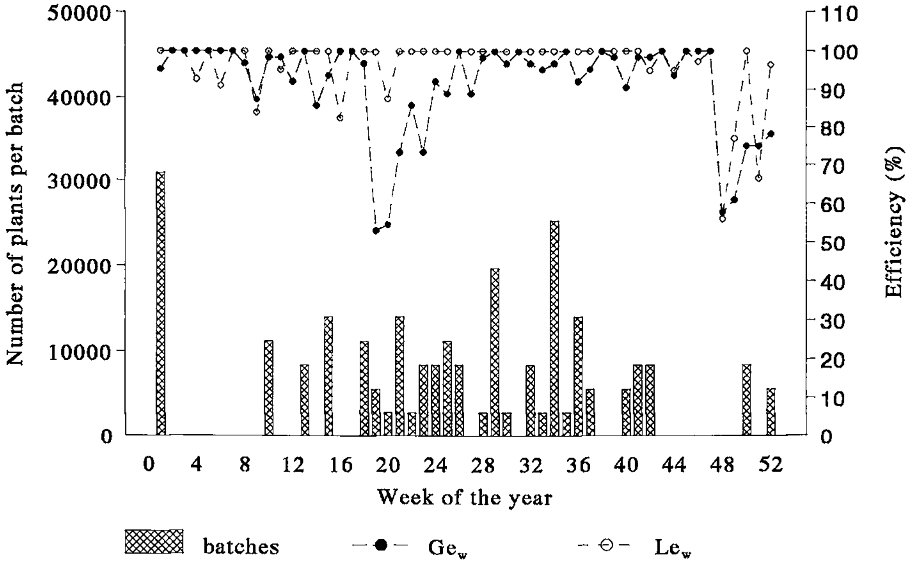

Figure 5.6 The number of plants per batch and the expected weekly utilization efficiencies of greenhouse area (Ge_w) and labour (Le_w) for the *cash flow* plan (P_3).

6

SIMULATION OF BASIC PROCESSES SUBJECT TO UNCERTAINTY

6.1 Introduction

In pot plant production, particularly crop growth and price formation lead to uncertainty during the implementation of tactical production plans. Consequently, operational problems, as defined in subsection 3.3.2, may occur. Therefore, in order to enable the investigation of the possibilities to solve these operational problems by operational decision-making both crop growth and price formation had to be incorporated in the pot plant nursery model.

Crop growth modeling has become an important method in agricultural research (Seligman, 1990). In particular summary models are applied for economic analysis of agricultural production systems (Berg *et al.*, 1988; Dent, 1975; Penning de Vries, 1990; Thornton, 1985). The purpose of the crop growth model in the present study was to simulate stochastic crop responses, which provoke operational management. Random environmental conditions had to result in simulated uncertainty with respect to the length of the cultivation-period similar to uncertainty growers experience in practice. Furthermore, the crop growth model was incorporated to simulate the expected consequences of the adaptation of cultivation-schedules. For both purposes a dynamic model was required.

In reality price formation of pot plants is the result of the confrontation of supply and demand on the market. For practical reasons, however, the process of price formation of marketable pot plants was in the present study modelled as part of the pot plant nursery model. The price formation model had to simulate weekly random prices for the specified pot plant product. Moreover, these simulated actual prices had to deviate randomly from tactical price forecasts as well as operational price forecasts. In this respect, the average deviation from operational price forecasts had to be smaller than the average deviation from tactical price forecasts. Furthermore, standard product attributes, like for foliage plants length, a corresponding pot size, plant quality and packing (Brons *et al.*, 1993; Koelemeijer *et al.*, 1994; Oprel, 1986), had to be specified. In addition, price reduction due to non-standard product attributes had to be incorporated in the price formation model.

6.2 Crop growth

6.2.1 Applied approach

In literature several physiological models for crop growth simulation have been presented (Dent & Blackie, 1979; France & Thornley, 1984; Goudriaan, 1977; Rabbinge *et al.*, 1989). These models are generally built from a 'process-control' point of view, which makes them excessively complex and detailed for managerial purposes. Moreover, none of these models takes account of the specific characteristics of pot plant production: (1) the pursue of an ornamental value, (2) the spacing of the plants during the cultivation and (3) the relatively low photosynthetic rate (Bierhuizen *et al.*, 1984; Ceulemans *et al.*, 1985; Lorenzo-Minguez *et al.*, 1985a; Lorenzo-Minguez *et al.*, 1985b; Lorenzo-Minguez *et al.*, 1986).

Larsen (1988) describes a dynamic model for *Senecio hybrida*. This model, however, was thought unsuitable for the present study, because it involves a flowering pot plant that can hardly be cultivated around the year in the Netherlands. Other approaches with respect to pot plant production are rather descriptive and static, and therefore unsuitable to study operational management (Buchwald, 1987; Frederick & Lemeur, 1992; Pytlinski, 1990). Instead, a new crop growth model was developed for the special purpose of the present study (Leutscher & Vogelezang, 1990). This model is structured according to the physiological processes in the plant and therefore enables dynamic simulation of crop growth. Moreover, it is specified for *Schefflera arboricola* 'Compacta'.

6.2.2 Structure of the model

The structure of the model is based on three plant physiological processes: (1) photosynthesis, (2) respiration and (3) growth. Crop growth is presented as the dry weight increase as the result of photosynthesis and respiration for maintenance and synthesis (figure 6.1).

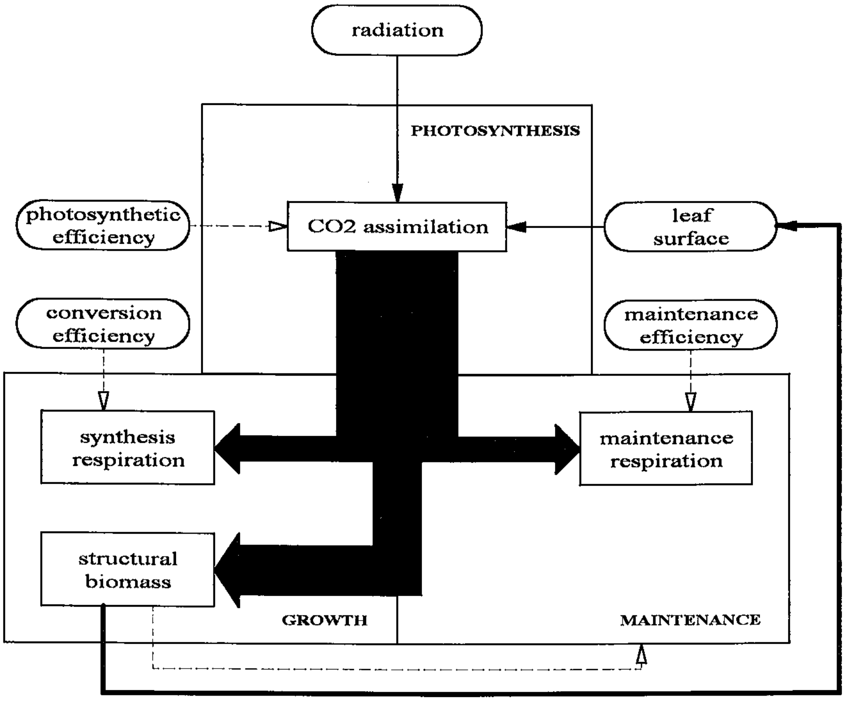

Figure 6.1 Relational diagram of the crop growth model. Crop growth is driven by radiation. Produced carbohydrates (black flow) are divided over growth and maintenance. Structural biomass increases leaf surface as well as maintenance respiration.

In the present crop growth model it is assumed that the crop is well supplied with water and nutrients and that it does not suffer from pests or diseases. Moreover, an average regime of temperature, CO_2-level and air humidity is assumed, which means that variations in crop growth rate are determined by radiation. The model consists of six main equations based on Gijzen (1992), Penning de Vries & Laar (1982) and Versteeg & Keulen (1986), and simulates crop growth day by day. The one-day time step for the simulation of long term crop responses is advocated by Penning de Vries *et al.* (1989).

In equation 6.1 the gross photosynthetic rate of a closed canopy (GPHST) is determined by the daylength and the daily sum of radiation.

$$\mathrm{GPHST} = \mathrm{DAYL} \times \mathrm{MAXPH} \times \left\{1 - e^{\left(-\mathrm{RSC} \times (\mathrm{DSR} / \mathrm{DAYL})\right)}\right\} \tag{6.1}$$

GPHST:	Gross photosynthetic rate of a closed canopy (g m^{-2} day^{-1}).
DAYL:	Daylength (h day^{-1}).
MAXPH:	Gross photosynthetic rate of a saturated and closed canopy (g m^{-2} h^{-1}).
RSC:	Radiation saturation coefficient (m^2 W^{-1}).
DSR:	Daily sum of global radiation (Wh m^{-2} day^{-1}).

Subsequently, the actual gross photosynthetic rate of a canopy is calculated (equation 6.2). This is an important operation, since pot plants are generally cultivated at relatively low plant densities, i.e. with low leaf area indexes (LAI). Thus, the actual gross photosynthetic rate (GPHOT) of a crop is determined by LAI and the extinction coefficient (EC), which represents the intercepted fraction of radiation per layer of leaves. Hence, with increasing LAI values GPHOT approximates to GPHST.

$$\mathrm{GPHOT} = \mathrm{GPHST} \times \left\{1 - e^{\left(-\mathrm{EC} \times \mathrm{LAI}\right)}\right\} \tag{6.2}$$

GPHOT:	Actual gross photosynthetic rate of the canopy (g m^{-2} day^{-1}).
GPHST:	Gross photosynthetic rate of a closed canopy (g m^{-2} day^{-1}).
EC:	Extinction coefficient.
LAI:	Leaf area index.

The photosynthetic products, i.e. carbohydrates, are used for maintenance and growth. Equation 6.3 calculates the demand of carbohydrates for maintenance respiration (MAINT).

$$\mathrm{MAINT} = \mathrm{TWT} \times \mathrm{MC} \tag{6.3}$$

MAINT: Maintenance respiration (g m^{-2} day^{-1}).
TWT: Total dry weight (g m^{-2}).
MC: Maintenance efficiency (g g^{-1} day^{-1}).

Subsequently, in equation 6.4 the actual dry weight increase per square meter is calculated. The conversion factor (CVF) represents the efficiency of the conversion of carbohydrates, remaining for growth, into structural biomass. The losses of this conversion are due to synthesis respiration.

$$\mathrm{GWT} = (\mathrm{GPHOT} - \mathrm{MAINT}) \times \mathrm{CVF} \tag{6.4}$$

GWT: Weight increase of the total canopy (g m^{-2} day^{-1}).
GPHOT: Actual gross photosynthetic rate of the canopy (g m^{-2} day^{-1}).
MAINT: Maintenance respiration (g m^{-2} day^{-1}).
CVF: Conversion factor.

The weight increase of the leaves (GLV) is determined by the fraction (FLV_λ) of the total crop weight increase which is distributed to leaves (equation 6.5). Here, FLV_λ depends on the developmental stage λ, where λ depends on the characteristics of the specific crop during cultivation.

$$\mathrm{GLV} = \mathrm{GWT} \times \mathrm{FLV}_\lambda \tag{6.5}$$

GLV: Weight increase of the leaves (g m^{-2} day^{-1}).
GWT: Weight increase of the total canopy (g m^{-2} day^{-1}).
FLV_λ: Fraction of the total weight increase in the leaves in the developmental stage λ.

Subsequently, GWT is added to the total weight (TWT) and GLV is added to the weight of leaves (WLV). The determination of WLV is important, because it provides the basis for calculating LAI (equation 6.6).

$$LAI = SLA_{\lambda} \times WLV \qquad (6.6)$$

LAI: Leaf area index.
SLA_{λ}: Specific leaf area in the developmental stage λ ($m^2\ g^{-1}$).
WLV: Weight of the leaves ($g\ m^{-2}$).

Here, the specific leaf area (SLA_{λ}) expresses the reciprocal value of the thickness of the leaves. LAI is calculated in order to make the transition to the next day of the cultivation (equation 6.2).

With these six equations it is possible to simulate crop growth day by day from potting until the first moment of spacing. Then the total dry weight (TWT), the dry weight in the leaves (WLV) and the leaf area index (LAI) are reduced corresponding to the reduction of the number of plants per square meter. Subsequently, crop growth can be simulated until the next spacing moment. Thus, crop growth is determined by the daily sum of radiation, the daylength, the starting weight of the plants, moments of spacing and subsequent plant densities. The simulation terminates when the crop attains a particular criterion for delivery.

6.2.3 Specification of the model

The present crop growth model was specified for *Schefflera arboricola* 'Compacta'. Appropriate data were available from experiments by Vogelezang (1991). These experiments were performed in a greenhouse with an average regime of temperature (20 °C), CO_2-level (350 μmol mol^{-1}) and relative humidity (72%). Furthermore, the extinction coefficient (EC), the maintenance efficiency (MC) and the conversion factor (CVF) were specified based on literature (table 6.1). The more crop specific parameters FLV_{λ} and SLA_{λ} were specified based on data obtained from Vogelezang.

Batches throughout the season were assumed to be in identical developmental stages when potted, spaced or delivered. Hence, three developmental stages were specified for three associated periods during cultivation: from potting until first spacing, from first spacing until second spacing, and from second spacing until delivery (table 6.2). Moreover, all values of FLV_{λ} and SLA_{λ} were considered constant throughout the year except for SLA_2. In fact, the specific leaf area is known to be not only depending on the developmental stage of the plant, but also on the level of radiation (Evans, 1972; Hunt, 1981). Thus, a seasonal pattern of SLA_2 (figure 6.2) was estimated based on available data (Vogelezang, 1991).

Table 6.1 Specification of general parameters.

Parameter	Value	Reference
EC =	0.7	(France & Thornley, 1984; Penning de Vries & Laar, 1982)
MC =	0.015 $g\ g^{-1}\ day^{-1}$	(Keulen & Wolf, 1986; Penning de Vries & Laar, 1982)
CVF =	0.7	(Keulen & Wolf, 1986; Penning de Vries & Laar, 1982)

Table 6.2 Specification of the specific leaf area (SLA_λ) and the fraction of the total weight increase in the leaves (FLV_λ) for each identified developmental stage λ.

Developmental stage λ	SLA_λ ($m^2\ g^{-1}$)	FLV_λ
1	0.015	0.64
2	*figure 6.2*	0.65
3	0.016	0.61

Thus, only the parameters RSC and MAXPH in equation 6.1 remained to be specified. In fact, equation 6.1 summarizes the process of photosynthesis, which in more detailed explanatory crop growth models is based on the response curve of leaf gross photosynthesis to absorbed Photosynthetically Active Radiation (PAR). Photosynthesis measurements of *Schefflera arboricola* were conducted in Antwerp (Belgium) (Ceulemans *et al.*, 1985; Lorenzo-Minguez *et al.*, 1985a; Lorenzo-Minguez *et al.*, 1985b; Lorenzo-Minguez *et al.*, 1986). From these experiments a leaf gross assimilation rate at light saturation, 20 °C and 350 μmol mol^{-1} CO_2 of 0.3 mg CO_2 m^{-2} s^{-1} could be derived. In addition, global radiation was assumed to involve 50% PAR (Keulen & Wolf, 1986) and the leaf initial light use efficiency was assumed to be equal to 0.015 mg CO_2 J^{-1} (Keulen & Wolf, 1986). Thus, with an estimated transmissivity of the greenhouse of 60% RSC was estimated to equal 0.015 m^2 W^{-1} for global radiation outside the greenhouse[1].

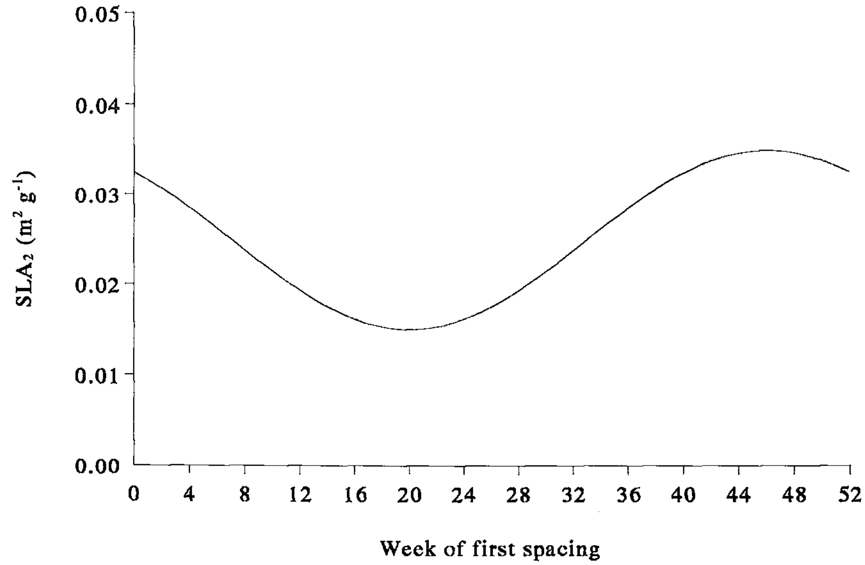

Figure 6.2 Course of SLA_2 throughout the year in the present crop growth model.

Subsequently, MAXPH was equalled to 1.5 g m^{-2} h^{-1} after a process of fitting the model's results to experimental data (figure 6.3). Since, in these experiments root dry weights were not measured, MAXPH in the present crop growth model does only relate to shoot growth. In fact, it was

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[1] RSC = (0.015 mg CO_2 J^{-1} / 0.3 mg $CO_2 m^{-2} s^{-1}$) × 0.5 × 0.6 = 0.015 $m^2 W^{-1}$

assumed a small percentage of the carbohydrates is used for root maintenance and root growth of *Schefflera arboricola* 'Compacta'. Thus, the model showed to be capable of simulating crop growth comparable to the experiments, except for the simulation of the first three weeks. Crop growth deviations in the first three weeks (not shown) are probably due to the potting of the rooted cuttings and the temporary presence of cutting-leaves. In order to enable satisfactory continued simulation of crop growth the total dry weight increase in the first week was standardized (figure 6.3).

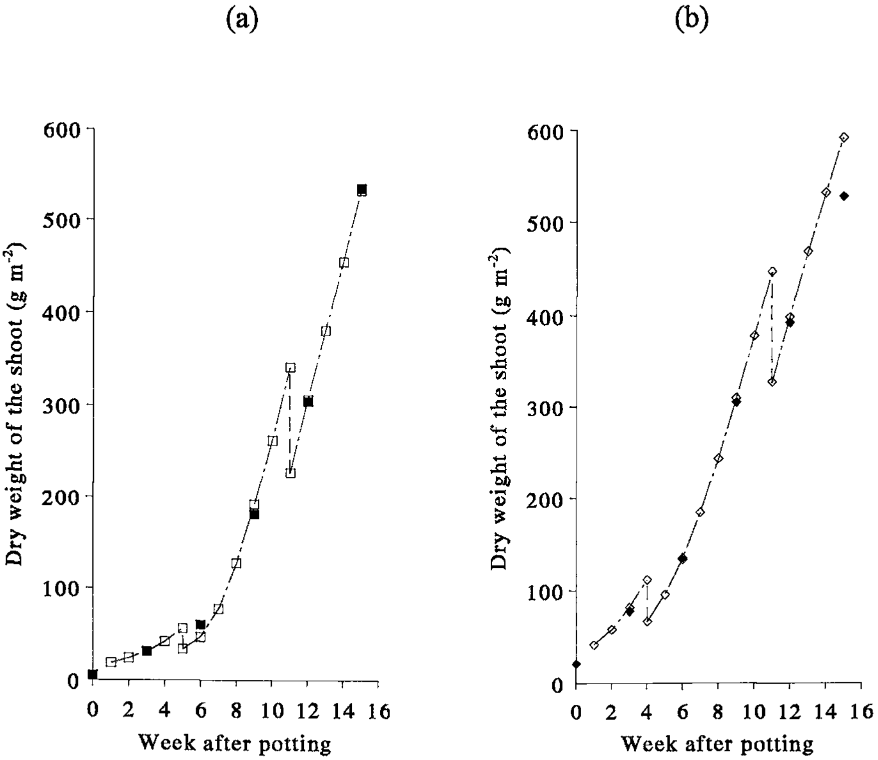

Figure 6.3 Measured (solid) and simulated (open) crop growth in experiment (a) started in week 6 (squares), and in experiment (b) started in week 13 by Vogelezang (1991). Vertical dotted lines indicate the moments of spacing in the experiments.

Where most parameters could be based on literature or experimental data, MAXPH was estimated by comparing the model's response with the experimental data (figure 6.3). Assuming 10 percent of the carbohydrates is transported to the roots, the fitted MAXPH (1.5 g m^{-2} h^{-1}) corresponds with

$(1.5/0.9) \times (44/30) \times (1000/3600) = 0.68$ mg CO_2 m^{-2} ground surface s^{-1}.

Compared to the reference leaf gross assimilation rate at light saturation (0.3 mg CO_2 m^{-2} leaf surface s^{-1}) this value seems not unrealistic. Moreover, *Schefflera arboricola* has a strong capability of adapting to the level of radiation (Andersson, 1988; Pass & Hartley, 1979), which may have had an influence on photosynthesis measurements as well as measured crop growth.

End of cultivation

The total length of plant and pot is commonly regarded as the delivery criterion for *Schefflera arboricola* 'Compacta'. The crop growth model, however, simulates dry weight increase. Therefore, dry weight per plant was related to the total length of plant and pot (figure 6.4). Although only few data were available, this relation was found acceptable. The intercept equals 10.12 cm, which approximates to pot height. Furthermore, the slope equals 2.74 cm g^{-1}, which corresponds rather well with data from other experiments with *Schefflera arboricola* 'Compacta' (Mortensen & Gislerød, 1990; Poole & Conover, 1988). Hence, the criterion for delivery of 60 cm plants corresponded with a dry matter weight of 18.2 g per plant.

Termination of pot plant cultivation lead to the assignment of several delivery batches as a consequence of heterogeneity. In the present crop growth model, heterogeneity within a batch was disregarded. Nevertheless, it may cause serious (and therefore relevant) problems in pot plant production management (Marcelis-van Acker & Leutscher, 1993). Due to heterogeneity, for instance, plants within a batch attain the delivery criterion at different moments. Thus, when the first plants attain the delivery criterion, the grower starts selecting marketable plants and composing a delivery batch.

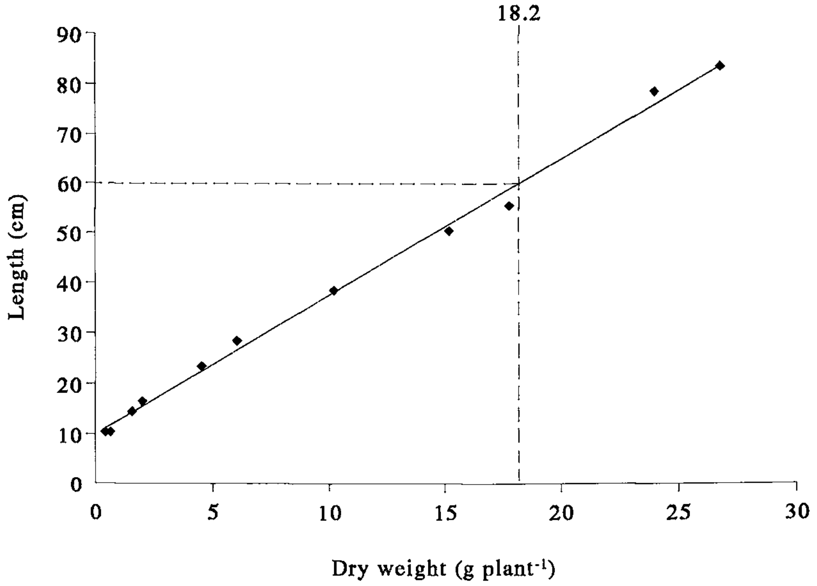

Figure 6.4 Relation between dry weight of the plant and total length of plant and pot (data from Vogelezang (1991)).

Although heterogeneity itself was disregarded in the crop growth model, its consequences were considered by assuming that the simulated dry weight related to the first delivery batch. Moreover, it was assumed that all batches were delivered in two delivery batches. The crop weight of the second delivery batch was assumed to be one week behind in growth, i.e. the weight of the second delivery batch was equal to the weight of the first delivery batch in the prior week. Furthermore, losses in production were assumed to amount 3% of the total number of plants of every batch. For batches potted from week 9 to 31, the first delivery batch was assumed to contain 45% of all marketable plants. For all other batches, the first delivery batch was assumed to contain only 20% of all marketable plants. These ratios were based on consultation of growers of *Schefflera arboricola* 'Compacta' and constant in the present study.

6.3 Price formation

6.3.1 Applied approach

The process of price formation has been described for several horticultural crops (Bouwman & Trip, 1990; Buchholz, 1985; Epperson *et al.*, 1986; Janecke, 1989; Janssen, 1984; Kortekaas, 1984; Oprel, 1985; White & Nicholson, 1984). Unfortunately, the modelling of price formation in pot plant production and trading has been rather inconclusive (Oprel, 1985). In Germany some studies have been conducted in order to describe changes in the supply and demand on the German pot plant market (Altmann & Alvensleben, 1984; Fey-Kimmig, 1982; Timm, 1982). These investigations, however, provided only limited information for the development of the price formation model in the present study. The major reason for this limited applicability was the rather high level of aggregation, on which these studies were conducted. Detailed modelling of price formation of horticultural products appeared to be rather difficult (Janecke, 1989; Janssen, 1984).

For the development of the present price formation model general literature on price modelling and price forecasting (Dannenbring & Starr, 1981; Makridakis & Wheelwright, 1978; Wheelwright & Makridakis, 1973) as well as annual statistics of the floriculture auction in Aalsmeer (The Netherlands) (VBA, 1982-1990) were studied. The poor accuracy of available data prohibited the development of a causal model as described by Makridakis & Wheelwright (1978) and Buchholz (1985). Thus, a normative price formation model was developed and specified for *Schefflera arboricola* 'Compacta' in 13 cm diameter pots and with a height of 60 cm. Moreover, deliveries or any other marketing activities of the modelled nursery were assumed not to affect price formation. Hence, the grower was assumed to be a price-acceptor, who could only decide whether to deliver now or later.

6.3.2 Structure of the model

The general structure of the price formation model involves three price determining factors: (1) an annual seasonal pattern, (2) a long term development and (3) short term disturbances (Epperson *et al.*, 1986; Hanf

& Kühl, 1986; Makridakis & Wheelwright, 1978; Werthwein, 1986; Wheelwright & Makridakis, 1973). The annual seasonal pattern is represented by tactical price forecasts (Pf_w) for every week during the year. These tactical price forecasts represent prices as expected prior to the cultivation and were therefore applied during tactical production planning.

The simulated actual price $\underline{Pa}_{mw}$ deviates from the tactical price forecast (Pf_w) randomly. Generally, the difference between Pf_w and $\underline{Pa}_{mw}$ is represented by a random forecast error in an additive model (Dannenbring & Starr, 1981; Hanf & Kühl, 1986; Walker & Helmers, 1984; Wheelwright & Makridakis, 1973). Consultation of growers and traders, however, indicated price deviations in Dutch pot plant trading increase proportionally with the price level. Therefore, in the present pot plant nursery model price formation is simulated by a multiplicative model with structural and incidental price deviations (equation 6.7).

$$\underline{Pa}_{mw} = Pf_w \times \underline{l}_m \times \underline{d}_{mw} \qquad (6.7)$$

$\underline{Pa}_{mw}$:	Random actual price in week w of scenario E_m (Dfl. plant^{-1}).
Pf_w:	Tactical price forecast in week w (Dfl. plant^{-1}).
$\underline{l}_m$:	Random structural price deviation ratio in scenario E_m.
$\underline{d}_{mw}$:	Random incidental price deviation ratio in week w of scenario E_m.

Structural price deviation ratios ($\underline{l}_m$) were determined from a normal distribution for every scenario of exogenous conditions[2]. Furthermore, incidental price deviation ratios ($\underline{d}_{mw}$) were determined from a second normal distribution for every week in every scenario. In this respect, normal distributions were applied because both variables were assumed to represent the consequence of many independent random effects (Bratley *et al.*, 1987). Moreover, both normal distributions had an expected value equal to one and a standard error depending on the significance of the particular type of price deviation.

The multiplied effect of both normally distributed random variables results in a symmetrical, but not necessarily normal distributed effect (Kendall *et al.*, 1977) with an expected value equal to one. Thus, in every week under every scenario this normative multiplicative stochastic price

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[2] As described in subsection 4.3.4, a set of 25 scenarios of exogenous conditions ($E_m \in \{E_1,...,E_{25}\}$ was randomly simulated and stored in order to be applied in every simulation-experiment.

formation model simulates a random actual price ($\underline{Pa}_{mw}$) from a symmetric distribution with an expected value equal to Pf_w. In order to utilize this rather straightforward approach successfully in the present study two additional aspects had to be modelled: (1) the establishment of operational price forecasts and (2) the reduction of prices due to non-standard product attributes.

Operational price forecasts

Price uncertainty reduces during the implementation of the tactical production plan. With respect to crop growth, uncertainty reduces more or less proportionally during the cultivation of a batch, because of the knowledge of current crop growth. This approach could also be applied with respect to price formation, as advocated by Hanf & Kühl (1986) and Werthwein (1986). Hence, the deviation of Pf_w from $\underline{Pa}_{mw}$ would gradually disappear in time.

In the present study, however, a discontinuous reduction of uncertainty was assumed, because delivery decisions were thought to be made only prior to the cultivation (on the tactical management level), and on the moment the crop attains the delivery-phase and becomes marketable. In the meantime, the grower was assumed not to adjust the tactical price forecast. Thus, the grower was assumed to have knowledge of the long term price trend during operational delivery decision-making. Consequently, the operational price forecast (Pf^*_{mw}) can be calculated according to equation 6.8.

$$Pf^*_{mw} = Pf_w \times l_m \tag{6.8}$$

Pf_w: Tactical price forecast in week w (Dfl. plant^{-1}).
Pf^*_{mw}: Operational price forecast in week w of scenario E_m (Dfl. plant^{-1}).
l_m: Structural price deviation ratio in scenario E_m.

Because the structural price deviation ratio is determined for every scenario of exogenous conditions, the operational price forecasts depend on the scenario applied in a particular simulation. Moreover, $\underline{d}_{mw}$ determines the difference between $\underline{Pa}_{mw}$ and Pf^*_{mw} on the short term (equation 6.9).

$$\underline{Pa}_{mw} = Pf^*_{mw} \times \underline{d}_{mw} \tag{6.9}$$

$\underline{Pa}_{mw}$: Random actual price in week w of scenario E_m (Dfl. plant^{-1}).
Pf^*_{mw}: Operational price forecast in week w of scenario E_m (Dfl. plant^{-1}).
$\underline{d}_{mw}$: Random incidental price deviation ratio in week w of scenario E_m.

Price reduction

The price formation model simulates the actual price ($\underline{Pa}_{mw}$) for batches which comply with standard product attributes. These standard product attributes are related to a specific crop weight (W^*), which is applied as delivery criterion in the crop growth model. For organizational or economic reasons, however, it is possible that batches are delivered before or after W^* is attained. On these occasions reduction of the simulated actual price ($\underline{Pa}_{mw}$) should be considered. For this purpose, four intervals of crop weight were distinguished in the price formation model (figure 6.5).

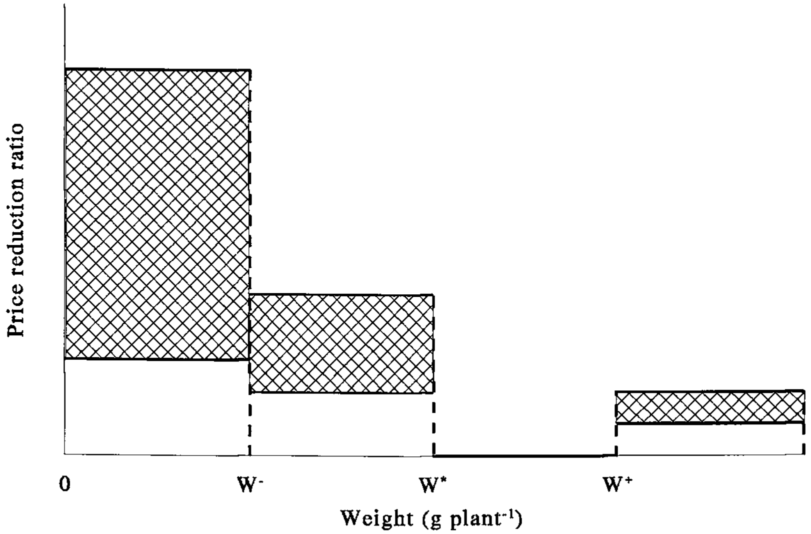

Figure 6.5 Representation of the maximum and minimum price reduction ratios in the four crop weight intervals.

In the first interval ($PW_{bw}<W^-$), the difference between the actual crop weight of the batch (PW_{bw}) and W^* is considerable and a relative large

reduction is applied. In the second interval ($W^{-}<PW_{bw}<W^{*}$), the difference is smaller and consequently the reduction is also smaller. In the third interval ($W^{*}<PW_{bw}<W^{+}$), crop weight is not significantly exceeding W^{*} and no reduction is applied. In the fourth interval ($W^{+}<PW_{bw}$), however, crop weight exceeds W^{*} to such an extent that the size of the plants is no longer in balance with the size of the pots, for which a moderate reduction is applied.

In the present price formation model, the level of price reduction depends also on the price level. For each crop weight interval a minimum and maximum price reduction level is applied. Moreover, a negative correlation between price level and price reduction is assumed, because there are better opportunities to sell products with non-standard attributes when the demand exceeds the supply on the market and the price level is relatively high. Thus, the random price reduction ratio ($\underline{PRR}_h$) of a delivery batch h is calculated in the present price formation model according to equation 6.10.

$$\underline{PRR}_h = p - \left(q \times \underline{d}_{mw}\right) \tag{6.10}$$

$\underline{PRR}_h$: Random price reduction ratio of delivery batch h.
$\underline{d}_{mw}$: Random incidental price deviation ratio in week w of scenario E_m.
p, q: Parameters.

In equation 6.10, p and q are positive parameters, which should be specified for every crop weight interval individually. Moreover, $\underline{PRR}_h$ represents the fraction of the simulated actual price $\underline{Pa}_{mw}$ (for products with standard attributes). Hence, $\underline{PRR}_h$ should in all cases equal a value between zero and one, where zero corresponds with standard product attributes. The random price for a specific delivery batch h ($\underline{Pd}_h$) is determined according to equation 6.11.

$$\underline{Pd}_h = \underline{Pa}_{mw} \times \left(1 - \underline{PRR}_h\right) \tag{6.11}$$

$\underline{Pd}_h$: Random price for delivery batch h (Dfl. plant^{-1}).
$\underline{Pa}_{mw}$: Random actual price for products with standard attributes in week w, i.e. the delivery moment of delivery batch h, of scenario E_m (Dfl. plant^{-1}).
$\underline{PRR}_h$: Random price reduction ratio of delivery batch h.

6.3.3 Specification of the model

The specification of the price formation model for 60 cm *Schefflera arboricola* 'Compacta' was hampered by a lack of accurate data. Auction statistics (VBA, 1982-1990) provided monthly average turnovers and sales volumes per species and cultivar. Pot plant sizes, however, were not distinguished, although they affect selling prices considerably. An other source of quantitative information (IKC, 1987-1992) presented only annual expectations with regard to the price of 60 cm *Schefflera arboricola* 'Compacta'. Finally, frequent visiting of pot plant nurseries provided important qualitative and to some extent quantitative information about the price formation process of foliage pot plants. All three sources of information were applied to specify weekly tactical price forecasts (Pf_w) for all 52 weeks of the year with 1987 and 1988 as reference years. Special events like for example Christmas in December and Mother's Day in May were taken into account. In addition, the weekly tactical price forecasts were aggregated to monthly tactical price forecasts in order to enable a comparison with the available auction statistics.

For every month of every year in the data set of auction statistics (VBA, 1982-1990) a monthly average price was calculated by dividing the monthly turnover by the monthly sales volume. Moreover, these prices were corrected for inflation on an annual basis (LEI, 1992). Thus, a set of nine annual series of prices in the 1988 currency were available. From this set the series of the years 1982 to 1989 were applied to determine multiple year average prices with standard errors for every month of the year.

Figure 6.6 shows the multiple year average prices with corresponding standard errors as well as the calculated monthly tactical price forecasts and the monthly average prices in 1990. The deviation between the multiple year average prices and the calculated monthly tactical price forecasts can be attributed to two major factors. Firstly, the available auction statistics included turnover and sales volume data of all sizes of *Schefflera arboricola* 'Compacta'. Although the 60 cm size is dominant (IKC, 1987-1992), the general price level might be affected due to the fact that the 60 cm size is the smallest size delivered at the auction. Secondly, the general price level corrected for inflation was rather low in 1987 and 1988 as compared to the other years in the data set.

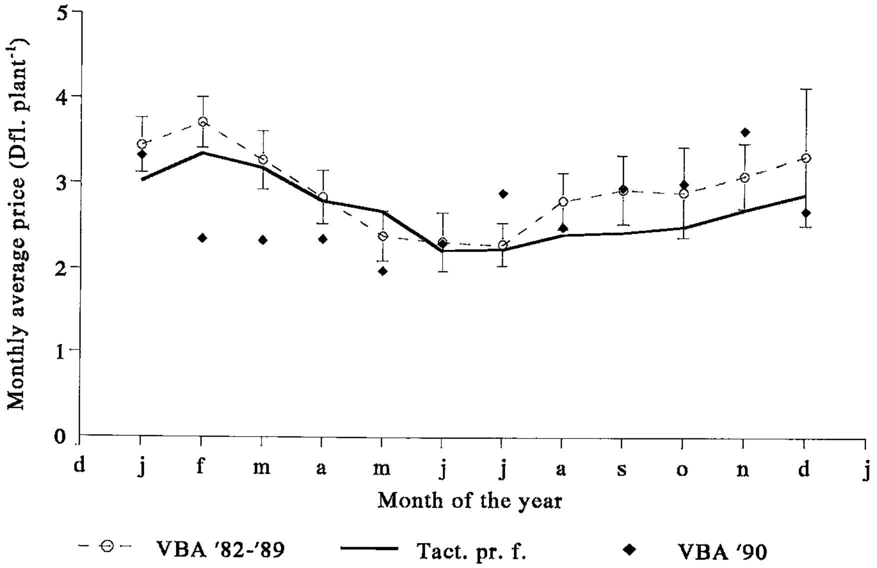

Figure 6.6 Representation of the multiple year average prices with corresponding standard errors (VBA '82-'90), calculated monthly tactical price forecasts (Tact. pr. f.), and the monthly average prices in 1990 (VBA '90).

The data of 1990 were applied to get an idea about the accuracy of the multiple year averages and the calculated monthly tactical price forecasts as estimators for the monthly averages in an additional year. For this purpose the Mean Absolute Percentage Error (MAPE) was introduced (Buchholz, 1985; Makridakis & Wheelwright, 1978) (equation 6.12).

$$\text{MAPE} = \left\{ \sum_{f=1}^{F} \left(\left| G_f - G^*_f \right| / G_f \right) \right\} \times (100 / F) \tag{6.12}$$

MAPE:	Mean absolute percentage error.
G_f:	Actual value.
G^*_f:	Predicted value.
F:	Number of values.

The multiple year averages (VBA '82-'89) predicted the course of monthly average prices in 1990 slightly more accurate (MAPE=18.3%) than the calculated monthly tactical price forecasts (MAPE=19.8%). Buchholz (1985) and Janecke (1989) showed that MAPE-values for horticultural products may easily amount up to 30%. In this respect, it should be emphasized that aggregated values can commonly be predicted more accurately, because short term deviations are compensated for in the aggregated average (Dannenbring & Starr, 1981). Moreover, Kortekaas (1984) concluded that about 70% of price variability in spray carnations was due to short term influences.

In order to enable the application of equation 6.7 the standard errors of $\underline{l}_m$ and $\underline{d}_{mw}$ had to be determined. The standard error of $\underline{l}_m$ was derived from the available auction statistics corrected for inflation. For this purpose, the monthly multiple year average prices in figure 6.6 were regarded as tactical price forecasts. Hence, deviations between monthly prices in the eight individual data series (VBA '82-'89) and these tactical price forecasts were considered to be due to structural (l_y) and incidental ($d_{y\delta}$) price deviation ratios comparable to equation 6.7. Thus, the standard error of l_y could be estimated if two assumptions were made. Firstly, it was assumed that the average value of l_y over all eight series equalled one. Secondly, the average annual values of the incidental price deviation ratio ($d_{y\delta}$) were assumed to equal one for every individual year. Consequently, l_y was calculated for all data series and the standard error of l_y could be estimated (table 6.3).

Furthermore, the Shapiro & Wilk test for normality (Shapiro & Wilk, 1965) did not lead to the rejection of the null hypothesis of normality (P=0.43). Thus, l_y was applied as estimator for $\underline{l}_m$ and the normal distribution of $\underline{l}_m$ was described according to equation 6.13.

$$\underline{l}_m = 1.00 + \left(0.06 \times \underline{\chi}_m\right) \tag{6.13}$$

$\underline{l}_m$: Random structural price deviation ratio in scenario E_m.
$\underline{\chi}_m$: Random standard normal variable, determined for every scenario E_m.

In addition, the standard error of $\underline{d}_{mw}$ had to be determined in relation to the desired level of price variability. Initially, a MAPE of 20% was applied, which corresponded with a standard error of $\underline{d}_{mw}$ equal to 0.23 (equation 6.14).

$$\underline{d}_{mw} = 1.00 + \left(0.23 \times \underline{\chi}_{mw}\right) \qquad (6.14)$$

$\underline{d}_{mw}$:	Random incidental price deviation ratio in week w of scenario E_m.
$\underline{\chi}_{mw}$:	Random standard normal variable, determined for every week in every scenario E_m.

With the specification of Pf_w and the normal distributions of $\underline{l}_m$ and $\underline{d}_{mw}$ the price formation model could be applied to simulate $\underline{Pa}_{mw}$ and Pf^*_{mw}.

Table 6.3 Annual price deviation ratio (l_y) derived from the auction statistics over the years 1982 to 1989.

year	l_y
1982	0.94
1983	1.02
1984	1.11
1985	0.99
1986	1.01
1987	0.93
1988	0.94
1989	1.06
average	1.00
standard error	0.06

Price reduction

Since the crop growth model was specified for 60 cm *Schefflera arboricola* 'Compacta' plants, W^* was equalled to 18.2 g plant^{-1} as followed from figure 6.4. Moreover, the transitional values W^- and W^+ were equalled to 16.38 g plant^{-1} and 20.02 g plant^{-1}, which corresponds with total plant lengths of respectively 55 cm and 65 cm. These values were chosen after consultation of growers. Similarly, the levels of reduction within the distinguished intervals were determined (table 6.4).

