TECHNICAL UNIVERSITY OF CRETE
School of Production Engineering and Management

INTELLIGENT MULTICRITERIA DECISION SUPPORT SYSTEMS & APPLICATIONS

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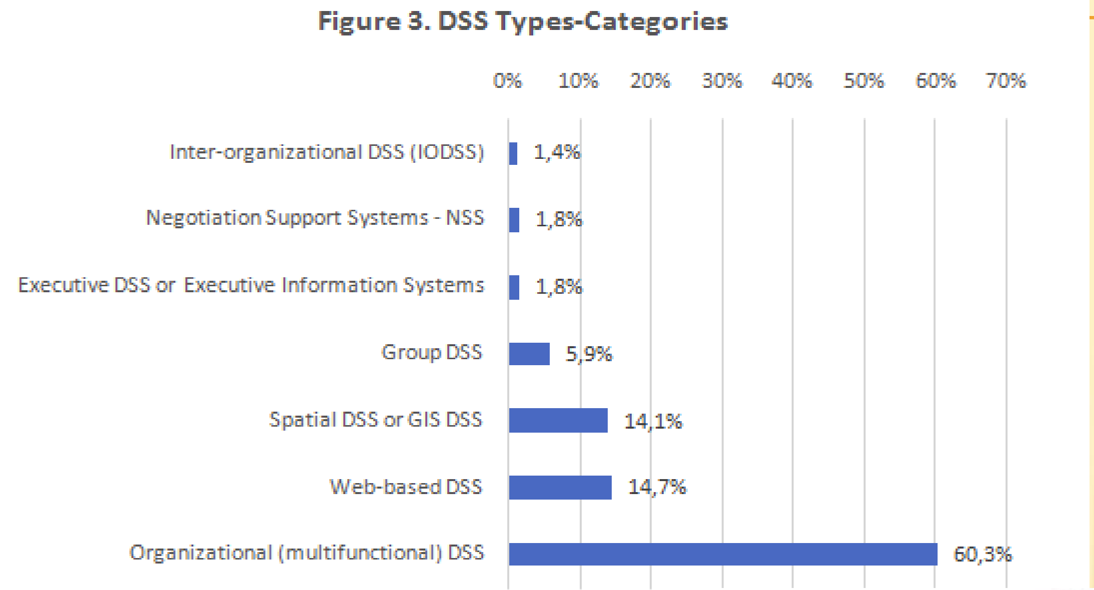
CONTENTS