Table 6.4 Minimum and maximum price reduction ratios (PRR_h) in the four distinguished crop weight intervals of the present price formation model.

crop weight interval	PRR_h minimum		PRR_h maximum
$< W^-$	0.15	-	0.60
$W^- - W^*$	0.10	-	0.25
$W^* - W^+$	0	-	0
$> W^+$	0.05	-	0.10

6.4 Discussion

6.4.1 Assessment of simulated crop growth and price formation

In order to assure both models simulated realistic outcomes and a realistic level of uncertainty crop growth and price formation were simulated under all 25 scenarios of exogenous conditions. Before discussing the results of these preliminary simulations, however, special attention should be directed to the simulation of the random standard normal variable (χ) as a basis for stochastic exogenous variables. The asymptotic character of the normal distribution was thought to possibly lead to undesired situations with extremely high or low outcomes. Therefore, all randomly simulated values of χ in the present study were submitted to the condition in equation 6.15.

$$\chi_{0.005} \leq \underline{\chi} \leq \chi_{0.995} \quad \Leftrightarrow \quad -2.58 \leq \underline{\chi} \leq 2.58 \qquad (6.15)$$

χ: Random standard normal variable.

For every optional potting moment in all 25 scenarios of exogenous conditions initial weights of the batch[3] were determined independently from a normal distribution with an expected value of 0.25 g per plant and a standard error of 0.058 g. This distribution was derived from the available experimental data obtained from Vogelezang (1991). Besides cutting weights, the annual course of daylength and the daily sum of radiation had to be modelled. Daylength was modelled as an annual function of latitude for Dutch circumstances (figure 6.7). Furthermore, the annual pattern of expected daily sum of radiation was determined by fitting a sinusoid function on data from the Royal Dutch Institute of Meteorology (Breuer, 1983; Breuer & Braak, 1989) (figure 6.7). In addition, proportional deviation variables were simulated randomly for every week in every scenario from a normal distribution with an expected value equal to zero and a standard error equal to 20%.

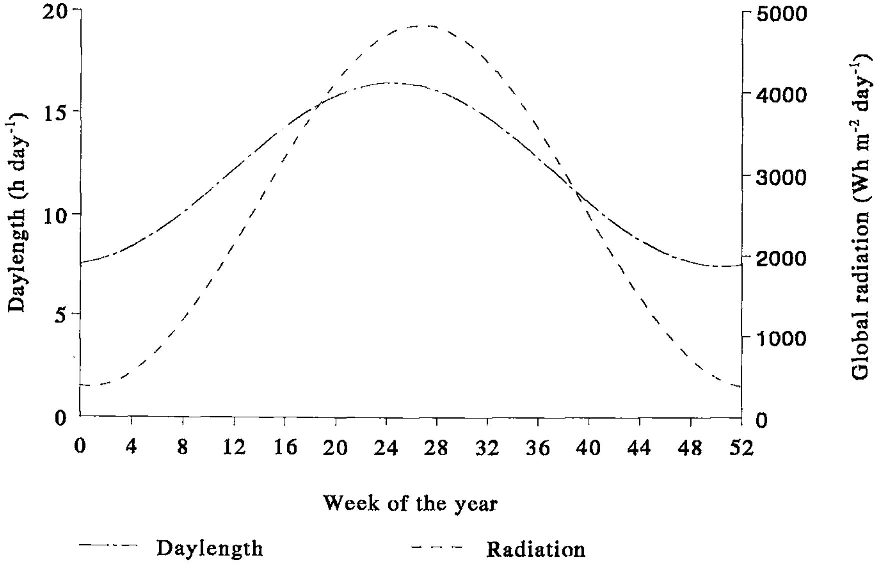

Figure 6.7 Daylength and daily sum of global radiation throughout the year in the present crop growth model.

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[3] Thus, all plants of one batch were assumed to have an identical initial weight, whereas this initial weight varied from batch to batch.

In other simulation studies, similar to the present one, the modelling of daily radiation receipts has been rather problematic (Lentz, 1987; Werthwein, 1986). Lentz (1987) applied an approach similar to the one in the present study with exception of stochastic deviations. Werthwein (1986), on the other hand, concluded that it would be better to apply historical data rather than simulated data. This approach, however, requires the availability of detailed representative historical data. In addition, Breuer & Braak (1989) demonstrated the application of one reference year in stead of various scenarios. As a consequence, however, only the mean response of the crop growth model throughout the year can be simulated. With respect to the simulated radiation in the present study, it should be admitted that only a limited predictive capability seems likely. Moreover, the independently simulated deviations disregard possible autocorrelation as discussed by France & Thornley (1984). Finally, the randomly simulated deviation variables caused realistic uncertainty with respect to the daily sum of radiation (Nonhebel, 1993).

Figure 6.8 shows the impact of the crop growth conditions on the length of the cultivation-period in the present study. It is founded on the simulation of the cultivation of batches potted every week throughout the year under all 25 scenarios and cultivated according to standard cultivation-schedules. Figure 6.8 clearly shows crop growth risk, i.e. the variation in cultivation-periods per week of potting, is larger in autumn and winter than in spring and summer. Moreover, the strong increase of cultivation-period from week 33 to week 35 is due to low level of daily global radiation particular in December. The batch potted in week 33 is delivered just before the period of low radiation levels, whereas the batch potted in week 35 is only delivered in January of the next year.

The results of these simulations should be compared to practical data. Unfortunately, these data were not available. However, growers indicated the simulated data were not unrealistic. Moreover, Frederick & Lemeur (1992) modelled crop growth of *Schefflera arboricola* 'Trinette', which is a variegated species, in the surrounding of Gent in Belgium and found a similar dynamic in the cultivation-periods of batches potted throughout the year. Thus, the present crop growth submodel was concluded to simulate a realistic pattern of the cultivation-periods throughout the year. Furthermore, the impact of random crop growth conditions on the variation in the length of the cultivation-period corresponded with growers' experiences.

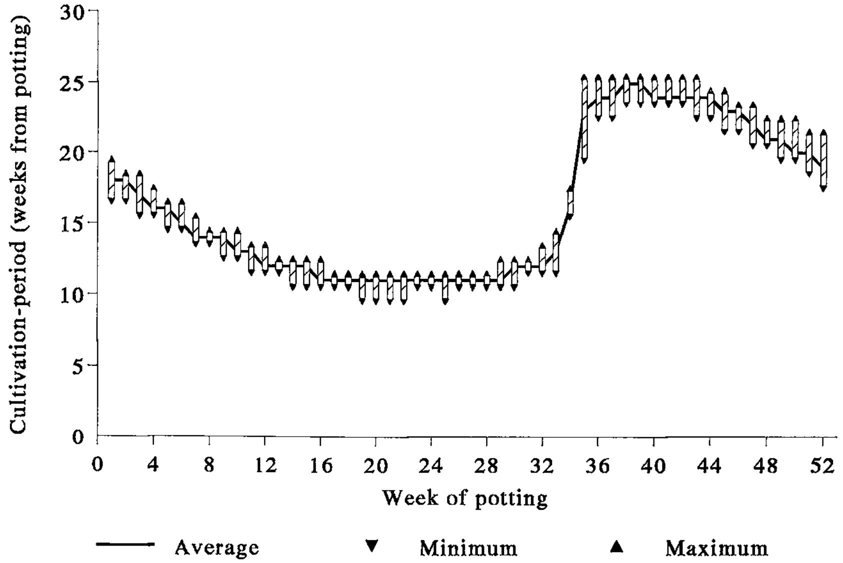

Figure 6.8 Impact of the crop growth conditions in the present study on the length of the cultivation-period. The bold line represents the mean cultivation-period of the batch potted in the corresponding week, whereas vertical lines connect the maximum and minimum cultivation-period over all 25 scenarios.

Price formation

The purpose of the present price formation model was to simulate price variability and to introduce price risk in the pot plant nursery model in order to provoke operational decision-making. In the present study, weekly random prices $\underline{Pa}_{mw}$ were simulated for all 25 scenarios of exogenous conditions by means of the present price formation model (figure 6.9). Consequently, the present price formation model was concluded to be capable of performing its intended function in the pot plant nursery model and to have limited validity. Considering the moderate ambition and the complexity of the Dutch pot plant market, it was concluded that application of the present price formation model in the pot plant nursery model was permissible under the condition of a careful analysis of the simulation results with respect to this aspect.

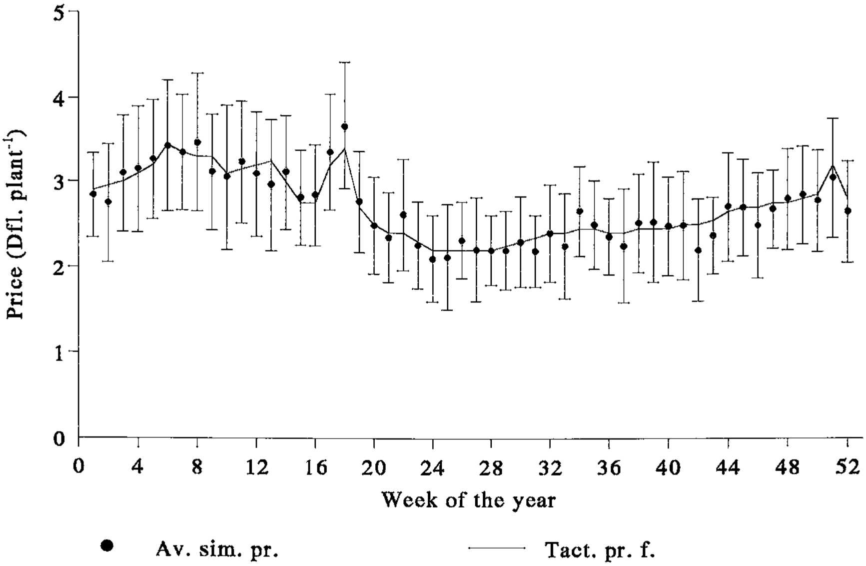

Figure 6.9 Weekly tactical price forecasts (Tact. pr. f.), average simulated prices (Av. sim. pr.) with corresponding standard errors of mean for every week during the simulation-period.

6.4.2 Appraisal of the models for crop growth and price formation

Although the values of one or two parameters and variables may seem open to question, the response of the present crop growth model shown in figure 6.8 was considered realistic. Hence, the model was concluded to be satisfactory with respect to its purpose in the present study. Nevertheless, the present crop growth model has some rather limiting properties one should be aware of. The present crop growth model does not respond to changes in temperature, CO_2-concentration and humidity. Therefore, the model could not be applied for the evaluation of operational management decisions which relate to greenhouse climate control. Furthermore, the present crop growth model does not describe the growth of the roots and the reduction of crop growth due to deficits of water and nutrients, and due to the damage of pests and diseases. These inadequacies of the model limit the general applicability, but do not forestall its application in the present pot plant nursery model. More problematic was the neglect of processes which affect quality. Particularly ornamental characteristics are important in this respect, since product attributes relate strongly to visual plant properties. Literature, however, shows the modelling of morphological plant responses is still very much in development (Causton & Venus, 1981; Charles-Edwards *et al.*, 1986; Evans, 1972; Gutíerrez *et al.*, 1994; Street & Oepik, 1976). Nevertheless, the level of radiation in combination with plant density is expected to affect these visual plant properties. Therefore, the opportunities to deviate from standard cultivation-schedules with respect to crop spacing were limited in the present study.

The structure of the price formation model is simple, yet affiliates with general understanding of price patterns (Werthwein, 1986; Wheelwright & Makridakis, 1973). The multiplicative character of the present model is an indication for heteroscedasticity (Dannenbring & Starr, 1981; Makridakis & Wheelwright, 1978). In the present study, heteroscedasticity is assumed, although not statistically proven from auction statistics. The standard errors in figure 6.9, however, show only small variations due to the moderate course of tactical price forecasts. An other aspect which should be discussed here is autocorrelation. In the present price formation model, autocorrelation is not explicitly modelled, although it generally is an important issue in price forecasting. However, the tactical price forecasts implicitly represents to some extent the effect of autocorrelation. Furthermore, the structural price deviation ratios ($\underline{l}_m$) are constant within every scenario. The weekly incidental price deviation ratios ($\underline{d}_{mw}$) are simulated independently, although short term autocorrelations seem plausible. In this respect, it should be argued that it is more likely that daily price deviations are autocorrelated. The aggregation of these daily price deviations to weekly price deviations can be expected to dissolve autocorrelation effects to a large degree.

As already admitted, the process of price reduction due to non-standard product attributes is modelled arbitrarily. Modelling of this aspect of price formation of foliage plants is problematic due to (1) the lack of general understanding of plant quality, (2) the lack of understanding of the effect of plant quality on the price formation process, and as a consequence of both (3) the lack of quantitative data about the plant quality-price relation of foliage plants. On the other hand, this aspect of interaction between crop growth and price formation could obviously not be neglected in the present study. In order to analyze the effect of the specified model for price reduction a sensitivity analysis was considered. This, however, would hardly have solved the basic problem of a lack of understanding. Instead the economic effect of price reduction due to non-standard product attributes was given special attention in the analysis of the simulation results.

The specification of the present price formation model was rather difficult. Auction statistics provided only aggregated data, prices were compensated for inflation on an annual basis, and records of pot plant nurseries were incomplete. Nevertheless, the present price formation model enables a realistic simulation of price variability and forecasting accuracy. The applied basic MAPE value of 20% should be regarded as a rather conservative estimation of price variability on the Dutch pot plant market. In fact, uncertainty with respect to price formation in pot plant production does not only affect nursery management, but also as the present study demonstrates nursery management research. Hence, as advocated by Bratley *et al.* (1987) a sensitivity analysis was conducted based on Buchholz (1985) and Janecke (1989). In this sensitivity analysis MAPE values of 15% and 30% were applied, with corresponding standard errors for $\underline{d}_{mw}$ of respectively 0.18 and 0.30.

7

SIMULATION OF NURSERY ORGANIZATION AND ACCOUNTING

7.1 Annual results

Since greenhouse area and labour are the main resource constraints for pot plant production, the nursery organization of these two types of resources is incorporated in the pot plant nursery model. Every week during the simulation greenhouse area units are allocated to present batches as far as necessary. For this purpose, the fixed location heuristic (Annevelink, 1992) is applied. Batches are fixed to a specific location when additional greenhouse area is required due to potting or spacing. Moreover, greenhouse area comes available for allocation as a result of re-spacing and delivery. Thus, the total greenhouse area allocated to all present batches can never exceed the available net greenhouse area. The annual organizational greenhouse area utilization efficiency over the complete simulation-period is calculated according to equation 7.1.

$$GE_{im} = \left\{ \sum_{w=1}^{52} Ga_w \right\} / (52 \times Gn) \times 100\% \qquad (7.1)$$

GE_{im}:	Annual organizational greenhouse area utilization efficiency of system variant i under scenario of exogenous conditions E_m.
Ga_w:	Allocated greenhouse area in week w (m^2).
Gn:	Net greenhouse area (m^2).

Similarly, the pot plant nursery model simulates the allocation of labour to present batches for crop handling and crop maintenance actions. As pointed out before, it is assumed a certain limited amount of regular labour (Lr_w) is available every week during the simulation-period. The sum of labour requirements of all present batches in a particular week, however, may exceed this amount. Therefore, additional temporary labour (Lh_w) can be hired. Thus, the annual labour utilization efficiency (LE_{im}) is calculated in the present pot plant nursery model according to equation 7.2.

$$LE_{im} = \left\{ \sum_{w=1}^{52} \left(La_w + Lh_w \right) \right\} / \left\{ \sum_{w=1}^{52} \left(Lr_w + Lh_w \right) \right\} \times 100\% \qquad (7.2)$$

LE_{im}:	Annual labour utilization efficiency of system variant i under scenario of exogenous conditions E_m.
La_w:	Allocated regular labour in week w (h).
Lh_w:	Extra hired labour in week w (h).
Lr_w:	Available regular labour in week w (h).

The annual labour utilization efficiency relates to regular labour as well as temporary labour. In this respect, LE_{im} will increase in case of extra labour requirements, for example due to additional re-spacing, satisfied by regular labour. Moreover, if such extra labour requirements are satisfied by extra hired temporary labour, LE_{im} will also increase though moderately. In fact, in the latter situation not only the numerator but also the denominator in equation 7.2 increases. Furthermore, LE_{im} decreases in case of re-scheduling of labour requirements from weeks with sufficient regular labour to weeks with already insufficient regular labour. Such operational adjustments request more temporary labour, whereas the total labour requirement remains unchanged.

Besides organizational consequences, economic consequences of the simulated pot plant production operations had to be modelled. Cost accounting in the present pot plant nursery model concentrates on the simulation of costs of operating assets such as pots, cuttings and packing material (table 5.2). In this respect, a form of accrual accounting, as described by Kay (1986) in contrast with cash accounting, is applied. For all production inputs which fluctuate during simulation costs are attributed on the moment of application. Thus, the availability of operating assets is disregarded, i.e. these assets are considered non-limiting and non-stored. Furthermore, returns are calculated based on the prices simulated by the price formation model (equation 7.3).

$$Rd_h = Pd_h \times n_h \tag{7.3}$$

Rd_h: Return of delivery batch h (Dfl.).
Pd_h: Price for delivery batch h (Dfl. plant^{-1}).
n_h: Number of plants of delivery batch h.

As indicated in equation 6.11, however, the price for a delivery batch may be reduced due to non-standard product attributes. Hence, special attention is directed to this aspect of price formation. For every delivery batch the loss due to price reduction (LR_h) is calculated according to equation 7.4.

$$\begin{aligned} LR_h &= \left(Pa_{mw} - Pd_h\right) \times n_h \\ &= \left(Pa_{mw} - \left\{Pa_{mw} \times \left(1 - PRR_h\right)\right\}\right) \times n_h \\ &= Pa_{mw} \times PRR_h \times n_h \end{aligned} \tag{7.4}$$

LR_h: Loss of return due to price reduction for delivery batch h (Dfl.).
Pa_{mw}: Actual price for products with standard attributes in week w, i.e. the moment of delivery of delivery batch h, in scenario of exogenous conditions E_m (Dfl. plant^{-1}).
Pd_h: Price for delivery batch h (Dfl. plant^{-1}).
n_h: Number of plants of delivery batch h.
PRR_h: Price reduction ratio of delivery batch h.

Consequently, the annual weighted price reduction percentage can be calculated over all batches delivered during the simulation-period (equation 7.5).

$$PRP_{im} = \left\{\sum_{b=1}^{B}\sum_{h=1}^{2} LR_h\right\} / \left\{\sum_{b=1}^{B}\sum_{h=1}^{2} Rd_h + LR_h\right\} \times 100\% \tag{7.5}$$

PRP_{im}: Annual weighted price reduction percentage of system variant i under scenario of exogenous conditions E_m.
LR_h: Loss of return due to price reduction for delivery batch h (Dfl.).
Rd_h: Return of delivery batch h (Dfl.).
B: Number of batches.

With the determination of PRP_{im} the importance of price reduction for non-standard product attributes could be analyzed.

In order to calculate the net farm income all costs and returns are totalled. The net farm income (NFI_{im}), however, is a flow concept, because the pot plant nursery is a transient state non-terminating system, which is only simulated over a restricted period of time (Barnard & Nix, 1973; Boehlje & Eidman, 1984; Kay, 1986). Therefore, not only annual total costs (TC_{im}) and annual total returns (TR_{im}) should be considered, but also the change in inventory value (CIV_{im}) (equation 7.6).

$$NFI_{im} = TR_{im} - TC_{im} + CIV_{im} \tag{7.6}$$

NFI_{im}:	Annual net farm income of system variant i under scenario of exogenous conditions E_m (Dfl. m^{-2} $year^{-1}$).
TR_{im}:	Annual total returns of system variant i under scenario of exogenous conditions E_m (Dfl. m^{-2} $year^{-1}$).
TC_{im}:	Annual total costs of system variant i under scenario of exogenous conditions E_m (Dfl. m^{-2} $year^{-1}$).
CIV_{im}:	Annual change in inventory value of system variant i under scenario of exogenous conditions E_m (Dfl. m^{-2} $year^{-1}$).

The change in inventory value over the reviewed period equals the difference between the value of the final system state and the value of the initial system state (equation 7.7).

$$CIV_{im} = \Psi_{FSS} - \Psi_{ISS} \tag{7.7}$$

CIV_{im}:	Annual change in inventory value of system variant i under scenario of exogenous conditions E_m (Dfl. m^{-2} $year^{-1}$).
Ψ_{FSS}:	Value of final system state (Dfl. m^{-2}).
Ψ_{ISS}:	Value of initial system state (Dfl. m^{-2}).

The units in equation 7.7 appear to be inconsistent, but this is due to the fact that Ψ_{ISS} and Ψ_{FSS} represent momentary values, whereas CIV_{im} relates to the intermediate year. The valuation of the system state in the present pot plant nursery model involves only present growing batches, because stockkeeping of operational assets is disregarded and the depreciation of capital assets is fixed.

7.2 Valuation of the final system state

7.2.1 Valuation of present growing batches

Because present growing batches are generally not marketable at the moment of valuation, it is difficult to determine their value (Boehlje & Eidman, 1984). Similar problems occur when composing a balance sheet (Barnard & Nix, 1973; Boehlje & Eidman, 1984; Buckett, 1988), and when calculating transfer prices, i.e. prices used to measure the value of goods furnished by one profit unit to one other responsibility unit of larger companies (Anthony, 1988; Anthony & Dearden, 1980; Tricker, 1976). In a sense, in the present study present growing batches are also transferred. However, not to an other responsibility unit, but to an other responsibility period. Thus, some theoretical foundation is available to solve the valuation problem in the present study. On the other hand, the applicability of these described valuation methods is limited, because the choice of valuation method should depend on the purpose of the exercise (Buckett, 1988).

In theory, the value of a present growing batch may be founded on three principles: (1) the current market situation, (2) negotiation or (3) costs. A market-based value, as advocated by Anthony (1988), should be determined according to the same method as used for sales to outside buyers. In pot plant production, however, such methods are rarely applied, because the auction clock system forces the grower to act as a price-taker. Thus, market-based valuation methods can only be applied for marketable batches and do not solve the problem of valuating present growing pot plants. Negotiation-based values, as described by Tricker (1976) for business units within a larger company, are irrelevant for the valuation of present growing batches in the present study. Because the transfer relates to two time periods instead of two business units no negotiation partners are present. Therefore, a cost-based valuation method is applied in the present pot plant nursery model. Figure 7.1 presents the cultivation-schedule of a virtual batch, which is subjected to valuation at a particular moment ($t=t^*$) before attaining the delivery phase. In the upper part of figure 7.1 the development of costs and returns of this batch are presented in order to determine the value of the batch at $t=t^*$. It shows costs increase gradually to the moment $t=t^*$, whereas returns remain nil to this moment and are only expected to compensate costs at the end of the cultivation.

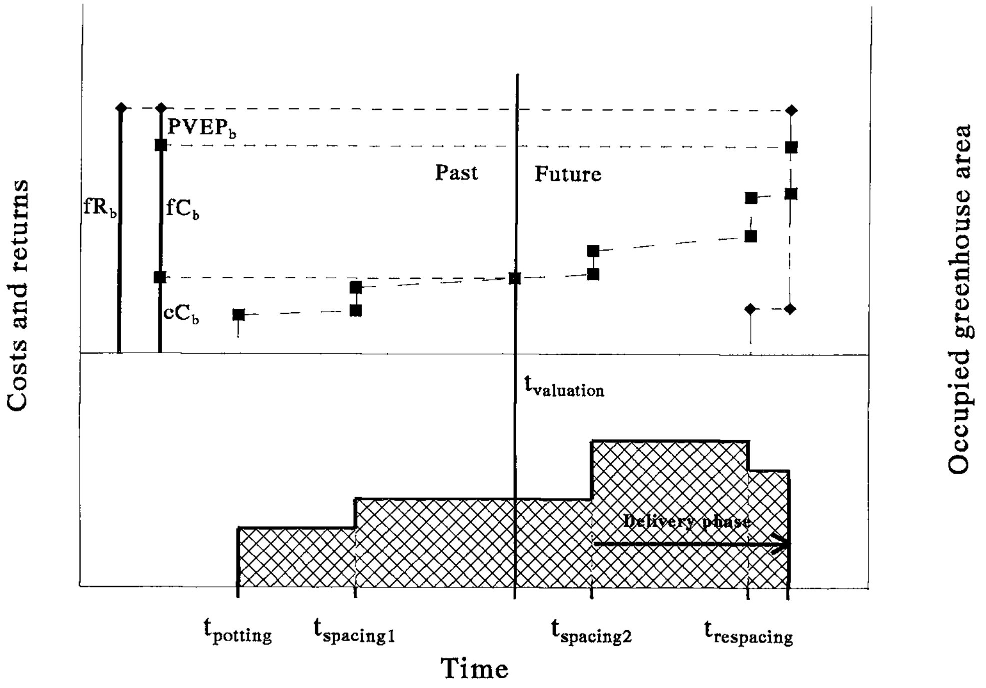

Figure 7.1 Valuation of a present growing batch with costs (■) and returns (♦) above and the greenhouse area requirement below.

For the purpose of establishing a balance sheet present growing batches are generally valued at current costs of the particular batch (cC_b) at the moment of valuation (Boehlje & Eidman, 1984; Buckett, 1988). These costs are assumed to represent replacement costs for a similar batch. Thus, the profit of these batches, which is partly due to cultivation before the moment of valuation, is disregarded. Schroeff (1970) claims profit is only established at the moment of delivery. This approach should be considered as rather conservative, which is generally regarded as a favourable accounting concept for taxation and assessment (Kay, 1986). In the present study, however, the purpose of valuation relates to the measurement of the performance of the system rather than to taxation or assessment of the current system state value. In this respect, Amir *et al.* (1991) describe an alternative approach to determine the value of present growing batches. They define the value of a present growing crop as the difference between the expected future returns ($E(fR_b)$) and the expected future costs ($E(fC_b)$).

When current returns are assumed to be nil, the difference between both described approaches concerns the expected profit. Thus, according to Amir *et al.* (1991) expected profit should be attributed to the particular batch at the moment of potting, whereas according to Schroeff (1970) and Boehlje & Eidman (1984) expected profit should be disregarded and actual profit is only attributed to the particular batch at the moment of delivery. In addition, expected profit could also be attributed proportionally with the increase of, for example, time, costs or the size of the plants. Thus, assuming a positive expected profit, the approach described by Amir *et al.* (1991) will result in the highest current value of a particular growing crop, whereas the approach described by Boehlje & Eidman (1984) will result in the lowest current value.

The value of a present growing batch exclusive of expected profit, as advocated by Boehlje & Eidman (1984), can be calculated according to equation 7.8.

$$\Psi(\mathrm{e.e.p.})_b = cC_b - cR_b = cC_b \qquad (7.8)$$

with

$cR_b = 0$

$\Psi(\text{e.e.p.})_b$:	Value exclusive of expected profit of batch b (Dfl.).
cC_b:	Current costs of batch b (Dfl.).
cR_b:	Current returns of batch b (Dfl.).

In equation 7.8 current returns are incorporated from a theoretical point of view. For other crops, like for example tomatoes and roses, current cost may be partially compensated already at the moment of valuation by current returns. With respect to pot plant production, however, current returns are assumed to be nil. In fact, if the pot plant batch is already partially delivered, it would be more favourable to determine the value of the remaining plants based on the market price of the plants already delivered. Furthermore, analog to Amir *et al.* (1991) the value inclusive of expected profit of a particular batch (b) can be calculated according to equation 7.9.

$$\Psi(\text{i.e.p.})_b = E(fR_b) - E(fC_b) \tag{7.9}$$

$\Psi(\text{i.e.p.})_b$:	Value inclusive of expected profit of batch b (Dfl.).
$E(fR_b)$:	Expected future returns of batch b (Dfl.).
$E(fC_b)$:	Expected future costs of batch b (Dfl.).

In this respect, $\Psi(\text{e.e.p.})_b$ is easier to determine than $\Psi(\text{i.e.p.})_b$. Current costs can be derived from the nursery's records almost directly, whereas future costs and returns have to be estimated. Hence, future costs and returns relate to the period after valuation and therefore involve expectations. Moreover, at least in theory all costs and returns should be converted to the present value at the moment of valuation. In this respect, current costs involve also interest on operating capital, and future costs and returns are discounted with the same interest rate. Subsequently, the present value of expected profit ($PVEP_b$) of the particular batch at the moment of valuation can be calculated according to equation 7.10 (Neufville, 1990).

$$\begin{aligned} \mathrm{PVEP}_b &= \left(\mathrm{cR}_b - \mathrm{cC}_b\right) + \left(E\left(\mathrm{fR}_b\right) - E\left(\mathrm{fC}_b\right)\right) \\ &= \Psi\left(\mathrm{i.e.p.}\right)_b - \Psi\left(\mathrm{e.e.p.}\right)_b \end{aligned} \tag{7.10}$$

PVEP_b: Present value of expected profit of batch b (Dfl.).
cR_b: Current returns of batch b (Dfl.).
cC_b: Current costs of batch b (Dfl.).
$E(\mathrm{fR}_b)$: Expected future returns of batch b (Dfl.).
$E(\mathrm{fC}_b)$: Expected future costs of batch b (Dfl.).
$\Psi(\mathrm{i.e.p.})_b$: Value inclusive of expected profit of batch b (Dfl.).
$\Psi(\mathrm{e.e.p.})_b$: Value exclusive of expected profit of batch b (Dfl.).

In the present pot plant nursery model, future returns and costs are estimated based on the current cultivation-schedule of the particular batch at the moment of valuation. Moreover, average exogenous conditions and no new adaptations of cultivation-schedules are assumed. In fact, future returns are based on tactical price forecasts for the expected moment of delivery, since operational price forecasts are assumed to become only available at the beginning of the delivery phase. Furthermore, variable costs are estimated based on the expected requirements derived from the current cultivation-schedule. Fixed costs, on the other hand, could not be estimated so easily. These costs consist mainly of labour costs and costs which relate to greenhouse area occupation.

The amount of greenhouse area and labour allocated to the particular batch in the post-valuation period follows from the current cultivation-schedule at the moment of valuation. The problem, however, is the price which should be set on these resources. Theoretically, the opportunity costs of both resources should be applied (Boehlje & Eidman, 1984). If resources are not completely allocated, opportunity costs are equal to zero. If, however, alternatives for allocation are optional, opportunity costs depend on the profitability of these alternatives, which makes the valuation problem rather difficult.

7.2.2 Change in inventory value

With the possibility of valuating individual present growing batches at any moment during their cultivation, Ψ_{ISS} and Ψ_{FSS} could be calculated in order to determine $\mathrm{CIV}_{\mathrm{im}}$. The initial system state, however, depends on the applied tactical production plan. Consequently, it would have been impractical to determine the value of the initial system state during every simulation run. In the present pot plant nursery model, the valuation problem is handled taking advantage of the annual cyclical character of the applied original tactical production plans. Because of this cyclical character, the initial and final system state of every individual simulation run are expected to be identical and consequently CIV_{im} is expected to equal zero. Moreover, deviations between the initial and final system state can only be due to adaptations of cultivation-schedules of batches present in the final system state during the simulation-period. The effect of these adaptations on the current costs on the moment of evaluation is incorporated in TC_{im}. In addition, the effect of these adaptations on expected future costs and returns in the post-simulation period had to be incorporated in CIV_{im} in order to attribute all financial consequences of adaptations of cultivation-schedules during the simulation-period to the net farm income over this period.

In order to enable determination of the effect of the applied strategies of operational management on future costs and future returns of batches present in the final system state a reference strategy[1] was used. This reference strategy (S_{ref}) involved a precise implementation of the original tactical production plan irrespective of the current course of endogenous and exogenous conditions. Thus, all batches in the final system state of a simulation run are individually subjected to a valuation based on their original cultivation-schedule and on their current cultivation-schedule. Consequently, in the pot plant nursery model CIV_{im} is calculated as the difference between both values over all batches in the greenhouse (equation 7.11). Subsequently, CIV_{im} is expressed per square meter gross greenhouse area and substituted in equation 7.6. Due to the calculation of the difference in value, the actual expected profit ($PVEP_{bref}$) is not included in the change in inventory value. Only the change in expected profit is included and consequently attributed to the net farm income over simulation-period (equation 7.11).

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[1] This reference strategy (S_{ref}) corresponds with the *passive* strategy (S_1). However, under the reference strategy (S_{ref}) batches are assumed to be delivered in the post-simulation period when standard product attributes are attained, whereas under the *passive* strategy (S_1) they are delivered as originally planned in the tactical production plan.

$$\begin{aligned}
\mathrm{CIV}_{\mathrm{im}} &= \sum_{b=1}^{B}\left\{\Psi(\mathrm{i.e.p.})_{\mathrm{bS}} - \Psi(\mathrm{i.e.p.})_{\mathrm{bS}_{\mathrm{ref}}}\right\} \\
&= \sum_{b=1}^{B}\left\{E(\mathrm{fR}_{\mathrm{bS}}) - E(\mathrm{fC}_{\mathrm{bS}}) - E\left(\mathrm{fR}_{\mathrm{bS}_{\mathrm{ref}}}\right) + E\left(\mathrm{fC}_{\mathrm{bS}_{\mathrm{ref}}}\right)\right\} \\
&= \sum_{b=1}^{B}\left\{\mathrm{PVEP}_{\mathrm{bS}} + \mathrm{cC}_{\mathrm{bS}} - \mathrm{PVEP}_{\mathrm{bS}_{\mathrm{ref}}} - \mathrm{cC}_{\mathrm{bS}_{\mathrm{ref}}}\right\} \\
&= \sum_{b=1}^{B}\left\{\left(\mathrm{PVEP}_{\mathrm{bS}} - \mathrm{PVEP}_{\mathrm{bS}_{\mathrm{ref}}}\right) + \left(\Psi(\mathrm{e.e.p.})_{\mathrm{bS}} - \Psi(\mathrm{e.e.p.})_{\mathrm{bS}_{\mathrm{ref}}}\right)\right\} \quad (7.11)
\end{aligned}$$

$\mathrm{CIV}_{\mathrm{im}}$:	Difference between the value of the final and initial system state (Dfl.).
$\Psi(\mathrm{i.e.p.})_{\mathrm{bS}}$:	Value inclusive of expected profit of batch b under strategy of operational management S_i (Dfl.).
$E(\mathrm{fR}_{\mathrm{bS}})$:	Expected future returns of batch b under strategy of operational management S_i (Dfl.).
$E(\mathrm{fC}_{\mathrm{bS}})$:	Expected future costs of batch b under strategy of operational management S_i (Dfl.).
$\mathrm{PVEP}_{\mathrm{bS}}$:	Present value of expected profit of batch b under strategy of operational management S_i (Dfl.).
$\mathrm{cC}_{\mathrm{bS}}$:	Current costs of batch b under strategy of operational management S_i (Dfl.).
$\Psi(\mathrm{e.e.p.})_{\mathrm{bS}}$:	Value exclusive of expected profit of batch b under strategy of operational management S_i (Dfl.).

An example of how $\mathrm{CIV}_{\mathrm{im}}$ is determined in the present pot plant nursery model is presented in appendix I.

7.2.3 Prices of labour and greenhouse area in the post-simulation period

Opportunity costs for future greenhouse area and labour requirements could not be calculated directly because the simulation of pot plant production operations obviously was limited to the simulation-period. The cyclical character of the applied tactical production plans, however, enabled the assumption of a renewed implementation of the original tactical production plan in the post-simulation period.

Batches present in the final system state relate to batches present in the initial system state. Consequently, under the reference strategy future labour and greenhouse area requirements of batches present in the final system state match with the amount of labour and greenhouse area allocated to corresponding batches in the initial system state. Thus, opportunity costs of these resources can be assumed equal to zero. For additional future requirements of labour and greenhouse area due to adaptations of cultivation-schedules, however, a realistic price per unit had to be applied.

In the present pot plant nursery model, the price for additional labour requirements is equalled to the price of temporary hired labour. Permanent labour is assumed to be allocated completely with opportunity costs which exceeded the price of hired labour. If, however, in a specific week permanent labour is not completely allocated and additional labour requirements are smaller than the available slack in the tactical production plan, the price for additional labour is equalled to zero. If, additional labour requirements exceed the available slack, a weighted average price for additional labour is calculated according to equation 7.12.

$$\mathrm{PaL}_{\mathrm{w}} = \left\{\left(\mathrm{Lar}_{\mathrm{w}} - \mathrm{Lsl}_{\mathrm{w}}\right) / \mathrm{Lar}_{\mathrm{w}}\right\} \times \mathrm{PhL} \tag{7.12}$$

PaL_w: Price of additional labour in week w if $\mathrm{Lar}_w > \mathrm{Lsl}_w$ (Dfl. h^{-1}).
Lar_w: Additional labour requirement in week w (h).
Lsl_w: Slack of available labour in week w (h).
PhL: Price of hired labour (Dfl. h^{-1}).

If due to the adaptation of cultivation-schedules less hired labour is required in a specific week in the post-simulation period, the corresponding financial benefit is attributed to the corresponding batches in accordance with their respective contributions.

In the pot plant nursery model, the price of additional greenhouse area requirements in the post-simulation period is determined for every week of the year. For every batch in the tactical production plan the occupied greenhouse area in every week ($\mathrm{OG}_{\mathrm{bw}}$) is determined. Moreover, all costs not related to the occupation of greenhouse area are subtracted from the total returns for each of these batches. Thus, the return to greenhouse area ($\mathrm{RtG}_{\mathrm{b}}$) is calculated for each batch. This return to greenhouse area is assumed to be proportional attributable to the total greenhouse area occupied by the particular batch. Thus, for every square meter occupied by a batch during its cultivation the costs of reallocation can be determined. Subsequently, the average costs of reallocation for greenhouse area in each week (CrG_w) can be determined according to equation 7.13.

$$CrG_w = \left\{ \sum_{b=1}^{B} \left(OG_{bw} / \left(\sum_{w=1}^{52} OG_{bw} \right) \right) \times RtG_b \right\} / Gn \qquad (7.13)$$

CrG_w:	Average costs of reallocation for greenhouse area in week w (Dfl. m^{-2}).
OG_{bw}:	Greenhouse area occupied by batch b in week w (m^2).
RtG_b:	Return to greenhouse area for batch b (Dfl.).
Gn:	Net greenhouse area (m^2).

In the present study, prior to the actual simulation-experiments the average costs of reallocating greenhouse area (CrG_w) were calculated for every week of the year in the applied tactical production plans in order to get an idea of the dynamics of this variable. Figure 7.2 shows that all three applied tactical production plans lead to similar dynamics.

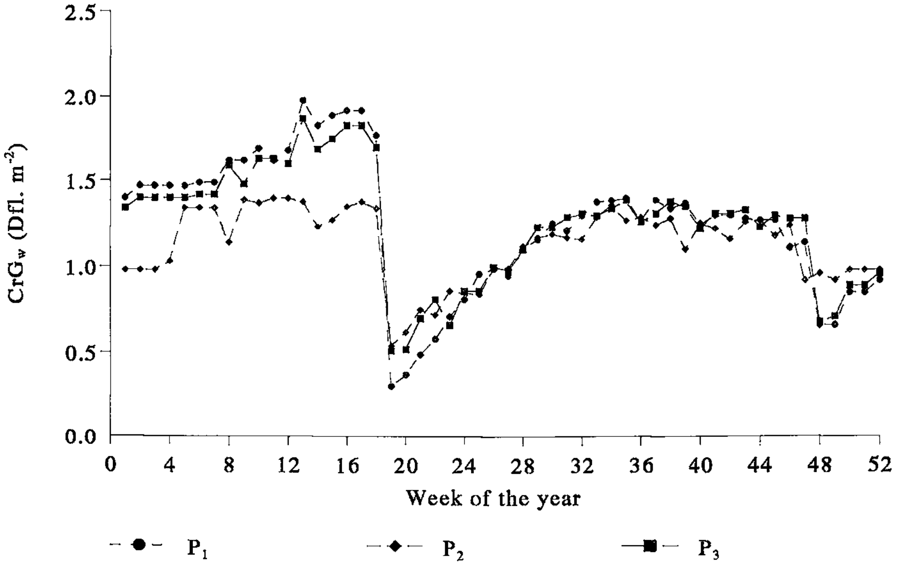

Figure 7.2 The average costs of reallocating greenhouse area (CrG_w) for every week of the year in the three applied tactical production plans.

The influence of the organizational greenhouse area utilization efficiency on the CrG_w becomes clear when figure 7.2 is compared with figures 5.4, 5.5 and 5.6. In addition, CrG_w can be compared with the average constant costs exclusive of regular labour as presented in table 5.2. In this respect, figure 7.2 shows that these average costs (0.89 Dfl. m^{-2} net greenhouse area $week^{-1}$) are not compensated by CrG_w in every individual week of the year. Over the total year, however, the average costs of reallocation exceed the average constant costs, indicating an expected profit as presented in table 5.3.

Equation 7.13 can be applied under the assumption of a complete allocation of greenhouse area. If in a specific week additional greenhouse area requirements are smaller than the available slack in the tactical production plan, the price for additional greenhouse area is equalled to zero. If, however, additional greenhouse area requirements exceed the available slack, a weighted average price for additional greenhouse area is calculated according to equation 7.14.

$$PaG_w = \{(Gar_w - Gsl_w) / Gar_w\} \times CrG_w \qquad (7.14)$$

PaG_w:	Price of additional greenhouse area in week w if $Gar_w > Gsl_w$ (Dfl. m^{-2}).
Gar_w:	Additional greenhouse area requirement in week w (m^2).
Gsl_w:	Slack of available greenhouse area in week w (m^2).
CrG_w:	Average costs of reallocation for greenhouse area in week w (Dfl. m^{-2}).

7.2.4 Appraisal of the final system state valuation method

The valuation of the final system state as described in the present section enables all economic consequences of the applied system variant and scenario of exogenous conditions to be attributed to the net farm income (NFI_{im}). Prior to the actual simulations it was rather difficult to predict the importance of the valuation of the final system state. Of course, CIV_{im} was expected to be zero, and valuation of the final system state could be expected to be of minor importance. On the other hand, however, it was possible particularly cultivation-schedules of batches present in the final system state were adapted, which would make valuation probably a relevant issue. Anyway, valuation of present growing batches was considered an interesting problem from a theoretical point of view and therefore analyzed in the present study.

Finally, all three applied tactical production plans were analyzed with respect to their initial (and consequently final) system state (table 7.1). The initial system state of tactical production plan P_2 involved most present growing plants and the largest average batch size. This should be attributed to the relatively large batch potted just before the end of the year under this tactical production plan (figure 5.5). Furthermore, the total current variable costs over all present batches were calculated as indication of the initial system state value.

Table 7.1 Some characteristics of the initial (and final) system state of the three applied tactical production plans in the present study.

	Tactical production plan		
	P_1	P_2	P_3
Number of batches present in the initial system state	7	7	8
Number of plants present in the initial system state	56,039	72,902	58,836
Average batch size	8,006	10,415	7,355
Total current variable costs (Dfl.)	62,068	80,422	65,752
Average current variable cost per plant present in the initial system state (Dfl. plant^{-1})	1.11	1.10	1.12

8

SIMULATION OF OPERATIONAL DECISION-MAKING

8.1 Introduction

Operational decision-making was incorporated in the pot plant nursery model in accordance with the theoretical framework described in section 3.3. Hence, the operational decision-making model simulates: (1) progress decision-making based on monitoring, (2) adoption decision-making on the single batch level, and (3) adoption decision-making on the multi batch level. Moreover, the model was structured in such a way that all five strategies of operational management could be analyzed. Finally, special attention was directed to the simulation of the attitude to operational price risk in relation to operational delivery decision-making.

8.2 Operational management

8.2.1 Definition of operational management options

In order to enable the simulation of all five strategies of operational management the decision-making structure described in the theoretical framework (figure 3.1) was modelled. With respect to progress decisions three options to respond to deviating crop growth and price formation records were formulated and incorporated in the model:

1. No consideration of operational problems despite any discrepancies in crop growth or price formation.

2. Consideration of type I and II operational problems, which relate to crop growth discrepancies.

3. Consideration of type I and II operational problems, which relate to discrepancies in crop growth, as well as type III and IV operational problems, which relate to discrepancies in price formation.

These options were applied in accordance with the specification of strategies of operational management applied in the present study (table 4.1). The first option was applied for simulations under the *passive* strategy (S_1) only. As a result, operational management was completely disregarded and all cultivation-schedules were implemented according to the given tactical production plan. Furthermore, the second option was applied for the *product quality* strategy (S_2), the *profitability* strategy (S_3) and the *flexible delivery* strategy (S_4). These strategies related to operational management with respect to crop growth only. Finally, the third option for monitoring was applied for the *active marketing* strategy (S_5). Thus, the number and types of operational problems depended on the option for progress decision-making triggered by the applied strategy of operational management.

In addition, two optional criteria for adoption decisions were formulated and incorporated in the model:

1. Restoration of compatibility between the tactical production plan and reality irrespective of profitability.

2. Restoration of compatibility between the tactical production plan and reality considering also profitability.

Because under the *passive* strategy (S_1) no operational problems were detected, no criterion for adoption decision-making at all was applied. Moreover, the first criterion was only applied for simulations under the *product quality* strategy (S_2). The intention of this strategy was to deliver all pot plants with standard product attributes. The second option was applied for the *profitability* strategy (S_3), the *flexible delivery* strategy (S_4) and the *active marketing* strategy (S_5). In fact, this second criterion involved a maximization of short term profit rather than the pursuit of a 'quality image' on the long term (table 4.1).

Apart from the criteria for progress and adoption decisions, the possibilities for the adaptation of cultivation-schedules, and thus for generating alternatives for the solution of operational problems, had to be formulated and incorporated. On the single batch level adaptation of cultivation-schedules could only involve problem batches, i.e. batches with operational problems at the moment. In the present study, these adaptations involved advancement or postponement of deliveries. In this respect, the number of delivery batches as well as the distribution of plants over these delivery batches could not be affected. As pointed out, in the present study the arrangement of delivery batches was based on a fixed pattern. Thus, advancement or postponement related to complete delivery patterns in case of operational crop growth problems and to individual delivery batches in case of operational problems due to price formation. So, since only under the *active marketing* strategy (S_5) the latter type of operational problems were considered, all other strategies related to advancement or postponement of complete delivery patterns. One exception, however, was made. In case of delayed crop growth, the complete delivery pattern could be postponed, but additionally it was also made possible to postpone all deliveries to the originally planned moment of delivery of the last delivery batch. This additional possibility enabled a limited postponement of deliveries without additional greenhouse area requirements.

On the multi batch level adaptation of cultivation-schedules could not only relate to current problem batches, but to all present and planned future batches. In the present study, the adaptation of cultivation-schedules of batches without operational problems could involve: (1) advancement of planned deliveries, (2) additional respacing, (3) postponement of spacing and (4) postponement of potting (table 8.1). Each of these cultivation-schedule adaptations resulted in additional slack of greenhouse area or labour, which could be applied to solve current operational problems by adopting the alternatives selected on the single batch level.

Table 8.1 Types of adaptations of pot plant cultivation-schedules applied in the present study.

Type of adaptation	Number of alternatives per batch	Effect on gr. h. area requir.[b)]	Effect on labour requir.[b)]	Effect on cultivation -period [c)]
<u>Single batch level:</u>				
Adv.[a)] of complete delivery batches	1	-	+/-	-
Adv. of individual delivery batches	>1	-	+/-	-
Postp.[a)] of deliveries due to delayed crop growth	2	+	-/+	+
Postp. of individual delivery batches	>1	+	-/+	+
<u>Multi batch level:</u>				
Adv. of planned deliveries	1	-	+/-	-
Respacing of partly delivered batches	1	-	+	none
Postp. of spacing	≥ 1	-	-/+	(+)
Postp. of potting new batches	1	-	-/+	(+)

[a)] 'Adv.'=advancement; 'Postp.'=postponement.

[b)] '-' = reduced resource requirements; '+' = extra resource requirements;
'+/-' = first extra requirements and later reduced requirements;
'-/+' = first reduced requirements and later extra requirements.

[c)] '-' = shorter cultivation-period; '+' = longer cultivation-period; '(+)' = possibly longer cultivation-period, not necessarily however.

In the present study, the advancement of planned deliveries related to batches which were not in the delivery phase and which were at least one week ahead in crop growth. Consequently, the cultivation-period of the particular batch could be reduced with one week. Furthermore, respacing could be applied for every partially delivered batch, i.e. between the delivery of the first and second delivery batch. Finally, spacing as well as potting could be postponed one week for entire batches. In conclusion, eight types of cultivation-schedule adaptations were incorporated in the operational management model. In table 8.1 for each type of adaptation the number of alternatives per batch, the effect on greenhouse area and labour requirements, and the effect on the cultivation-period of the particular batch are indicated.

Finally, the criterion for feasibility of the tactical production plan had to be defined. In the present study, the tactical production plan was considered feasible if the resource constraints for greenhouse area and labour were not violated. Moreover, these resource constraints were applied in a lexicographical order of priority. Although this method can be criticized (Keeney & Raiffa, 1976; Neufville, 1990), it was applied in the present study because greenhouse area was regarded more restrictive as a constraint compared to labour. In fact, additional labour was available to a limited extent.

8.2.2 Progress decision-making

In the operational decision-making model, progress decisions are based on monitoring all batches in the delivery phase for operational problems. If one or more operational problems are detected for a particular batch, the progress decision for this batch is negative. With respect to operational problems due to crop growth discrepancies (type I and II operational problems), it is checked whether the delivery criterion is attained in accordance with the current tactical production plan. If a batch has attained the delivery criterion before the planned moment, an advancement of planned deliveries is considered. In this respect, advancement of deliveries should forestall price reduction due to a crop weight which exceeds the transitional value W^+. Moreover, if a batch has not attained the delivery criterion, although deliveries are planned to start at the instant, a postponement of planned deliveries is considered. Furthermore, with respect to operational problems due to discrepancies between tactical price forecasts on the one hand, and operational price forecasts and actual prices on the other hand (type III and IV operational problems), it is checked whether advanced or postponed deliveries could improve profitability of the particular batch.

8.2.3 Single batch adoption decision-making

In order to solve the operational problems on the single batch level alternatives are generated for all problem batches individually. If the operational problem is due to advanced crop growth, the entire delivery pattern may be advanced. Hence, the second delivery batch is also in the alternative cultivation-schedule planned to be delivered in the week following the first delivery. Consequently, these problem batches have only one alternative: starting deliveries on the instant. If the operational problem, however, is due to delayed crop growth, two alternative cultivation-schedules are generated. As pointed out, the first alternative involves a postponement of the complete delivery pattern, whereas the second alternative involves a postponement of the first delivery batch only. Furthermore, in case of operational problems due to price formation several alternative cultivation-schedules may be generated, by advancing and postponing individual delivery batches independently.

For every operational problem (k) a set of alternatives (A_k) is composed. If A_k is empty, of course no adoption decision can be made. Moreover, in case A_k consists of only one alternative, this alternative is automatically regarded as candidate for adoption with respect to the particular operational problem. Since this candidate restores compatibility between the tactical production plan and reality, it should be adopted. The criteria for adoption, however, may consider also profitability. Therefore, the expected economic effect on the short term is determined for every alternative (a).

The economic effect (EE_a) is calculated as the effect on the expected gross margin. Here, fixed costs are left out of consideration, because they do not affect the operational decision. In fact, fixed costs relate to limited resources, which are applied as constraints in operational decision-making.

Thus, in case the adoption criterion concerns profitability, candidates for adoption with negative expected economic effects are rejected directly. In addition, EE_a is also applied to select the most profitable alternative in case A_k consists of multiple alternatives for the particular operational problem. As a consequence, for every problem batch one alternative may be selected as a solution for the particular operational problem under the condition of feasibility of the tactical production plan. These selected alternatives are included in the preliminary solution set (Ω). Subsequently, the preliminary solution set is projected on the current tactical production plan.

Feasibility of the tactical production plan is determined by checking whether resource constraints are violated. For this purpose, the expected consequences on the resource constraints (greenhouse area and labour) are determined for every selected alternative (ω) in the preliminary solution set Ω. Moreover, the operational decision horizon (T), i.e. the most remote moment in which any selected alternative requires limited resources, is determined. Thus, for every selected alternative the organizational effect ($AR_{\omega ct}$) on every constraint (c) can be determined for every week from the current week ($t=t^*$) until T. In fact, a positive value of $AR_{\omega ct}$ represents an additional requirement of resource. Such additional requirements can be satisfied by slack resources (Sl_{ct}). Consequently, decreased resource requirements, i.e. negative $AR_{\omega ct}$ values, lead to additional slack resources. So, for all constraints the projected slack (PS_{ct}) can be calculated for every week until T (equation 8.1).

$$PS_{ct} = \sum_{\omega=1}^{\Omega}\left(Sl_{ct} - AR_{\omega ct}\right) \tag{8.1}$$

PS_{ct}:	Projected slack of the limited resource c in week t according to the tactical production plan after adaptation.
Sl_{ct}:	Slack of the limited resource c in week t according to the current tactical production plan.
$AR_{\omega ct}$:	Additional requirement of limited resource c in week t of the selected alternative ω.
Ω:	Current number of alternatives in the preliminary solution set Ω.

Negative projected slacks indicate resource deficits (RD_{ct}), which jeopardize feasibility of the tactical production plan (equations 8.2 and 8.3).

$$RD_{ct} = -PS_{ct} \qquad \text{(if } PS_{ct} < 0\text{)} \tag{8.2}$$

$$RD_{ct} = 0 \qquad \text{(if } PS_{ct} \geq 0\text{)} \tag{8.3}$$

RD_{ct}: Resource deficit of the limited resource c in week t after projection of Ω on the current tactical production plan.
PS_{ct}: Projected slack of the limited resource c in week t according to the tactical production plan after adaptation.

In order to determine whether feasibility of the tactical production plan is jeopardized by the current preliminary solution set Ω, all resource deficits are aggregated for every individual resource constraint over the operational planning-period (equation 8.4).

$$OF_c = \sum_{t=t^*}^{T} RD_{ct} \tag{8.4}$$

OF_c: Objective function for limited resource of type c.
RD_{ct}: Resource deficit of the limited resource c in week t after projection of Ω on the current tactical production plan.

Thus, the greenhouse area constraint is violated if the associated objective function (OF_1) is greater than zero. Similarly, the labour constraint is violated if the associated objective function (OF_2) is greater than zero. In this respect, aggregated resource deficits are referred to as objective functions, because of the pursued feasibility of the tactical production plan. Consequently, if the feasibility of the tactical production plan is not jeopardized, Ω is regarded as final solution set and all included alternatives are adopted. If feasibility of the tactical production plan, however, is jeopardized by the current preliminary solution set, further analysis on the multi batch level is required to solve current operational problems.

8.2.4 Multi batch adoption decision-making

On the multi batch level all operational problems and all batches are considered simultaneously. Therefore, one general set of alternatives (A) is composed. This general set of alternatives consists of all K sets A_k for the individual operational problems and additionally generated alternatives.

These new alternatives involve batches without operational problems, from which cultivation-schedules are adapted with respect to potting, spacing, deliveries and respacing. After the set **A** is established, organizational effects (AR_{act}) and economic effects (EE_a) are determined for every alternative (a). Moreover, the decision horizon (T) is determined again. The decision basis is completed with the definition of one more alternative. This alternative does not relate to any batch, but represents the employment of extra labour at a fixed price per hour. Subsequently, this set of alternatives is applied in an iterative heuristic search procedure in order to find a feasible solution set.

Every iteration of the heuristic search procedure consists of four consecutive steps. In every iteration only one alternative included in **A** can be added to Ω or one selected alternative (ω) can be removed from Ω. In fact, the modelled search procedure involves a solution-generating heuristic, as defined by Dannenbring and Starr (1981), with add and drop heuristics. The best immediate option, i.e. the alternative with the largest per-unit contribution to the current objective function, is selected to be either included or excluded from Ω. In the first step of the heuristic search procedure the set of currently optional alternatives A^* is composed based on A and the current contents of Ω. For all selected alternatives in Ω reversal alternatives are included in A^*. These reversal alternatives represent the removal of the particular selected alternative from Ω. Consequently, reversal alternatives have opposite organizational and economic effects compared to the corresponding selected alternatives. Furthermore, all alternatives that do not relate to a batch with already an alternative included in Ω are also included in A^*. Thus, the preliminary solution set can also on the multi batch level contain only one alternative per batch at the most.

In the second step of the heuristic search procedure all optional alternatives are examined with respect to the currently relevant effect on resource constraints over the operational planning-period. For this purpose a decision table is applied (table 8.2). The upper part of the decision table consists of conditions with respect to the effect of the particular alternative on the particular resource constraint and the deficit of the particular constraint. Moreover, the lower part defines the procedure for determining the relevant effect of the alternative on the particular resource (rE_{act}). In this respect, the decision table provides a clear survey of the process (Vanthienen, 1988). Moreover, it relates to the application of IF-THEN knowledge rules as described by for instance Rellier & Chédru (1992) and Turban (1990). Hence, the relevant effect rE_{act} is determined based on the principle of contribution to objectives (Koontz & O'Donnell, 1976).

Table 8.2 Decision table for the determination of rE_{act}.

$PS_{ct} < 0$?	yes			no		
$AR_{act} > 0$?	yes	no		yes		no
$AR_{act} > PS_{ct}$	yes	yes	no	yes	no	no
$rE_{act} = 0$					☐	☐
$rE_{act} = PS_{ct}$			☐			
$rE_{act} = -AR_{act}$	☐	☐				
$rE_{act} = PS_{ct} - AR_{act}$				☐		

Table 8.2 shows rE_{act} equals zero, if there is no current resource deficit, except if the additional requirement exceeds the available slack. Moreover, if there is already a current resource deficit, rE_{act} equals $-AR_{act}$, except if adaptation is projected to reduce resource requirements to an extent larger than the current resource deficit. Subsequently, these derived relative effects rE_{act} are aggregated again over the whole operational planning-period (equation 8.5).

$$trE_{ac} = \sum_{t=1}^{T} rE_{act} \tag{8.5}$$

trE_{ac}: Total relevant effect of alternative a on constraint c.
rE_{act}: Relevant effect of alternative a on constraint c in week t.

The total relevant effect (trE_{ac}) represents the contribution of the alternative to the satisfaction of the particular constraint c in case the alternative is included in the preliminary solution set Ω. Hence, a positive trE_{ac} indicates that OF_c will be reduced if the alternative is selected.

In the third step of the heuristic search procedure the best immediate alternative in A^* is determined. This best immediate alternative (α) may either represent an alternative to be added to Ω or an alternative to be removed from Ω, i.e. a reversal alternative. In order to determine this alternative (α) one out of two optional criteria is applied. In case of a desired reduction of the current objective function irrespective of profitability equation 8.6 is applied. Moreover, if profitability should also be considered, equation 8.7 is applied.

$$trE_{\alpha c} = \max_{a}\left\{trE_{ac} \middle| trE_{ac>0}\right\} \tag{8.6}$$

$trE_{\alpha c}$:	Total relevant effect of the selected alternative α on constraint c.

$$EE_{\alpha} / trE_{\alpha c} = \max_{a}\left\{EE_{a} / trE_{ac} \middle| trE_{ac>0}\right\} \tag{8.7}$$

EE_{α}:	Expected economic effect of the selected alternative α (Dfl.).
$trE_{\alpha c}$:	Total relevant effect of the selected alternative α on constraint c.

Equations 8.6 and 8.7 are initially applied for the greenhouse area constraint (c=1). If $OF_1=0$, however, the labour constraint is considered (c=2). Moreover, if two or more alternatives are equal with respect to the applied criterion, the other criterion is applied. In addition to the condition of a positive trE_{ac}, three other conditions may be applied depending on the current situation. If $OF_1=0$, i.e. the greenhouse area constraint is satisfied, the additional condition i (equation 8.8) is applied in order to assure that the greenhouse area constraint is not violated again.

$$\text{i:} \quad trE_{\alpha 1} \geq 0 \tag{8.8}$$

$trE_{\alpha 1}$:	Total relevant effect of alternative α on the greenhouse area constraint.

Furthermore, if $OF_1=0$ and $EE_{\alpha}<0$, the additional condition ii (equation 8.9) is applied in order to determine whether it would be economical to satisfy the labour constraint with extra hired labour.

$$\text{ii:} \quad -EE_{\alpha} / trE_{\alpha 2} < PhL \tag{8.9}$$

EE_{α}:	Expected economic effect of the selected alternative α (Dfl.).
$trE_{\alpha 2}$:	Total relevant effect of the selected alternative α on the labour constraint (h).
PhL:	Price of hired labour (Dfl. h^{-1}).

Both additional conditions i and ii are applied for equation 8.6 as well as equation 8.7. Finally, if equation 8.7 is applied and $EE_\alpha<0$, the additional condition iii (equation 8.10) is applied in order to determine whether the anticipated new preliminary solution set is expected to be profitable as a whole.

$$\text{iii:} \quad -EE_\alpha \leq \sum_{\omega=1}^{\Omega} EE_\omega \tag{8.10}$$

EE_α:	Expected economic effect of the selected alternative α (Dfl.).
EE_ω:	Expected economic effect of the alternative ω included in Ω (Dfl.).
Ω:	Current number of alternatives in the preliminary solution set Ω.

Thus, the best immediate alternative α is determined. If α involves a reversal alternative, the corresponding alternative ω is removed from Ω. Moreover, it is removed from **A** in order to avoid cycling. Furthermore, if α does not involve a reversal alternative, it is added to Ω.

Subsequently, in the fourth step of the heuristic search procedure the preliminary solution set is projected again on the current tactical production plan. If all constraints are satisfied, Ω is regarded as final solution set for current operational problems. If one or more resource constraints are still violated, the heuristic search for a feasible solution continues with the next iteration. This process continues until a feasible solution set is found or Ω is empty. Moreover, if Ω does no longer include alternatives of problem batches, it is emptied and the heuristic search process is consequently terminated. Hence, after termination of the iterative heuristic search procedure Ω is empty or includes one or more alternative cultivation-schedules for problem batches. In the latter case, of course, Ω may also include alternative cultivation-schedules of batches without operational problems.

Finally, adoption decisions are made based on the contents of the final solution set. So, for all operational problems without an alternative in the final solution set no candidate for adoption is available, and the adoption decision is consequently negative. Furthermore, for all operational problems with an alternative in the final solution set one candidate for adoption is available, which is consequently adopted in the tactical production plan as a replacement of the problematic cultivation-schedule.

Moreover, the alternative cultivation-schedules included in the final solution set and not related to problem batches are adopted also in order to assure feasibility of the tactical production plan.

Hence, not all negative progress decisions lead to adoption of alternative cultivation-schedules in the tactical production plan. In the case of negative adoption decisions advanced or delayed crop growth may lead to price reduction and deliveries may not lead to the highest possible returns for the particular batch. The word 'may' is applied here to indicate uncertainty. This uncertainty is due to the fact that rejection thresholds for progress decisions relate to stochastic processes and to uncertainty during operational decision-making.

In conclusion, the model for progress and adoption decision-making simulates the adaptation of the tactical production plan based on a given strategy of operational management and in response to information about crop growth and price formation. Adoption decision-making particularly on the multi batch level is founded on the principles of linearity, additivity and nonnegativity as formulated by Neufville (1990). Appendix II provides an example of adoption decision-making as modelled in the present study and relates the present heuristic search procedure on the multi batch level to linear programming.

8.3 Attitude to operational price risk

8.3.1 Definition of delivery options

A normative model of delivery decision-making considering the grower's risk attitude was developed based on the expected utility theory (Anderson *et al.*, 1977; Keeney & Raiffa, 1976; Sinn, 1983; Smidts, 1990; Zentner *et al.*, 1981). This model was incorporated in the present pot plant nursery model to simulate the process of operational decision-making with respect to type III and IV operational problems. These types of operational problems relate to a situation where the grower should choose one of two options. The first options (A) concerns immediate delivery of the particular delivery batch and is therefore definitive. The second option (B) is more speculative and concerns delivery at a later moment. Hence, the consequence of the second option (B) is uncertain. Thus, the possible outcomes of the present delivery decision-making model are:

Option *A*: Deliver the delivery batch in week w with a non-random and known price (Pa_w).

Option *B*: Postpone the delivery of the delivery batch to week w+1 with non-random and known additional costs (Ca) and an uncertain future price ($\underline{Pa}_{w+1}$).

For option *B* an operational price forecast (Pf^*_{w+1}) is assumed to be available, where the eventual actual price ($\underline{Pa}_{w+1}$) is randomly simulated from a symmetric distribution with an expected value equal to Pf^*_{w+1} and a variance $\sigma^2\{\underline{Pa}_{w+1}\}$ (section 6.3).

It seems conceivable a grower prefers a certain price (option *A*) instead of the chance of a higher price (option *B*) even if Pa_w is somewhat smaller than Pf^*_{w+1}. In such a situation, the behaviour of the grower is characterized as risk averse. In fact, risk averse behaviour involves preference for a non-random outcome lower than the expected value of the symmetric probability distribution. In this respect, the certainty equivalent (CE) can be defined as the lowest non-random outcome the decision maker is willing to accept in exchange for a probability distribution (Smidts, 1990). The difference between the expected value and the certainty equivalent (CE) is defined as the risk premium (RP), i.e. the amount the decision maker is willing to give up from the expected value in order to avoid the risk associated with a probability distribution (Keeney & Raiffa, 1976). Thus, the utility of the certainty option (*A*) equals the expected utility of the risky option (*B*), if the actual price (Pa_w) equals the certainty equivalent of $\underline{Pa}_{w+1}$. In this respect, utility is usually expressed on a linear scale from zero for the lowest possible outcome to one for the highest possible outcome (Neufville, 1990). Consequently, the utility (u) of every possible outcome (x) of the risky option can be determined by means of the utility function (u(x)).

Generally, utility functions are analyzed to obtain information about the decision-maker's attitude toward risk (Keeney & Raiffa, 1976; Neufville, 1990). It should be noticed, however, ratios between measures on an ordered metric scale do not have any meaning. Moreover, a linear utility function corresponds with risk neutral behaviour, whereas a concave utility function indicates risk aversion and a convex utility function indicates risk preference. In case of a non-neutral risk attitude the degree of risk aversion or risk preference can be expressed by the coefficients of absolute and proportional risk aversion as defined by Pratt (1964) and Arrow (1965)[1].

In the present model, a constant Pratt-Arrow coefficient of absolute risk aversion is assumed, since all individual delivery decisions contributed to the same objective, i.e. maximization of the annual profit. Hence, every individual delivery decision during the simulated implementation of the tactical production plan is taken with the same urge to increase the annual profit. Such a constantly risk averse or a constantly risk seeking attitude corresponds with a negative exponential utility function (equation 8.11) and a constant Pratt-Arrow coefficient of absolute risk aversion (r).

$$u(x) = 1 - e^{\left(-r \times \left[x - \min(x)\right]\right)} / 1 - e^{\left(-r \times \left[\max(x) - \min(x)\right]\right)} \qquad (8.11)$$

u(x): Utility function of an outcome x, with $\min(x) \leq x \leq \max(x)$.
r: Pratt-Arrow coefficient of absolute risk aversion.

In equation 8.11 a positive Pratt-Arrow coefficient of absolute risk aversion (r) results in a concave curve and represents risk aversion, whereas a negative the Pratt-Arrow coefficient of absolute risk aversion (r) results in a convex curve and represents risk preference. Table 8.3 shows the possible values of the risk premium (RP), the certainty equivalent (CE) and the Pratt-Arrow coefficient of absolute risk aversion (r) as well as the shape of the utility function in case of risk averse, risk neutral and risk seeking behaviour. Figure 8.1 shows utility functions which correspond with mean levels of risk aversion found by Smidts (1990), who did an extensive investigation on marketing decisions of Dutch potato producers under price risk. In this investigation the expected price was 40 cts. kg^{-1} with a minimum of 10 cts. kg^{-1} and a maximum of 70 cts. kg^{-1}. According to equation 8.11, the certainty equivalent ($u(x)=0.50$) equals 27.7 cts. kg^{-1} for the Pratt-Arrow coefficient of absolute risk aversion of $r=0.031$. Thus, with an expected price of 40 cts. kg^{-1}, the risk premium equals 12.3 cts. kg^{-1} at this level of risk aversion.

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[1] In case of absolute risk aversion, deviations from the expected value are perceived as absolute amounts, whereas in case of proportional risk aversion deviations are perceived as percentages of the expected value.

Table 8.3 Summary of characteristics of risk averse, risk neutral and risk seeking behaviour.

Attitude to risk	RP	CE	r	utility function
risk averse	>0	<*E*(x)	>0	concave
risk neutral	=0	=*E*(x)	=0	linear
risk seeking	<0	>*E*(x)	<0	convex

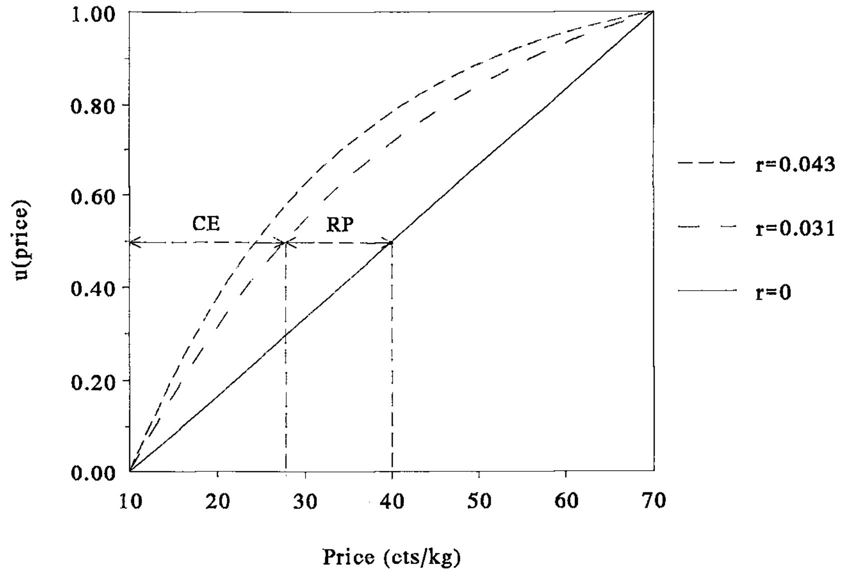

Figure 8.1 Utility functions as determined among Dutch potato producers in 1984 (r=0.043) and 1985 (r=0.031) (Smidts, 1990).

8.3.2 Structure of the decision model

Although the reason for modelling the grower's risk attitude was price risk, the price per plant is not an appropriate measure to evaluate risk related to delivery in pot plant production. In fact, the grower can not deliver individual plants. Instead, the delivery batch is the smallest unit for which one of the two options can be chosen. Moreover, in the present study the size of the delivery batches was fixed in the applied tactical production plans and delivery batches of various sizes were delivered throughout every simulation run. Hence, the delivery decision was expected to depend also on the size of the batch (n_h). Therefore, the net return of the certainty option (nR_A) was compared with the certainty equivalent of the random net return of the risky option (CE_B).

The net return of the certainty option depends on the current actual price (Pa_w) minus auction commission (table 5.2) multiplied by the number of plants of the delivery batch (equation 8.12).

$$nR_A = n_h \times 0.94 \times Pa_w \tag{8.12}$$

nR_A: Net return of option A (Dfl.).
n_h: Number of plants of the particular delivery batch.
Pa_w: Actual price in week w (Dfl. plant^{-1}).

With respect to the risky option (B), the expected future net return ($E(\underline{nR}_B)$) is determined similarly. The postponement of delivery, however, can also be expected to lead to additional costs (Ca) (equation 8.13).

$$E\left(\underline{nR}_B\right) = n_h \times 0.94 \times E\left(\underline{Pa}_{w+1}\right) - Ca \tag{8.13}$$

$E(\underline{nR}_B)$: Expected future net return of option B (Dfl.).
n_h: Number of plants of the particular delivery batch.
$E(\underline{Pa}_{w+1})$: Expected actual price in week w+1 (Dfl plant^{-1}).
Ca: Additional costs of postponed delivery (Dfl.).

Recalling equation 6.9, $E(\underline{Pa}_{w+1})$ is equal to the operational price forecast (Pf^*_{w+1}), because the incidental price deviation ($\underline{d}_{w+1}$) is normally distributed with a mean equal to one and a variance equal to 0.0529 (equation 6.14).

According to Keeney & Raiffa (1976) the certainty equivalent of option B (CE_B) can be calculated with equation 8.14 under the assumption of a negative exponential utility function, i.e. a constant Pratt-Arrow coefficient of absolute risk aversion (r), and normally distributed net returns.

$$CE_B \approx \mu\{\underline{nR}_B\} - 0.5 \times r \times \sigma^2\{\underline{nR}_B\} \tag{8.14}$$

CE_B: Certainty equivalent of option B (Dfl.).
$\mu\{\underline{nR}_B\}$: Mean net return of option B (Dfl.).
r: Pratt-Arrow coefficient of absolute risk aversion Dfl.$^{-1}$).
$\sigma^2\{\underline{nR}_B\}$: Variance of the net return of option B (Dfl^2).

Equation 8.14 can be derived through a second order Taylor series expansion of the utility function (equation 8.11). This derivation can be found for example in Keeney & Raiffa (1976) page 161.

In order to apply equation 8.14 the mean (μ) and the variance (σ^2) of the distribution of $\underline{nR}_B$ are determined. As pointed out in section 6.3, $\underline{Pa}_{w+1}$ is normally distributed around Pf^*_{w+1}. Therefore, $\mu\{\underline{nR}_B\}$ can be determined according to equation 8.15.

$$\begin{aligned} \mu\{\underline{nR}_B\} &= E(\underline{nR}_B) \\ &= n_h \times 0.94 \times E(\underline{Pa}_{w+1}) - Ca \\ &= n_h \times 0.94 \times Pf^*_{w+1} - Ca \end{aligned} \tag{8.15}$$

$\mu\{\underline{nR}_B\}$: Mean net return of option B (Dfl.).
$E(\underline{nR}_B)$: Expected future net return of option B (Dfl.).
n_h: Number of plants of the particular delivery batch.
$E(\underline{Pa}_{w+1})$: Expected actual price in week w+1 (Dfl. plant^{-1}).
Ca: Additional costs of postponed delivery (Dfl.).
Pf^*_{w+1}: Operational price forecast for week w+1 (Dfl. plant^{-1}).

Besides the certainty equivalent of option B (CE_B), the risk premium of option B (RP_B) can be calculated. Since the expected value of option B ($E(\underline{nR}_B)$) is equal to $\mu\{\underline{nR}_B\}$, the risk premium of option B (RP_B) can be calculated according to equation 8.16.

$$\begin{aligned} \mathrm{RP}_B &= E\left(\underline{\mathrm{nR}}_B\right) - \mathrm{CE}_B \\ &= 0.5 \times \mathrm{r} \times \sigma^2\left\{\underline{\mathrm{nR}}_B\right\} \end{aligned} \qquad (8.16)$$

RP_B: Risk premium of option B (Dfl.).
$E(\underline{\mathrm{nR}}_B)$: Expected future net return of option B (Dfl.).
CE_B: Certainty equivalent of option B (Dfl.).
r: Pratt-Arrow coefficient of absolute risk aversion ($\mathrm{Dfl.}^{-1}$).
$\sigma^2\{\underline{\mathrm{nR}}_B\}$: Variance of the net return of option B ($\mathrm{Dfl.}^2$).

In order to determine $\sigma^2\{\underline{\mathrm{nR}}_B\}$ equations 6.9 and 8.15 are combined (equation 8.17).

$$\begin{aligned} \underline{\mathrm{nR}}_B &= \mathrm{n_h} \times 0.94 \times \underline{\mathrm{Pa}}_{\mathrm{w+1}} - \mathrm{Ca} \\ &= \mathrm{n_h} \times 0.94 \times \mathrm{Pf}^*_{\mathrm{w+1}} \times \underline{\mathrm{d}}_{\mathrm{mw+1}} - \mathrm{Ca} \end{aligned} \qquad (8.17)$$

$\underline{\mathrm{nR}}_B$: Random net return of option B (Dfl.).
$\mathrm{n_h}$: Number of plants of the particular delivery batch.
$\underline{\mathrm{Pa}}_{\mathrm{w+1}}$: Random actual price in week w+1 (Dfl. plant^{-1}).
Ca: Additional costs of postponed delivery (Dfl.).
$\underline{\mathrm{d}}_{\mathrm{mw+1}}$: Random incidental price deviation ratio in week w+1 of scenario $\mathrm{E_m}$.
$\mathrm{Pf}^*_{\mathrm{w+1}}$: Operational price forecast for week w+1 (Dfl. plant^{-1}).

Thus, the variance of the net return of option B ($\sigma^2\{\underline{\mathrm{nR}}_B\}$) can be determined according to equation 8.18.

$$\begin{aligned} \sigma^2\left\{\underline{\mathrm{nR}}_B\right\} &= \left(\mathrm{n_h}\right)^2 \times (0.94)^2 \times \left(\mathrm{Pf}^*_{\mathrm{w+1}}\right)^2 \times \sigma^2\left\{\underline{\mathrm{d}}_{\mathrm{w+1}}\right\} \\ &= \left(\mathrm{n_h}\right)^2 \times (0.94)^2 \times \left(\mathrm{Pf}^*_{\mathrm{w+1}}\right)^2 \times 0.0529 \end{aligned} \qquad (8.18)$$

$\sigma^2\{\underline{\mathrm{nR}}_B\}$: Variance of the net return of option B (Dfl^2).
$\mathrm{n_h}$: Number of plants of the particular delivery batch.
$\mathrm{Pf}^*_{\mathrm{w+1}}$: Operational price forecast for week w+1 (Dfl. plant^{-1}).
$\sigma^2\{\underline{\mathrm{d}}_{\mathrm{w+1}}\}$: Variance of the incidental price deviation in week w+1.

Since r is constant as well as $\sigma^2\{\underline{\mathrm{d}}_{\mathrm{w+1}}\}$, RP_B depends on the size of the batch ($\mathrm{n_h}$) and the level of the operational price forecast ($\mathrm{Pf}^*_{\mathrm{w+1}}$). Consequently, option B is only chosen if $\mathrm{CE}_B > \mathrm{nR}_A$ (equations 8.19 to 8.24).

$$\mathrm{CE}_B > \mathrm{nR}_A \tag{8.19}$$

$$\Leftrightarrow \mu\{\underline{\mathrm{nR}}_B\} - \mathrm{RP}_B > \mathrm{nR}_A \tag{8.20}$$

$$\Leftrightarrow \left(\mathrm{n_h} \times 0.94 \times \mathrm{Pf}^*{}_{\mathrm{w+1}}\right) - \mathrm{Ca} - \mathrm{RP}_B > \mathrm{n_h} \times 0.94 \times \mathrm{Pa_w} \tag{8.21}$$

$$\Leftrightarrow \mathrm{n_h} \times 0.94 \times \left(\mathrm{Pf}^*{}_{\mathrm{w+1}} - \mathrm{Pa_w}\right) > \mathrm{Ca} + \mathrm{RP}_B \tag{8.22}$$

$$\Leftrightarrow \mathrm{n_h} \times 0.94 \times \left(\mathrm{Pf}^*{}_{\mathrm{w+1}} - \mathrm{Pa_w}\right) > \mathrm{Ca} + \left(0.5 \times \mathrm{r} \times \sigma^2\{\underline{\mathrm{nR}}_B\}\right) \tag{8.23}$$

$$\begin{aligned}\Leftrightarrow \mathrm{n_h} \times 0.94 \times \left(\mathrm{Pf}^*{}_{\mathrm{w+1}} - \mathrm{Pa_w}\right) &> \\ \mathrm{Ca} + \left(0.5 \times \mathrm{r} \times (\mathrm{n_h})^2 \times (0.94)^2 \times (\mathrm{Pf}^*{}_{\mathrm{w+1}})^2 \times 0.0529\right)\end{aligned} \tag{8.24}$$

CE_B:	Certainty equivalent of option *B* (Dfl.).
nR_A:	Net return of option *A* (Dfl.).
$\mu\{\underline{\mathrm{nR}}_B\}$:	Mean net return of option *B* (Dfl.).
RP_B:	Risk premium of option *B* (Dfl.).
$\mathrm{n_h}$:	Number of plants of the particular delivery batch.
$\mathrm{Pf}^*{}_{\mathrm{w+1}}$:	Operational price forecast for week w+1 (Dfl. plant^{-1}).
$\mathrm{Pa_w}$:	Actual price in week w (Dfl. plant^{-1}).
Ca:	Additional costs of postponed delivery (Dfl.).
RP_B:	Risk premium of option *B* (Dfl.).
r:	Pratt-Arrow coefficient of absolute risk aversion (Dfl.$^{-1}$).
$\sigma^2\{\underline{\mathrm{nR}}_B\}$:	Variance of the net return of option *B* (Dfl^2).

In order to satisfy the constraint represented in equations 8.19 to 8.24 and to decide to postpone deliveries larger batches and batches with higher operational price forecasts, i.e. batches with higher expected future net returns, require larger differences between $\mathrm{Pf}^*{}_{\mathrm{w+1}}$ and $\mathrm{Pa_w}$. This phenomenon is due to the quadratic effects in equation 8.18 and consequently on RP_B (equations 8.23 and 8.24). This effect corresponds with the assumed absolute aversion to the risk of net return associated with option B.

8.3.3 Specification of price risk attitudes

In the present price risk attitude model, constant absolute risk aversion is assumed as in similar studies, like Arnold (1988), Bosch & Eidman

(1987), Chalfant *et al.* (1990) and McSweeny *et al.* (1987). The assumption of constant absolute risk aversion, however, is also criticized (Cochran *et al.*, 1990; Dyer & Sarin, 1982). It is argued that risk aversion is relative to wealth. In the present study, however, the change in wealth over the simulation-period is relatively small. As pointed out before, the efforts of the grower to increase profit are assumed constant throughout every simulation run.

Specification of the Pratt-Arrow coefficient of absolute risk aversion was rather problematic, because this variable has no general absolute meaning (Allais, 1984). Howard (1988) relates the level of risk tolerance[2] to sales, net income and equity of larger companies. In order to specify the constant Pratt-Arrow coefficient of absolute risk aversion in the present study the same procedure was applied on published data with respect to risk in farm management (table 8.4).

Table 8.4 Risk tolerance (τ) relative to before tax net income (BTNI) as derived from some studies on farm management.

	Chalfant *et al.* (1990)	McSweeny *et al.* (1987)	Bosch & Eidman (1987)	Bosch & Eidman (1987)
BTNI (1000 $)	62.6 to 77.1	39 to 40.2	46.3	46.3
r (10^{-3} $\$^{-1}$)	0.35 to 2.92	0.4	0.1 to 0.3	0.3 to 1.5
τ ($)	342 to 2857	2500	3333 to 10^4	667 to 3333
τ / BTNI (10^{-3})	4 to 46	62 to 64	72 to 216	14 to 72

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[2] Clemen (1991) and Howard (1988) measure risk tolerance (τ) instead of risk aversion, where $\tau=1/r$.

The price risk attitude model was applied to analyze effects of risk averse and risk seeking behaviour on operational management as compared to risk neutral behaviour. Hence, the Pratt-Arrow coefficient of absolute risk aversion is an endogenous variable of the model with a default value $r=0$. This variable was varied in a sensitivity analysis with respect to the attitude to operational price risk. With an average family spending income of approximately 60,000 Dfl. in Dutch pot plant production and with reference to table 8.4 the Pratt-Arrow coefficient of absolute risk aversion was set on $r=0.0002$ for risk averse behaviour and on $r=-0.0002$ for risk seeking behaviour[3]. A second level of risk averse behaviour was defined ($r=0.0004$) in order to analyze effects of very risk averse behaviour.

Evaluation of the specified Pratt-Arrow coefficients

Prior to any simulation, the specified Pratt-Arrow coefficients were evaluated based on six relevant cases of operational delivery decision-making. In these six cases, three values for the number of plants of the delivery batch were applied: $n_h=2500$, $n_h=5000$ and $n_h=7500$. In view of figures 5.4, 5.5 and 5.6 these sizes of delivery batches can be characterized as respectively small, common and large. Furthermore, based on figure 6.9 two values for the operational price forecast were applied: $Pf^{*}_{w+1}=2.50$ and $Pf^{*}_{w+1}=3.50$. The purpose of this exercise was to demonstrate that the specified Pratt-Arrow coefficients of absolute risk aversion lead to a realistic consideration of risk (associated with the operational price forecasts) in the present simulation context.

For each of the six cases the risk premium per plant (RP_B/n_h) was calculated for every risk attitude (table 8.5). In fact, actual delivery decisions based on equations 8.19 to 8.24 were not evaluated. The risk premium per plant increases with the size of the delivery batch and with the operational price forecast (table 8.5). Hence, a grower with a constant Pratt-Arrow coefficient of absolute risk aversion is willing to except a relatively lower price per plant to avoid risk for plants in larger batches and when operational price forecasts are higher. Furthermore, table 8.5 shows the applied values of the Pratt-Arrow coefficient of absolute risk aversion lead to realistic risk premiums per plant.

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[3] This corresponds with a risk tolerance / net income ratio of 83.10^{-3}.

Table 8.5 Effect of batch size and operational price forecast on the risk premium per plant (RP_B/n_h) for the six investigated cases (Dfl. $plant^{-1}$).

		n_h		
		2500	5000	7500
$Pf^*=2.5$	$r = -0.0002$	-0.07	-0.15	-0.22
	$r = 0$	0	0	0
	$r = 0.0002$	0.07	0.15	0.22
	$r = 0.0004$	0.15	0.29	0.44
$Pf^*=3.5$	$r = -0.0002$	-0.14	-0.29	-0.43
	$r = 0$	0	0	0
	$r = 0.0002$	0.14	0.29	0.43
	$r = 0.0004$	0.29	0.57	0.86

The effects of batch size and operational price forecasts are additive since they determine the expected return of option *B*. Figure 8.2 shows a decreasing probability of a random outcome lower than CE_B with increasing expected outcomes of option *B* for $r>0$ and an increasing probability for $r<0$. In this respect, a decreasing probability of a random outcome lower than CE_B refers to lower certainty equivalents (CE_B), since the distribution of the random outcome remains unchanged. So, the model simulates a grower's attitude which, when the stake gets bigger, is more risk averse if $r>0$ and more risk seeking if $r<0$.

As a final check, the magnitude of the present positive values of the Pratt-Arrow coefficient of absolute risk aversion, i.e. $r=0.0002$ and $r=0.0004$, were converted to the context of the investigation by Smidts (1990). This conversion, described in appendix III, resulted in an identical x-axis for all six cases with $\min(\underline{x})=20.56$ cts. and $\max(\underline{x})=80.56$ cts., which approximately corresponds with the 50/50 binary lottery 10 cts. / 70 cts. Smidts applied. Figures 8.3 and 8.4 show the converted Pratt-Arrow coefficients of absolute risk aversion for respectively the original values $r=0.0002$ and $r=0.0004$.