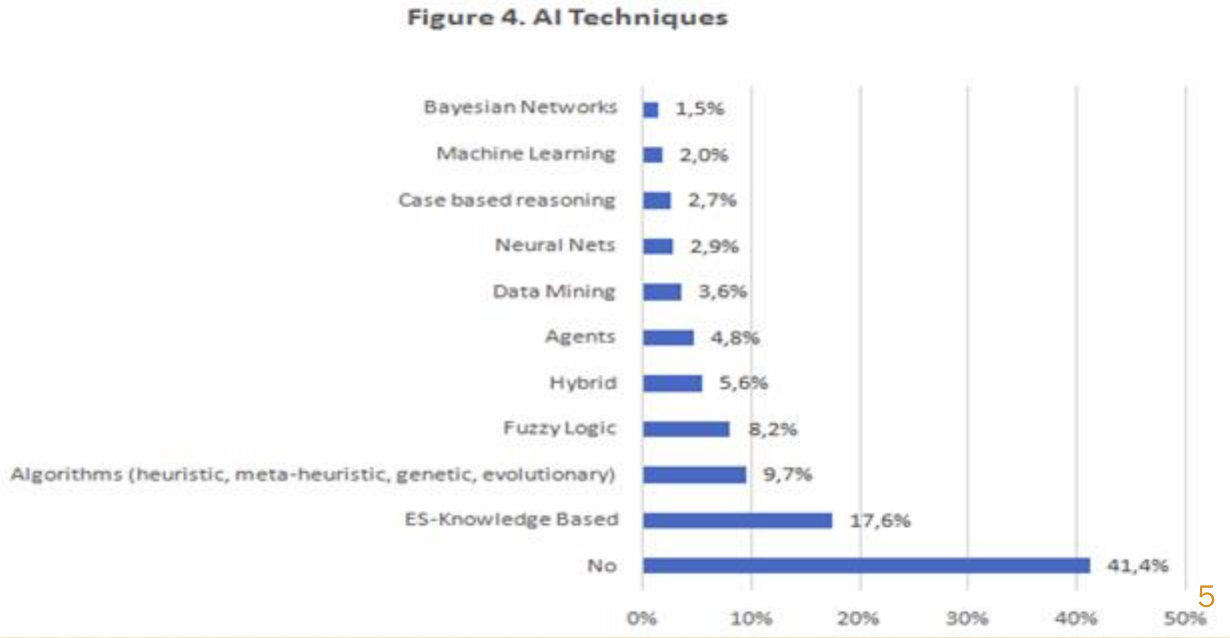
DSS APPLICATIONS

DECISION SUPPORT SYSTEMS APPLICATIONS: A LITERATURE REVIEW

- Data extraction and checking tasks were followed as suggested by Brereton et al. (2007).
- The review is in progress while so far 660 published DSS applications have been registered (including journals, PhDs, and conferences proceedings.
- The information we gather is the following:
  - (1) Year of Publication
  - (2) Categories and Types
  - (3) AI Techniques
  - (4) Knowledge Representation Techniques
  - (5) Knowledge Source
  - (6) Uncertainty Level
  - (7) Application Area
  - (8) Operating System
  - (9) Problem Types
  - (10) Decision Making Phase
  - (11) Management Level
  - (12) Methods Used
  - (13) Multicriteria Analysis Methods