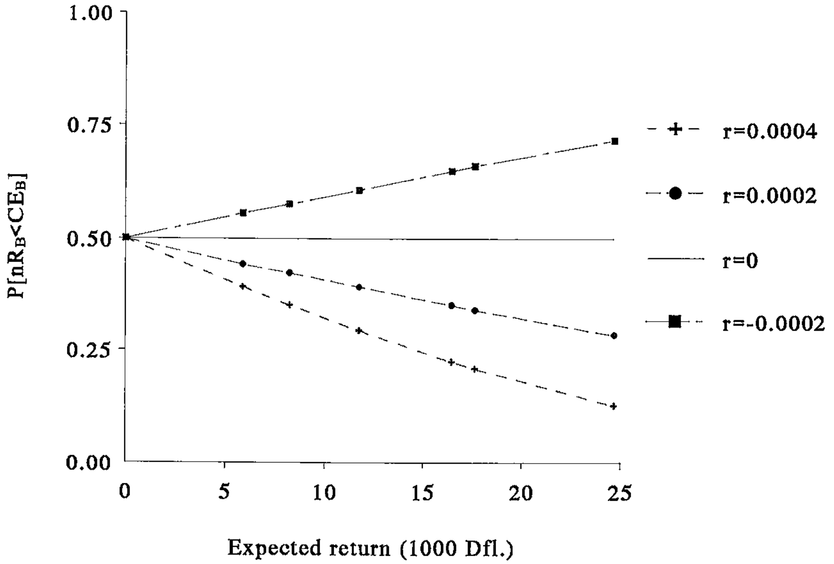

Figure 8.2 Effect of $E(\underline{nR}_B)$ on the probability of a random outcome lower than CE$_B$ for the six investigated cases.

The converted Pratt-Arrow coefficients of absolute risk aversion increase with the size of the delivery batch as well as with the operational price forecast (Pf*). Hence, although a constant attitude to operational price risk (in terms of money) is assumed throughout the simulated year, individual delivery decisions are considered differently depending on the operational price forecast and the size of the delivery batch.

With almost identical x-axes a comparison of the converted values of the Pratt-Arrow coefficients of absolute risk aversion with the mean Pratt-Arrow coefficients of absolute risk aversion found by Smidts seems justifiable. Figure 8.3 demonstrates that r=0.0002 results in a risk averse behaviour which approximately corresponds with what Smidts found. Moreover, figure 8.4 indicates that r=0.0004 represents a rather extreme risk averse attitude. Overall, however, figures 8.3 and 8.4 underline the credibility of the magnitude of the values of the Pratt-Arrow coefficient of absolute risk aversion in the present study.

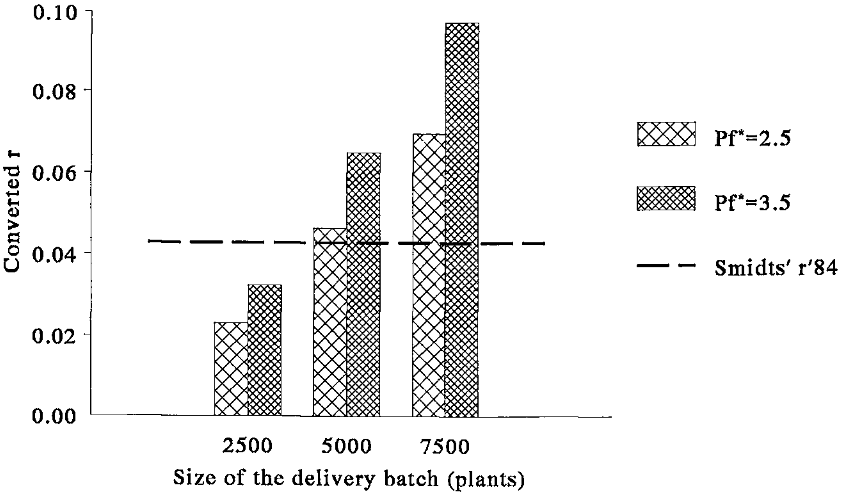

Figure 8.3 Comparison of the converted values of the Pratt-Arrow coefficient of absolute risk aversion from the original value r=0.0002 for the six investigated cases with Smidts (1990).

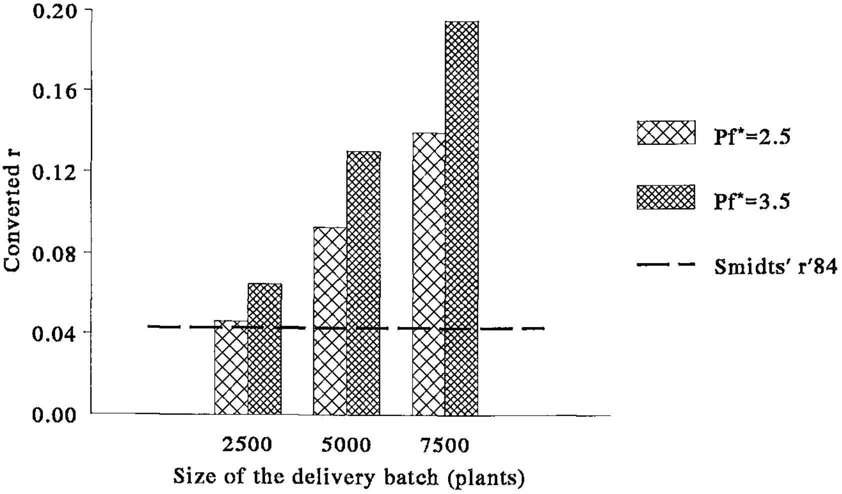

Figure 8.4 Comparison of the converted values of the Pratt-Arrow coefficient of absolute risk aversion from the original value r=0.0004 for the six investigated cases with Smidts (1990).

8.3.4 Appraisal of the model

The present model of operational price risk attitude was inspired by the formulation of the operational problem of reconsidering planned deliveries. Moreover, it affiliates with the general procedure of operational management. Although others, like Berg (1987) and Hanf & Kühl (1986), approach the planning of deliveries as a dynamic problem and apply dynamic optimization techniques, the present model concerns only the decision of delivering at once or not. In the present study, however, the dynamic dimension of the planning of deliveries was assumed to be considered on the tactical level.

Given the present definition of the operational problem of reconsidering planned deliveries, the expected utility theory offers a suitable and widely applied foundation for a normative model. Nevertheless, the expected utility theory is not undisputed (Allais, 1984; Kahneman & Tversky, 1979; Kahneman & Tversky, 1984; Musser & Musser, 1984; Rescher, 1983; Smidts, 1990). Critical reviews, however, concentrate particularly on the application of the theory in positive decision analysis and the measuring of risk aversion. In the present study, expected utility theory was only applied as normative approach commonly accepted in literature. Moreover, risk aversion was not actually measured, but specified within the context of the present study as advocated in such situations by Musser & Musser (1984).

8.4 Evaluation

With the modelling of operational decision-making behaviour by the virtual grower the present pot plant nursery model was completed. As a result, operational problems due to deviating crop growth patterns and price fluctuations could be simulated in a realistic simulation context. Moreover, these operational problems could be solved one way or another. Finally, the consequences of these solutions could be simulated and lead to output of the model.

As pointed out in chapter 4 at the beginning of this part of the thesis, validation of the complete pot plant nursery model was rather problematic. Due to the exploratory character of the research validation of the complete model more or less coincided with its application. Hence, the validity of the complete model, i.e. the degree of confidence in the model for its intended purpose (Gass, 1983), could only be discussed after experimentation with the model. Nonetheless, the appraisal of individual submodels (in the previous chapters) gave sufficient confidence prior to simulation-experimentation to apply the present pot plant nursery model to investigate operational decision-making in pot plant production.

PART III

SIMULATION EXPERIMENTS

9

EXPERIMENTAL DESIGN AND ANALYSIS

9.1 Introduction

After programming and verifying, the pot plant nursery model was applied to investigate the effect of operational management on the implementation of tactical production plans under uncertainty. As pointed out before, the present simulation model was specified for an imaginary, though representative Dutch pot plant nursery producing foliage plants. Hence, simulation experiments served merely an exploratory and demonstration purpose. In this respect, the effects of the formulated operational management strategies on the eventual economic result of the nursery as well as on individual decisions during the implementation of the tactical production plan were analyzed.

Since operational management was thought necessary because of uncertainty during tactical production planning, first the effect of the randomly simulated exogenous conditions on the nursery's economic result was investigated. The stochastic patterns of crop growth and price formation (triggered by exogenous conditions) were expected to result in annual net farm incomes which considerably fluctuated over all 25 replications. To investigate the effect of exogenous condition, net farm income under the *passive* strategy (S_1) was analyzed, because under this particular strategy of operational management no cultivation-schedule adaptations were considered. Under all other strategies of operational management net farm income was also affected by operational decision-making.

Subsequently, it was investigated how the five formulated strategies of operational management affected the implementation of tactical production plans. In this respect, both annual economic and organizational output variables and individual decision events were considered. More specifically, it was tested whether strategies of operational management had a significant effect on net farm income. Since the performance of operational management was expected to depend on the applied tactical production plan, the effects of tactical production plans and the interaction effects between strategies of operational management and tactical production plans were also tested.

To gain more insight in the effects of the strategies of operational management during the simulations individual decision events as well as annual economic and organizational output variables (other than the NFI_i) were analyzed. With respect to the individual decision events, several aspects were investigated:

1. Which types of operational problems occurred during the simulation?

2. How were these operational problems dispersed over the annual simulation-period?

3. How were operational problems solved?

4. What was the economic impact of cultivation-schedule adaptations for different types of operational problems?

5. To which extent was the heuristic search procedure used to solve operational problems?

Answers to these questions should provide explanations for differences in net farm income and should correspond with the intentions of applied strategies of operational management and tactical production plans.

As pointed out in subsection 6.4.2, the modelling of price variability and price reduction was rather problematic in the present study. Moreover, the grower's attitude to operational price risk was expected to affect operational management. Therefore, the effects of these factors on operational decision-making were investigated by means of two additional sensitivity analyses.

9.2 Simulation experiments

The results of a single simulation run of the present pot plant nursery model were affected by five factors:

1. The scenario of exogenous conditions (E_m).

2. The strategy of operational management (S_i).

3. The tactical production plan (P_i).

4. The level of price variability (V_i).

5. The attitude to operational price risk (R_i).

As described in subsection 4.3.4, the same set of scenarios of exogenous conditions was applied for all system variants (i), i.e. combinations of S_i, P_i, V_i, and R_i. These scenarios of exogenous conditions were applied as replications of uncertain circumstances, providing the individual simulation run with a specific course of randomly simulated disturbances. Moreover, the other four factors were varied or standardized in the various simulation experiments (table 9.1).

In the original simulation experiment, all formulated five strategies of operational management (table 4.1) were combined with all three tactical production plans (table 4.2) to 15 system variants. These 15 system variants were simulated under a *standard* level of price variability (V_2) (subsection 6.4.2) and a *neutral* attitude to operational price risk (R_2) (subsection 8.3.3). Different strategies of operational management and different tactical production plans were expected to lead to different adaptations of cultivation-schedules and eventually to different annual net farm incomes. Of course, the simulated results were expected to depend also on the properties of the present pot plant nursery model and its simulated environment. Therefore, two sensitivity analyses were executed in addition to the original simulation experiment.

Table 9.1 Specification of the simulation experiments conducted in the present study.

Simulation experiment		
Factors	Levels	Number of system variants (N)
Original simulation experiment		
Strategy of oper. man.	$S_i \in \{S_1, S_2, S_3, S_4, S_5\}$	
Tactical prod. plan	$P_i \in \{P_1, P_2, P_3\}$	15
Price variability	$V_i = V_2$	
Price risk attitude	$R_i = R_2$	
Sensitivity analysis on price variability		
Strategy of oper. man.	$S_i = S_5$	
Tactical prod. plan	$P_i \in \{P_1, P_2, P_3\}$	9
Price variability	$V_i \in \{V_1, V_2, V_3\}$	
Price risk attitude	$R_i = R_2$	
Sensitivity analysis on price risk attitude		
Strategy of oper. man.	$S_i = S_5$	
Tactical prod. plan	$P_i \in \{P_1, P_2, P_3\}$	12
Price variability	$V_i = V_2$	
Price risk attitude	$R_i \in \{R_1, R_2, R_3, R_4\}$	

In the first sensitivity analysis the level of price variability for delivered pot plants was varied. The reason for this sensitivity analysis on price variability was the limited information available about pot plant price formation in the Netherlands. Hence, in addition to the *standard* level of price variability (V_2) applied in the original simulation experiment two extra levels of price variability were taken into consideration: (1) *low* price variability (V_1) and (2) *high* price variability (V_3). In the second sensitivity analysis the attitude toward operational price risk was varied. In the original simulation experiment *risk neutral* behaviour (R_2) was assumed, whereas in the second sensitivity analysis three additional price risk attitudes were taken into consideration: (1) *risk seeking* behaviour (R_1), (2) *risk averse* behaviour (R_3), and (3) *very risk averse* behaviour (R_4). As in the original simulation experiment all three formulated tactical production plans were applied in both sensitivity analyses.

In both sensitivity analyses the *active marketing* strategy (S_5) was applied as a standard. This particular strategy was chosen because it was expected to be most sensitive to the varied factors. In this respect, 'sensitive' refers to the operational decisions made during simulation and not to the final economic and organizational consequences. The purpose of the two sensitivity analyses was to investigate how price variability and operational price risk attitude affected operational decision-making during simulation rather than the simulated net farm income. By definition, operational decision-making under the *passive* strategy (S_1) and the *product quality* strategy (S_2) was insensitive to price variability as well as price risk attitude. Hence, both strategies were inappropriate for sensitivity analysis.

In relation to the purpose of the sensitivity analyses the *active marketing* strategy (S_5) was preferred to the *profitability* strategy (S_3) and the *flexible delivery* strategy (S_4), because S_5 was more comprehensive. Only the *active marketing* strategy (S_5) related to operational management in response to crop growth as well as price formation. Hence, the effect of price variability on operational decision-making could be investigated with respect to all four types of operational problems under the *active marketing* strategy (S_5). Moreover, the attitude to operational price risk particularly affected operational delivery decisions. By standardizing the strategy of operational management in both sensitivity analyses the number of systems variants could be reduced to a manageable number.

9.3 Analysis of net farm income

9.3.1 General approach

Most attention in the analysis of simulation results was directed to differences in net farm income between system variants, because profitability was regarded as main criterion for the performance of management. For the original simulation experiment a complete analysis was conducted, whereas for both sensitivity analyses some of the statistical techniques described below were omitted. This difference related to the different objectives of original simulation experiment on one hand and both sensitivity analyses on the other.

Before describing the statistical analysis techniques applied to investigate simulated annual net farm incomes, it should be emphasized that in all simulation experiments the tactical production plan (P_i) was regarded as a qualitative factor. This, implied no ranking could be made between the formulated tactical production plans (P_1, P_2 and P_3). Because this factor was varied in all simulation experiments, interpolation between system variants and extrapolation to additionally formulated system variants made no sense (Kleijnen, 1987). Furthermore, the results of system variants were only analyzed within the context of the particular simulation experiment. One system variant for each of the applied tactical production plans, however, was applied in all three simulation experiments and enabled the link between the original simulation experiment and both sensitivity analyses.

In the original simulation experiment the strategy of operational management (S_i) was regarded as a qualitative ordinal factor with levels classified from passive operational management (no cultivation-schedule adaptations) to a rather sophisticated level of operational management. Beforehand, the annual net farm income of the simulated pot plant nursery was expected to increase with the level of sophistication of the operational management strategy. This particular expectation was tested in two ways, which both took account of the statistical dependency which resulted from the application of the same set of 25 scenarios for every system variant. In fact, the stochastic events included in these scenarios were regarded as so-called 'common random numbers' (Bratley *et al.*, 1987; Kleijnen, 1988; Kleijnen, 1992; Yang & Nelson, 1991).

9.3.2 Friedman statistic

One approach to deal with the consequences of common random numbers was a comparison of individually simulated annual net farm income (NFI_{im}) per scenario. For this purpose the nonparametric Friedman statistic was applied in the original simulation experiment of the present study (Friedman, 1940). This technique involved the ranking of the simulated NFI_{im} per scenario from 1 to J, where J is the number of levels of the investigated factor. Actually, the Friedman statistic relates to 'single factor' experiments and could therefore only be applied for every tactical production plan individually. Thus, for each tactical production plan individually all five strategies of operational management were ranked from 1 to 5 (J=5) for every individual scenario (E_m) based on the simulated NFI_{im}. Subsequently, the cumulative ranknumbers (CRN_j) were determined over all applied scenarios (equation 9.1).

$$CRN_j = \sum_{m=1}^{25} m_{jm} \qquad (9.1)$$

CRN_j: Cumulative ranknumber of level j of the factor 'strategy of operational management'.

m_{jm}: Ranknumber of level j of the factor 'strategy of operational management' for scenario of exogenous condition E_m.

The underlying assumption of this test was that every order of NFI_{im} for any scenario of exogenous conditions was equally probable (Kleijnen, 1987; Laan, 1983). Hence, the null hypothesis of the Friedman statistic was:

$$H_0 : CRN_1 = CRN_2 = CRN_3 = CRN_4 = CRN_5$$

Rejection of the null hypothesis implied at least one of the levels of the analyzed strategies of operational management tended to lead to greater (or smaller) NFI_{im} than at least one other level of this factor. Furthermore, if H_0 was rejected the cumulative ranknumbers were compared pairwise in order to determine which strategies of operational management lead to higher NFI_{im} significantly often. In the present study, a 5% significance level was applied to test null hypotheses of the Friedman statistic.

In conclusion, the Friedman-test provided information about the probabilities of higher or lower results of strategies of operational management for every tactical production plan individually without any concern with respect to the magnitude of these differences. Moreover, the Friedman statistic did not provide any information about the interactions between tactical production plan and strategy of operational management.

9.3.3 Regression metamodelling

A second approach to the comparison of simulated annual net farm incomes applied in the present study was regression metamodelling (Kleijnen, 1988; Kleijnen, 1992; Kleijnen & Groenendaal, 1992; Yang & Nelson, 1991). This approach involved the development of a linear regression model for the average responses of the applied system variants in a particular simulation experiment. Hence, separate regression metamodels were developed, which describe the behaviour of the present pot plant nursery model in each of the three simulation experiments.

Regression metamodelling enabled the simultaneous analysis of both factors varied in the simulation experiment. Thus, besides the main effects of both factors also their interaction could be investigated. Moreover, regression metamodelling compensated for statistical dependency due to common random numbers by taken the covariance matrix into account. Because the number of replications was identical for all applied system variants, average responses ($\overline{NFI_i}$) could be applied in the regression metamodel instead of individual observations (NFI_{im}) (Kleijnen & Groenendaal, 1992).

The regression metamodels consisted completely of dummy explanatory variables, because the factors varied in the simulation experiments were regarded qualitative or were expected to have a nonlinear effect on net farm income. Each dummy variable in the present regression models represented the replacement of the 'standard' level of one of the investigated factors by a non-'standard' level (table 9.2). Thus, in case a system variant consisted of the particular non-'standard' level, the corresponding dummy variable (D_{ij}) equalled one, while otherwise this dummy variable (D_{ij}) equalled zero.

With these dummy variables regression metamodels for the original simulation experiment (equation 9.2), the sensitivity analysis on price variability (equation 9.3), and the sensitivity analysis on price risk attitude (equation 9.4) were formulated. These regression metamodels did not only involve the main effects of the individual factor levels, but also interaction effects which related to the product of two dummy variables of the investigated factors.

$$\begin{aligned}\overline{NFI_i} = {} & \beta_0 + \beta_1.D_{i1} + \beta_2.D_{i2} + \beta_3.D_{i3} + \beta_4.D_{i4} + \beta_5.D_{i5} + \beta_6.D_{i6} + \\ & \beta_{13}.D_{i1}.D_{i3} + \beta_{14}.D_{i1}.D_{i4} + \beta_{15}.D_{i1}.D_{i5} + \beta_{16}.D_{i1}.D_{i6} + \\ & \beta_{23}.D_{i2}.D_{i3} + \beta_{24}.D_{i2}.D_{i4} + \beta_{25}.D_{i2}.D_{i5} + \beta_{26}.D_{i2}.D_{i6}\end{aligned} \tag{9.2}$$

$$\begin{aligned}\overline{NFI_i} = {} & \beta_0 + \beta_1.D_{i1} + \beta_2.D_{i2} + \beta_3.D_{i3} + \beta_4.D_{i4} + \\ & \beta_{13}.D_{i1}.D_{i3} + \beta_{14}.D_{i1}.D_{i4} + \\ & \beta_{23}.D_{i2}.D_{i3} + \beta_{24}.D_{i2}.D_{i4}\end{aligned} \tag{9.3}$$

$$\begin{aligned}\overline{NFI_i} = {} & \beta_0 + \beta_1.D_{i1} + \beta_2.D_{i2} + \beta_3.D_{i3} + \beta_4.D_{i4} + \beta_5.D_{i5} + \\ & \beta_{13}.D_{i1}.D_{i3} + \beta_{14}.D_{i1}.D_{i4} + \beta_{15}.D_{i1}.D_{i5} + \\ & \beta_{23}.D_{i2}.D_{i3} + \beta_{24}.D_{i2}.D_{i4} + \beta_{25}.D_{i2}.D_{i5}\end{aligned} \tag{9.4}$$

$\overline{NFI_i}$:	Average simulated annual net farm income of system variant i.
β_j:	Regression coefficient.
D_{ij}:	Dummy explanatory variable.

Table 9.2 Representation of the explanatory dummy variables for the regression metamodels of the three simulation experiments.

Simulation experiment Dummy variable	Meaning
Original simulation experiment	
D_{i1}	*reference* plan (P_1) →[a] *extra slack* plan (P_2)
D_{i2}	*reference* plan (P_1) → *cash flow* plan (P_3)
D_{i3}	*passive* strategy (S_1) → *product quality* strategy (S_2)
D_{i4}	*passive* strategy (S_1) → *profitability* strategy (S_3)
D_{i5}	*passive* strategy (S_1) → *flexible delivery* strategy (S_4)
D_{i6}	*passive* strategy (S_1) → *active marketing* strategy (S_5)
Sensitivity analysis on price variability	
D_{i1}	*reference* plan (P_1) → *extra slack* plan (P_2)
D_{i2}	*reference* plan (P_1) → *cash flow* plan (P_3)
D_{i3}	*standard* price variability (V_2) → *low* price variability (V_1)
D_{i4}	*standard* price variability (V_2) → *high* price variability (V_3)
Sensitivity analysis on price risk attitude	
D_{i1}	*reference* plan (P_1) → *extra slack* plan (P_2)
D_{i2}	*reference* plan (P_1) → *cash flow* plan (P_3)
D_{i3}	*risk neutral* behaviour (R_2) → *risk seeking* behaviour (R_1)
D_{i4}	*risk neutral* behaviour (R_2) → *risk averse* behaviour (R_3)
D_{i5}	*risk neutral* behaviour (R_2) → *very risk averse* behaviour (R_4)

[a] '→' = replaced by.

Regression metamodelling in the present study was based on so-called 'saturated designs'. This implied that for every system variant an unique combination of explanatory variables was included in the regression metamodel to 'estimate' the average simulated annual net farm income ($\overline{NFI}_i$). In fact, saturated design metamodelling is characterized by a number of regression coefficients equal to the number of observations in a particular simulation experiment, which prohibits statistical validation of the regression metamodel due to a lack of degrees of freedom (Kleijnen, 1987). This conceivable disadvantage, however, was in the present study not regarded as essential, because due to the qualitative factors involved in all system variants the predictive potential of the regression metamodels was already limited. The main purpose of the regression metamodels in the present study was to describe the response of the $\overline{NFI}_i$ to the applied system variants rather than predict the $\overline{NFI}_i$ of additionally formulated system variants. Hence, regression metamodelling was applied to determine the main effects and interaction effects of replacement of the 'standard' levels of both factors.

In each of the regression metamodels the regression coefficient β_0 represents the average annual net farm income for the 'standard' system variant (i=1), which involved 'standard' levels of the investigated factors and for which all dummy variables equalled zero. The other regression coefficients represent the effect on the average annual net farm income of a change of the system variant as represented by the corresponding dummy variable. The interaction effects involve the change in $\overline{NFI}_i$ due to a simultaneous replacement of both 'standard' levels of the investigated factors insofar as not could be explained by the individual main effects. All regression coefficients except β_0 were tested for the null hypothesis H_0: $\beta_j=0$ as described by Kleijnen (1992). Rejection of this null hypothesis for a particular regression coefficient implied a significant effect of the replacement represented by the corresponding dummy variable(s) on net farm income. In the present study, individual regression coefficients were tested by means of the Student *t* statistic at the 5% significance level.

Finally, no estimated errors were included in the regression metamodel, because linear regression lead to a perfect fit with the average simulated net farm incomes due to the saturated design. Moreover, the saturated design enabled the application of the ordinary least square (OLS) estimator without consideration of alternative generalized least square estimators, because all estimators would have resulted in identical regression metamodels (Kleijnen, 1988). Furthermore, although regression metamodels gave a perfect fit with average responses $(\overline{NFI}_i)$ in the present study, their performance as estimator of individual observations (NFI_{im}) was expected to be only moderate due to variance. The coefficient of determination (R^2-adjusted) was applied as measure of accuracy (Friedman & Friedman, 1985; Kleijnen, 1987). This R^2-adjusted gives an indication of variance of simulated annual net farm incomes in the simulation experiment.

9.4 Analysis of decision events and additional annual results

The decision events as well as the additional annual results were not analyzed to prove statistical significant differences between investigated system variants, but rather to find explanations for the statistical significant differences in annual net farm incomes between system variants. Decision events were surveyed and classified according to the type of operational problem involved, its characteristics in terms of greenhouse area and labour deficits, and whether it was solved by adaptation of cultivation-schedules. Hence, dispersion of decision events over the various replications was disregarded and no statistical analysis was applied on these data.

Since NFI_{im} equalled the difference between annual total returns (TR_{im}) and annual total costs (TC_{im}) corrected for the change in inventory value (CIV_{im}), these three economic output variables were investigated to provide explanations for differences in $\overline{NFI}_i$ between system variants. In addition, the three organizational output variables were analyzed in order to support and confirm explanations for changes in the numbers of various types of operational problems and their solution.

Economic impact of individual adaptation types

All non-passive strategies of operational management were expected to lead to at least two types of operational problems solved by adaptation of cultivation-schedules. Thus, effects of operational management strategies on net farm income could not be related to operational problem types directly. Therefore, the economic impact of different types of cultivation-schedule adaptations in the simulation experiments was estimated.

For each type of operational problem solved by adaptation at least two subtypes, i.e. adaptation types, were distinguished. Operational problems of a particular type solved by adaptation of cultivation-schedules despite a negative expected economic effect were indicated by the symbol 'n'. Moreover, operational problems solved by adaptation and characterized by a positive expected economic effect were indicated by the symbol 'p'. The economic impact of these adaptation types was not identical to the expected economic effect of generated alternatives defined in subsection 8.2.3. In fact, the economic impact of adaptation types did not relate to individual decision events, but represented an estimated average value.

For each tactical production plan individually, differences in $\overline{NFI}_i$ between strategies of operational management were related to differences in the number of operational adaptation types. This resulted in sets of linear relations, which could be solved mathematically. In case of only one adaptation type changing in number, the economic impact of that particular adaptation type was calculated for the particular tactical production plan. In case of two adaptation types changing in number, the mathematical solution of the particular set resulted in an isovalue relation for the combined economic impact of these two adaptation types. Such an isovalue economic impact relation describes the feasible economic impact values of the individual adaptation types. Finally, by comparing corresponding isovalue economic impact relations of all three tactical production plans generalized economic impact values for each operational adaptation type could be estimated.

10

PERFORMANCE OF THE MODEL:

EFFECTS OF TACTICAL AND OPERATIONAL MANAGEMENT

10.1 Introduction

Prior to the analysis of the effects of the strategy of operational management and the tactical production plan on the simulation results some properties of the simulated model and applied factors (S_i and P_i) should be discussed. These properties were expected to affect simulation results in a general way and should be well understood before discussing simulation results.

In the present study, simulated returns were expected to vary to a larger degree than simulated costs. In contrast to returns, the simulation of costs did not involve any direct random parameter in the present pot plant nursery model. To some extend annual costs increased with annual returns, because auction costs were calculated as a percentage of returns. Also, annual costs increased with the amount of extra temporary labour hired to implement adaptations of cultivation-schedules. Finally, annual costs were affected by the length of the individual cultivation-schedules, because of the effect of interest on operating capital.

With respect to the formulated strategies of operational management, special attention should be directed to the *flexible delivery* strategy (S_4) and the *active marketing* strategy (S_5). In contrast to the other strategies of operational management, under the *flexible delivery* strategy (S_4) and the *active marketing* strategy (S_5) no fixed moments of delivery in every week were applied. Hence, under these strategies of operational management the grower could deliver batches between originally fixed delivery moments in order to avoid price reduction due to an average plant weight greater than the transitional value W^+. Consequently, the replacement of the *profitability* strategy (S_3) by the subsequent *flexible delivery* strategy (S_4) was expected to lead to different operational decisions. Under the *flexible delivery* strategy (S_4) batches were expected to be delivered without price reduction, whereas under the *profitability* strategy (S_3) the delivery of the same batches was considered for advancement because of the expected negative effect of applied price reduction on profitability.

The replacement of the *flexible delivery* strategy (S_4) by the subsequent *active marketing* strategy (S_5) lead also to an important change in the properties of the model. Under the *active marketing* strategy (S_5) the grower was assumed to know the actual simulated price for the current week, whereas under strategies of operational management S_3 and S_4 the operational price forecast was applied. This difference related to the assumed availability of a price offer under S_5 particularly for type III and IV operational problems (section 8.3). Hence, the availability of a reduced though certain price could initiate advanced deliveries of batches which did not yet attained standard product attributes under the *active marketing* strategy (S_5), whereas under the *flexible delivery* strategy (S_4) under identical circumstances, except for the availability of the certain price offer, advancement of deliveries was rejected.

With respect to the formulated tactical production plans special attention should be directed to the *extra slack* plan (P_2). In this particular tactical production plan extended cultivation-schedules were applied (table 4.2). Hence, in all cases without crop growth delay standard product attributes were attained before the conservatively planned delivery moments. Thus, under the *passive* strategy (S_1) high levels of price reduction were expected. Moreover, under the other strategies of operational management advancement of deliveries was considered in these cases. These situations were recorded as type I operational problems (table 3.1), although identical growing patterns for the two other tactical production plans (with standard cultivation-schedules) were not. In this respect, the definition of operational problems was consistently applied for all tactical production plans, i.e. consideration of advancement or postponement of deliveries as planned in the tactical production plan. In case of considered advancement of conservatively planned delivery moments, as in the *extra slack* plan (P_2), the operational problem particularly concerned the required reallocation of labour.

10.2 Net farm income

10.2.1 Effects of exogenous conditions

Stochastic patterns of crop growth and price formation lead to considerable variation of the annual net farm income over the 25 applied scenarios of exogenous conditions under the *passive* strategy (S_1) (figure 10.1).

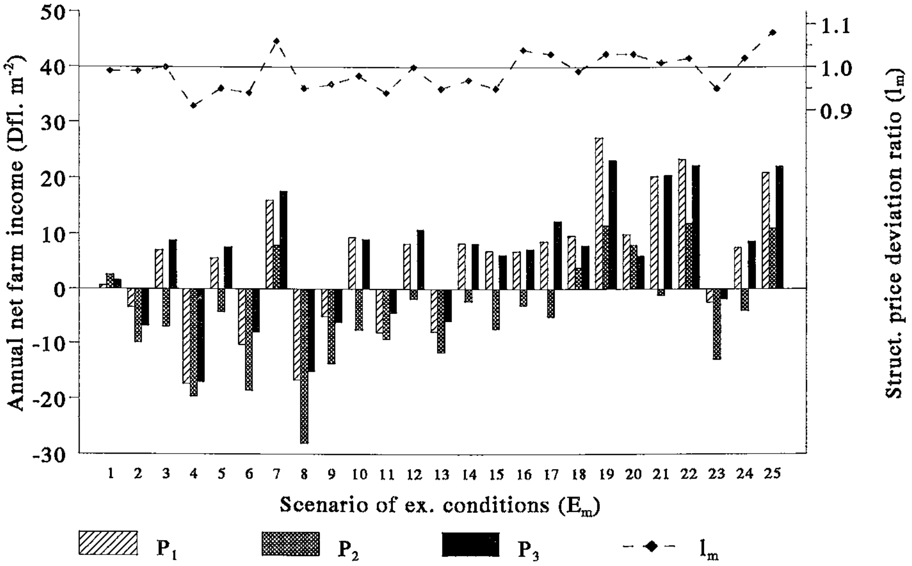

Figure 10.1 Annual net farm incomes (NFI_{im}) under the *passive* strategy (S_1) for the *reference* plan (P_1), the *extra slack* plan (P_2) as well as the *cash flow* plan (P_3) and the structural price deviation ratio (l_m) for every scenario of exogenous conditions.

The structural price deviation ratio (l_m) for every individual scenario of exogenous conditions was included in figure 10.1 to visualize its effect on net farm income. Annual net farm incomes seem to correlate positively with each other per scenario of exogenous conditions, which should be attributed to the application of common random numbers.

For every tactical production plan the simulated net farm income under the *passive* strategy (S_1) was significantly lower than the expected net farm income ($P<0.05$). Table 10.1 shows $\overline{NFI}_i$ is particularly reduced for the *extra slack* plan (P_2). The relatively low simulated net farm income is mainly due to price reduction as a result of deviating crop growth patterns. Because of the extended cultivation-schedules, relatively many of such deviations occurred under the *extra slack* plan (P_2). Over the entire simulation-period price fluctuations can be expected to have little effect on net farm income, since they can affect price formation both positively and negatively[1].

Table 10.1 Comparison of expected net farm incomes versus average simulated net farm incomes under the *passive* strategy (S_1) (with corresponding standard errors of mean) for all three tactical production plans (Dfl. m^{-2} $year^{-1}$).

	Tactical production plans		
	P_1	P_2	P_3
Expected NFI	10.99	6.09	10.94
Average simulated NFI	5.00 (2.36)	-4.44 (2.04)	5.35 (2.26)
Difference	5.99	10.13	5.59

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[1] The effect of price fluctuations (on operational decision-making) is further discussed in relation to the sensitivity analysis on price variability (section 11.2).

Both figure 10.1 and table 10.1 show considerable variances for the simulated $\overline{\mathrm{NFI}}_i$. The Shapiro and Wilk test for normality was applied for every tactical production plan individually to determine whether the 25 simulated NFI_{im} were significantly not normally distributed. At a critical experimentwise error rate according to the Bonferroni inequality[2] of 0.15 the null hypothesis H_0: *normal distribution of* NFI_{im} *per tactical production plan* was not rejected. Moreover, the variation in simulated NFI_{im} seemed realistic compared to available statistics (LEI, 1990-1992). Thus, the set of 25 scenarios of exogenous conditions can be concluded to lead to a realistic distribution of NFI_{im} per system variant.

10.2.2 Regression metamodelling of average annual net farm income

The saturated regression metamodel of the original simulation experiment can be divided into (1) the intercept, i.e. the average annual net farm income of the system variant P_1S_1, (2) the main effects, and (3) the interaction effects (table 10.2). Because of the saturated design, the regression metamodel perfectly fits to the actual average simulated annual net farm incomes.

Compared to the *reference* plan (P_1) the *extra slack* plan (P_2) lead to a significant reduction of the $\overline{\mathrm{NFI}}_i$ ($P<0.05$), whereas the *cash flow* plan (P_3) had no significant effect ($P>0.05$). This conclusion corresponds with the expected annual net farm incomes in table 5.3, although the simulated difference in $\overline{\mathrm{NFI}}_i$ between P_1 and P_2 was larger than expected. Hence, it can be concluded that under the *passive* strategy (S_1) the reduction of $\overline{\mathrm{NFI}}_i$ due to uncertainty depends on the characteristic of the tactical production plan, as also discussed in subsection 10.2.1 with respect to table 10.1.

There was no significant effect of the replacement of the *passive* strategy (S_1) by the *product quality* strategy (S_2) on $\overline{\mathrm{NFI}}_i$ ($P>0.05$). Replacement of the *passive* strategy (S_1) by either the *profitability* strategy (S_3), the *flexible delivery* strategy (S_4), or the *active marketing* strategy (S_5), however, did lead to a significant improvement of $\overline{\mathrm{NFI}}_i$ ($P<0.05$).

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[2] Bonferroni's inequality states that the probability of a joint event does not exceed the sum of probabilities of individual events (Kleijnen & Groenendaal, 1992).

Table 10.2 Regression metamodel of the simulated average annual net farm income per system variant ($\overline{NFI_i}$) in the original simulation experiment.

Effect	*System variant*	$\hat{\beta}_j$ (Dfl. m^{-2})	t_{24}	*P*
Intercept				
β_0	P_1S_1	5.00	-	-
Main effects				
β_1	*extra slack (P_2)*	-9.44	8.86	< 0.01*
β_2	*cash flow (P_3)*	0.35	0.84	0.41
β_3	*product quality (S_2)*	0.19	0.23	0.82
β_4	*profitability (S_3)*	1.61	2.21	0.04*
β_5	*flexible delivery (S_4)*	5.98	7.99	< 0.01*
β_6	*active marketing (S_5)*	9.88	8.57	< 0.01*
Interactions				
β_{13}	P_2S_2	3.20	1.87	0.07
β_{14}	P_2S_3	2.86	2.60	0.02*
β_{15}	P_2S_4	3.05	3.20	< 0.01*
β_{16}	P_2S_5	5.65	3.07	< 0.01*
β_{23}	P_3S_2	1.53	2.17	0.04*
β_{24}	P_3S_3	1.15	3.32	< 0.01*
β_{25}	P_3S_4	0.83	2.17	0.04*
β_{26}	P_3S_5	0.73	1.55	0.13

* Significantly different from zero at the 5% level.

Except for system variants P_2S_2 and P_3S_5 significant positive regression coefficients were found for all interactions ($P<0.05$). This indicates a strong interdependence between the effect of operational management on net farm income and the applied tactical production plan. In fact, the effect of operational management under the inferior *extra slack* plan (P_2) was greater than could be expected from the individual main effects of replacing S_1. Thus, operational management partially compensated poor tactical production planning (figure 10.2).

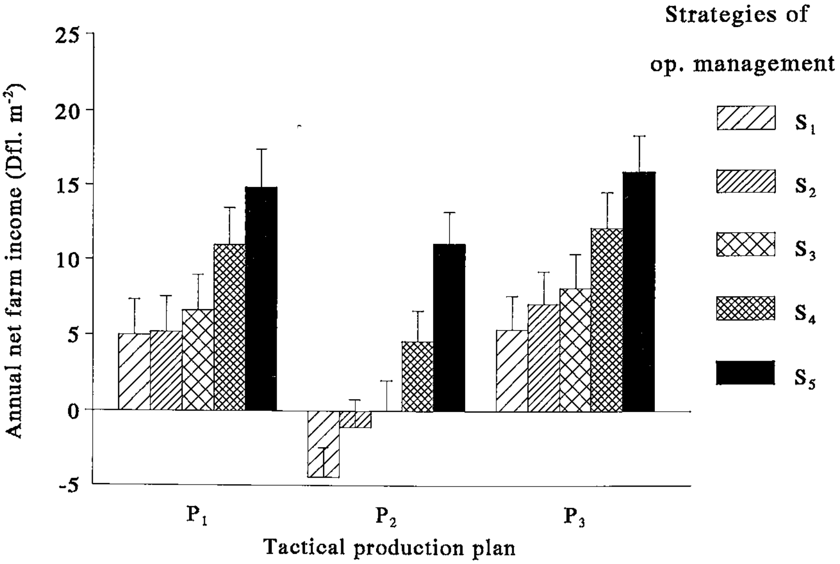

Figure 10.2 Average simulated annual net farm income (Dfl. m^{-2}) with corresponding standard errors of mean for all applied system variants in the original simulation experiment.

Although the regression metamodel showed a perfect fit with simulated $\overline{NFI_i}$, the prediction of individual observations (NFI_{im}) per simulation run was rather poor (R^2-adjusted=0.17). The reason for this poor performance was the considerable variance of NFI_{im} per system variant, which resulted from the application of 25 scenarios of randomly simulated exogenous conditions. Thus, the question remained whether operational management improved profitability only on average ($\overline{NFI_i}$) or for each of the applied scenarios of exogenous conditions. The application of common random numbers and the conclusion of normally distributed NFI_{im} per system variant in combination with rather similar variances, however, suggested more comprehensive strategies of operational management lead in many cases, i.e. for most scenarios of exogenous conditions, to higher NFI_{im} compared to more simple strategies of operational management.

10.2.3 Analysis of profitability improvement

The Friedman statistic was applied to test whether one of the strategies of operational management lead for significantly more scenarios of exogenous conditions to a higher net farm income than one of the other strategies. For all three tactical production plans individually the null hypothesis H_0: *equal annual net farm incomes per scenario of exogenous conditions for all five strategies of operational management* was rejected ($P<0.05$). Moreover, pairwise comparison of all five strategies of operational management lead to identical conclusions for every tactical production plan. The *product quality* strategy (S_2) as well as the *profitability* strategy (S_3) did not lead significantly often to higher NFI_{im} compared to the *passive* strategy (S_1) ($P>0.05$). Moreover, no significant difference in probability of a higher NFI_{im} between S_2 and S_3 was found ($P>0.05$). Furthermore, both the *flexible delivery* strategy S_4 and the *active marketing* strategy (S_5) resulted significantly often in higher NFI_{im} compared to S_1, S_2 and S_3 ($P<0.05$), whereas there was no significant difference in probability of a higher NFI_{im} between S_4 and S_5 ($P>0.05$).

Thus, according to the Friedman statistic there was no significant effect of replacing the *passive* strategy (S_1) by the *profitability* strategy (S_3), whereas the corresponding regression coefficient (β_4) in the regression metamodel (table 10.2) was concluded to be significantly different from zero. This apparent contradiction relates to the fact that not all improvements of net farm income over all 25 scenarios are of equal absolute importance. Moreover, significance levels for the null hypotheses of both applied statistics were in fact rather close ($P=0.04$ for the null hypothesis H_0: $\beta_4=0$ of the regression metamodel and for the Friedman statistic $P=0.06$, $P=0.06$ and $P=0.17$ for the pairwise comparison of S_1 and S_3 under respectively P_1, P_2 and P_3). In conclusion, the combination of the Friedman statistic and regression metamodelling showed that operational management strategies affected net farm income for individual scenarios of exogenous conditions as well as the average net farm income over the complete set of 25 scenarios of exogenous conditions.

10.3 Decision events

10.3.1 Operational problems

Considerable differences in the number and type of operational problems were recorded between the tactical production plans as well as the applied strategies of operational management (table 10.3). The *passive* strategy (S_1) was not included in table 10.3, because under this particular strategy of operational management no operational problems were considered. For all other strategies of operational management four types of operational problems at the most could be identified.

As defined in table 3.1, type I operational problems were caused by advanced crop growth and type II operational problems by delayed crop growth. Moreover, type III operational problems involved the consideration of advanced deliveries (if expected profitable) for all delivery batches, whereas type IV operational problems involved the postponement of deliveries. Type III and IV operational problems were only taken into consideration under the *active marketing* strategy (S_5). Thus, no type III and IV operational problems could be recorded under the *product quality* strategy (S_2), the *profitability* strategy (S_3), and the *flexible delivery* strategy (S_4). These strategies (S_2 to S_4) only considered operational problems with respect to crop growth. Hence, the total number of operational problems was almost identical under these strategies of operational management, whereas it increased under the *active marketing* strategy (S_5) for all three tactical production plans.

Not only different strategies of operational management lead to different numbers and types of operational problems, also different tactical production plans did. Under the *extra slack* plan (P_2) no type II operational problems at all were recorded. The number of type I operational problems, however, was relatively high because of the extended cultivation-schedules. With 28 batches in this tactical production plan, about 40% of the batches was considered for advancement of deliveries. Furthermore, the number of type I and II operational problems under the *reference* plan (P_1) and the *cash flow* plan (P_3) were affected to some extent by the applied strategy of operational management. This effect was due to the fact that operational problems were solved differently under different operational management strategies, which consequently affected the further course of the particular simulation run.

Table 10.3 Representation of the decision events which occurred in the simulation experiment.

Tactical production plan	P_1				P_2				P_3			
Strategy of operational management	S_2	S_3	S_4	S_5	S_2	S_3	S_4	S_5	S_2	S_3	S_4	S_5
Average number of operational problems per year												
type I	1.5	1.4	1.4	0.9	11.3	11.3	11.3	11.3	1.2	1.2	1.2	1.1
type II	2.7	2.7	2.7	2.8	0.0	0.0	0.0	0.0	3.5	3.5	3.5	3.5
type III	-	-	-	3.8	-	-	-	5.8	-	-	-	3.4
type IV	-	-	-	7.1	-	-	-	3.3	-		-	6.8
total	4.2	4.1	4.1	14.6	11.3	11.3	11.3	20.4	4.7	4.7	4.7	14.8
Number of problems with greenhouse area deficits												
type II	2.3	2.2	2.2	2.4	0.0	0.0	0.0	0.0	2.6	2.4	2.4	2.5
type IV	-	-	-	1.0	-	-	-	0.3	-	-	-	1.4
total	2.3	2.2	2.2	3.4	0.0	0.0	0.0	0.3	2.6	2.4	2.4	3.9

Continuation of table 10.3.

Tactical production plan	P_1				P_2				P_3			
Strategy of operational management	S_2	S_3	S_4	S_5	S_2	S_3	S_4	S_5	S_2	S_3	S_4	S_5
Number of adaptations of cultivation-schedules												
type I	1.5	1.4	0.1	0.6	11.3	8.3	0.1	3.6	1.2	1.1	0.0	0.4
type II	1.2	1.0	1.0	0.9	0.0	0.0	0.0	0.0	2.2	2.2	2.2	1.9
type III	-	-	-	2.9	-	-	-	4.7	-	-	-	2.7
type IV	-	-	-	5.1	-	-	-	2.6	-	-	-	4.7
total	2.7	2.4	1.1	9.5	11.3	8.3	0.1	10.9	3.4	3.3	2.2	9.7
Percentage of problems resolved by adaptation (%)												
	64	59	27	65	100	73	1	53	72	70	47	66

Surprisingly, the number of type I operational problems was identical under the *extra slack* plan (P_2) and the *active marketing* strategy (S_5), despite a considerable number of type III and IV operational problems. In fact, some of these type III and IV operational problems related to batches for which no type I operational problems were recorded. Moreover, for some batches which were first advanced as type I operational problem the second delivery batch was subsequently advanced once more as type III operational problem. In some other cases, the second delivery batch was postponed as type IV operational problem after an initial advancement of the complete batch. Hence, particularly for the *extra slack* plan (P_2) type III and IV operational problems were recorded for batches for which already type I operational problems were recorded.

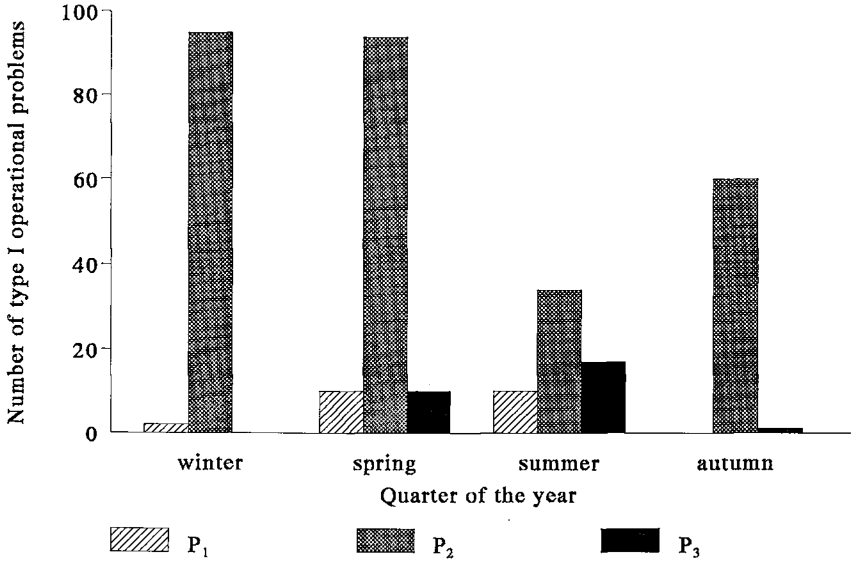

Figure 10.3 Number of type I operational problems per season for each of the applied tactical production plans under the *active marketing* strategy (S_5).

Besides the number and type of operational decision events, some other characteristics were analyzed. All decision events in the present simulation experiment involved labour deficits. Greenhouse area deficits, on the other hand, occurred only in some of the decision events with type II and IV operational problems[3] (table 10.3).

The moment of occurrence of the four types of operational problems under the *active marketing* strategy (S_5) was analyzed. Under the *reference* plan (P_1) and under the *cash flow* plan (P_3) type I operational problems occurred particularly in spring[4] and summer (figure 10.3). Under the *extra slack* plan (P_2), however, type I operational problems occurred throughout the whole year, due to the extended cultivation-schedules.

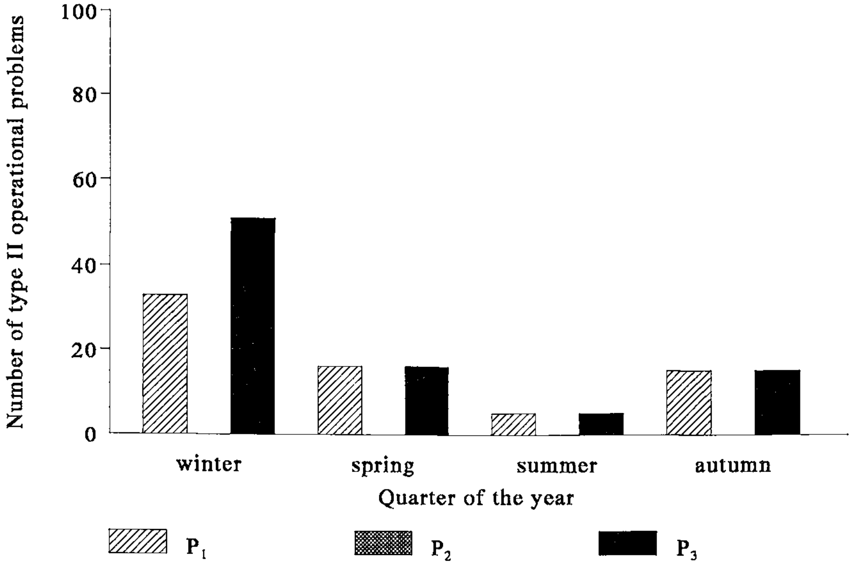

Figure 10.4 Number of type II operational problems per season for each of the applied tactical production plans under the *active marketing* strategy (S_5).

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[3] In fact, type I and III operational problems by definition never lead to greenhouse deficits.

[4] In this respect, winter was defined as the first 13 weeks of the year, spring as the next 13 weeks and so on.

Type II operational problems occurred particularly in winter, and to a lesser degree in spring and autumn (figure 10.4). Thus, it can be concluded crop growth was more often delayed when crops grew relatively slow and more often advanced when crops grew relatively fast. This conclusion corresponds broadly with figure 6.8. Type III operational problems occurred throughout the whole year, because deliveries were considered for advancement during all seasons (figure 10.5).

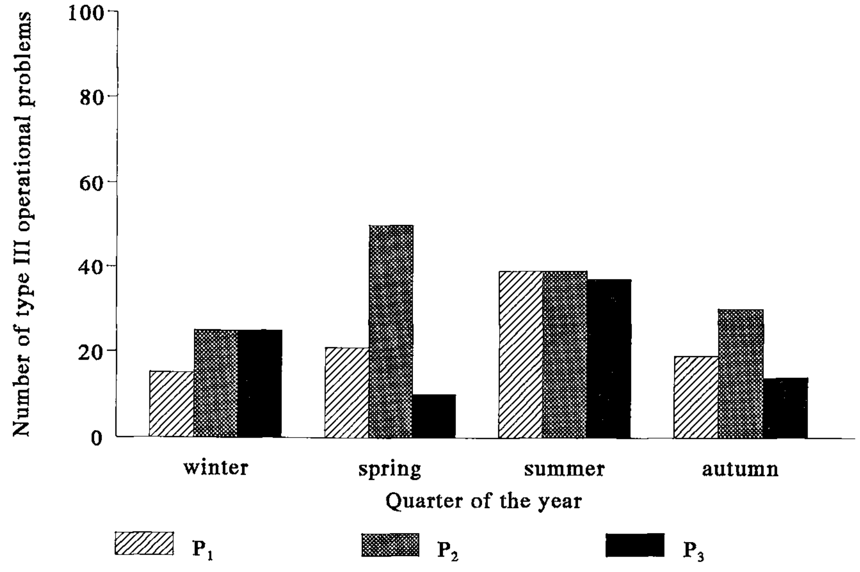

Figure 10.5 Number of type III operational problems per season for each of the applied tactical production plans under the *active marketing* strategy (S_5).

Type IV operational problems occurred particularly in autumn and winter (figure 10.6), although they were, as type III operational problems, initiated by the availability of the certain price offer. The explanation for the fact that less type IV operational problems occurred in spring and summer is the higher rate of crop growth in this period. As a result, these plants are more likely to grow out of proportion when deliveries are postponed, which would lead to price reduction. Such anticipated price reduction obviously makes postponement of deliveries less profitable. Type III operational problems, on the other hand, in all cases involved batches which did not yet had attained standard product attributes[5]. Hence, price reduction was for type III operational problems independent of the season.

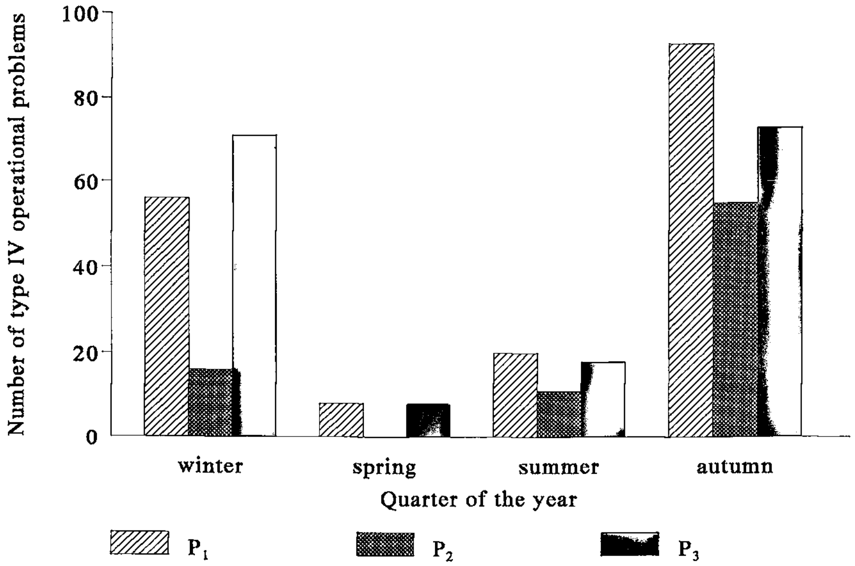

Figure 10.6 Number of type IV operational problems per season for each of the applied tactical production plans under the *active marketing* strategy (S_5).

10.3.2 Operational solutions

As pointed out before, an operational decision could involve either an adaptation of cultivation-schedules or confirmation of the current tactical production plan notwithstanding foreseen unfavourable future consequences. Besides the number and type of operational problems,

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[5] By definition advancement of deliveries of a batch which already attained standard product attributes was recorded as a type I operational problem.

table 10.3 also shows how many of these operational problems were solved by an adaptation of cultivation-schedule. In addition to table 10.3, it should be mentioned all operational cultivation-schedule adaptations required extra labour.

Under the *product quality* strategy (S_2) all type I operational problems were solved by an adaptation of the cultivation-schedule. Thus, no batches were delivered 'beyond' standard product attributes. Under the *profitability* strategy (S_3), however, particularly for the *extra slack* plan (P_2) the number of type I operational problems solved by adaptation of cultivation-schedules was considerably reduced. This reduction was due to the additional condition of profitability under S_3 (equation 8.7). Hence, under the *profitability* strategy (S_3) adaptations of cultivation-schedules were only implemented if they were expected to be profitable, whereas under the *product quality* strategy (S_2) these adaptations were implemented irrespective of expected profitability. Thus, in case of the profitability criterion some batches with advanced crop growth were delivered 'beyond' standard product attributes, because of a higher expected profit.

Furthermore, hardly any type I operational problem was solved by adaptation of cultivation-schedules under the *flexible delivery* strategy (S_4). This is because under S_4 (and S_5) batches were no longer assumed to be delivered at a fixed moment in every week. Thus, under the *profitability* strategy (S_3) for both originally planned deliveries and advanced deliveries price reduction was applied, whereas under the *flexible delivery* strategy (S_4) price reduction was only applied for advanced deliveries. Consequently, advancement of deliveries became less profitable under the *flexible delivery* strategy (S_4). Under the *active marketing* strategy (S_5) the number of type I operational problems solved by adaptation of cultivation-schedules increased compared to the *flexible delivery* strategy (S_4), although the same assumption with respect to deliveries was applied under S_5. This was due to the availability of a certain price offer for advanced deliveries under S_5, where under S_4 the operational price forecast was applied. Hence, advanced deliveries became preferable in some cases, because the actual price was higher than the operational price forecast.

With respect to type II operational problems, not all decision events under the *product quality* strategy (S_2) lead to an adaptation of cultivation-schedules. As expected, type II operational problems appeared to be more difficult to solve by adaptation of cultivation-schedules than type I operational problems, because of the extra greenhouse area requirements for type II operational problems. Thus, although preferred, not all type II operational problems under the *product quality* strategy (S_2) could be solved by adaptation. Furthermore, the number of type II operational problems solved by adaptation was fairly stable under the *profitability* strategy (S_3) and the *flexible delivery* strategy (S_4). The reduction of this number under the *active marketing* strategy (S_5) relates to the additionally specified and resolved type III and IV operational problems. In some cases, a type II operational problem could not be solved by adaptation under S_5, because type IV operational problems were solved before using slack greenhouse area, which was under the other strategies (S_2 to S_4) applied to solve the particular type II operational problem.

With respect to the solution of type III and IV operational problems only a comparison of the three applied tactical production plans was possible, since these types of operational problems were only considered under the *active marketing* strategy (S_5). Under the *reference* plan (P_1) and the *cash flow* plan (P_3) operational delivery decisions involved particularly postponements of deliveries, i.e. speculation for higher future prices, whereas under the *extra slack* plan (P_2) these types of operational decisions particularly involved advancement of deliveries, i.e. taking advantage of current prices. This difference is again due to the extended cultivation-schedules in the *extra slack* plan (P_2). Because of the conservatively planned moments of delivery in the *extra slack* plan (P_2), many opportunities for delivery occurred before postponement of deliveries was taken into consideration. Consequently, the probability of advanced deliveries, i.e. type I and III operational problems solved by adaptation, increased with the number of such opportunities.

In conclusion, a considerable number of decision events were recorded in the present simulation experiment. With 27 to 28 batches per year operational problems were recorded for about 1 out of every 7 batches under system variant P_1S_2 to for about 2 out of every 3 batches under system variant P_2S_5. The percentage of operational problems solved by adaptation of cultivation-schedules varied from 1% to 100%. Moreover, all operational cultivation-schedule adaptations required small amounts of extra labour. Furthermore, differences in number, type and characteristics of simulated operational problems as well as their solution could be related to differences among the applied combinations of tactical production plan and strategy of operational management.

10.4 Additional annual results

10.4.1 Returns, costs, and inventory value

Average annual total returns ($\overline{\mathrm{TR}}_i$) increased for every applied tactical production plan with the level of sophistication of operational management (figure 10.7). Annual costs ($\overline{\mathrm{TC}}_i$), however, were almost constant per tactical production plan and showed relatively small standard errors of mean (figure 10.8) due to only indirect stochastic influences. In addition, the change in inventory value ($\overline{\mathrm{CIV}}_i$) appeared to be relatively small (figure 10.9)[6].

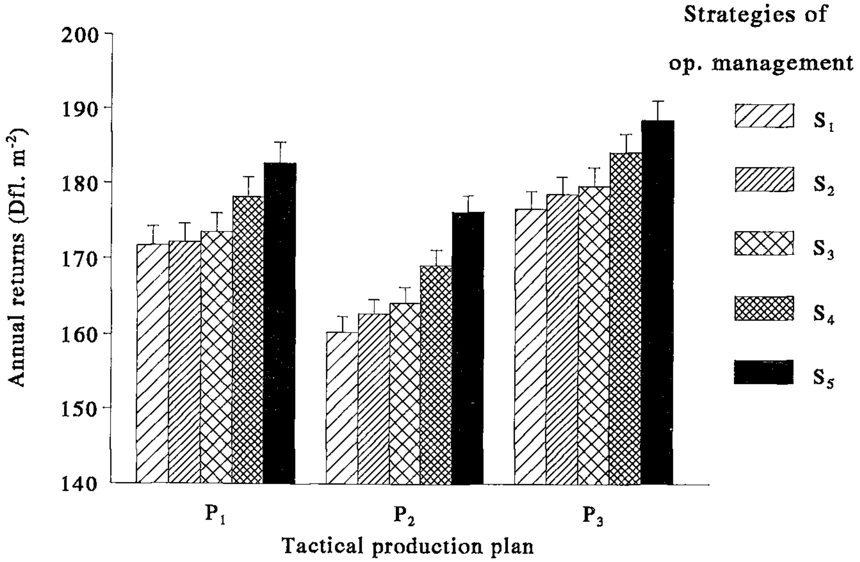

Figure 10.7 Average simulated annual total returns (Dfl. m^{-2}) with corresponding standard errors of mean for all applied system variants in the original simulation experiment.

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[6] It should be noticed that the vertical axis of figure 10.9 is not of the same scale as those of figures 10.7 and 10.8.

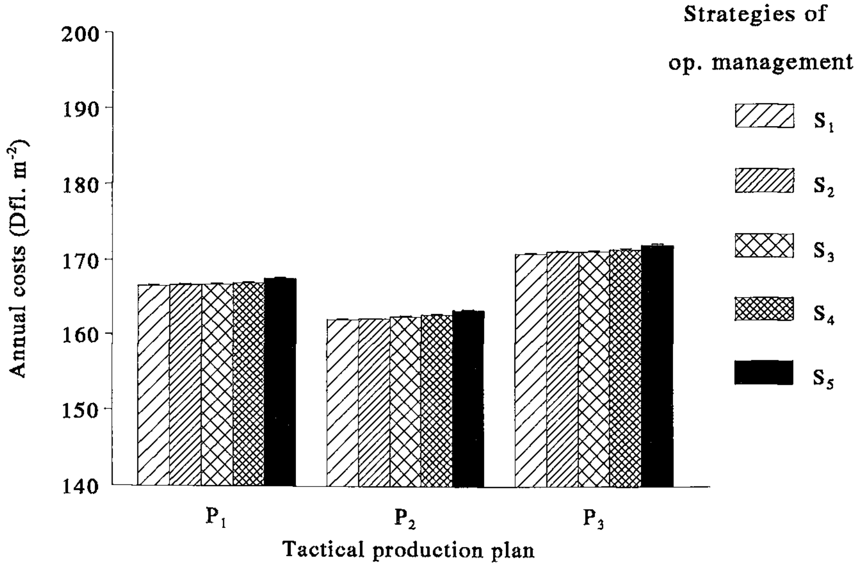

Figure 10.8 Average simulated annual total costs (Dfl. m^{-2}) with corresponding standard errors of mean for all applied system variants in the original simulation experiment.

Thus, differences in net farm income in the present simulation experiment are particularly due to differences in $\overline{TR}_i$. Although this may be considered as a peculiarity of the present model[7], it is important to notice that cost of extra hired labour and interest on operating capital hardly affected operational management benefits. Moreover, the effect of operational decision-making on the final system state can be ignored in the present simulation experiment.

In contrast to what could be expected based on equation 7.11, the change in inventory value under the *passive* strategy (S_1) was not equal to zero (figure 10.9). Changes in inventory value under the *passive* strategy (S_1) were due to the assumption that also in the post-simulation period batches were delivered as originally planned, whereas under the reference

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[7] The peculiarity is the limited variation of total annual costs due to the absence of direct stochastic influences (section 10.1)

strategy, as described in subsection 7.2.2, batches were expected to be delivered when they attained standard product attributes. Consequently, different cultivation-periods, different prices and different price reduction ratios lead to different expected future costs and returns for individual batches and eventually to a change in inventory value under the *passive* strategy (S_1). Furthermore, all $\overline{CIV}_i$ in the present simulation experiment were negative. Although, some of the individual CIV_{im} were positive, most CIV_{im} were negative. This can be explained by the fact that present growing batches at the end of the year are most likely somewhat delayed (figure 6.8).

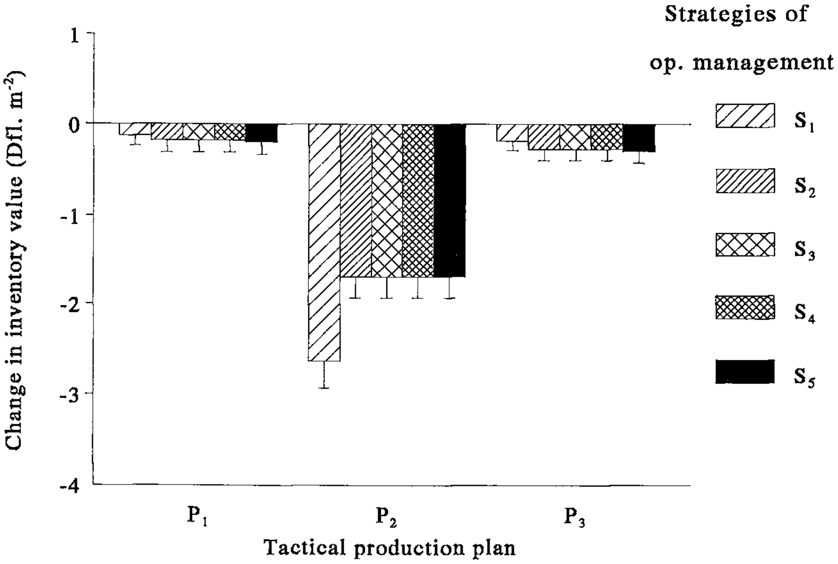

Figure 10.9 Average simulated change in inventory value (Dfl. m^{-2}) with corresponding standard errors of mean for all applied system variants in the original simulation experiment.

The relatively high (negative) level of $\overline{CIV}_i$ under the *extra slack* plan (P_2), in contrast to the other two tactical production plans, was due to a multiplier effect because of the higher number of plants in the final system state (table 7.1) in combination with the very large batch which was only present in the final system state of the *extra slack* plan (P_2) (figure 5.5).

10.4.2 Price reduction

The strategies of operational management affected the average annual weighted price reduction percentage ($\overline{\mathrm{PRP}}_i$) considerably (figure 10.10). Price reduction appeared to be the highest under the *passive* strategy (S_1). Furthermore, the fixed moments of delivery in every week under the *passive* strategy (S_1), the *product quality* strategy (S_2) and the *profitability* strategy (S_3) lead to the expected large $\overline{\mathrm{PRP}}_i$. Since the *flexible delivery* strategy (S_4) is identical to the *profitability* strategy (S_3) except for the fixed delivery moments, the differences in $\overline{\mathrm{PRP}}_i$ between both strategies should be completely attributed to this property.

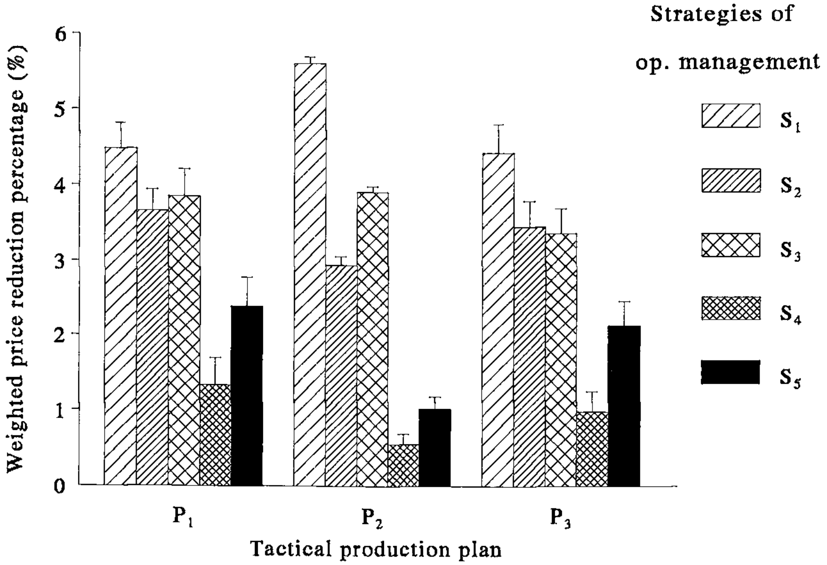

Figure 10.10 Average simulated annual weighted price reduction percentage (%) with corresponding standard errors of mean for all applied system variants in the original simulation experiment.

Comparing the strategies of operational management in sequential order, the product *quality strategy* (S_2) lead, as expected, to a reduction of $\overline{\mathrm{PRP}}_i$. Moreover, for the *extra slack* plan (P_2) the *profitability* strategy (S_3)

resulted in a higher $\overline{PRP_i}$ as compared to S_2 due to the number of type I operational problems not solved by adaptation. These operational problems were not solved by adaptation, because under S_3 adaptation was only applied if expected to be profitable. Under the *active marketing* strategy (S_5) $\overline{PRP_i}$ increased compared to the *flexible delivery* strategy (S_4) due to the type III operational problems considered under the *active marketing* strategy (S_5). For some type III operational problems advanced deliveries of batches which had not yet attained standard product attributes were expected to be profitable despite price reduction. In conclusion, the changes in $\overline{PRP_i}$ correspond with the changes in operational problems (table 10.3).

10.4.3 Greenhouse area and labour utilization efficiency

The average simulated annual organizational greenhouse area utilization efficiency ($\overline{GE_i}$) was fairly stable for the *reference* plan (P_1) and *the cash flow* plan (P_3) (figure 10.11). Operational adaptation of cultivation-schedules lead only to marginal reallocations of greenhouse area. For the *extra slack* plan (P_2), however, larger differences in $\overline{GE_i}$ were found. This was related to the number of type I operational problems solved by adaptation. Obviously, under the *passive* strategy (S_1) $\overline{GE_i}$ was relatively high, because advancement of deliveries was impossible. Under the *product quality* strategy (S_2), however, in many cases deliveries were advanced and additionally allocated greenhouse area remained non-utilized, which lead to a reduction of $\overline{GE_i}$. Moreover, under the *profitability* strategy (S_3) as well as under the *flexible delivery* strategy (S_4) $\overline{GE_i}$ increased with the number of type I operational problems not solved by adaptation.

For all tactical production plans figure 10.11 shows a reduction of $\overline{GE_i}$ under the *active marketing* strategy (S_5). This reduction particularly relates to the type III operational problems solved by adaptation. With most type III operational problems solved by adaptation for the *extra slack* plan (P_2), $\overline{GE_i}$ obviously decreased mostly for this particular plan.

The general high level of the average annual labour utilization efficiency ($\overline{LE_i}$) explains why all operational decision events in the present simulation experiment involved labour deficits (figure 10.12). Moreover, ($\overline{LE_i}$) in general decreased with the level of sophistication of the applied operational management strategy. This, relates to the increase of the number of cultivation-schedule adaptations. As explained in relation to equation 7.2, the effect of such adaptations on LE_{im} depends on the circumstances. In conclusion, it seems conceivable more adaptations lead to more complexity and consequently affect efficiency negatively. Hence, the increase of $\overline{LE}_i$ under the *flexible delivery* strategy (S_4) particularly for *the extra slack* plan (P_2) can also be explained by this principle. In fact, the number of adaptations was relatively low under S_4 (table 10.3).

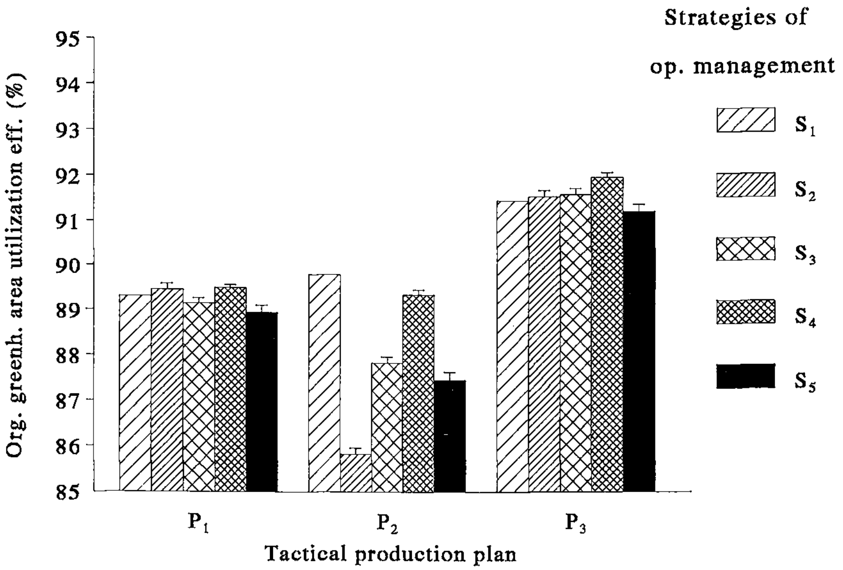

Figure 10.11 Average simulated organizational greenhouse area utilization efficiency (%) with corresponding standard errors of mean for all applied system variants in the original simulation experiment.

It should be noticed that in figures 10.11 and 10.12 under the *passive* strategy (S_1) the organizational output variables GE_{im} and LE_{im} were constant, because every individual cultivation-schedule was implemented as originally planned irrespective of exogenous conditions.

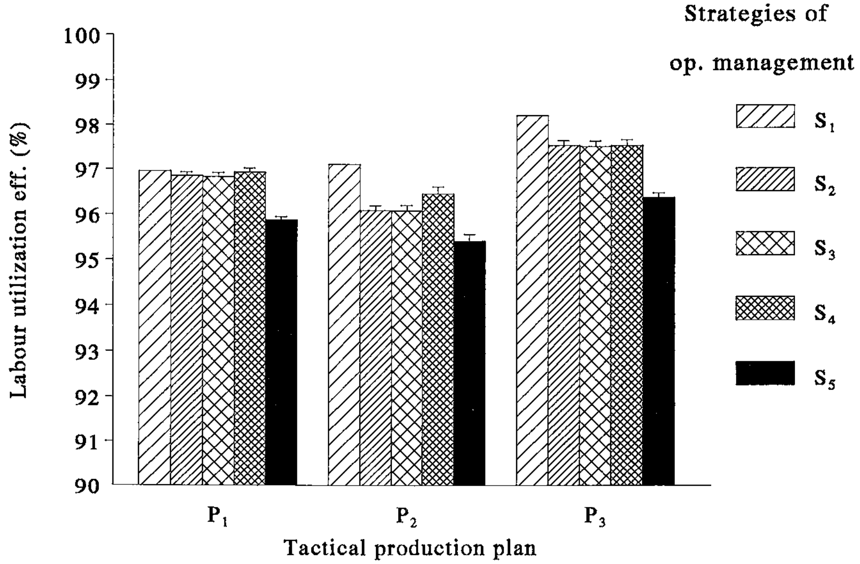

Figure 10.12 Average simulated labour efficiency (%) with corresponding standard errors of mean for all applied system variants in the original simulation experiment.

11

SENSITIVITY OF THE MODEL:

EFFECTS OF PRICE VARIABILITY AND PRICE RISK ATTITUDE

11.1 Introduction

The main purpose of the first sensitivity analysis was to determine whether price variability affected operational decision-making and consequently net farm income. Beforehand, such an effect could be expected, because the solution of particular type III and IV operational problems was focused on taking advantage of high prices. These high prices were most likely due to positive price deviations, which would increase with price variability. In addition, the sensitivity analysis on price variability was used to investigate the simulated price reductions more in detail. As pointed out before, the sensitivity to the price risk attitude was analyzed separately in the second sensitivity analysis.

In the first sensitivity analysis, price variability was varied by changing the standard error of the incidental price deviation ratio ($\sigma\{\underline{d}_{mw}\}$). In this respect, it should be understood the random standard normal variable for every individual incidental price deviation ratio remained unchanged (equation 6.14). Hence, with an increasing level of price variability the incidental price deviation ratio increased if it was already greater than one and decreased if it was lower than one. Under the *active marketing* strategy (S_5) three levels of price variability (table 11.1) were combined with all three formulated tactical production plans to nine system variants. All nine system variants were simulated under the assumption of a risk neutral attitude towards operational price risk (R_2).

Table 11.1 Description of the three levels of price variability applied in the first sensitivity analysis.

Level	Description	$\sigma\{\underline{d}_{mw}\}$	MAPE
V_1	*low* price variability	0.18	15%
V_2	*standard* price variability	0.23	20%
V_3	*high* price variability	0.30	30%

The second sensitivity analysis was applied to determine the effect of the grower's attitude to operational price risk on operational decision-making and consequently on net farm income. This attitude was expected to affect operational decision-making, because operational decisions were made under risk. As pointed out before, operational risk in the present study concerned particularly price risk. The operational price risk attitude was expected to affect particularly type III and IV operational problems. Since the *active marketing* strategy (S_5) was the only formulated strategy, which explicitly considered such operational problems with respect to price formation, this strategy was applied in the second sensitivity analysis. Moreover, risk aversion was expected to lead to more type III operational problems solved by adaptation, whereas risk preference was expected to lead to more type IV operational problems solved by adaptation. Overall, risk averse behaviour as well as risk preference were expected to have a negative effect on net farm income, since in both cases the perceived utility of future deliveries was biased.

In the second sensitivity analysis the attitude to operational price risk was varied by applying four values of the Pratt-Arrow coefficient of absolute risk aversion (r). Thus, under the *active marketing* strategy (S_5) four levels of price risk aversion (table 11.2) were combined with the three formulated tactical production plans to twelve system variants. Moreover, the standard level of price variability (V_2) was applied, as in the original simulation experiment.

Table 11.2 Description of the four levels of price risk attitude applied in the second sensitivity analysis.

Level	Description	Pratt-Arrow coefficient of absolute risk aversion (r) ($\times 10^{-4}$)
R_1	*risk seeking* behaviour	-2
R_2	*risk neutral* (standard) behaviour	0
R_3	*risk averse* behaviour	2
R_4	*very risk averse* behaviour	4

11.2 Price variability

11.2.1 Net farm income

The saturated regression metamodel showed price variability had indeed a positive effect on net farm income (table 11.3). The regression coefficients β_3 for *low* price variability and β_4 for *high* price variability showed a significant effect of price variability on $\overline{NFI_i}$ ($P<0.05$). In addition, it is interesting to see that in contrast to the results of the original simulation experiment the effect of replacement of the *reference* plan (P_1) by the *extra slack* plan (P_2) was not significant ($P>0.05$), whereas replacement by the *cash flow* plan (P_3) resulted in a moderate, yet significant, improvement of $\overline{NFI_i}$ ($P<0.05$).

The effect of the *extra slack* plan (P_2) on net farm income, though larger than the effect of the *cash flow* plan (P_3), was not significant due to the relatively large standard error of the particular regression coefficient. In the original simulation replacement of the *reference* plan (P_1) by the *cash* *flow* plan (P_3) already pointed in the direction of a positive effect on $\overline{NFI_i}$ (table 10.2). Since, in the present sensitivity analysis all simulation runs were executed under the *active marketing* strategy (S_5), comprehensive operational management can be concluded to have a greater effect on net farm income under the *cash flow* plan (P_3) than under the *reference* plan (P_1). Consequently, this difference should increase with price variability. Table 11.3, however, does not show any significant interaction between price variability and tactical production plan at all. Nevertheless, the interactions between P_3 and price variability tend in the expected direction.

Table 11.3 Regression metamodel of the simulated average annual net farm income per system variant ($\overline{NFI_i}$) in the sensitivity analysis on price variability.

Effect	*System variant*	$\hat{\beta}_j$ (Dfl. m^{-2})	t_{24}	*P*
Intercept				
β_0	P_1V_2	14.88	-	-
Main effects				
β_1	*extra slack*	-3.79	-1.83	0.08
β_2	*cash flow*	1.07	2.26	0.03*
β_3	*low pr. variability*	-2.21	-6.12	< 0.01*
β_4	*high pr. variability*	3.12	6.03	< 0.01*
Interactions				
β_{13}	P_2V_1	-0.29	-0.67	0.51
β_{14}	P_2V_3	-0.67	-0.56	0.58
β_{23}	P_3V_1	-0.14	-0.79	0.44
β_{24}	P_3V_3	0.36	1.47	0.15

* Significantly different from zero at the 5% level.

Figure 11.1 indicates the effect of price variability on the variability of the annual net farm income, i.e. on the standard errors of mean of $\overline{NFI}_i$, was rather small. This observation corresponds with the conclusion that variation in NFI_{im} was particular due to crop growth deviations (subsection 10.2.1).

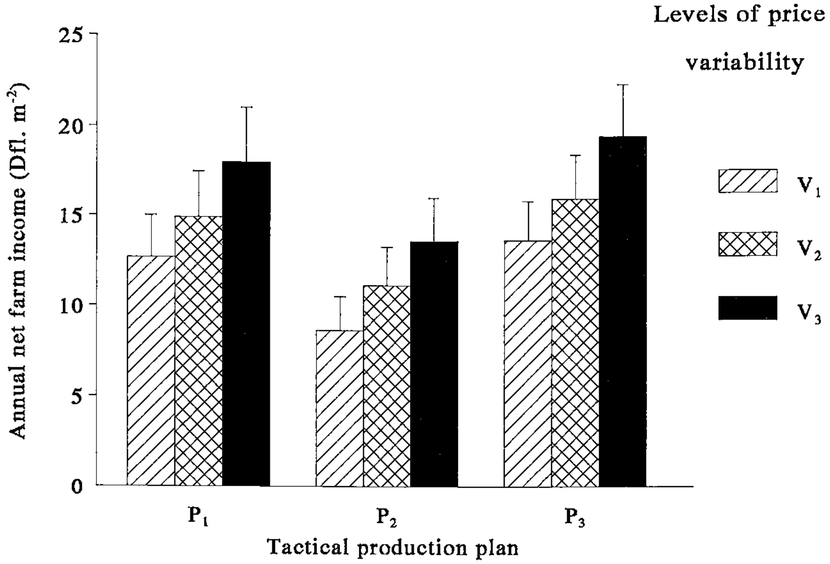

Figure 11.1 Average simulated annual net farm income (Dfl. m^{-2}) with corresponding standard errors of mean for all applied system variants in the sensitivity analysis on price variability.

11.2.2 Decision events

Analysis of decision events indicated the positive effect of price variability on $\overline{NFI}_i$ correlated with the number of decision events which resulted in adaptation of cultivation-schedules. Differentiation of these decision events to the four types of operational problems showed particularly the number of type III operational problems was affected by price variability (table 11.4).

Table 11.4 Representation of the decision events which occurred in the sensitivity analysis on price variability.

Tactical production plan	P_1			P_2			P_3		
Level of price variability	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3
Average number of operational problems per year									
type I	0.9	0.9	0.9	11.3	11.3	11.4	1.1	1.1	1.1
type II	2.8	2.8	2.8	0.0	0.0	0.0	3.4	3.5	3.5
type III	3.1	3.8	4.7	5.5	5.8	6.4	2.9	3.4	4.5
type IV	7.2	7.1	7.0	3.3	3.3	3.3	6.8	6.8	6.8
total	14.0	14.6	15.4	20.1	20.4	21.1	14.2	14.8	15.9
Number of cultivation-schedule adaptations per year									
type I	0.5	0.6	0.6	2.8	3.6	3.6	0.3	0.4	0.5
type II	0.9	0.9	0.9	0.0	0.0	0.0	2.0	1.9	2.0
type III	2.0	2.9	4.0	3.6	4.7	5.4	1.8	2.7	3.6
type IV	4.9	5.1	5.4	2.4	2.6	2.8	4.5	4.7	4.8
total	8.3	9.5	10.9	8.8	10.9	11.8	8.6	9.7	10.9
Percentage of problems solved by adaptation (%)									
	59	65	71	44	53	56	61	66	69

The number of type III operational problems increased with price variability, because advancement of delivery (for economic reasons) became in many cases more favourable. The difference between the certain price offer for direct deliveries and the operational price forecast for later deliveries changed, because the actual simulated price for the current week was affected by the incidental price deviation ratio (equation 6.9).

Advancement of deliveries (type III operational problems) was most likely to be considered when certain price offers for direct deliveries were higher than expected. Consequently, with increasing price variability higher certain price offers for direct deliveries lead to more type III operational problems. Moreover, the increase of the number of type III operational problems solved by adaptation can be related to the increase of the difference between the certain price offer for direct deliveries and the operational price forecasts for later deliveries while additional costs of postponed delivery remained unchanged.

The number of type IV operational problems decreased for the *reference* plan (P_1) with price variability, while the number of type IV operational problems solved by adaptation increased for all tactical production plans (table 11.3). Principally, type IV operational problems were most likely to occur when certain price offers were lower than expected due to an incidental price deviation ratio lower than one. Some of the decision events with type IV operational problems, however, related to certain price offers for direct deliveries based on incidental price deviation ratios greater than one. Postponement of deliveries in these situations was taken into consideration despite certain price offers for direct deliveries based on positive incidental price deviation ratios, because price forecasts were relatively high in the weeks following the original planned moment of delivery[1]. Understandably, the number of these type IV operational problems decreased with price variability. On the other hand, with increasing price variability more type IV operational problems with certain price offers based on incidental price deviation ratios lower than one were solved by adaptation. For these decision events postponement became more favourable with the increasing difference between the certain price offer for direct deliveries and the operational price forecast for later deliveries.

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[1] Due to the application of standard cultivation-schedules and tactical price forecasts such opportunities were not perceived during tactical production planning.