DECISION SUPPORT SYSTEMS APPLICATIONS: A LITERATURE REVIEW





DECISION SUPPORT SYSTEMS APPLICATIONS: A LITERATURE REVIEW

Figure 13. Management Level

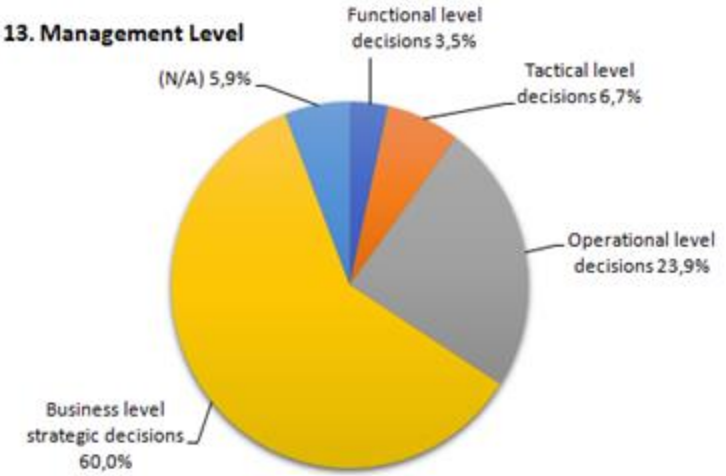


Figure 5. Knowledge Representation Techniques

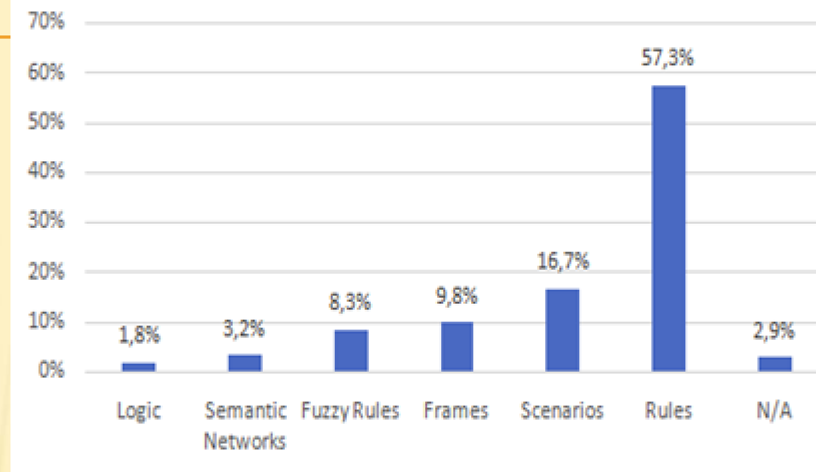


Table 9. Distribution of entries by Area and AI Techniques

AREA / AI TECHNIQUES	ES-Knowledge Based	Algorithms	Fuzzy Logic	Hybrid	Agents	Data Mining	Neural Nets	Case based reasoning	Machine Learning	Bayesian Networks	No	TOTAL
Environmental and Natural resource Management	21	12	13	5	4	4	2	2		3	62	128
Clinical-Health Care	19	2	3	4	1	3	3	3	4	3	23	68
Finance	16	5	3	5	1	2	3	1			27	63
Scheduling in manufacturing environment	10	5	5	3	4		3	2	3		27	62
Business Management	8	7	10	2	3	1		2	1	1	26	61
Agriculture	10	1	2		2	4	1	3	2		26	51
Marketing strategy	8	2	2	11	3	1	2	1	1		10	41
Supply Chain Management		7	7		5	1		1		1	16	38
Emergent Management	8	3	3		1		2	1			8	26
Aggregate Production Planning	5	4			1		2			1	11	24
Transportation	1	4	2	4	1						10	22
Production Line Development	2	2	1	2		1		1	1		9	19
Internet/Web Technologies		1	1		4	5					3	14
Education	2	1	1	1					1	1	4	11
New Product Development	2	3				1		1			4	11
Electricity Industry	1	1	1		1		1				3	8
Logistics	2	3			1						2	8
Tourism Management						1					2	3
Crime Investigation	1											1
Job Satisfaction		1										1
TOTAL	116	64	54	37	32	24	19	18	13	10	273	660

MCDA METHODS

MULTICRITERIA DECISION ANALYSIS

The need to find solutions on decision-making problems and at the same time preserve the multidimensional nature of these problems prompted for **the need of evolution of Multiple Criteria Decision Analysis (MCDA) methods**.

Because of the existence of multiple and often conflicting evaluation criteria, multicriteria problems belong to the family of **low structured decision making problems**.

Accordingly, the number of criteria and the complexity of their interrelations, affect the preference system of the decision maker, which in turn is characterized by a **low structure degree**.

Consequently, the decisions belong to the **semi-structured category**, a fact that generates the necessity for supporting the decision maker with the development of appropriate multicriteria models.

MULTICRITERIA DECISION ANALYSIS

The beginning:

fundamental ideas of multicriteria analysis were already established from the 18th century (Bernoulli and Cramer)