11.2.3 Other annual results

Analysis of the annual economic and organizational output variables (other than net farm income) indicated price variability particularly affected annual total returns ($\overline{TR_i}$) and the annual weighted price reduction percentage ($\overline{PRP_i}$). Annual total costs ($\overline{TC_i}$) and the change in inventory value ($\overline{CIV_i}$) were hardly affected by price variability. Moreover, small changes in annual organizational greenhouse area utilization efficiency ($\overline{GE_i}$) and annual labour utilization efficiency ($\overline{LE_i}$) were found. These small differences corresponded with changes in decision events as in the original simulation experiment. With respect to the increase of the average annual total returns ($\overline{TR_i}$) with price variability (figure 11.2), no distinction could be made between the direct effect of price variability through price formation (equation 6.9) and price reduction (equation 6.10), and the indirect effect of price variability through operational decision-making.

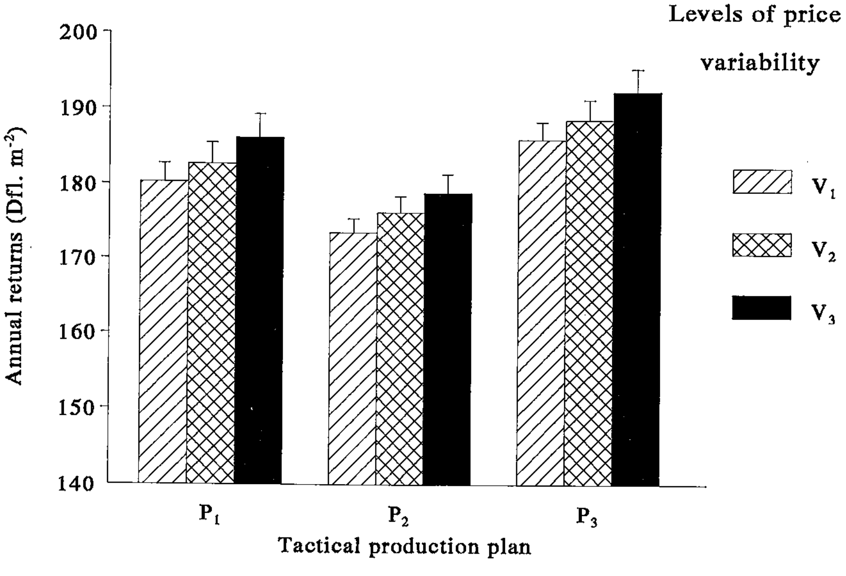

Figure 11.2 Average simulated annual total returns (Dfl. m^{-2}) with corresponding standard errors of mean for all applied system variants in the sensitivity analysis on price variability.

Figure 11.3 shows $\overline{PRP}_i$ increased with price variability. Analysis of the absolute loss of returns due to price reduction indicated in the present sensitivity analysis price reduction particularly related to early deliveries (table 11.5). This observation should be related to the number of type III operational problems solved by adaptation. As pointed out before, the increase of this number related to higher prices for direct deliveries due to incidental price deviation ratios greater than one. Hence, individual price reduction ratios (PRR_h) were lower (equation 6.10). $\overline{PRP}_i$, however, increased with price variability (despite lower price reduction ratios) due to a strong increase of the number of advanced deliveries with non-standard product attributes as solution for type III operational problems.

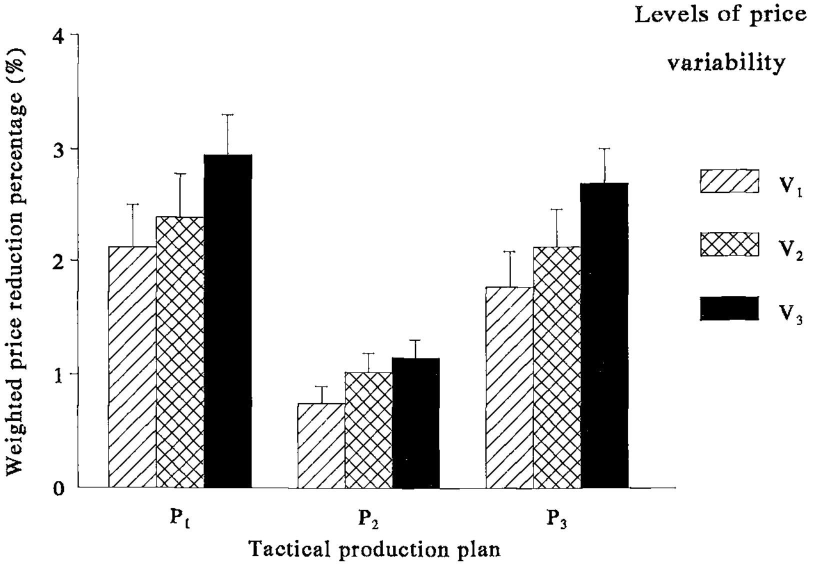

Figure 11.3 Average simulated weighted price reduction percentage (%) with corresponding standard errors of mean for all system variants in the sensitivity analysis on price variability.

Under the *extra slack* plan (P_2) price reduction related also to postponed deliveries (table 11.5). These price reductions were the result of type IV operational problems solved by adaptation. Such price reductions were deliberately accepted when they were expected to be compensated by relatively high future prices. Such decision events were particularly recorded under the *extra slack* plan (P_2), because of the applied extended cultivation-schedules. For both other tactical production plans reallocation of greenhouse area and labour was more problematic. Moreover, more extra labour had to be hired, which made postponement of deliveries less favourable.

Table 11.5 Average absolute annual loss of returns due to price reduction (Dfl. m^{-2} $year^{-1}$) per crop weight interval for every system variant in the sensitivity analysis on price variability.

	Level of price variability		
	V_1	V_2	V_3
reference plan (P_1)			
$< W^-$	0.05	0.20	0.86
$W^- - W^*$	3.85	4.28	4.80
$W^* - W^+$	-[a]	-[a]	-[a]
$> W^+$	0.00[b]	0.00[b]	0.00[b]
Total	3.90	4.48	5.66
extra slack plan (P_2)			
$< W^-$	0.04	0.12	0.25
$W^- - W^*$	0.57	0.99	1.17
$W^* - W^+$	-[a]	-[a]	-[a]
$> W^+$	0.72	0.73	0.66
Total	1.33	1.84	2.08
cash flow plan (P_3)			
$< W^-$	0.11	0.25	0.98
$W^- - W^*$	3.26	3.88	4.41
$W^* - W^+$	-[a]	-[a]	-[a]
$> W^+$	-[a]	-[a]	-[a]
Total	3.37	4.13	5.39

[a] No price reduction in this crop weight interval.

[b] < 0.005

The effect of price variability on the particular absolute loss of returns due to price reduction for the classification '$>W^{+}$' under the *extra slack* plan (P_2) was not straightforward. With price variability the number of type IV operational problems solved by adaptation increased (table 11.4), while the loss of returns was the lowest for *high* price variability (V_3). Individual price reduction ratios, however, decreased with price variability, because of incidental price deviation ratios greater than one. Hence, these two effects on the absolute loss of returns due to price reduction partially compensated each other.

11.3 Price risk attitude

11.3.1 Net farm income

The saturated regression metamodel showed a significant effect of risk aversion, i.e. β_4 for *risk averse* behaviour and β_5 for *very risk averse* behaviour, on $\overline{\text{NFI}}_i$ ($P<0.05$) (table 11.6). Moreover, no significant effect of risk preference, i.e. β_3 for *risk seeking* behaviour, was found ($P>0.05$). Furthermore, the main effects (β_1 and β_2) for the replacement of the *reference* plan (P_1) were identical to those in the first sensitivity analysis. This, of course, is not surprising since both regression metamodels with only one of these regression coefficients equal to one refer to the same system variants ($P_2S_5V_2R_2$ and $P_3S_5V_2R_2$).

Only the interaction effects with respect to risk aversion for the *extra slack* plan (P_2) were found to have a significant effect on $\overline{\text{NFI}}_i$ ($P<0.05$). In fact, risk aversion resulted in a stronger reduction of $\overline{\text{NFI}}_i$ for the *reference* plan (P_1) and the *cash flow* plan (P_3) than for the *extra slack* plan[2] (P_2), which is also demonstrated in figure 11.4.

Figure 11.4 indicates variation of the level of price risk aversion did not lead to dramatic changes in standard errors of mean of $\overline{\text{NFI}}_i$. Net farm income variances under *risk averse* behaviour (R_3) and *very risk averse* behaviour (R_4) were considerable. As discussed in subsection 10.2.1, net farm income variances were particularly due to the application of the set of 25 different scenarios of exogenous conditions. Nevertheless, operational

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[2] Analysis of individual decision events (subsection 11.3.2) and annual weighted price reduction percentages (subsection 11.3.3) show this relates to the application of extended cultivation-schedules in the *extra slack* plan (P_2).

price risk aversion lead for all three applied tactical production plans to a small reduction of variance in net farm income.

Table 11.6 Regression metamodel of the simulated average annual net farm income per system variant ($\overline{\text{NFI}}_i$) in the sensitivity analysis on price risk attitude.

Effect	*System variant*	$\hat{\beta}_j$ (Dfl. m^{-2})	t_{24}	*P*
Intercept				
β_0	P_1R_2	14.88	-	-
Main effects				
β_1	*extra slack*	-3.79	-1.83	0.08
β_2	*cash flow*	1.07	2.26	0.03^*
β_3	*risk seeking*	-0.20	-0.45	0.66
β_4	*risk averse*	-5.67	-4.55	$< 0.01^*$
β_5	*very risk averse*	-11.75	-7.97	$< 0.01^*$
Interactions				
β_{13}	P_2R_1	-0.89	-1.27	0.22
β_{14}	P_2R_3	3.68	2.45	0.02^*
β_{15}	P_2R_4	7.04	5.21	$< 0.01^*$
β_{23}	P_3R_1	-0.62	-1.70	0.10
β_{24}	P_3R_3	-0.20	-0.45	0.66
β_{25}	P_3R_4	-1.21	-1.11	0.28

* Significantly different from zero at the 5% level.

More surprising, however, was that risk seeking behaviour hardly affected $\overline{\text{NFI}}_i$. In search of an explanation for this observation several possibilities were verified. Under risk preference, the risk premium of the late delivery option is negative (equation 8.16) and therefore partially compensated by additional costs of late deliveries (equation 8.22). Consequently, compared to the *risk neutral* attitude (R_2), the number of type III and IV operational problems solved by adaptation could be expected to change to a larger degree under the *risk averse* attitude (R_3) than under the *risk seeking* attitude (R_1). Moreover, with respect to price reduction due to non-standard product attributes, risk preference was most likely to lead to deliveries of batches which went 'beyond' standard product attributes. As shown in table 6.4, price reduction in such cases was modelled to be moderate compared to deliveries before standard product attributes were attained. Hence, biased perception of future prices and consequently of future price reductions were expected to have a relatively low impact on net farm income under the *risk seeking* attitude (R_1).

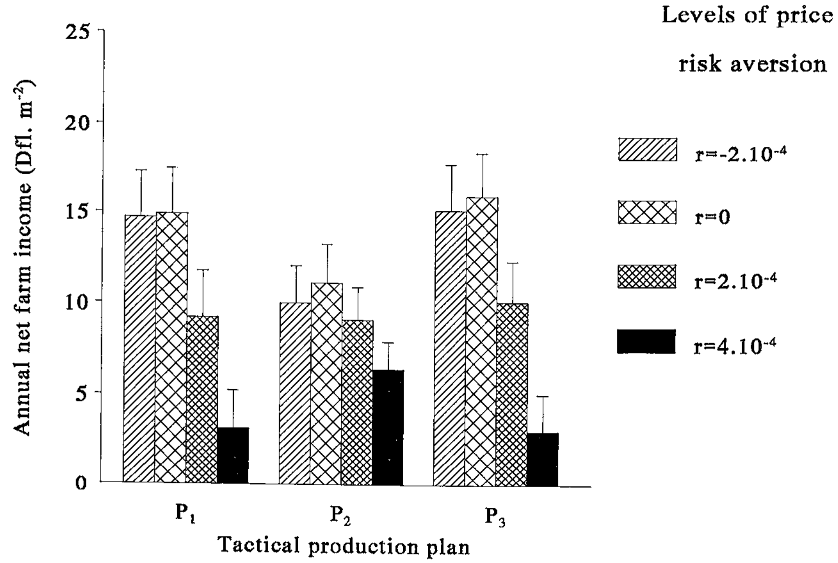

Figure 11.4 Average simulated annual net farm incomes (Dfl. m^{-2}) with corresponding standard errors of mean for all applied system variants in the sensitivity analysis on price risk attitude.

11.3.2 Decisions events

With respect to individual decision events, variation of the level of price risk aversion affected particularly type III and IV operational problems, as could be expected from the first sensitivity analysis. The number of type III operational problems solved by adaptation increased with the level of risk aversion (figure 11.5a). In this respect, the *reference* plan (P_1) and the *cash flow* plan (P_3) responded very similar to risk aversion, whereas the number of type III operational problems solved by adaptation seemed less sensitive to risk aversion under the *extra slack* plan (P_2). Furthermore, the number of type IV operational problems solved by adaptation reduced with risk aversion (figure 11.5b).

Risk aversion in the present sensitivity analysis initiated early deliveries fairly similar to price variability in the first sensitivity analysis. In contrast to the positive effect on $\overline{NFI_i}$ of early deliveries due to price variability, however, the increase of early deliveries with risk aversion lead to reduction of $\overline{NFI_i}$. In this respect, it should be emphasized in the first sensitivity analysis (on price variability) prices were actually changed. In the present sensitivity analysis (on operational price risk attitude), however, prices were identical to those in the original simulation experiment. Only the perception of uncertain future prices was modified.

Under the *risk averse* attitude (R_3) and the *very risk averse* attitude (R_4) uncertain future prices were 'undervalued'. In these cases the certainty equivalent, applied in the operational decision-making procedure (section 8.3), was lower than the operational price forecast. Therefore, in some cases early deliveries appeared to be attractive, where in fact they were not profitable. Conversely, under the *risk seeking* attitude (R_1) future prices were 'overvalued' and some cases of late deliveries turned out to be less profitable than the rejected early deliveries. As a result, the biased perception of future prices was expected to lead to reduced average annual total returns.

Indeed, figure 11.6 shows a considerable reduction of $\overline{TR_i}$ particularly for the *reference* plan P_1 and the *cash flow* plan (P_3) with risk aversion. For the *extra slack* plan (P_2) the reduction was relatively small, which corresponds with the positive interaction effects in table 11.5. This deviating observation for the *extra slack* plan (P_2), however, could not be explained by the number of type III and IV operational problems solved by adaptation (figure 11.5).

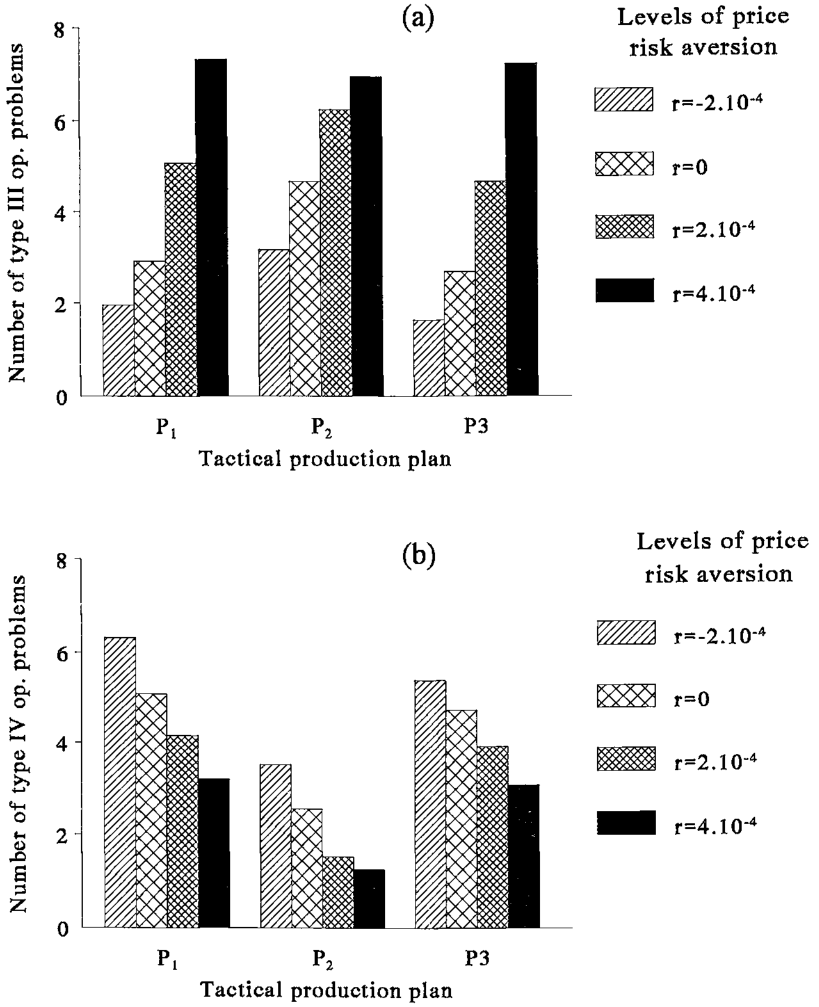

Figure 11.5 Average number per year of type III (a) and type IV (b) operational problems solved by adaptation in the sensitivity analysis on price risk attitude.

Finally, figure 11.5 shows *risk seeking* behaviour (R_1) resulted in less type III operational problems and more type IV operational problems solved by adaptation compared to the *risk neutral* behaviour (R_2), although these differences seem to be somewhat smaller than between *risk neutral* behaviour (R_2) and *risk averse* behaviour (R_3). Thus, the number of operational problems solved by adaptation of cultivation-schedules did not provide a full explanation for the observed moderate effect of risk preference on $\overline{NFI_i}$. Therefore, particularly the average simulated weighted price reduction percentage ($\overline{PRP_i}$) was analyzed.

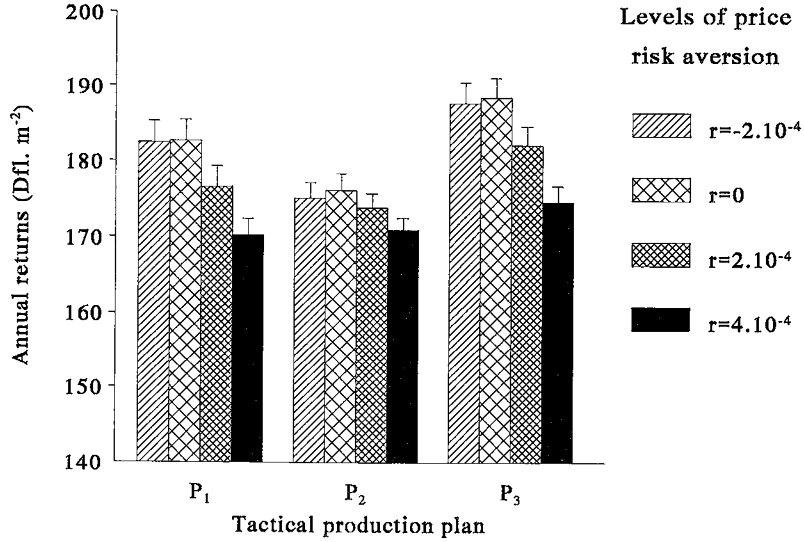

Figure 11.6 Average simulated annual total returns (Dfl. m^{-2}) with corresponding standard errors of mean for all system variants in the sensitivity analysis on price risk attitude.

11.3.3 Price reduction

Figure 11.7 shows the response of the average simulated annual weighted price reduction percentage ($\overline{PRP_i}$) to the price risk attitude. Particularly for the *reference* plan (P_1) and the *cash flow* plan (P_3), price reduction under the *risk seeking* attitude (R_1) and under the *risk neutral* attitude (R_2)

appeared to be fairly close, while the equivalent level of *risk averse* behaviour (R_3) resulted in relatively high levels of price reduction. Moreover, for the *extra slack* plan (P_2) risk averse attitudes had hardly any effect on $\overline{PRP_i}$. Thus, differences in $\overline{NFI_i}$ among system variants related to differences in price reduction rather than in the number of type III and IV operational problems.

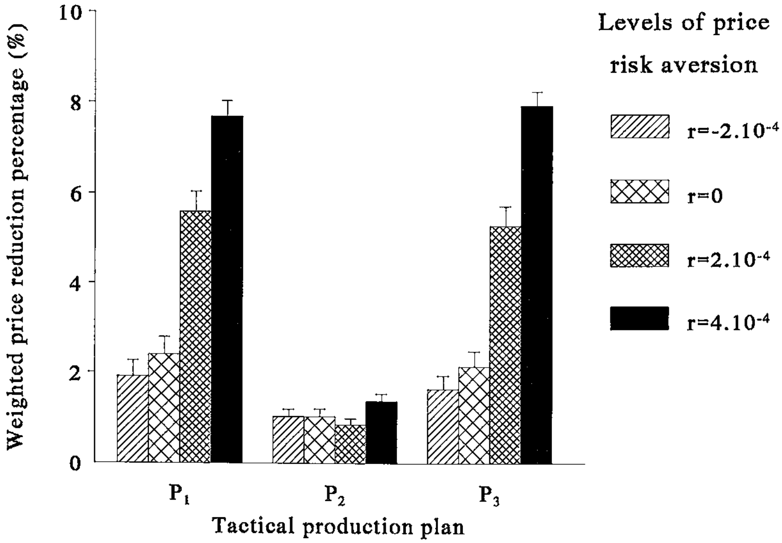

Figure 11.7 Average simulated annual weighted price reduction percentage (%) with corresponding standard errors of mean for all system variants in the sensitivity analysis on price risk attitude.

In conclusion, in particular price reduction accounts for the moderate effect of *risk seeking* behaviour (R_1) on net farm income. As concluded from table 11.5, price reduction under the *active marketing* strategy (S_5) was particularly due to the delivery of batches which did not yet attained standard product attributes. Hence, particularly the increasing number of type III operational problems with risk aversion lead to increasing price reduction and consequently to lower net farm incomes. Moreover, the generally low level of $\overline{\mathrm{PRP}_i}$ under the *extra slack* plan (P_2) corresponds with the relatively low absolute loss of returns due to price reduction in table 11.5 and the significant positive interaction effects in table 11.6.

11.4 Evaluation of sensitivity

The first sensitivity analysis demonstrated the pot plant nursery model was fairly sensitive to the level of price variability under the *active marketing* strategy (S_5). Price variability appeared to affect particularly the number of type III operational problems and their solution. Since this type of operational problem could not be identified under the other four strategies of operational management (S_1 to S_4), the effect of price variability on operational decision-making under these strategies can be expected to be smaller. The effect of price variability on $\overline{\mathrm{NFI}_i}$ through price formation and price reduction, however, may be greater under these strategies of operational management than under the *active marketing* strategy (S_5), because of the inability to identify and solve type III and IV operational problems.

The sensitivity analysis on price risk attitude demonstrated operational decision-making was rather sensitive to non-neutral behaviour to operational price risk. Only under risk averse behaviour this resulted in a considerable reduction of net farm income. In addition, the effects of risk aversion on operational decision-making under strategies of operational management S_1 to S_4 were expected to be smaller than the effects found in the present sensitivity analysis. Since under the *passive* strategy (S_1) and the *product quality* strategy (S_2) economic consequences were completely disregarded during operational decision-making, no effect of the attitude to operational price risk was expected under these strategies. Moreover, the effect of the attitude to operational price risk under the *profitability* strategy (S_3) and the *flexible delivery* strategy (S_4) was expected to be smaller than under S_5, because only under S_5 type III and type IV operational problems were taken into consideration. Finally, the sensitivity analysis on price risk attitude confirmed adaptation of delivery patterns based on a biased perception of future prices due to non-neutral risk attitudes in the end leads to reduced profitability.

Non-neutral risk attitudes affected the difference in average annual net farm income ($\overline{\text{NFI}}_j$) between the *active marketing* strategy (S_5) and the *passive* strategy (S_1). Table 11.7 shows this difference for all four risk attitudes applied in the second sensitivity analysis. Because the simulated results under the *passive* strategy (S_1) were independent of the operational price risk attitude, differences are due to the effects discussed in section 11.3. Particularly under the *reference* plan (P_1) and the *cash flow* plan (P_3) the positive effect on the difference in $\overline{\text{NFI}}_j$ between S_1 and S_5 is reduced by risk aversion. In case of the *very risk averse* attitude (R_4), the *active marketing* strategy (S_5) even lead to a lower $\overline{\text{NFI}}_j$ than under the *passive* strategy (S_1).

Table 11.7 Differences (Dfl. m^{-2}) in average annual net farm income ($\overline{\text{NFI}}_j$) between the *active marketing* strategy (S_5) and the *passive* strategy (S_1) for every system variant in the sensitivity analysis on price risk attitude.

Price risk attitude		Tactical production plan		
		P_1	P_2	P_3
R_1	(*risk seeking*)	9.68	14.44	9.78
R_2	(*risk neutral*)*	9.88	15.53	10.60
R_3	(*risk averse*)	4.21	13.54	4.73
R_4	(*very risk averse*)	-1.87	10.82	-2.36

* The differences as found in the original simulation experiment (table 10.2).

Although the sensitivity of the pot plant nursery model to price variability and to price risk attitude were investigated separately, a final comment can be made on the expected interaction between both factors. As pointed out before, in case of a non-neutral attitude price variability can also be expected to affect the certainty equivalent for later deliveries. Hence, the effect of price variability on the number of type III and IV operational problems, their solution, and on $\overline{\text{NFI}}_j$ can be expected to depend on the level of risk aversion. An indication of the interaction effect of price variability and price risk attitude can be derived from equations 8.16 and 8.18. These equations show that the risk premium for later deliveries increases with risk aversion and price variability. Moreover, the multiplication in equation 8.16 indicates the presence of an interaction effect. Thus, increasing price variability in case of risk aversion can be expected to lead to lower certainty equivalents. Consequently, more type III operational problems solved by adaptation and less type IV operational problems solved by adaptation can be expected.

12

EVALUATION OF OPERATIONAL MANAGEMENT WITHIN THE SIMULATION CONTEXT

12.1 Introduction

After the presentation and discussion of the annual results and decision events from the original experiment and the two sensitivity analyses, operational management was evaluated within the simulation context. Hence, an attempt was made to select the most favourable strategy of operational management in the simulation context. Furthermore, the economic impact of individual adaptation types was estimated. The purpose of this exercise was to provide additional information about the effects of operational management on profitability. Finally, the use of the heuristic search procedure in the simulation experiment was evaluated.

12.2 Strategies of operational management

The question of the most favourable strategy of operational management remains difficult to answer. Although quantitative analysis showed significant differences in simulated annual net farm incomes due to different strategies of operational management, it was also perceived applied strategies had a 'cost-side'. The present pot plant nursery model, however, focused on effectiveness rather than on efficiency of operational decision-making. Therefore, the simulated total costs of the modelled pot plant nursery did not account for differences in operational management costs. In fact, such management costs were assumed to be included in the overhead costs, which were fixed in the present simulation experiments. Thus, the simulated annual net farm income should be corrected for operational management costs before an evaluation of applied strategies. In this respect, not only costs of working hours, computers, and so on (Stein, 1991) should be taken into account, but also the 'costs' of management efforts. Particularly the *active marketing* strategy (S_5), which lead to the highest average annual net farm incomes in the simulation experiments, was expected to lead to relatively high management efforts. Furthermore, operational management costs should be related to the size of the nursery and the size of individual batches because of 'economies of scale'.

In addition to the costs of operational management, the present pot plant nursery model did also not consider long term effects of operational management on returns and consequently on net farm income. In particular, the *product quality* strategy (S_2) was expected to lead to a positive long term effect. It is common knowledge the grower's reputation among traders plays an important role in Dutch pot plant price formation. Hence, a quality product reputation may function as a safeguard, for which traders are willing to pay a structural higher price. Thus, the *product quality* strategy (S_2) may lead to higher net farm incomes on the long run, although with exception of the *extra slack* plan (P_2) it hardly paid off on the simulated short run. Unfortunately, such long run effects could not be simulated by the applied pot plant nursery model. On the other hand, however, the results of the original simulation experiment showed deliveries of batches with non-standard product attributes could not be completely avoided by operational management as modelled in the present study.

A conclusive comparison of the formulated strategies of operational management within the simulation context required extra information in addition to the simulation results. The pot plant nursery model did not provide such information, because most effects previously described went beyond the individual nursery level. The efficiency of foremost active marketing decision-making was thought to depend on the way the industry and auctions are organized. Moreover, long term effects on price formation relate to the total of individual responses of suppliers and buyers on the market.

A general evaluation of the strategies of operational management was even more problematic due to the limited feasibility to generalize the simulation results, even for the particular modelled pot plant nursery. Besides the three applied tactical production plans, for example, additional plans could have been formulated. Simulation of operational management for such additional tactical production plans could have lead to deviating results. Furthermore, the applied set of strategies of operational management, although focusing on the two major sources of uncertainty in pot plant production, could have been extended with additional strategies. Finally, the application of various scenarios of exogenous conditions resulted in considerable variance of the simulated annual net farm incomes. Hence, the choice of a most favourable strategy of operational management itself involved decision-making under risk, which is affected by subjective factors like judgement, risk attitude and personal objectives. In conclusion, evaluation of operational management could hardly be reduced to the selection of an 'optimal' strategy of operational management based on the simulation results.

12.3 Economic impact of operational adaptations

Because no 'optimal' strategy of operational management could be selected, the impact of different types of operational problems was determined. Hence, additional information was obtained for the evaluation of operational management within the simulation context. Differences in $\overline{NFI}_i$ between system variants were due to different numbers and types of operational problems solved by adaptation of cultivation-schedules. Thus, operational problems which did not lead to adaptation of cultivation-schedules were not relevant in the present analysis of economic impact[1].

In order to estimate the economic impact of type I and II adaptations the results of the original simulation experiment under the *passive* strategy (S_1), the *product quality* strategy (S_2) and the *profitability* strategy (S_3) were taken into consideration. As pointed out, differences in numbers of type I and II adaptations between the *product quality* strategy (S_2) and the *profitability* strategy (S_3) involved operational problems with a negative economic impact. So, under the *product quality* strategy (S_2) type I^n and II^n adaptations were separated from type I^p and II^p adaptations. Moreover,

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[1] The calculation of isovalue economic impact relations is described in section 9.4.

under the *profitability* strategy (S_3) only type I^p and II^p adaptations were assumed. The difference in $\overline{NFI}_i$ between both strategies of operational management for each of the tactical plans was related to the number of type I^n and II^n adaptations under the *product quality* strategy (S_2). Differences in $\overline{NFI}_i$ between the *profitability* strategy (S_3) and the *passive* strategy (S_1) were related to number of type I^p and II^p adaptations under the *profitability* strategy (S_3).

Figures 12.1 and 12.2 show the isovalue economic impact relations for all three tactical production plans. Intersections A, B and C in figure 12.1 mark the values for which two out of three tactical production plans lead to a common economic impact equilibrium for type I^p and II^p operational problems. Hence, the economic impact of type I^p adaptations was estimated to be about Dfl. 1800, whereas for type II^p adaptations an economic impact of approximately Dfl. 3700 was estimated.

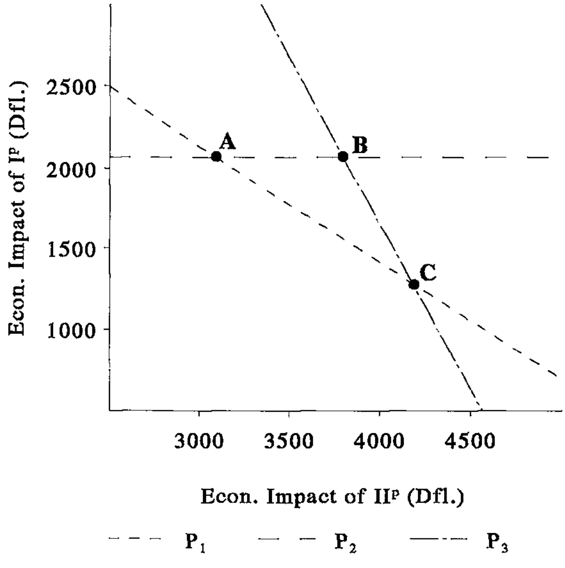

Figure 12.1 Representation of isovalue economic impact relations of type I^p and II^p adaptations in the original simulation experiment.

In addition, figure 12.2 shows for each tactical production plan the economic impact isovalue lines of type I^n and II^n adaptations. Due to the absence of type II^n adaptations constant economic impact values for type I^n adaptations were calculated for the *extra slack* plan (P_2) and the *cash flow* plan (P_3). Moreover, these constants were unfortunately inconclusive, i.e. Dfl. -1352 and Dfl. -49920. Hence, the economic impact of type I^n adaptations could hardly be estimated. Furthermore, the economic impact of type II^n adaptations, which only occurred for the *reference* plan (P_1), was estimated to be approximately Dfl. -22000.

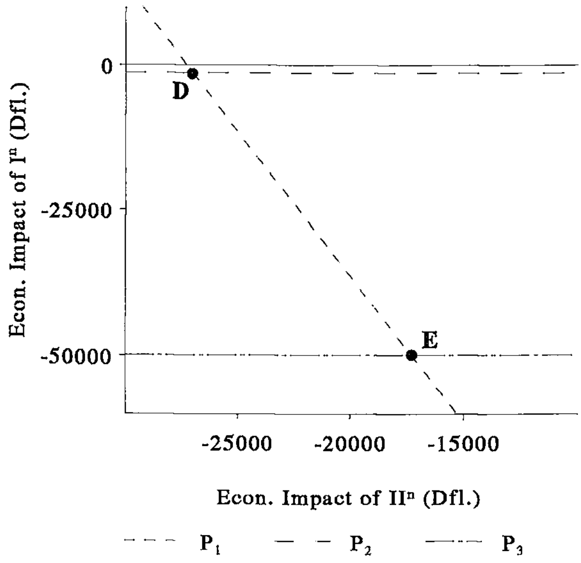

Figure 12.2 Representation of isovalue economic impact relations of type I^n and II^n adaptations in the original simulation experiment.

In conclusion, the economic impact of type I^p adaptations was estimated to be relatively low compared to type II^p adaptations. Moreover, particularly in case of many type I^n adaptations, i.e. for the *extra slack* plan (P_2), the economic impact of type I^n adaptations was expected to be moderate.

Finally, type II^n adaptations for the *reference* plan (P_1) were expected to have a relatively large economic impact.

In order to estimate the economic impact of type III and IV adaptations simulation results under the *active marketing* strategy (S_5) were taken into consideration. As pointed out before, these operational problem types were only recorded under this particular strategy of operational management. In this respect, the change in the number of type III and IV adaptations in the sensitivity analysis on price risk attitude were related to corresponding differences in simulated $\overline{NFI}_j$. For this purpose, type III and IV adaptations were independently divided in four adaptation types.

Under the *risk neutral* attitude (R_2) all type III operational problems solved by adaptation of cultivation-schedules were assumed to be profitable. Under the *risk seeking* attitude (R_1), however, some of these profitable operational problems did no longer lead to adaptation of cultivation-schedules. Only the 'very' profitable type III operational problems were solved by adaptation of cultivation-schedules. Thus, type III operational problems under the *risk neutral* attitude (R_2) were subdivided in type III^p and III^{pp} adaptations, where type III^{pp} adaptations represented the 'very' profitable type III operational problems also recorded under the *risk seeking* attitude (R_1). Furthermore, under the *risk averse* attitude (R_3) and the *very risk averse* attitude (R_4) type III operational problems with (by risk-neutral standards) moderately negative expected economic effects were solved by adaptation (III^n). Similarly, type III^{nn} adaptations were recorded only under the *very risk averse* attitude (R_4).

With respect to type IV operational problems three adaptation types with a positive expected economic effect and one adaptation type with a negative expected effect were distinguished. As pointed out before, type IV adaptations involved postponement of deliveries. Hence, type IV^{ppp} adaptations occurred under all applied price risk attitudes. Type IV^{pp} adaptations were only recorded under price risk attitudes R_1, R_2 and R_3, whereas type IV^p adaptations were only recorded under price risk attitudes R_1 and R_2. Type IV^n adaptations occurred only under the *risk seeking* attitude (R_1).

For each of the applied tactical production plans isovalue economic impact relations of type III^p and IV^n adaptations, type III^n and IV^p adaptations, as well as type III^{nn} and IV^{pp} adaptations were calculated (figures 12.3 and 12.4). Figure 12.3 shows no intersection of the isovalue economic impact relation of type III^{p} and IV^{n} adaptations for the *reference* plan (P_1) with the corresponding relations for the two other tactical production plans. Moreover, the intersection F points at relatively low economic impacts of type III^{p} and IV^{n} adaptations. Hence, the economic impact of type III^{p} adaptations was estimated to be about Dfl. 1500. Consequently, the economic impact of type III^{pp} adaptations was expected to exceed this estimation. In addition, type IV^{n} adaptations were estimated to have an economic impact of approximately Dfl. -150.

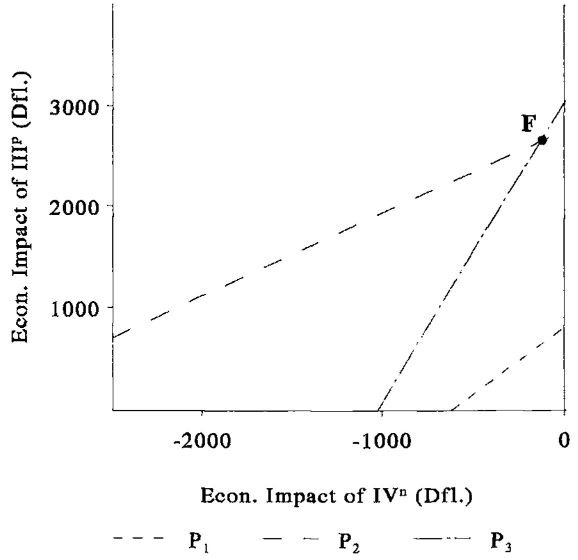

Figure 12.3 Representation of isovalue economic impact relations of type III^{p} and IV^{n} adaptations in the sensitivity analysis on price risk attitude.

Figure 12.4 is more complex to understand. It consists of economic impact isovalue lines of type III^{n} and IV^{p} adaptations as well as type III^{nn} and IV^{pp} adaptations. Thus, the latter, i.e. the bold lines for each tactical production plan, should lie below the corresponding lines of III^{n} and IV^{p} adaptations. Thus, for the *cash flow* plan (P_3) intersection H marks the point from which to the left the presented isovalue lines should be regarded as inconsistent. As a result, the two equilibria of type III^{nn} and IV^{pp} isovalue lines (intersections G and I) should be disregarded. Because all intersections were rather close to each other, however, no strict interpretation was given to intersection H. Moreover, with exception of the *extra slack* plan (P_2) the economic impact of type III^{n} and III^{nn} operational problems was expected to be not so much different based on figure 12.4. Thus, the economic impact of type III^{nn} adaptations was approximately Dfl. -9000. In addition, the economic impact of type III^{n} adaptations was expected to be somewhat less negative. Furthermore, the economic impact of type IV^{pp} adaptations was estimated to be about Dfl. 4500. Hence, the economic impact of type IV^{p} adaptations was expected to lie between zero and this estimated Dfl. 4500, whereas the economic impact of type IV^{ppp} adaptations was expected to be higher than Dfl. 4500.

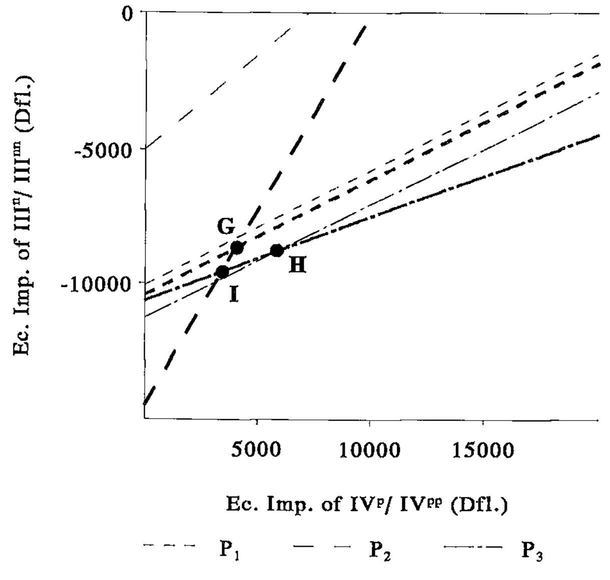

Figure 12.4 Representation of isovalue economic impact relations of type III^{n} and IV^{p} adaptations as well as of type III^{nn} and IV^{pp} adaptations (bold lines) in the sensitivity analysis on price risk attitude.

12.4 Use of the heuristic search procedure

The heuristic search procedure was developed and incorporated in the present pot plant nursery model to solve operational problems on the multi batch level. Hence, it could be questioned whether it was actually used in the present simulation experiment and lead to decision events in which various cultivation-schedules were adapted. Of course, the use of the heuristic search procedure depended on the applied tactical production plans and exogenous conditions. Obviously, the heuristic search procedure was only used in case of operational problems that came to the multi batch level of operational adoption decision-making. Moreover, the recorded use did also depend on the applied strategy of operational management. Furthermore, solutions with several adapted cultivation-schedules, although feasible in view of greenhouse area and labour constraints, could be rejected under the *profitability* strategy (S_3), the *flexible delivery* strategy (S_4) and the *active marketing* strategy (S_5), because the total economic effect of all considered adaptations was expected to be negative.

The objective of the heuristic search procedure was to solve the violations of greenhouse area and labour constraints, which resulted from adoption decision-making on the single batch level. In this respect, table 10.3 already showed all 1622 operational problems solved by adaptation in the original simulation experiment required additional hired labour. Thus, all these operational problems were solved at the multi batch level by means of the heuristic search procedure. Only in 225 decision events, however, cultivation-schedules of batches without operational problems were adapted in addition to the problem batch. This could be regarded as an indication of the inability to solve labour constraint violations by means of rescheduling other batches. On the other hand, however, this was considered to be more likely due to the possibility of hiring exact amounts of required additional labour at a relatively low price. Furthermore, it should be emphasized greenhouse area constraints could only be violated by type II and IV operational problems. Hence, cultivation-schedule adaptations of batches without current operational problems only occurred in combination with these two operational problem types.

In all 1622 decision events which were solved by adaptation in the original simulation experiment not even one involved advancement of planned deliveries of a batch without a current operational problem. Most likely, this type of multi batch level adaptation was never applied, because it could only be applied for batches which were at least one week advanced in crop growth. Obviously, such crop growth advancements particularly occurred when batches attained the delivery phase, which then resulted in type I operational problems. In addition, respacing of partly delivered batches without current operational problems was applied only three times. All three cases were recorded under the *active marketing* strategy (S_5) in combination with the *cash flow* plan (P_3) and related to type IV operational problems. Respacing adaptations in the present simulation context were generally not useful, because batches (of *Schefflera arboricola* 'Compacta') were delivered in only two delivery batches over a short period of time. Under the *product quality* strategy (S_2), the *profitability* strategy (S_3) as well as the *flexible delivery* strategy (S_4) for the *cash flow* plan (P_3) five type II operational problems were solved by adaptation on the multi batch level in combination with postponed potting.

The most recorded multi batch level adaptation type was the postponement of spacing. This particular adaptation type for batches without current operational problems occurred in combination with type II operational problems under all *non-passive* strategies of operational management (S_2, S_3, S_4 and S_5) for the *reference* plan (P_1) as well as the *cash flow* plan (P_3). Moreover, no postponed spacing adaptations were recorded for the *extra slack* plan (P_2) due to the absence of type II operational problems.

Under the *product quality* strategy (S_2) the relative number of postponed spacing adaptations[2] was greater than one for the *reference* plan (P_1) (figure 12.5). It meant, on average, every type II operational problem solved by adaptation of cultivation-schedules was combined with more than one postponed spacing adaptation. Furthermore, for the *reference* plan (P_1) as well as the *cash flow* plan (P_3) the relative number of postponed spacing adaptations was reduced under the *profitability* strategy (S_3) and the *flexible delivery* strategy (S_4) compared to the *product quality* strategy (S_2). This reduction was due to the additional condition of profitability. Type II operational problems solved by adaptation on the multi batch level

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[2] This relative number is defined as the average number of postponed spacing adaptations per type II operational problem solved by adaptation.

in combination with postponed spacing adaptations were relatively often expected to have a negative effect on the net farm income. Furthermore, the relative number of postponed spacing adaptations was even more reduced under the *active marketing* strategy (S_5). This second reduction resulted from the identification of type III and IV operational problems, which affected type II operational problems.

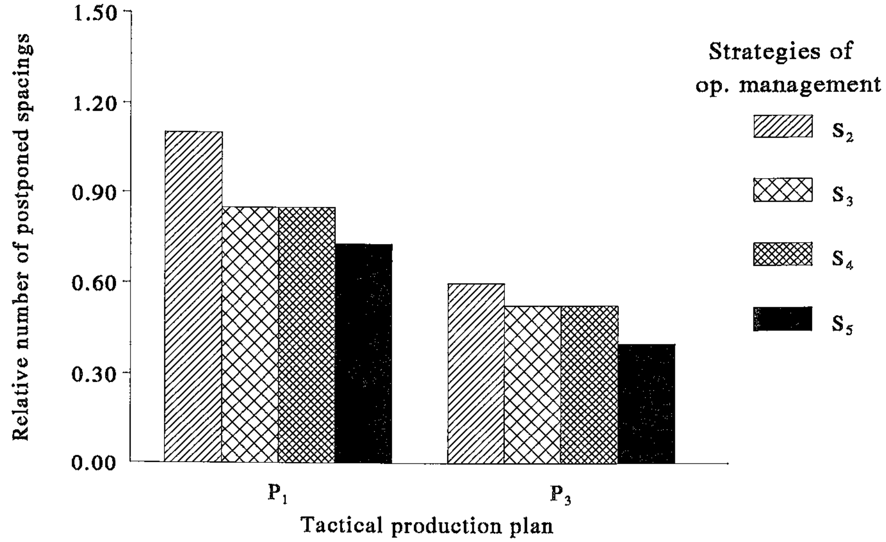

Figure 12.5 Relative number of postponed spacing adaptations on the multi batch level of operational adoption decision-making in the original simulation experiment.

In conclusion, only 225 adaptations of batches without current operational problems were implemented on a total of 1622 decision events solved by adaptation of cultivation-schedules in the original simulation experiment. Hence, operational adoption decision-making on the multi batch level was regarded to be of minor importance during the simulations of the modelled pot plant nursery. With respect to the solution of type II operational problems in particular, however, the developed heuristic search procedure appeared to frequently provide satisfactory solutions, which included adaptations of cultivation-schedules of other batches.

PART IV

GENERAL DISCUSSION

13

EVALUATION OF THE RESEARCH

13.1 Introduction

The simulation experiments showed clear effects of operational management and tactical production planning on net farm income, as well as sensitivity of net farm income to price variability and grower's attitude to operational price risk. Analysis of simulation results indicated opportunities to improve the performance of management in pot plant production by operational decision-making (which was the general goal of the present study (section 1.2)). Before discussing the implications of this outcome, however, the research itself should be evaluated in order to determine the level of confidence in the simulation results. This evaluation concerns the applied methodology, the validity of the present pot plant nursery model and the formulated concept of operational decision-making.

13.2 Evaluation of the methodology

The simulation approach enabled controlled experimentation with (a model of) the pot plant nursery system, which would otherwise not have been possible. On the other hand, simulation modelling required the conceptualization of operational management in relation to only a limited number of relevant processes. Thus, processes leading to uncertainty other than crop growth and price formation were disregarded[1]. Moreover, not all possible options to respond to deviating patterns of crop growth and price formation were taken into consideration[2]. Nevertheless, simulation proved to be useful for the purpose of the present study. In this multi disciplinary investigation physiological, organizational, economic, and (to some extent) psychological processes could be incorporated in one model. Hence, the interactions between these processes could be analyzed in detail based on clear observations.

With respect to the experimental design, some aspects should be further discussed here. Firstly, in each simulation experiment only two factors were varied. Although this rather straightforward experimental approach enabled particularly a thorough analysis of decision events, interactions between for example price variability and price risk attitude could not be analyzed. Secondly, the application of the same set of scenarios of exogenous conditions for all system variants, i.e. common random numbers, complicated the analysis of simulation results. This complication could be solved by means of regression metamodelling and the Friedman statistic. Thirdly, due to the saturated design formulated regression metamodels have little predictive value. In this respect, however, one should bear in mind that the application of an imaginary pot plant nursery already limited possibilities for generalization of simulation results and therefore predictions of absolute effects for individual nurseries.

Regression metamodelling was particularly useful to investigate effects on the overall output variable (net farm income). One readily comprehensible equation comprised all results of extensive simulation experimentation. In case of unequal variances or non-normal distributions of simulation results between system variants, however, the usefulness of regression metamodelling is limited. In such cases, the Friedman statistic provides additional information which may help to select an 'optimal' system variant.

In conclusion, the present research methodology was successfully applied to investigate operational management in pot plant production. The theoretical framework of adaptive decision-making proved itself applicable to a situation with rather common characteristics for pot plant production.

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[1] For example, the occurrence of pests or the availability of resources.

[2] For example, preventive control or complete new tactical production planning.

Hence, a general assessment should further involve a discussion on the logic of the theoretical concept as well as the validity of the applied model, before generalizing the results from the simulation experiments. With respect to the applied methodology itself, the present study indicated a normative approach based on system analysis and simulation, integrating theory from different disciplines, may contribute to the understanding of the functioning of complex systems. Particularly with respect to decision-making of an individual person, in this case the grower, a multi-disciplinary analysis may prove itself useful also for practical purposes. From a scientific point of view the applied research methodology showed that integration between different disciplines is possible if a certain level of abstraction can be obtained and a normative modelling approach is accepted.

13.3 Validity of the model

As in any other simulation study, validity of the model and its basic assumptions is an important prerequisite for general assessment of the investigated process. Usually, validation precedes the actual application of the model, but in the present study application and validation more or less coincided due to the exploratory character of the research. Hence, only individual modules were validated and appraised prior to the simulation experiments. Here, the validity of the complete pot plant nursery model will be discussed.

Basically, validity is the degree of confidence in the model for its intended purpose (Balci & Sargent, 1984; Gass, 1983; Sargent, 1984; Schlesinger *et al.*, 1979). The purpose of the pot plant nursery model in the present study was exploration of opportunities for operational decision-making. Hence, simulation experimentation had to provide directional results based on valid relations in the model rather than precise output for predictive purposes. Moreover, because the present model was applied to investigate a normative concept of operational decision-making validation was mainly based on rationalism rather than empiricism (Naylor & Finger, 1967).

With respect to logical validity (based on rationalism), static logic should be distinguished from dynamic logic (Pidd, 1992). Static logic relates to rules, equations and distributions in the model, whereas dynamic logic relates to the resulting behaviour of the model. Here, validation of the whole model particularly relates to the completeness of the model (static logic), and the dynamic behaviour of the model (dynamic logic).

In addition to the required logical validity, the general level and variation of annual economic output variables were also taken into consideration. In the present study, however, possibilities for statistical validation (based on empiricism), as advocated by for instance Harrison (1991), Kleijnen & Groenendaal (1992), McCarl (1984), and Pidd (1992), were limited, because of the lack of empirical data. Nevertheless, the pot plant nursery model was concluded to be empirical valid in the present study (subsection 10.2.1).

Completeness of the model

With respect to the completeness of the model, the question was whether all relevant processes were incorporated in the model. As pointed out before, long term effects and nursery transcending effects on price formation were not incorporated in the model. Moreover, active marketing in the present study only involved the determination of the moment of delivery. So, common marketing instruments like product development, distribution and promotion were not considered. For the purpose of the present study, however, this did not invalidate the pot plant nursery model. In fact, these disregarded effects and marketing opportunities particularly relate to strategic management.

For the analysis of tactical and operational management in pot plant production, the most important processes were incorporated in the model. The number of options for decision-making, however, was limited. As pointed out before, the possibility of developing a completely new tactical production plan for the rest of the simulation-period was disregarded. Furthermore, other possible operational adaptation options, like for example 'batch branching' and other plant densities in one or more cultivation-phases, were also not taken into consideration.

In the present study, greenhouse climate control was also disregarded as means for operational management. Incorporation of this particular process as a tool for operational management would have enabled the investigation of preventive crop growth control strategies, whereas in the present study crop growth control had a merely curative character. In pot plant production, however, opportunities for such preventive control are rather limited due to the simultaneous presence of many batches in different developmental stages. In fact, greenhouse climate control in this respect seems more important in situations, where a single crop is cultivated over a longer period of time. Hence, the disregarding of greenhouse climate control does not so much invalidate the present model, but rather restricts the translation of the present findings to other greenhouse production systems. In conclusion, the present pot plant nursery model incorporates all relevant processes for the investigation of operational management as described in the theoretical framework, but this does not mean the model represents all possible options for operational management in greenhouse horticulture.

Dynamic behaviour of the model

Besides crop growth and price formation (discussed in chapter 6), the dynamic behaviour of the pot plant nursery model is determined by the individual decision events. Hence, the plausibility of individual events of operational decision-making should be evaluated. At this point, the interrelationship between experimentation and validation in the present study becomes clear. Because the simulated decision events were based on a normative decision-making concept and depended on current circumstances, their plausibility could only be evaluated after simulation experimentation. Therefore, the presentation of the simulation results was accompanied by a search for plausible explanations for the observed phenomena. Thus, the dynamic logic of the individual decision events can be concluded from the discussion of simulation results.

Another important aspect that affected the dynamic behaviour of the pot plant nursery model as a whole was the definition of the time scale, i.e. the length of the simulation-period and of the individual time steps. Because of the annual simulation-period various decision events were investigated within the same simulation run. Although this complicated the analysis of individual decision events, it enabled the analysis of the interrelationship between decision events as well as the effect of the season on the occurrence of operational problems and their solution. Moreover, it required the formulation of an initial system state and the valuation of the final system state.

Because of the given initial system state crop growth risk at the beginning of the simulation-period may have been slightly reduced. Nevertheless, the numbers of decision events over the complete simulation-period were substantial. More problematic, however, was the weekly time step applied in the present pot plant nursery model. Because the daily calculated rate of crop growth was particularly in summer relatively high, batches sometimes passed the optimal delivery stage without being delivered. As pointed out, this phenomenon was anticipated only under market oriented strategies of operational management (S_4 and S_5). If, however, a daily time step would have been applied, this phenomenon would also not have occurred under the other strategies of operational management (S_2 and S_3). Hence, the weekly time step applied in the present model seriously affected opportunities to deliver plants with standard product attributes. On the other hand, the application of a daily time step would have required a more comprehensive representation of the elaboration decisions. Moreover, the complexity of labour and greenhouse area allocation would have increased.

A final comment should be made to the simulated patterns of exogenous conditions affecting crop growth and price formation. As pointed out in section 6.4, these input variables of the pot plant nursery model were simulated randomly and independently prior to the simulation experiments. Furthermore, for the exploratory purpose of the present study these simulated exogenous conditions sufficed. For other purposes (such as prediction of net farm incomes of actual pot plant nurseries), however, historical data should be preferred to independently simulated data, because the latter lack possible interactions. Thus, for such purposes the limited availability of historical data may become a problem.

Logic validity

In conclusion, the present pot plant nursery model was believed to be logically valid for the purpose of investigating the formulated theoretical framework for operational management. Alternative applications of the present model, however, should be carefully considered, since validity of the simulation model is strongly depending on its purpose. Furthermore, the practical validity[3] of the present model is rather limited, because of methodological issues discussed before as well as limited knowledge of the processes involved.

13.4 Validity of the concept

The theoretical framework was mainly based on a normative view on operational decision-making in pot plant production. The intention of the present study was not to investigate the consequences of operational management as actually executed in practice, but rather to investigate the consequences of possible strategies of operational management consistently applied during the implementation of tactical production plans. Consequently, the assessment of operational management in the present study is due to remain rather normative.

Basically, the validation of the concept underlying the model, i.e. the theoretical framework described in chapter 3, focused on two questions:

1. Is application of the concept by actual growers plausible?

2. Is application of the concept by actual growers likely to be satisfactory?

Although both questions may seem related (assuming rational behaviour), they reflect different aspects of the validity issue. The first question concerns the logical validity of the concept in relation to characteristics of pot plant production. The second question concerns the practical validity of the concept in relation to characteristics of pot plant growers.

The logical validity of the present concept of operational management in pot plant production relies on the interpretation of literature described in part II of the present study. Moreover, discussions with other scientists in this field of research contributed to the so-called 'face validity' (Gass, 1983) of the concept. In addition, plausibility of specific types of

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[3] The usefulness of the model to predict effects of operational management on individual pot plant nurseries.

adaptations of cultivation-schedules was verified during consultations of growers. Two main points, however, limit the logical validity of the concept. Firstly, the existence of a tactical production plan or at least cultivation-schedules of present growing batches was assumed. Although maybe hardly imaginable for farm management theoreticians, consultation of pot plant growers showed that this is in reality not always the case. Probably in such situations growers have some kind of 'plan' in their mind, but it remains questionable whether this can take over the function of the tactical production plan as conceived in the present concept. Secondly, in the present study all operational deviations were regarded as incidental. Operational deviations, however, may also be structural and should then lead to new tactical production planning. With these two reservations it seems plausible the present concept of operational management in pot plant production could be applied.

As already pointed out in chapter 12, it is difficult to fully survey and assess all possible costs, efforts and benefits. The risky choice for a satisfactory strategy of operational management can be expected to be affected by the grower's risk attitude. In case of a non-neutral attitude toward annual net farm income risk, variances related to different strategies of operational management should be taken into consideration in addition to the simulated averages. For this purpose, certainty equivalents, as described in section 8.3, could be calculated based on the expected utility assumption. Alternatively, more general approaches could be applied, like probabilistic dominance (Keeney & Raiffa, 1976), also called stochastic dominance (King & Robison, 1984; Zentner *et al.*, 1981). In view of the simulation experiments, however, the combination of regression metamodelling and the Friedman statistic should be preferred, since these approaches take the statistical dependence due to the application of common random numbers into account. A final point in relation to the variance of annual net farm income concerns tax. Depending on the legal form of the nursery differences in simulated before tax incomes can be expected to be reduced due to a progressive tax regime (Monke *et al.*, 1992; Taylor, 1986).

Despite the focus on net farm income, personal objectives should be mentioned as a matter of concern in choosing the most favourable strategy of operational management. Besides income maximization, the grower may consider other objectives (Fairweather & Keating, 1994; Harling & Quail, 1990; Nix, 1987). Although the five formulated strategies of operational management were regarded to represent a sequential order of increasing sophistication, they can also be seen as different operational management styles. Consequently, in that case the strategy of operational management should be regarded as pure qualitative factor in the simulation experiments with no ranking whatsoever similar to the tactical production plan.

The conception of operational management styles would suggest strategies of operational management should be appraised on their fit to more intangible goals rather than on the average simulated annual net farm income. In this respect, the *passive* strategy (S_1) for instance would reflect a strong dislike of last moment rescheduling of operations. Moreover, the grower's reputation resulting from the *product quality* strategy (S_2) would also satisfy social objectives. Furthermore, the difference between internal orientated operational management of crop growth and external orientated operational management of price formation should be recognized. Both types of operational management require different skills and reflect a different inclination of the grower's activities. Hence, the difference between the *profitability* strategy (S_3), the *flexible delivery* strategy (S_4) and the *active marketing* strategy (S_5) should not be seen as gradual, but rather as discontinuous and therefore separating different styles of operational management.

In conclusion, the present concept of operational management in pot plant production is practical valid, insofar as (assuming the presence of a tactical production plan) it offers the pot plant grower an useful paradigm to consider and respond to threats and opportunities due to uncertainty during the implementation of a tactical production plan. In addition, the grower should be aware of possible structural deviations, which may be best solved by new tactical production planning. Furthermore, the present concept should be elaborated to an operational management strategy in agreement with the style and objectives of the individual grower.

13.5 Evaluation of research objective

In conclusion, all three steps of the research approach (section 1.2) have been completed successfully. As discussed in this chapter, the conceptual framework and the pot plant nursery model are valid for the purpose of the present study. Moreover, the usefulness of operational management in pot plant production was demonstrated by means of simulation experimentation, although not a single 'optimal' strategy could be pointed out. The latter, however, was particularly due to the consideration that such a choice should depend on the characteristics of the individual nursery and grower.

In addition, a general assessment of operational management in pot plant production based on the present research is restricted by the characteristics of the modelled nursery:

1. Standard product attributes can be attained following different cultivation-schedules from the same moment of potting.

2. At any moment several batches in different developmental stages are cultivated simultaneously.

3. Crop growth and development can not be completely controlled.

4. Price formation can not be controlled at all.

5. Delivery of batches with non-standard product attributes lead only to limited price reductions.

These prerequisites commonly apply to pot plant production, although particularly for flowering pot plants the impact of deviations from standard product attributes can be expected to be far more drastic than for foliage pot plants. Nevertheless, operational decision-making is believed to improve the performance of management on pot plant nurseries in general.

14

IMPLICATIONS OF THE RESEARCH

14.1 Introduction

The present study clearly shows the limitations of a straightforward implementation of tactical production plans formulated under uncertainty and thus the importance of adaptive operational decision-making. On the other hand, the potentials of adaptive operational decision-making are limited. Therefore, production management should be a balance between tactical planning and adaptive decision-making based on the features of uncertainty as well as the grower's preferences.

In this final chapter, the implications of the present research for practical operational management (as a way of dealing with uncertainty) by individual growers are discussed. Furthermore, implications for further research and opportunities for computerized management support are discussed.

14.2 Strategies of operational management

Once aware of the opportunities of operational management, growers will realize that they already make operational decisions. These decisions, however, will probably be made without much structural consideration. Hence, a first question to be answered is whether these operational decisions comply with a particular strategy. Subsequently, the question of what would be the 'optimal' strategy will arise.

As pointed out before, the choice of an 'optimal' strategy of operational management is rather problematic. In fact, this choice is a strategic decision made under uncertainty considering probably multiple objectives. Moreover, the strategy of operational management should comply with other strategic decisions and derived tactical objectives. For example, the *product quality* strategy (S_2) reflected a typical strategic philosophy, which would be best combined with the *extra slack* plan (P_2) in order to give full priority to quality image objective. On the other hand, the internal oriented *profitability* strategy (S3) relates to quite a different strategic philosophy[1]. The emphasis on internal nursery management would best correspond with a tactical objective of minimum cost prices for seasonal dispersed products. Furthermore, the sensitivity analysis on price risk attitude pointed out that the *active marketing* strategy (S_5) should not be applied in case of a philosophy based on severe risk aversion.

In conclusion, formulating a strategy of operational management is a rather complex decision problem, which seems more a consequence of other (strategic) decisions and circumstances, than the starting-point of the nursery's philosophy. Furthermore, also the choice for a particular strategy of operational management is often only an initial decision, which should be elaborated, monitored and possibly adapted during its implementation.

14.3 Dealing with uncertainty

Because of the complexity of the pot plant production system and its dependence on rather unpredictable exogenous conditions, uncertainty during decision-making is inevitable. As pointed out before, uncertainty results in stress due to a lack of alternatives, a lack of accessible information and a lack of time for decision-making. This stress may result in maladaptive behaviour and is commonly negatively appreciated.

The present study offers some direct and indirect leads for dealing with uncertainty. First of all, the present exploratory research contributes to

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[1] In retrospect, the name *profitability* seems not truly appropriate for this strategy, because profitability could be improved by developing a more external orientation of management.

the grower's knowledge of the managed production system in general and to the understanding of opportunities and limitations of operational management in particular. Adaptive operational decision-making requires considerable cognitive efforts of the grower as well as good knowledge of the managed system and its physical and social environment. Furthermore, the formulated and investigated operational decision-making paradigm can be applied to reveal more operational adaptation alternatives and to enable faster decision-making. Hence, it should contribute to the reduction of stress in case of deviations from planning premises during the implementation of tactical production plans.

More indirectly, the present study implies flexibility as well as robustness of the tactical production plan are important prerequisites for dealing with uncertainty. Flexibility relates to the possibilities for adjustment of initial decisions during their implementation (Kingwell *et al.*, 1992). In this respect, Keeney & Raiffa (1976) speak of the ability to anticipate to unexpected circumstances. Heady (already in 1952) emphasized the importance of considering reallocation of resources when actual conditions deviate from expectations. In addition, other methods to incorporate flexibility in tactical plans can be considered, like for instance incorporating slack resources and buffers of half finished products (Tapiero, 1988) and the use of multi-applicable machinery (Kassicieh & Schultz, 1987). In short, all such measures are meant to provide the grower with possibilities to adjust tactical decisions, i.e. enable operational management. Hence, flexible tactical production plans should be implemented under comprehensive strategies of operational management in order to fully benefit from this characteristic.

Robustness relates to the insensitivity of the nursery's performance to unexpected exogenous conditions. Hence, robust tactical production plans would require hardly any operational adaptation of cultivation-schedules. In the present study, for example, (the lack of) robustness can be related to the number of decision events and eventually to the standard error of the mean net farm income over a set of scenarios. Moreover, robustness can be associated with risk avoidance. Price risk, for example, can be avoided by contracting deliveries (Keeney & Raiffa, 1976). Furthermore, cultivation-schedules can be made more robust by increasing the degree of control over crop growth. Generally, this is achieved by investing in technical equipment. Thus, the production process can be standardized (Tapiero, 1988) and tactical production plans become more robust to weather conditions. In conclusion, robust tactical production plans can be implemented under rather passive strategies of operational management.

14.4 Further research

Several points for further research should be considered. These options relate to:

1. The limited validity of the present pot plant nursery model.
2. The specific domain of investigation in the present study.
3. The specific subject of investigation in the present study.
4. The exploratory character of the present study.

The validity of the present pot plant nursery model may be improved by extending the model with additional aspect of greenhouse cultivation and nursery management. Moreover, specific modules, like for instance for crop growth and price formation, may be improved. In addition, specific aspects of the present study can be studied in more detail. In this respect, further research may be directed to the risk associated with rejection thresholds for (operational) progress decision-making. Both theoretically and empirically this process has got relatively little attention compared to adoption decision-making and is consequently poorly understood. In addition, it seems interesting to investigate pot plant grower's characteristics empirically with respect to the ability to (1) make operational adjustments in tactical production plans, and (2) learn to understand the behaviour of the managed system in its uncertain environment.

The operational management concept in the present study may be applied in other domains. Moreover, the research methodology may be useful to investigate other scientific problems. Such applications may give an impression of the general applicability of both. Besides the research methodology and the concept of operational management, specific modules of the pot plant nursery model could also be used for other scientific problems. In this respect, however, their limited validity for other purposes should be well considered.

The present pot plant nursery model in combination with the research methodology can be used to investigate related subjects within the pot plant production domain. With some additional modelling, for instance, principles of the Prospect-theory described by Kahneman & Tversky (1979) could be incorporated in the module which simulates risk averse behaviour with respect to price forecasts. Hence, the effect of different representations of risk averse behaviour on operational decision-making could be investigated. An other possible application of the present pot plant nursery model may be to investigate the features and effects of flexibility and robustness of tactical production plans.

In addition to this exploratory investigation, further research may also be concentrated on the development of actual management support software. The present pot plant nursery model includes basic elements for functional tools. Moreover, the theoretical framework and the associated discussion on the relation between tactical planning and adaptive operational decision-making, dealing with uncertainty and grower's characteristics provide useful points of departure for such research.

14.5 Opportunities for computerized management support

14.5.1 Computerized management support in general

The introduction of personal computers in recent years opened new opportunities to improve management and decision-making in general. Concepts of various types of computerized management support systems have been developed and implemented, like for instance Management Information Systems (MIS), Decision Support Systems (DSS), and Expert Systems (ES) (Davis & Olson, 1984; Parker & Al-Utaibi, 1986; Sprague & Watson, 1989; Turban, 1990). In pot plant production two main concepts of computerized management support have been introduced. In practice data recording systems have been applied on a relatively large scale (NRLO, 1991). Often such systems are used to exchange and evaluate data on nursery performance among growers (Leeuwis, 1993). In research, planning systems have been developed based on operations research techniques (Annevelink, 1989; Basham & Hanan, 1983; Håkansson, 1991; Krafka *et al.*, 1989; Ludwig, 1991). The latter type of system, however, is not widely applied in practice for the moment. Gollwitzer (1991) found successful implementation of such systems on individual nurseries was impeded by the complexity of the managed production system as well as the applied management support techniques in relation to personal grower's characteristics and the organizational situation. In addition, the present study suggests the usefulness of tactical production plans is rather limited if no additional operational management support is offered.

In principle, computerized management support systems could improve effectiveness as well as efficiency of farm management (Ives *et al.*, 1980). In research, however, emphasis generally has been on effectiveness rather than on efficiency (Parker & Al-Utaibi, 1986). Cognitive efforts and financial costs of decision-making, as mentioned in the present study, have often been ignored. Systems introduced in pot plant production are in most cases focused on making better decisions rather than making them more efficiently. Furthermore, computerized systems can be focused on supporting the grower's process of decision-making or be more functional in the sense of providing (1) more accurate information based on forecasting models, (2) alternatives for the solution of particular problems, or even (3) final answers derived by means of optimization models. For the moment, most systems focus on functional management support, although they often implicitly also provide a kind of process orientated 'support' in the way they enforce the structure of the decision-making process. This, of course, can be rather problematic. Although process orientated support can be helpful (Gold *et al.*, 1990; Howard, 1988; Westerberg, 1993), the danger is that the user is forced into a structure of decision-making which does not fit to his own style of decision-making. Therefore, the process support function of a management support system should be well considered and explicitly documented.

Learning

So far this discussion has been concentrated on direct support of individual decisions. Computerized management support, however, may also be approached from a different angle. The present study did not result in a ready to use software application for the support of operational management. Instead, strategies of operational management were analyzed by means of simulation with a model of a representative imaginary pot plant nursery. Such analyses, however, could also be executed by growers for their own nursery. Moreover, execution of such analyses in groups under the supervision of an expert could be even more instructive. Hence, computerized management support could be applied to improve decision-making and management indirectly. Gollwitzer (1991) found that lack of understanding of the managed system as well as of the possibilities and reliability of tools for support have been important reasons for the poor acceptance of computerized management support systems in practice. Hence, indirect management support (by means of simulation models) may lead to awareness of management opportunities and may contribute to the grower's learning process with respect to management.

14.5.2 Computerized management support in pot plant production

As pointed out, the first generation management support systems, i.e. data recording systems and particularly tactical planning systems, have not lead to the expected improvement of nursery management (Gollwitzer, 1991; NRLO, 1991). Besides other plausible reasons for this disappointing result, a main cause is the narrow scope of existing systems to specific management problems. Recording data can only be expected to be perceived as useful on the long term, if it is incorporated in a repetitive cycle of decision-making (like the present theoretical framework for operational management). Furthermore, the function of tactical production plans in pot plant production is limited due to uncertainty. Hence, the final question is which implications can be derived from the present study in order to develop more appreciated management support software for pot plant production.

Individual modules

Individual modules and methods in the present pot plant nursery model may be transformed into useful management support tools in addition to already existing systems. As a basic tool, a greenhouse area-time interface could be developed, by which the current tactical production plan as well as the greenhouse area occupation record are presented. Hence, growers could anticipate operational problems possibly supported by the formulated heuristic search procedure.

An other implication from the present study is already under investigation. As pointed out, tactical production planning is generally based on standard cultivation-schedules, whereas usually there are various options to come to a final product given a particular initial crop. Therefore, in addition to the present study, at Wageningen Agricultural University the possibilities of cultivation-schedule optimization are investigated. For this purpose also additional efforts are made to improve the crop growth model.

Tactical Operational Management Information System (TOMIS)

Besides linking up existing systems, one can also think of developing a completely new type of system, which offers an integrated approach to pot plant production management. As in the present study, such an integrated approach may relate to farm economics, horticultural production technology, marketing, resource allocation, and plant physiology. Moreover, the three management functions (planning, implementation and control) could be integrated both on the tactical level and on the operational level.

At Wageningen Agricultural University the required features of such a Tactical Operational Management Information System (TOMIS) are studied in a multi-disciplinary group of scientists (Beulens and Hofstede, 1992). The main implications of the present study to the development of such a TOMIS for pot plant production are:

1. The present framework of operational management is a useful concept of dealing with uncertainty.

2. The importance of various grower's characteristics related to decision-making under uncertainty should be recognized and various styles of operational management should be anticipated.

3. A functional integration of tactical and operational decision-making can lead to improved management performances, yet requires a flexible approach toward time-axes of individual problems.

Before making the decision to invest in the development of a fully fledged TOMIS, however, further research with respect to intangible initial as well as ongoing consequences seems necessary (Stein, 1991). Furthermore, empirical investigation of relevant grower's characteristics and management styles may give an indication for the appreciation of possible support tools. In this respect, it is important to keep in mind that, as in the present study, normative models can help to understand the behaviour of a managed system, but can not prescribe how to control it successfully.

APPENDICES

APPENDIX I

Annual change in inventory value (CIV_{im})

This example demonstrates how individual present growing batches were valuated in the final system state of the applied pot plant nursery model. In fact, the contribution of one individual batch to CIV_{im} is calculated under various operational management strategies. Moreover, in correspondence with the complexity of the valuation problem the particular batch is assumed to have not yet attained the delivery phase at the moment of valuation. Hence, current returns (cR_b) are nil and a market-based valuation method can not be applied.

In order to demonstrate different features of the valuation method applied in the pot plant nursery model three different strategies of operational management are considered. Each of these strategies is assumed to result in a different cultivation-schedule of batch b starting from the same original cultivation-schedule and assuming identical exogenous conditions. In this respect, the reference strategy (S_{ref}) leads to the implementation of the original cultivation-schedule of batch b, i.e. without operational adaptations. The second strategy (S_i) is assumed to have initiated an adaptation of the cultivation-schedule during the simulation run, which resulted in cost-savings before the moment of valuation without affecting crop growth. Hence, under strategy S_i current costs (cC_b) are lower than under S_{ref}. Moreover, since crop growth is not affected, the plants of batch b in the final system state under S_i are identical to those under S_{ref}. Consequently, expected future costs ($E(fC_b)$) and returns ($E(fR_b)$) are identical under both strategies of operational management. Finally, the third investigated strategy (S_j) is assumed to initiate an adaptation of the cultivation-schedule of batch b, which resulted in even greater cost-savings, but also reduced crop growth. Thus, under strategy S_j current costs (cC_b) are the lowest. Furthermore, expected future costs ($E(fC_b)$) and expected future returns ($E(fR_b)$) under S_j are different from those under both other strategies. In fact, under strategy S_j the plants of batch b in the final system state are smaller compared to those for both other strategies. Hence, the expected required period until possible deliveries is longer under strategy S_j.

Now, the contribution of batch b to CIV_{im} under each of the three investigated strategies can be calculated (table I.1). In fact, this contribution is equal to the difference between the value of the batch inclusive of expected profit under the investigated strategy and the value of the particular batch inclusive of expected profit under the reference strategy. Consequently, the contribution to CIV_{im} of batch b under the reference strategy is nil by definition. Furthermore, the contribution of batch b under strategy S_i is also nil. This corresponds with the fact that under these two strategies the plants of batch b in the final system state are identical. A valuation exclusive of expected profit, however, would have lead to a Dfl. 200 (11600 - 11400 = 200) difference with the reference strategy. In the latter situation the cost-saving effect would have been included in CIV_{im}. And because in the pot plant nursery model all current costs were included in the annual total costs (TC_{im}), the cost-saving effect would have been taken into account double.

For strategy of operational management S_j a negative contribution to CIV_{im} (Dfl. -2800) is calculated despite a considerable cost-saving effect during the simulation run. Regarding the present value of expected profit of batch b in the final system state under strategy S_j, the adaptation of the cultivation-schedule of batch b under strategy S_j is calculated to 'cost' Dfl. 1800. In this case CIV_{im} compensates the cost-saving effect during the simulation run, included in the simulated annual total returns (TC_{im}).

Table I.1 Contribution of batch b to CIV_{im} in the present example (Dfl.).

	Strategy		
	S_{ref}	S_i	S_j
Economic results of batch b during the simulation-period			
cC_{bS}	11600	11400	10600
cR_{bS}	0	0	0
$\psi(e.e.p.)_{bS} = cC_{bS} - cR_{bS}$	11600	11400	10600
$\psi(e.e.p.)_{bS_{ref}} - \psi(e.e.p.)_{bS}$	0	200	1000
Economic results of batch b during the post-simulation period			
$E(fC_{bS})$	12800	12800	13900
$E(fR_{bS})$	27400	27400	25700
$\psi(i.e.p.)_{bS} = E(fR_{bS}) - E(fC_{bS})$	14600	14600	11800
$PVEP_{bS} = \psi(i.e.p.)_{bS} - \psi(e.e.p.)_{bS}$	3000	3200	1200
Contribution to CIV_{im}			
$= \psi(i.e.p.)_{bS} - \psi(i.e.p.)_{bS_{ref}}$	0	0	-2800

APPENDIX II

Adoption decision-making

This example demonstrates the heuristic search procedure for operational management applied in the pot plant nursery model. The example relates to a case of limited scale in which the *profitability* strategy (S_3) is applied to solve a problem of delayed crop growth. The context of the problem in the present example consists of a total available greenhouse area of 20 units, i.e. benches which can be allocated to one batch only, and the availability of 50 hours of labour in each week (table II.1). At t=1 four batches are present and two additional batches are planned to be potted in period t=1 to t=10. Because at t=3 and t=9 labour requirements exceed the availability of labour, additional labour is hired in the amounts of respectively 23.20 and 1.88 hours. In the present example, batches b=1 and b=2 are in the delivery phase at t=1. Furthermore, batch b=1 is assumed to be delayed, whereas batch b=2 is assumed to be growing according to its current cultivation-schedule. Thus, K=1 and operational adoption decision-making is initialized.

On the single batch level only one alternative (a_1) is generated for batch b=1 representing the postponement of both deliveries of this batch with one week (table II.2). After determination of all AR_{1ct}, EE_1 (with $EE_1>0$) and T (with T=3) the preliminary solution set $\Omega = \{a_1\}$ is projected on the current tactical production plan (table II.3). This projection leads to the conclusion that the preliminary solution set Ω is not feasible with $OF_1=5$ and $OF_2=18.47$. Thus, further analysis on the multi batch level is required to resolve the current operational problem.

Operational adoption decision-making on the multi batch level starts with the composition of the general set of alternatives A (table II.4). In the present example the general set of alternatives A consists of seven options besides the single batch alternative (a_1). Alternative a_2 represents the postponement of the first delivery of b=1 only. Moreover, all other additional alternatives relate to other batches present at t=1 or to batches planned to be potted in the period t=1 to T (with T=3). Alternative a_3 represents the respacing of batch b=2 at t=3, i.e. after the first delivery of b=2. Alternative a_4 represents the postponement of the last spacing of batch b=3. This postponement of spacing, however, results in a crop growth delay and therefore postponed deliveries. Moreover, $EE_4<0$, because in the present example the selling price at t=9 is assumed to be lower than at t=8. Alternatives a_5, a_6 and a_7 represent different combinations of postponement of the first and second spacing moment of batch b=4. Finally, alternative a_8 represents the postponement of potting of batch b=5 from t=3 to t=4. For batch b=6 postponement of potting is not considered, because b=6 is planned to be potted only after the initial T (with T=3).

After the general set of alternatives **A** is extended with the possibility to hire extra labour at 25 Dfl. $hour^{-1}$ and the operational decision horizon is determined again (T=10). Subsequently, the set of currently optional alternatives $\mathbf{A}^*$ for the first iteration of the heuristic search procedure for a feasible solution set is derived from **A** (table II.5). At this point, a_1 represents a reversal alternative for the projected single batch solution of the operational problem. Moreover, alternative a_2 is not included in $\mathbf{A}^*$, because it relates to batch b=1 for which already an alternative is included in the preliminary solution set Ω.

Table II.5 demonstrates also the selection of an alternative according to equation 8.7. Because OF_1 is after adoption decision-making on the single batch level greater than one, equation 8.7 is applied with c=1. Hence, because $trE_{a1}\leq0$, alternatives a_4, a_5, a_6 and a_7 are disqualified (marked as 'X'). Moreover, although alternatives a_3 and a_8 are equal with respect to applied criterion (equation 8.7), alternative a_8 is preferred because of equation 8.6. Thus, in the first iteration of alternative a_8 is included in the preliminary solution set Ω. Consequently, $\Omega=\{a_1, a_8\}$. The projection of this preliminary solution set Ω on the current tactical production plan demonstrates that criterion c=1 is still violated (table II.6).

Hence, a second iteration of the heuristic search procedure on the multi batch level of operational adoption decision-making is started (table II.7). In this second iteration alternative a_3 is selected and included in the preliminary solution set Ω. As a result, the greenhouse area constraint is satisfied (table II.8). And consequently, since one labour constraint is still violated ($OF_2>0$), c=2 is applied in the third iteration (table II.9). In the third iteration alternative a_5 and a_7 are equal for equation 8.7 as well as equation 8.6. Moreover, both alternatives confirm to the relevant additional conditions (equations 8.8 and 8.9). In this situation it makes no difference for the current problem which of the two alternatives is selected. Both alternatives relate to batch b=4 and therefore exclude each other. In such cases, the less radical alternative is selected in the present study. Since alternatives for a same batch are generated more or less in a sequence of increasing complexity, the alternative with the lowest index, i.e. in this case a_5, is selected to be included in the preliminary solution set Ω. Moreover, the possibility of hiring additional labour instead of including alternative a_5 in the preliminary solution set Ω was rejected, because of $EE_5=0$. Projection of this preliminary solution set Ω after the third iteration, with $\Omega=\{a_1, a_8, a_3, a_5\}$, leads to the conclusion that both constraints are no longer violated (table II.10). Consequently, the operational problem in the present example is solved by a postponement of both deliveries of batch b=1 in combination with the respacing of batch b=2 at t=3 and postponement of first spacing of batch b=4 as well as potting batch b=5. Moreover, the overall expected economic effect of this compound solutions amounts Dfl. 1175 (table II.12).

The present example does not show the removal of selected alternatives from the preliminary solution set. In the second iteration this would have occurred if alternative a_3 would not have been optional. Table II.7 shows that alternative a_1 would have been selected. Because this alternative was already selected, this would have resulted in the removal of alternative a_1 from the preliminary solution set Ω. Moreover, alternative a_1 would have been replaced in the preliminary solution set by alternative a_2 as pointed out in the general description of the applied procedure. If in one of the subsequent iterations alternative a_2 would also have been removed from the preliminary solution set Ω, no alternatives for batch b=1, i.e. the original problem batch, would have been left in the preliminary solution set Ω. Consequently, the preliminary solution set Ω would have been emptied.

Regarding the operations applied during operational adoption decision-making, the linear character of the demonstrated heuristic search procedure points at a possible association with linear programming (lp). In fact, the present decision event could also be modelled as a semi-integer lp-model (table II.11). Optimization of this lp-model results in the same final solution set. In fact, both methods (the applied heuristic search procedure as part of the operational adoption decision-making process and linear programming) involve similar operations. Every iteration involves the updating of constraint violations and slack, the determination of the contribution of each optional alternative to the objective function in the current situation and the selection of the alternative with the highest contribution. Despite the similarity between both methods and the identical result for the present example, there are some important differences. The applied heuristic search procedure, for instance, starts with alternatives for problem batches in the preliminary solution set and a violation of constraints. In fact, a kind of backtracking is applied in order to attain a feasible solution set. The solution set in the lp-optimization, on the other hand, may include alternatives with $EE_a>0$, which do not contribute to the reduction of the current OF_c, whereas in the applied heuristic search procedure on the multi batch level of operational adoption decision-making alternatives are selected only if $trE_{ac}>0$. Consequently, it should be concluded that not in all cases both methods will result in identical solutions. The basic difference between both methods relates to the definition of the problem. Similar to tactical production planning the lp-model represents an allocation problem, whereas the present heuristic search procedure on the multi batch level of operational adoption decision-making links up with the problem of adapting cultivation-schedules of individual batches. Only because these adaptations lead to a violation of constraints of limited resources re-allocation is considered.