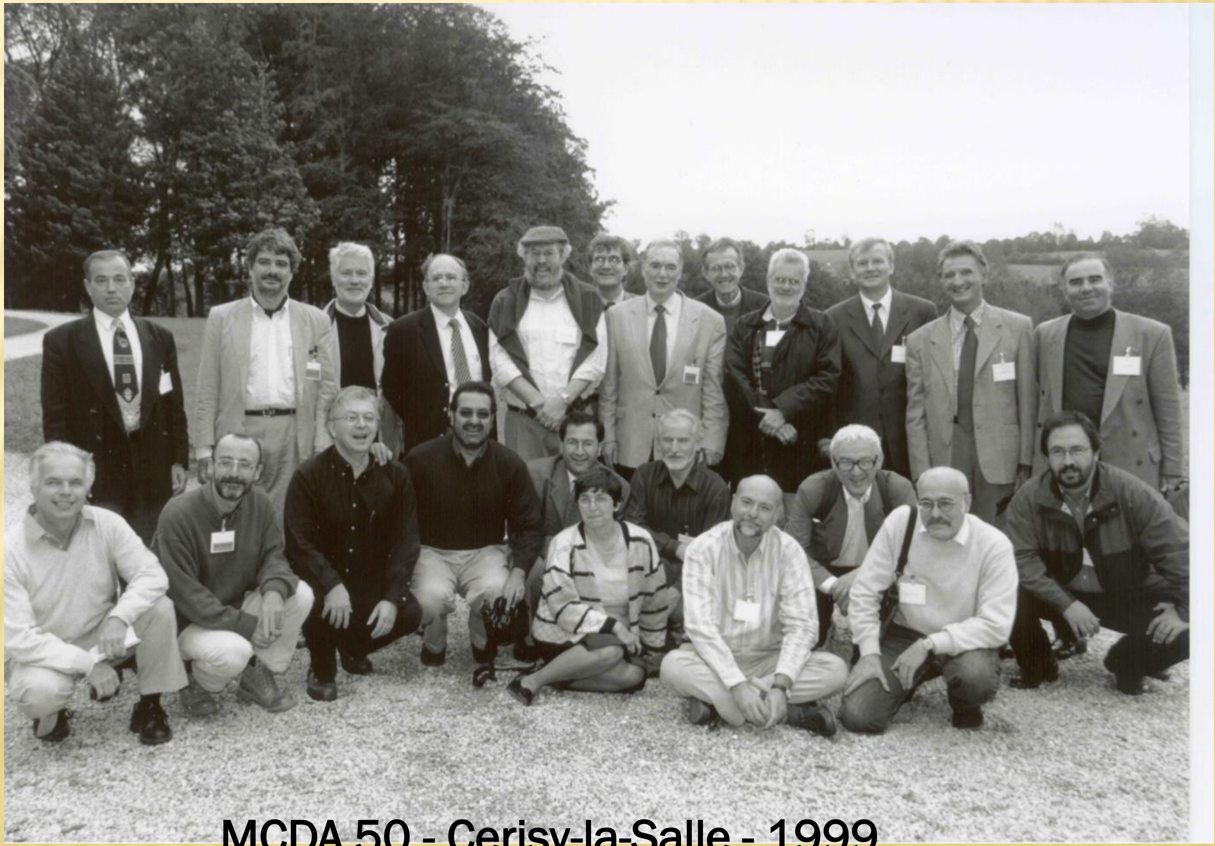
theoretical background and axiomatic foundation for multiple criteria decision problems began two centuries later with the work of von Neumann and Morgenstern (1944) and Savage (1954).

rapid evolution after the accomplishment of the first MCDM conference in 1972 in the University of South Carolina.

MULTICRITERIA DECISION ANALYSIS

Different approaches in the decision-making process:

- The American school or **Multiple Criteria Decision Making (MCDM)**
- The European/French school or **Multiple Criteria Decision Aid (MCDA)**



MCDA 50 - Cerisy-la-Salle - 1999

MULTICRITERIA DECISION ANALYSIS

The fundamental points of the MCDA framework are (Roy, 1990):

- In general, **more than one decision makers are involved in the decision making process.**
- The **objective of multicriteria analysis is not to point out to the decision maker better solutions** but rather to lead the decision maker to the selection of a satisfying solution through a process of progressive understanding and improvement of his/her abilities and knowledge.

GENERAL MODELLING FRAMEWORK IN MCDA

The **general modelling framework in multicriteria analysis** is determined by the following four successive and interactive stages (Roy (1975; 1990):

- **1st stage: Decision objective.**

  Each problem is decomposed in a finite or continuous set of alternatives, actions, decisions $A = \{a_i, i = 1, 2, ..., n\}$. The set of alternative actions can be characterized as:

  - Fixed,
  - Revisable,
  - Comprehensive,
  - Fragmented.

GENERAL MODELLING FRAMEWORK IN MCDA

DECISION PROBLEM

- There is an objective or objectives to be attained
- There are many alternative ways for attaining the objective(s). They constitute a **set of actions** ***A*** (alternatives, solutions, objects, acts, …)

GENERAL MODELLING FRAMEWORK IN MCDA

Types of problematic (Roy, 1985):

- **Problematic α:** The ***choice*** of one and only one alternative from the set *A* of alternative actions.

  Question: *How to choose the best action*?