Table II.1 Presentation of the greenhouse area (c=1) and labour (c=2) requirements of the batches in the example prior to operational decision-making.

t	Slack		b=1		b=2		b=3		b=4		b=5		b=6	
	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2
1	1	23.68	6	16.51	6	2.80	4	2.80	3	4.21				
2	1	8.01	6	18.47	6	16.51	4	2.80	3	4.21				
3	1	0.00			6	18.47	6	11.20	3	4.21	4	39.32		
4	4	24.77					6	2.80	6	16.81	4	5.62		
5	4	37.38					6	2.80	6	4.20	4	5.62		
6	4	37.38					6	2.80	6	4.20	4	5.62		
7	0	6.88					6	16.51	6	4.20	8	22.41		
8	0	21.73					6	18.47	6	4.20	8	5.60		
9	0	0.00							9	16.80	8	5.60	3	29.48
10	0	35.99							9	4.20	8	5.60	3	4.21

Table II.2 Additional requirements (AR_{act}) of alternative a_1.

t	a_1 (b=1) c=1	c=2
1	0	-13.71
2	0	-1.96
3	6	18.47
4		
5		
6		
7		
8		
9		
10		
EE_a	1175	

Table II.3 Result of the projection of the preliminary solution solution set Ω, established on the single batch level, on the current tactical production plan.

t	PS_{1t}	PS_{2t}
1	1	37.39
2	1	9.97
3	-5	-18.47
4	4	24.77
5	4	37.38
6	4	37.38
7	0	6.88
8	0	21.73
9	0	0.00
10	0	35.99
OF_c	5	18.47

$\Omega = \{a_1\}$

$$\sum_{\omega=1}^{\Omega} EE_w = 1175$$

Table II.4 Representation of the general set of alternatives **A** with their additional requirements of greenhouse area (c=1) and labour (c=2) AR_{act} on the multi batch level of operational adoption decision-making.

	a_1		a_2		a_3		a_4		a_5		a_6		a_7		a_8	
	(b=1)		(b=1)		(b=2)		(b=3)		(b=4)		(b=4)		(b=4)		(b=5)	
t	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2		
1		-13.71		-13.71												
2		-1.96		13.71												
3	6	18.47			-2	8.40	-2	-8.40							-4	-39.32
4								8.40	-3	-12.60			-3	-12.60		33.70
5										12.61				12.61		
6																
7								-13.71								
8								-1.96								
9							6	18.47			-3	-12.60	-3	-12.60		
10										12.60		12.60				
EE_a	1175		645		0		-560		0		0		0		0	

Table II.5 Representation of the set of currently optional alternatives **A*** with their relevant effects (rE_{act}) on greenhouse area occupation (c=1) and labour utilization (c=2). Moreover, presentation of the selection process in the first iteration of the heuristic search procedure.

	a_1		a_3		a_4		a_5		a_6		a_7		a_8	
	(b=1)		(b=2)		(b=3)		(b=4)		(b=4)		(b=4)		(b=5)	
t	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2
1														
2														
3	5	18.47	2	-8.40	2	8.40							4	18.47
4														-8.93
5														
6														
7														
8														
9					-6	-18.47								
10														
trE_{ac}	5	18.47	2	-8.40	-4	-10.07	0	0.00	0	0.00	0	0.00	4	9.54
EE_a	-1175		0		-560		0		0		0		0	
EE_a/trE_{a1}	-235		0		X		X		X		X		0	

Table II.6 Result of the projection of the preliminary solution set Ω on the current tactical production plan after the first iteration.

t	PS_{1t}	PS_{2t}
1	1	37.39
2	1	9.97
3	-1	20.85
4	4	-8.93
5	4	37.38
6	4	37.38
7	0	6.88
8	0	21.73
9	0	0.00
10	0	35.99
OF_c	1	8.93

$\Omega = \{a_1, a_8\}$

$$\sum_{\omega=1}^{\Omega} EE_W = 1175$$

Table II.8 Result of the projection of the preliminary solution set Ω on the current tactical production plan after the second iteration.

t	PS_{1t}	PS_{2t}
1	1	37.39
2	1	9.97
3	1	12.45
4	4	-8.93
5	4	37.38
6	4	37.38
7	0	6.88
8	0	21.73
9	0	0.00
10	0	35.99
OF_c	0	8.93

$\Omega = \{a_1, a_8, a_3\}$

$$\sum_{\omega=1}^{\Omega} EE_W = 1175$$

Table II.7 Representation of the set of currently optional alternatives **A*** with their relevant effects (rE_{act}) on greenhouse area occupation (c=1) and labour utilization (c=2). Moreover, presentation of the selection process in the second iteration.

t	a_1 (b=1)		a_3 (b=2)		a_4 (b=3)		a_5 (b=4)		a_6 (b=4)		a_7 (b=4)		a_8 (b=5)	
	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2
1														
2														
3	1		1		1								-4	-18.47
4						-8.40		12.61				12.61		8.93
5														
6														
7														
8														
9					-6	-18.47								
10														
trE_{ac}	1		1		-5	-26.87	0	12.61	0	0.00	0	12.61	-4	-9.54
EE_a	-1175		0		-560		0		0		0		0	
EE_a/trE_{a1}	-1175		0		X		X		X		X		X	

Table II.9 Representation of the set of currently optional alternatives **A*** with their relevant effects (rE_{act}) on greenhouse area occupation (c=1) and labour utilization (c=2). Moreover, presentation of the selection process in the third iteration.

	a_1		a_3		a_4		a_5		a_6		a_7		a_8	
	(b=1)		(b=2)		(b=3)		(b=4)		(b=4)		(b=4)		(b=5)	
t	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2	c=1	c=2
1														
2														
3			-1										-3	-26.87
4						-8.40		12.61				12.61		8.93
5														
6														
7														
8														
9					-6	-18.47								
10														
trE_{ac}	0	0.00	-1	0.00	-6	-26.87	0	12.61	0	0.00	0	12.61	-3	-17.94
EE_a	-1175		0		-560		0		0		0		0	
EE_a/trE_{a2}	X		X		X		0		X		0		X	

Table II.10 Result of the projection of the preliminary solution set Ω on the current tactical production plan after the third iteration.

t	PS_{1t}	PS_{2t}
1	1	37.39
2	1	9.97
3	1	12.45
4	7	3.67
5	4	37.38
6	4	37.38
7	0	6.88
8	0	21.73
9	0	0.00
10	0	35.99
OF_c	0	0.00

$\Omega = \{a_1, a_8, a_3, a_5\}$

$$\sum_{\omega=1}^{\Omega} EE_W = 1175$$

Table II.11 Representation of the present example as a semi-integer lp-model.

$$\max \{1175.a_1 + 645.a_2 - 560.a_4 - 25.Lh_1 - 25.Lh_2 - 25.Lh_3 - 25.Lh_4\}$$

subject to

$$\begin{array}{cccccccccccccc}
a_1 & + a_2 & & & & & & & & & & & = & 1 \\
 & & & & a_5 & + a_6 & + a_7 & & & & & & \leq & 1 \\
6a_1 & & - 2a_3 & - 2a_4 & & & & - 4a_8 & & & & & \leq & 1 \\
 & & & 6a_4 & & - 3a_6 & - 3a_7 & & & & & & \leq & 0 \\
-1.96a_1 & + 13.71a_2 & & & & & & & -Lh_1 & & & & \leq & 8.01 \\
18.47a_1 & & + 8.4a_3 & - 8.4a_4 & & & & - 39.32a_8 & & - Lh_2 & & & \leq & 0 \\
 & & & 8.4a_4 & - 12.6a_5 & & - 12.6a_7 & + 33.7a_8 & & & - Lh_3 & & \leq & 24.77 \\
 & & & 18.47a_4 & & - 12.6a_6 & - 12.6a_7 & & & & & - Lh_4 & \leq & 0
\end{array}$$

and

$a_1,\ldots, a_8$ are integer variables of the alternatives: 0 or 1;

$Lh_1,\ldots, Lh_4$ are the variables for extra hired labour: ≥ 0 and $\leq Lh_{max}$.

APPENDIX III

Conversion of the Pratt-Arrow coefficient

The conversion of the applied values of the Pratt-Arrow coefficient of absolute risk aversion (r) to the context of Smidts' investigation is based on the principle that in order to maintain the same behaviour r has to be divided by the same factor as the scale of the x-axis is multiplied by. Here, Ca is assumed to equal zero. Thus, every decision case is characterized by a minimum outcome (min($\underline{x}$)) and a maximum outcome (max($\underline{x}$)) (equations III.1 and III.2).

$$\min(\underline{x}) = n_h \times 0.94 \times Pf^*_{w+1} \times \min(\underline{d}_{w+1}) \qquad \text{(III.1)}$$

$\min(\underline{x})$: Lowest possible random outcome of the uncertain event (Dfl.).
n_h: Number of plants of the particular delivery batch (plant).
Pf^*_{w+1}: Operational price forecast for week w+1 (Dfl plant^{-1}).
$\min(\underline{d}_{w+1})$: Lowest possible incidental price deviation in week w+1.

$$\max(\underline{x}) = n_h \times 0.94 \times Pf^*_{w+1} \times \max(\underline{d}_{w+1}) \qquad \text{(III.2)}$$

$\max(\underline{x})$: Highest possible random outcome of the uncertain event (Dfl.).
n_h: Number of plants of the particular delivery batch (plant).
Pf^*_{w+1}: Operational price forecast for week w+1 (Dfl. plant^{-1}).
$\max(\underline{d}_{w+1})$: Highest possible incidental price deviation in week w+1.

The minimum and maximum value of the incidental price deviation can be determined according to equations III.3 and III.4.

$$\min(\underline{d}_{w+1}) = 1 + 0.23 \times \chi_{0.005} = 1 + (0.23 \times -2.58) = 0.4066 \qquad \text{(III.3)}$$

$\min(\underline{d}_{w+1})$: Lowest possible incidental price deviation in week w+1.
$\chi_{0.005}$: Standard normal variable with $P[\chi<\chi_{0.005}]=0.005$.

$$\max\left(\underline{d}_{w+1}\right) = 1 + 0.23 \times \chi_{0.995} = 1 + (0.23 \times 2.58) = 1.5934 \qquad \text{(III.4)}$$

$\max(\underline{d}_{w+1})$: Highest possible incidental price deviation in week w+1.
$\chi_{0.005}$: Standard normal variable with $P[\chi<\chi_{0.005}]=0.005$.

In the first step of conversion, the difference between risk of the net return of the total delivery batch in the present study and price risk as analyzed by Smidts (1990) is compensated (equations III.5, III.6 and III.7).

$$\begin{aligned} \min(\underline{x})^* &= \min(\underline{x}) \,/\, n_h \\ &= 0.94 \times Pf^*{}_{w+1} \times \min\left(\underline{d}_{w+1}\right) \\ &= 0.4066 \times 0.94 \times Pf^*{}_{w+1} \end{aligned} \qquad \text{(III.5)}$$

$\min(\underline{x})^*$: Converted $\min(\underline{x})$ after the first step of conversion (Dfl. plant^{-1}).
$\min(\underline{x})$: Lowest possible random outcome of the uncertain event (Dfl.).
n_h: Number of plants of the particular delivery batch (plant).
$Pf^*{}_{w+1}$: Operational price forecast for week w+1 (Dfl. plant^{-1}).
$\min(\underline{d}_{w+1})$: Lowest possible incidental price deviation in week w+1.

$$\begin{aligned} \max(\underline{x})^* &= \max(\underline{x}) \,/\, n_h \\ &= 0.94 \times Pf^*{}_{w+1} \times \max\left(\underline{d}_{w+1}\right) \\ &= 1.5934 \times 0.94 \times Pf^*{}_{w+1} \end{aligned} \qquad \text{(III.6)}$$

$\max(\underline{x})^*$: Converted $\max(\underline{x})$ after the first step of conversion (Dfl. plant^{-1}).
$\max(\underline{x})$: Highest possible random outcome of the uncertain event (Dfl.).
n_h: Number of plants of the particular delivery batch (plant).
$Pf^*{}_{w+1}$: Operational price forecast for week w+1 (Dfl. plant^{-1}).
$\max(\underline{d}_{w+1})$: Highest possible incidental price deviation in week w+1.

$$r^* = r \times n_h \qquad \text{(III.7)}$$

r^*: Converted r after the first step of conversion (plant Dfl.$^{-1}$).
r: Pratt-Arrow coefficient of absolute risk aversion (Dfl.$^{-1}$).
n_h: Number of plants of the particular delivery batch (plant).

Thus, $\min(\underline{x})^*$ and $\max(\underline{x})^*$ represent the minimum and maximum possible prices of individual plants in every individual case. In the second step of conversion, the magnitude of the random outcome of the uncertain event is harmonized with the magnitude of Smidts' problem by applying a compensating factor (equations III.8, III.9 and III.10).

$$\begin{aligned}\min(\underline{x})^{**} &= \min(\underline{x})^{*} \times E(\underline{x}) / 0.94 \times \mathrm{Pf}^{*}{}_{w+1} \\ &= 0.4066 \times E(\underline{x}) \qquad \text{(III.8)}\end{aligned}$$

$\min(\underline{x})^{**}$: Converted min($\underline{x}$) after the second step of conversion (Dfl.).
$\min(\underline{x})^{*}$: Converted min($\underline{x}$) after the first step of conversion (Dfl. plant^{-1}).
$E(\underline{x})$: Expected value of the uncertain event (Dfl.).
$\mathrm{Pf}^{*}{}_{w+1}$: Operational price forecast for week w+1 (Dfl. plant^{-1}).

$$\begin{aligned}\max(\underline{x})^{**} &= \max(\underline{x})^{*} \times E(\underline{x}) / 0.94 \times \mathrm{Pf}^{*}{}_{w+} \\ &= 1.5934 \times E(\underline{x}) \qquad \text{(III.9)}\end{aligned}$$

$\max(\underline{x})^{**}$: Converted max($\underline{x}$) after the second step of conversion (Dfl.).
$\max(\underline{x})^{*}$: Converted max($\underline{x}$) after the first step of conversion (Dfl. plant^{-1}).
$E(\underline{x})$: Expected value of the uncertain event (Dfl.).
$\mathrm{Pf}^{*}{}_{w+1}$: Operational price forecast for week w+1 (Dfl. plant^{-1}).

$$r^{**} = r^{*} \times 0.94 \times \mathrm{Pf}^{*}{}_{w+1} / E(\underline{x}) \qquad \text{(III.10)}$$

r^{**}: Converted r after the second step of conversion (Dfl.$^{-1}$).
r^{*}: Converted r after the first step of conversion (plant Dfl.$^{-1}$).
$\mathrm{Pf}^{*}{}_{w+1}$: Operational price forecast for week w+1 (Dfl. plant^{-1}).
$E(\underline{x})$: Expected value of the uncertain event (Dfl.).

Subsequently, the distance from min($\underline{x}$) to max($\underline{x}$) is harmonized with the width of the x-axis in Smidts' investigation. In order to establish a distance from min($\underline{x}$)** to max($\underline{x}$)** of Dfl 0.60 equation III.11 should be valid.

$$E(\underline{x}) = \min(\underline{x})^{**} + 0.3 \qquad \text{(III.11)}$$

$E(\underline{x})$: Expected value of the uncertain event (Dfl.).
$\min(\underline{x})^{**}$: Converted min($\underline{x}$) after the second step of conversion (Dfl.).

Substitution of min($\underline{x}$)** by 0.4066 $E(\underline{x})$ (equation III.8) results in $E(\underline{x})$ equal to Dfl 0.5056. Finally, in the last step of conversion the unit of the x-axis is converted to cents (cts.) as in Smidts' investigation (equations III.12, III.13 and III.14).

$$\begin{aligned}\min(\underline{x})^{***} &= \min(\underline{x})^{**} \times 100 \\ &= 100 \times 0.4066 \times E(\underline{x}) = 20.56 \qquad \text{(III.12)}\end{aligned}$$

$\min(\underline{x})^{***}$: Converted min($\underline{x}$) after the third step of conversion (cts.).
$\min(\underline{x})^{**}$: Converted min($\underline{x}$) after the second step of conversion (Dfl.).
$E(\underline{x})$: Expected value of the uncertain event (Dfl.).

$$\begin{aligned}\max(\underline{x})^{***} &= \max(\underline{x})^{**} \times 100 \\ &= 100 \times 1.5934 \times E(\underline{x}) = 80.56 \qquad \text{(III.13)}\end{aligned}$$

$\max(\underline{x})^{***}$: Converted max($\underline{x}$) after the third step of conversion (cts.).
$\max(\underline{x})^{**}$: Converted max($\underline{x}$) after the second step of conversion (Dfl.).
$E(\underline{x})$: Expected value of the uncertain event (Dfl.).

$$\begin{aligned}r^{***} &= r^{**} \times 100 \\ &= \left\{r \times n_h \times 0.94 \times Pf^{*}{}_{w+1}\right\} / \left\{E(\underline{x}) \times 100\right\} \qquad \text{(III.14)}\end{aligned}$$

r^{***}: Converted r after the third step of conversion (cts.$^{-1}$).
r^{**}: Converted r after the second step of conversion (Dfl.$^{-1}$).
r: Pratt-Arrow coefficient of absolute risk aversion (Dfl.$^{-1}$).
n_h: Number of plants of the particular delivery batch (plant).
$Pf^{*}{}_{w+1}$: Operational price forecast for week w+1 (Dfl. plant^{-1}).
$E(\underline{x})$: Expected value of the uncertain event (Dfl.).

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SUMMARY

Introduction

This thesis deals with operational management on pot plant nurseries. Pot plant production in Western Europe is characterized by a complex organization of labour and greenhouse area. Therefore, tactical production planning, i.e. planning before the start of the cultivation, is required. A major problem of tactical production planning is uncertainty. In pot plant production, uncertainty particularly relates to crop growth and price formation. During the implementation of a tactical production plan actual conditions may deviate from planning premises. As a result the ex ante tactical production plan may no longer be satisfactory. Hence, operational decision-making should be applied in order to adjust the tactical production plan to current conditions. Such operational adjustments should be submitted to the condition that further implementation of the tactical production plan is not prohibited. Of course, the grower may also consider new tactical production planning every time adaptation of cultivation-schedules seems necessary. In the present study, however, frequent reconsideration of the tactical production plan as a whole was regarded to be inconsistent with its medium term guideline function. In the present study, operational management is investigated within the context of a pot plant nursery and under the assumed presence of a tactical production plan.

Theoretical framework

In the present study, the tactical production plan is regarded as a general guideline for medium term future production. This function of the tactical production plan particularly concerns the number and size of batches as well as their potting moments. Because of its general character the tactical production plan requires on one hand elaboration and allows on the other hand for small-scale adaptations during its implementation. The elaboration of the tactical production plan and any adaptations relate to cultivation-schedules of individual batches. In this respect, a pot plant batch is defined as a lot of plants of the same species or cultivar potted at the same time and

cultivated according to the same cultivation-schedule. Moreover, a cultivation-schedule describes all cultivation actions that should be taken during cultivation in order to achieve the desired pot plant product.

Since operational management is a rarely studied subject in farm management, a theoretical framework is formulated. Operational management involves elaboration, progress and adoption decisions with respect to the given tactical production plan. Elaboration decisions relate to the cultivation-schedules of individual batches in the tactical production plan. Progress decisions are about whether actual performance is sufficiently in accordance with the grower's objectives. 'Sufficiently', in this respect, is measured in terms of non-violation of rejection thresholds. In case of insufficient compatibility, progress decisions are negative and continuation of the implementation of the tactical production plan is reconsidered. During such a reconsideration adoption decisions are made, which are about adoption or rejection of alternative actions. Thus, progress decision-making may lead to operational problems, where operational problems refer to situations which concern trouble or opportunities. In case of opportunities, the actual problem is deciding whether to take advantage of the perceived opportunity.

The pot plant nursery model

A model of an imaginary pot plant nursery, which is representative for Dutch nurseries producing foliage plants, was formulated. This pot plant nursery model simulated the implementation of a given tactical production plan over a period of one year under a specified strategy of operational management. In order to provoke operational problems during the simulated implementation of the tactical production plan random exogenous variables had to affect crop growth and price formation.

The crop growth module simulated realistic crop growth deviations for individual batches. The incorporation of various pot plant products in the model was not regarded to be essential. Therefore, the crop growth module was specified for only one product, i.e. *Schefflera arboricola* 'Compacta'. Moreover, the crop growth module related to product attributes which affect price formation. The price formation module simulated random prices based on tactical price forecasts and the product attributes of the delivered pot plants. It was assumed that the supply of the simulated nursery on the market had no effect on price formation. Moreover, the price formation module enabled the simulation of operational price forecasts, as to represent the reduction of uncertainty on the short term.

Strategies of operational management

Five strategies of operational management were formulated. The *passive* strategy (S_1) involved no operational adaptation whatsoever. Under the *passive* strategy all cultivation-schedules were implemented exactly according to the initial tactical production plan. Under the *product quality* strategy (S_2), price reductions were tried to be avoided by adapting cultivation-schedules. Hence, under this strategy the objective of operational management was to deliver pot plants with standard product attributes as much as possible. In this respect, short term profitability was disregarded. Conversely, under the *profitability* strategy (S_3) cultivation-schedules were only adapted to crop growth deviations if such adaptations are expected to be profitable on the short term. Both strategies of operational management S_2 and S_3 involved the monitoring and correction of crop growth deviations only.

Under strategies of operational management S_1, S_2 and S_3 pot plants were assumed to be monitored, treated and delivered at fixed moments during every week based on the premises of the tactical production plan. Of course, operational management could lead to delivery between these fixed moments. Thus, under the *flexibility delivery* strategy (S_4) the assumption of fixed moments of delivery in each week was dropped. Besides, this strategy was identical to S_3. Finally, the *active marketing* strategy (S_5) involved the adaptation of cultivation-schedules due to crop growth deviations as well as due to discrepancies between tactical price forecasts, on the one hand, and actual prices and operational price forecasts on the other hand.

Tactical production plans

Three tactical production plans were based on the same description of the imaginary nursery and on average exogenous conditions with regard to crop growth and price formation. The *reference* plan (P_1) was developed by applying standard technological coefficients and a profitability objective function in a linear programming model. In addition, the *extra slack* plan (P_2), was based on the same linear programming model, except for the length of the standard cultivation-schedules. In order to cope with the consequences of possible delayed crop growth all cultivation-schedules were extended with one week. The *cash flow* plan (P3), was based on the standard linear programming model except for the interest rate on operating capital, which was raised in order to represent a situation with liquidity problems.

Price variability and price risk attitude

In addition to the formulated strategies of operational management and tactical production plans, three levels of price variability and four attitudes to operational price risk were taken into consideration. Besides the *standard* level of price variability (V_2), a *low* level of price variability (V_1) and a *high* level of price variability (V_3) were formulated. The reason these three levels of price variability were taken into consideration was the limited information available about pot plant price formation. Hence, sensitivity of operational decision-making to the level of price variability could be investigated. Similarly, in addition to the *risk neutral* attitude to operational price risk (R_2) three non-neutral attitudes were formulated: *risk seeking* behaviour (R_1), *risk averse* behaviour (R_3), and *very risk averse* behaviour (R_4).

Simulation experiments

Every simulation with the pot plant nursery model was influenced by a given course of exogenous conditions. Because the purpose of the present study was to analyze implementation of tactical production plans under uncertainty, these exogenous conditions were simulated randomly prior to any simulation experimenting with the pot plant nursery model. Each scenario of exogenous conditions consisted of a course of stochastic variables which affected the simulation of either crop growth or price formation in the pot plant nursery model. Hence, a set of 25 scenarios of exogenous conditions was applied to replicate individual system variants under various uncertain conditions.

Three simulation experiments were conducted. In the original simulation experiment all fifteen combinations of tactical production plan and strategy of operational management were investigated. In this experiment *standard* price variability (V_2) and a *risk neutral* attitude to operational price risk (R_2) were assumed. In addition, a sensitivity analysis on price variability was conducted, in which all three tactical production plans were combined with three levels of price variability. Finally, in a second sensitivity analysis the effect of the operational price risk attitude on operational decision-making was examined. Four risk attitudes were combined with all three formulated tactical production plans to twelve system variants, which were investigated under all 25 scenarios of exogenous conditions. In both sensitivity analyses the *active marketing* strategy (S_5) was applied, because it represented the most comprehensive strategy of operational management in the present study and because it was expected to be most sensitive to the investigated factors.

Simulation results

Regression metamodelling and the Friedman statistic were applied to analyze simulated annual net farm incomes. Besides, the number and type of individual operational decision events as well as their solution were investigated.

Original experiment

The original simulation experiment showed no significant main effect of the replacement of the *passive* strategy (S_1) by the *product quality* strategy (S_2) on net farm income. Replacement of the *passive* strategy (S_1) by either the *profitability* strategy (S_3), the *flexible delivery* strategy (S_4), or the *active marketing* strategy (S_5), however, lead to a significant improvement of net farm income. Furthermore, replacement of the *reference* plan (P_1) by the *extra slack* plan (P_2) lead to a significant reduction of net farm income, whereas the *cash flow* plan (P_3) had no significant effect. In addition, the strategy of operational management and the tactical production plan showed considerable interaction in their effect on net farm income.

Besides the effects on net farm income, the strategy of operational management and the tactical production plan affected the number and type of operational problems as well as their solution. Under the *passive* strategy (S_1) no operational problems were considered by definition. Operational problems due to crop growth patterns deviating from tactical planning premises were considered and recorded under all other strategies of operational management. Moreover, operational problems related to deviating prices were only considered under the *active marketing* strategy (S_5). As a result, most operational problems were recorded under this strategy (S_5). With respect to the tactical production plans, the *reference* plan (P_1) and the *cash flow* plan (P_3) lead to rather similar patterns of decision events, whereas the *extra slack* plan (P_2) resulted in a completely different pattern due to the extended cultivation-schedules in this plan.

Solution of the operational problems by postponement of deliveries appeared to be more difficult than solution by advancement of deliveries. Postponement, in contrast to advancement, required additional greenhouse area, which often was not available and could not be re-allocated from other batches. In contrast, additional labour requirements hardly ever prohibited cultivation-schedules adaptations, because of the possibility to hire exact amounts of extra labour. In conclusion, recorded decision events corresponded with the intentions of the applied strategies of operational management and explained their effects on net farm income.

Sensitivity analysis on price variability

Under the *active marketing* strategy (S_5) operational decision-making was fairly sensitive to price variability. Compared to the *standard* level of price variability (V_2), *low* price variability (V_1) resulted in a reduction of net farm income, whereas *high* price variability (V_3) lead to a higher net farm income. The effect of price variability particularly related to advancement of deliveries of batches which did not yet attained standard product attributes. With increasing price variability more opportunities occurred to benefit from relatively high prices by early delivery despite price reduction, while delivery at moments with negatively deviating prices could be avoided in most cases under all three levels of price variability. Hence, comprehensive operational management appeared most beneficial in a situation of high price variability.

Sensitivity analysis on price risk attitude

Under the *active marketing* strategy (S_5) operational decision-making was fairly sensitive to non-neutral behaviour to operational price risk. In this respect, however, *risk averse* behaviour (R_3 and R_4) lead to a significant reduction of net farm income, whereas the *risk seeking* attitude (R_1) resulted in net farm incomes similar to the *risk neutral* attitude (R_2). This difference should be attributed to price reduction due to non-standard product attributes. Risk aversion particularly lead to advanced deliveries of batches which did not yet attained standard product attributes. Risk preference, on the other hand, particularly lead to postponement of deliveries. Where in both cases operational decision-making was based on a biased perception of future prices, incorrect decisions in case of risk aversion had more negative consequences on profitability due to price reduction.

Discussion

Although the simulation results showed significant differences in net farm income due to strategies of operational management, no 'optimal' strategy is selected. It is perceived the formulated strategies did not only lead to different monetary benefits, but also to different management efforts. Moreover, possible long term effects and nursery transcending effects of individual strategies are not considered by the pot plant nursery model. In addition, it should be argued the formulated strategies of operational management can also be regarded as separate operational management styles. Hence, the 'optimal' strategy of operational management should be determined for every grower individually taking into account personal objectives and the nursery's 'philosophy'.

In conclusion, the applied methodology was successful in exploring the opportunities for operational management in pot plant production based on a rather normative approach and integrating theory from various scientific disciplines. Furthermore, simulation experimentation with the validated pot plant nursery model showed significant impact of operational management on the nursery's performance. Hence, the present study indicates several opportunities for beneficial support of operational management on pot plant nurseries.

SAMENVATTING

Introduktie

Dit proefschrift heeft betrekking op operationeel management in de potplantenteelt. De potplantenteelt in West-Europa kenmerkt zich door een complexe organisatie van arbeid en kasoppervlak. Daarom is taktische produktieplanning, d.w.z. planning voorafgaande aan de teelt, noodzakelijk. Een groot probleem bij het opstellen van een taktisch produktieplan is onzekerheid. In de potplantenteelt heeft onzekerheid vooral betrekking op groei en prijsvorming van planten. Tijdens de uitvoering van het taktisch produktieplan kan daardoor de werkelijke situatie op het bedrijf dusdanig afwijken van het taktische verwachtingspatroon dat verdere uitvoering van het ex ante taktisch produktieplan niet langer opportuun is. In dergelijke situaties kan de tuinder natuurlijk een geheel nieuw taktisch produktieplan opstellen, maar daarmee gaat de richtinggevende funktie op middellange termijn verloren. Het lijkt daarom verstandiger het bestaande taktisch produktieplan aan te passen aan de aktuele omstandigheden. Dergelijke operationele aanpassingen van het taktisch produktieplan moeten voldoen aan de voorwaarde dat zij een verdere uitvoering van het (aangepaste) plan niet in de weg staan. In dit onderzoek worden de mogelijkheden en beperkingen van operationeel management onderzocht binnen de context van een potplantenbedrijf en onder de aanname van de aanwezigheid van een taktisch produktieplan.

Theoretisch concept

In dit onderzoek wordt het taktisch produktieplan gezien als een globale richtlijn voor produktie op de middellange termijn. Deze funktie van het taktisch produktieplan heeft vooral betrekking op het aantal partijen, hun omvang en hun moment van oppotten. Vanwege het globale karakter dient het taktisch produktieplan tijdens de uitvoering nader gespecificeerd te worden. Anderzijds biedt het de mogelijkheid kleinschalige aanpassingen door te voeren. Daarbij staan de teeltschema's van individuele partijen centraal. Een partij potplanten kan in dit verband worden gedefinieerd als een verzameling planten van dezelfde soort of cultivar die op hetzelfde moment is opgepot en volgens een gelijk teeltschema wordt behandeld. Daarbij geeft het teeltschema weer welke handelingen tijdens de teelt verricht moeten worden om het gewenste standaard eindprodukt te verkrijgen.

Omdat in de agrarische bedrijfseconomie weinig aandacht wordt besteed aan operationeel management, is in dit proefschrift allereerst een theoretisch concept geformuleerd toegesneden op de potplantenteelt. Operationeel management omvat de nadere specificering van taktische besluiten, voortgangscontrole en aanpassing van taktische besluiten. Indien bepaalde vooraf gedefinieerde grenswaarden overschreden worden, zijn voortgangsbeslissingen negatief en is er sprake van een operationeel probleem. Een dergelijk probleem kan verband houden met zowel een bedreiging als met een kans op een beter resultaat. Aanpassingsbeslissingen hebben betrekking op de keuze van alternatieven, waarmee slechte resultaten vermeden kunnen worden of waarmee ingespeeld kan worden op kansrijke situaties.

Het potplantenbedrijfsmodel

Het ontwikkelde simulatiemodel is gebaseerd op een beschrijving van een fictief, representatief bedrijf dat bladplanten produceert. Het potplantenbedrijfsmodel simuleert de uitvoering van een gegeven taktisch produktieplan over de periode van één jaar onder een ex ante gedefinieerde operationele managementstrategie. Om operationele problemen tijdens de gesimuleerde uitvoering van het taktisch produktieplan te bewerkstelligen beïnvloeden externe faktoren zowel gewasgroei als prijsvorming.

De gewasgroeimodule simuleerde realistische afwijkingen van de verwachte teeltduur voor individuele partijen. Omdat het voor het doel van dit onderzoek niet essentieel was of het gesimuleerde bedrijf één of meer produkten voortbracht, werd het model enkel voor *Schefflera arboricola* 'Compacta' gespecificeerd. Voorts werd in de gewasgroeimodule een relatie gelegd tussen gewasgroei en produktattributen die de prijsvorming beïnvloeden. De prijsvormingsmodule simuleerde realistische stochastische patronen van wekelijkse prijzen gebaseerd op meerjaren gemiddelden en gesimuleerde produktattributen. Hierbij werd aangenomen dat de afleverbeslissingen op het gesimuleerde bedrijf geen effekt hadden op de prijsvorming. Voorts was de prijsvormingsmodule door middel van operationele prijsverwachtingen in staat de afname van het prijsrisico op korte termijn te simuleren.

Operationele managementstrategieën

Vijf operationele managementstrategieën werden gedefinieerd. De *passieve* strategie (S_1) sloot operationele aanpassingen uit. Daardoor werden alle teeltschema's exact uitgevoerd zoals ze oorspronkelijk gepland waren. Onder de *produktkwaliteit* strategie (S_2) werden prijsredukties als gevolg van afwijkende produktattributen zo veel mogelijk vermeden door operationele aanpassing van teeltschema's. De bedoeling van deze strategie was dus zoveel mogelijk planten af te leveren die voldeden aan de standaardbeschrijving van het produkt ongeacht het korte termijn effekt op de winstgevendheid. Korte termijn winst stond juist centraal onder de *rentabiliteit* strategie (S_3). Operationele aanpassingen werden onder deze strategie slechts doorgevoerd indien winst op korte termijn werd verwacht. Beide strategieën S_2 en S_3 richtten zich overigens alleen op de oplossing van operationele problemen als gevolg van vertraagde of versnelde gewasgroei.

Onder de strategieën S_1, S_2 en S_3 werd aangenomen dat planten op vaste wekelijkse momenten werden beoordeeld, behandeld en afgeleverd. Operationele besluitvorming kan natuurlijk ook inhouden dat van deze vaste momenten wordt afgeweken. Onder de *flexibele aflever* strategie (S_4) werd de aanname van aflevering op vaste wekelijkse momenten losgelaten. Overigens was deze strategie identiek aan S_3. Tenslotte werd de *marktgerichte* strategie (S_5) geformuleerd. Deze strategie was niet alleen gericht op teeltduurafwijkingen, maar ook op verschillen tussen enerzijds taktische prijsverwachtingen en anderzijds werkelijke prijzen en operationele prijsverwachtingen.

Taktische produktieplannen

Drie taktische produktieplannen werden gebaseerd op dezelfde omschrijving van het fictieve potplantenbedrijf en op dezelfde meerjarengemiddelden van gewasgroei en prijsvorming beïnvloedende externe faktoren. Het *referentie* plan (P_1) werd ontwikkeld aan de hand van standaard technische coëfficiënten en een winstmaximalisatie doelstelling in een lineair programmeringsmodel. Het *extra leegloop* plan (P_2) was gebaseerd op hetzelfde lineair programmeringsmodel, behalve wat betreft de lengte van de standaard teeltschema's. Om de gevolgen van eventuele groeivertragingen op te kunnen vangen werden alle teeltschema's met één week verlengd in dit plan. Het *liquiditeit* plan (P_3) was ook gebaseerd op het standaard lineair programmeringsmodel. Om een bedrijfssituatie met een slechte liquiditeit te representeren werd echter het rentepercentage over het omlopend vermogen verhoogd.

Prijsvariabiliteit en risicohouding

In aanvulling op de geformuleerde operationele managementstrategieën en taktische produktieplannen werden drie niveaus van prijsvariabiliteit en vier attitudes ten opzichte van operationeel prijsrisico gedefinieerd. Naast het *standaard* niveau van prijsvariabiliteit (V_2) werd een *laag* niveau (V_1) en een *hoog* niveau (V_3) aangehouden. De reden voor drie niveaus van prijsvariabiliteit was gelegen in de beperkte beschikbaarheid van informatie met betrekking tot prijsfluktuaties op de potplantenmarkt. Met deze drie niveaus kon de gevoeligheid van operationele besluitvorming voor prijsvariabiliteit onderzocht worden. Vergelijkbaar werden naast de *risico neutrale* attitude ten opzichte van operationeel prijsrisico (R_2) drie niet neutrale attitudes gedefinieerd: *risico minnend* gedrag (R_1), *risico mijdend* gedrag (R_3) en *zeer risico mijdend* gedrag (R_4).

Simulatie-experimenten

Elke simulatie met het potplantenbedrijfsmodel werd beïnvloed door een gegeven scenario van externe faktoren. Omdat het de bedoeling was uitvoering van het taktisch produktieplan onder onzekerheid te simuleren, werden 25 verschillende scenario's van gewasgroei en prijsvorming beïnvloedende externe faktoren op stochastische wijze gesimuleerd voorafgaand aan de feitelijke simulatie-experimenten. Deze scenario's werden in de verschillende simulatie-experimenten toegepast om de te onderzoeken systeemvarianten onder onzekere omstandigheden te kunnen herhalen.

Drie verschillende simulatie-experimenten werden uitgevoerd. In het basisexperiment werden alle vijftien mogelijke combinaties van taktisch produktieplan en operationele managementstrategie onderzocht. Hierbij werd uitgegaan van een *standaard* niveau van prijsvariabiliteit (V_2) en van *risico neutraal* gedrag (R_2). Voorts werd een gevoeligheidsanalyse met betrekking tot prijsvariabiliteit uitgevoerd, waarin de drie geformuleerde taktische produktieplannen gecombineerd werden met de drie gedefinieerde niveaus van prijsvariabiliteit tot negen te onderzoeken systeemvarianten. Tot slot was een tweede gevoeligheidsanalyse gericht op de houding tot operationeel prijsrisico. Alle vier attitudes werden gecombineerd met de drie taktische produktieplannen tot twaalf systeemvarianten, die weer onder alle 25 scenario's van externe faktoren werden gesimuleerd. In beide gevoeligheidsanalyses werd de *marktgerichte* strategie (S_5) toegepast, omdat deze strategie de meest uitgebreide vorm van operationeel management representeerde en omdat deze strategie geacht werd het meest gevoelig te zijn voor de te onderzoeken faktoren.

Simulatie-resultaten

De analyse van de gesimuleerde bedrijfsresultaten werd uitgevoerd met behulp van regressie metamodellering en de verdelingsvrije Friedman test. Daarnaast werden individuele beslissingssituaties nader onderzocht wat betreft aantallen, typering en oplossing tijdens de simulaties van de verschillende systeemvarianten.

Basis-experiment

Toepassing van de *produktkwaliteit* strategie (S_2) in plaats van de *passieve* strategie (S_1) had geen significant effekt op het bedrijfsresultaat. Vervanging van de *passieve* strategie (S_1) door de *rentabiliteit* strategie (S_3), de *flexibele aflever* strategie (S_4) of de *marktgerichte* strategie (S_5) daarentegen leidde tot een significante verbetering van het bedrijfsresultaat. Voorts resulteerde vervanging van het *referentie* plan (P_1) door het *extra leegloop* plan (P_2) in een reduktie van het bedrijfsresultaat, terwijl het *liquiditeit* plan (P_3) geen significante verandering in bedrijfsresultaat tot gevolg had. Naast verschillende hoofdeffekten waren ook verscheidene interakties tussen operationele managementstrategieën en taktische produktieplannen significant.

Behalve op het bedrijfsresultaat hadden de operationele managementstrategieën en de taktisch produktieplannen ook effekt op de aantallen van typen operationele problemen, alsmede op de wijze waarop deze problemen werden opgelost. Onder de *passieve* strategie (S_1) werden per definitie geen operationele problemen vastgesteld. Voorts konden en werden onder alle overige strategieën operationele problemen als gevolg van afwijkende gewasgroei gesignaleerd. Operationele problemen gerelateerd aan prijsafwijkingen konden alleen worden vastgesteld onder de *marktgerichte* strategie (S_5). Daardoor werden onder deze strategie (S_5) de grootste aantallen operationele problemen gesignaleerd. Een vergelijking van taktische plannen liet zien dat het *referentie* plan (P_1) en het *liquiditeit* plan (P_3) in vergelijkbare patronen van operationele beslissingssituaties resulteerden. Het *extra leegloop* plan (P_2) leverde als gevolg van de toegepaste verlengde teeltschema's een duidelijk afwijkend patroon op.

Oplossing van operationele problemen door middel van uitstel van afleveren bleek meer problematisch dan oplossing door middel van vervroegde afleveringen. In tegenstelling tot vervroeging, leidde uitstel van afleveren tot extra kasoppervlakbehoefte, waarin niet altijd voorzien kon worden door gebrek aan leegloop en beperkte mogelijkheden voor reallocatie. Extra arbeidsbehoeften bleken nauwelijks belemmerend te zijn voor de oplossing van operationele problemen door aanpassing van teeltschema's, vanwege de mogelijkheid om exacte hoeveelheden extra arbeid in te huren. Concluderend kon worden vastgesteld dat de individuele beslissingssituaties overeenkwamen met de intenties van de verschillende operationele managementstrategieën. En op deze wijze boden operationele beslissingssituaties plausibele verklaringen voor geconstateerde effekten van operationeel management op het bedrijfsresultaat.

Prijsvariabiliteit-gevoeligheidsanalyse

Onder de *marktgerichte* strategie (S_5) was operationele besluitvorming gevoelig voor prijsvariabiliteit. Vergeleken met het *standaard* niveau van prijsvariabiliteit (V_2) resulteerde *lage* prijsvariabiliteit (V_1) in een significante reduktie van het bedrijfsresultaat en *hoge* prijsvariabiliteit (V_3) in een significante verbetering van het bedrijfsresultaat. Het effekt van prijsvariabiliteit was vooral te wijten aan het aantal beslissingen tot vervroegde aflevering van partijen die nog niet voldeden aan de standaard produktbeschrijving. Bij een toename van prijsvariabiliteit ontstonden meer situaties waarin vervroegde aflevering ondanks prijsreduktie aantrekkelijk was, terwijl bij alle niveaus van prijsvariabiliteit relatief lage prijzen meestal vermeden konden worden. Bij toenemende prijsvariabiliteit wordt aktief operationeel management daardoor aantrekkelijker.

Risicohouding-gevoeligheidsanalyse

Onder de *marktgerichte* strategie (S_5) was operationele besluitvorming gevoelig voor niet risico neutraal gedrag ten opzichte van operationele prijsverwachtingen. Daarbij leidde *risico avers* gedrag (R_3 en R_4) wel en *risico minnend* gedrag (R_1) niet tot een significant effekt op het bedrijfsresultaat. Dit verschil was toe te schrijven aan prijsreduktie als gevolg van het afleveren van planten die nog niet voldeden aan de standaard produktbeschrijving. *Risico avers* gedrag (R_3 en R_4) leidde vooral tot meer vervroegde afleveringen van niet standaard produkten, terwijl *risico minnend* gedrag (R_1) vooral leidde tot meer uitstel van aflevering. Terwijl in beide gevallen operationele besluitvorming was gebaseerd op vertekende prijsverwachtingen, hadden incorrecte beslissingen in geval van *risico avers* gedrag (R_3 en R_4) een sterker negatief effekt op het bedrijfsresultaat als gevolg van de bijkomende prijsreduktie.

Discussie

Alhoewel de verschillende operationele managementstrategieën tot significante verschillen in bedrijfsresultaat leiden, kan geen 'optimale' strategie worden aangewezen. De geformuleerde strategieën leiden namelijk niet alleen tot verschillende geldelijke voordelen, maar vragen ook een verschillende managementinspanning. Voorts waren mogelijke lange termijn effekten en bedrijfsoverstijgende effekten van individuele strategieën niet opgenomen in het potplantenbedrijfsmodel. De geformuleerde operationele managementstrategieën kunnen daarnaast ook gezien worden als verschillende operationele managementstijlen. Vanuit een dergelijk perspektief zou de 'optimale' strategie bepaald moeten worden aan de hand van de doelstellingen van de individuele tuinder en de filosofie van zijn bedrijf.

Tot besluit kan worden geconcludeerd dat de ontwikkelde methodologie succesvol is toegepast voor de verkenning van opties voor operationeel management in de potplantenteelt. Theorie vanuit verschillende wetenschappelijke disciplines werd geïntegreerd op basis van een tamelijk normatieve benaderingswijze. De simulatie-experimenten met het gevalideerde potplantenbedrijfsmodel tonen aan dat operationeel management het bedrijfsresultaat op verschillende wijzen beïnvloedt. Aldus biedt deze studie verschillende aanknopingspunten voor zinvolle ondersteuning van operationeel management in de potplantenteelt.

CURRICULUM VITAE

Klaas Jan Leutscher werd geboren op 3 december 1963 te Lochem. In 1982 behaalde hij het VWO-diploma aan de Alexander Hegius Scholengemeenschap te Deventer, waarna hij in Wageningen zijn opleiding vervolgde aan de Landbouwuniversiteit. In september 1987 slaagde hij voor het doctoraalexamen van de studierichting Tuinbouw (oriëntatie sociaal-economisch) met de afstudeervakken Agrarische Bedrijfseconomie en Groenteteelt. Aansluitend trad hij als assistent in opleiding in dienst van de vakgroep Agrarische Bedrijfseconomie van de Landbouwuniversiteit. Sinds juli 1989 is hij als universitair docent verbonden aan de vakgroep Tuinbouwplantenteelt van de dezelfde universiteit.