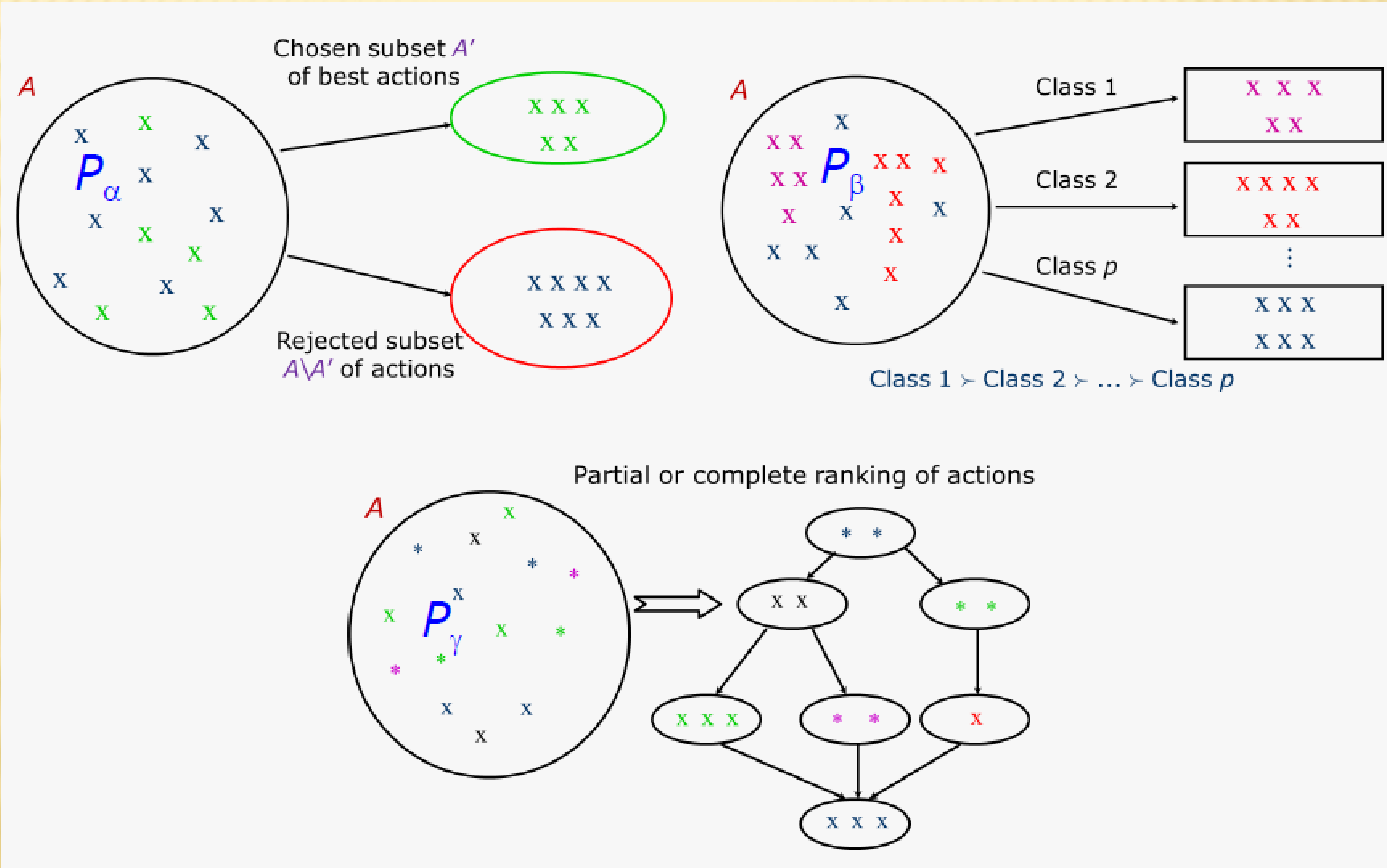
- **Problematic β:** The ***sorting*** of the alternative actions into classes (groups) that share some specific attributes.

  Question: *How to classify actions in to pre-define decision classes*?

- **Problematic γ:** The ***ranking*** of the alternative actions from the most to the least preferred.

  Question: *How to order actions from the best to the worst*?

- **Problematic δ:** The ***simple description*** of the actions and their consequences in a language that can be fully conceivable by the managers.


Chosen subset A′
of best actions
A
Pα
Rejected subset
A\A′ of actions
A
Pβ
Class 1
Class 2
Class p
Class 1 ≻ Class 2 ≻ … ≻ Class p
Partial or complete ranking of actions
A
Pγ

GENERAL MODELLING FRAMEWORK IN MCDA

2nd stage: Analysis of elementary consequences.

Each alternative can be analysed according to a set of attributes or a cloud of elementary consequences (Roy, 1985).

The analysis of the cloud of elementary consequences of each alternative action guides the analysts to the choice and modelling of a **consistent family of criteria** $F = \{g_1, g_2, \ldots, g_m\}$, that will be used in order to evaluate the alternatives and reach the final decision.

The criteria are modelled using real functions $g_j: A \longrightarrow R$, $a \longrightarrow g_j(a)$, where **$g_j(a)$ is the evaluation of the action** according to the ***j-th*** criterion.

The true criteria should fulfil the following conditions:

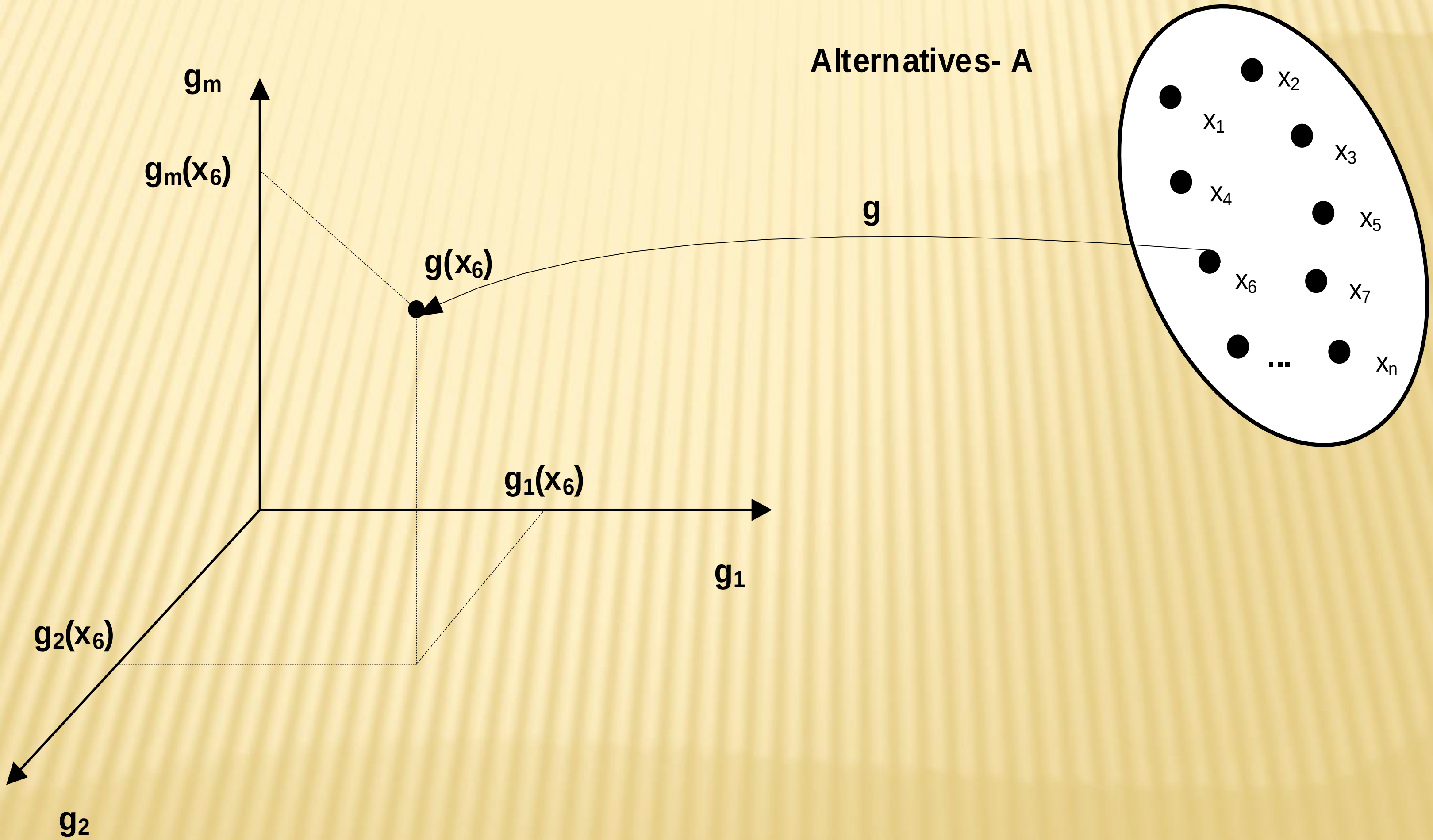
- **Monotonicity:** They should preserve monotonicity and be consistent with the individual preferences:

  $g_j(a) > g_j(b) \Leftrightarrow a \succ b$

  $g_j(a) = g_j(b) \Leftrightarrow a \sim b$

- **Exhaustiveness:** They should be exhaustive according to the limitations in the available information
- **Non redundancy:** They should avoid redundancy (non redundant)

GENERAL MODELLING FRAMEWORK IN MCDA



Representation of set A in multicriteria modeling

GENERAL MODELLING FRAMEWORK IN MCDA

Multicriteria table:

		Criteria			
		g_1	g_2	….	g_m
Decision alternatives	a_1	$g_1(a_1)$	$g_2(a_1)$	….	$g_m(a_1)$
	a_2	$g_1(a_2)$	$g_2(a_2)$	….	$g_m(a_2)$
	…	…	…	….	…
	a_n	$g_1(a_n)$	$g_2(a_n)$	….	$g_m(a_n)$

GENERAL MODELLING FRAMEWORK IN MCDA

3rd stage: Development of the global preference model (decision model or model of behaviour).

This stage involves the aggregation of the criteria by applying a specific model of holistic preferences.

4th stage: Elaboration and implementation of scenarios.

Analyst attempts to find answers in the decision maker's questions ("what-if" scenarios).

THEORETICAL MULTICRITERIA ANALYSIS APPROACHES

Value system approach or Multiattribute Utility Theory (MAUT)

The value system approach or multiattribute utility theory (MAUT) aims to develop a value system that aggregates the decision-maker's preferences on the total set of criteria, based on strict assumptions, like complete and transitive relation. The estimated value system provides a quantitative way to aid the final decision (von Neumann and Morgenstern, 1947; Adams and Fagot, 1959; Yntena and Torgerson (1961), Miller and Starr, 1969; Huber, 1974; Keeney and Raiffa, 1976; 1993; Fishburn, 1972; 1977; Vincke, 1985; French, 1993; etc.

Multiattribute utility theory is founded on two basic assumptions:

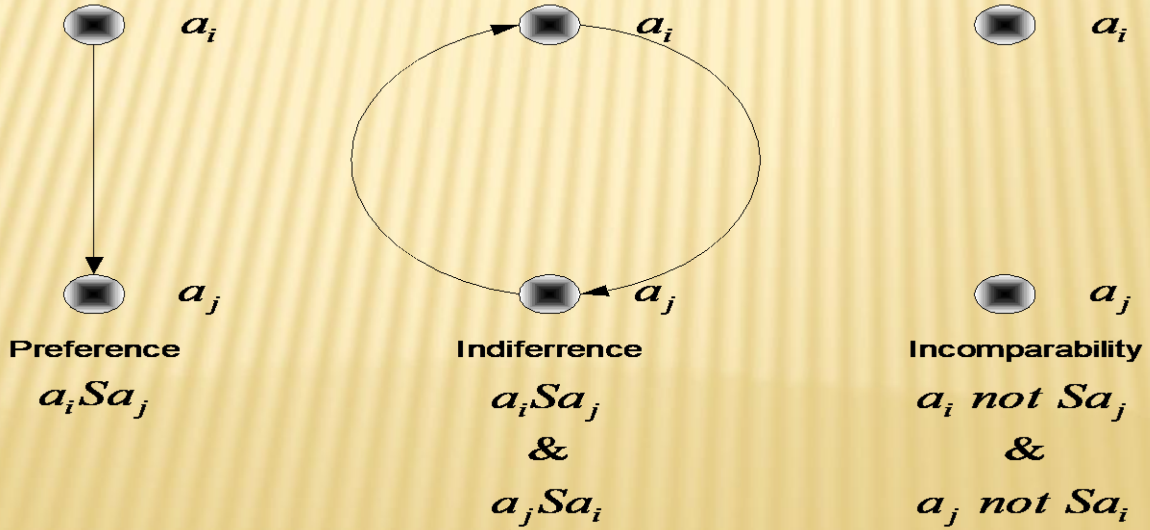
- All the possible actions can be compared to each other.
- The preferences of the alternative actions are transitive.

THEORETICAL MULTICRITERIA ANALYSIS APPROACHES

Outranking relations

The outranking relations approach, using a non compensatory process, aims to the development of outranking relations that allow the incomparability among the decision actions. This particular approach is not bounded into a mathematical model but it results in partial preference structures of the decision actions. Thus, it aids the decision-maker in taking a ‘good’ decision.

The theory of outranking methods has been inspired by the work of Roy (1968) with the development and application of the ELECTRE family methods.



Binary preference relations

THEORETICAL MULTICRITERIA ANALYSIS APPROACHES

Multiobjective mathematical programming or multiobjective optimization approach

The multiobjective mathematical programming aims to solve problems with (Goicoechea *et al*., 1982, Hwang and Masud, 1979; Hwang and Yoon, 1981; Zeleny, 1974; 1982; Steuer, 1986; Jaszkiewicz and Slowinski, 1995):

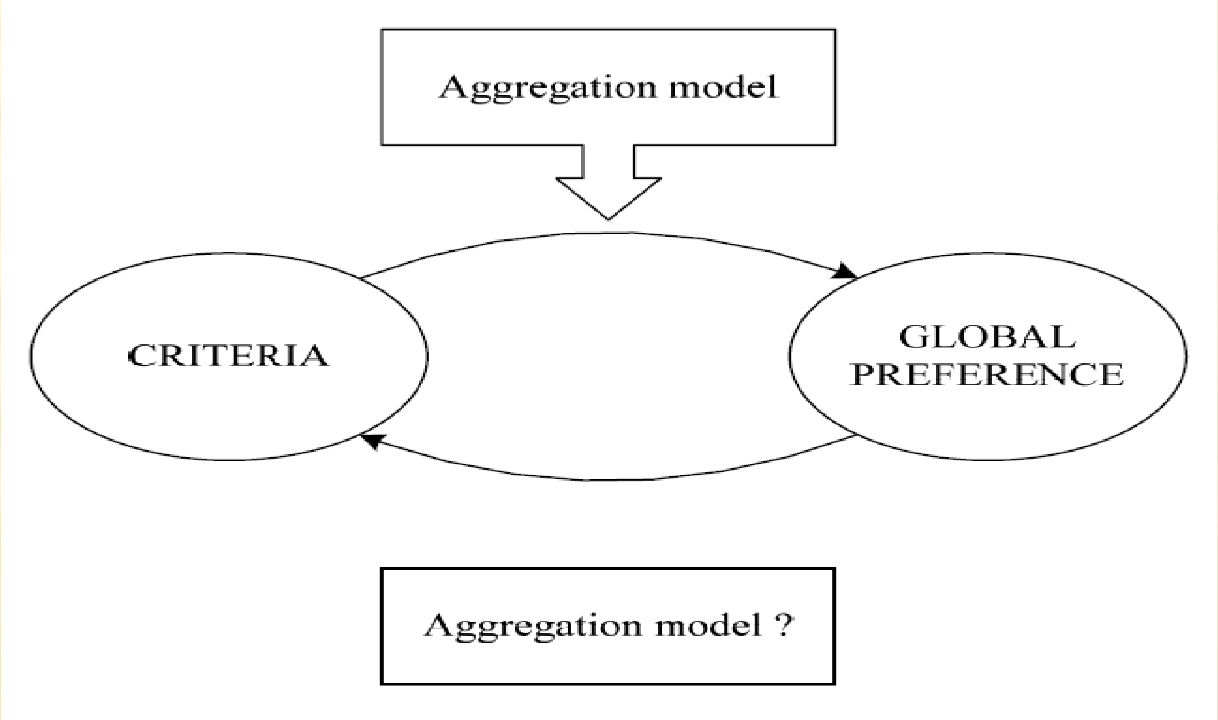
- no discrete alternatives actions, and
- more than one objective functions.

THEORETICAL MULTICRITERIA ANALYSIS APPROACHES

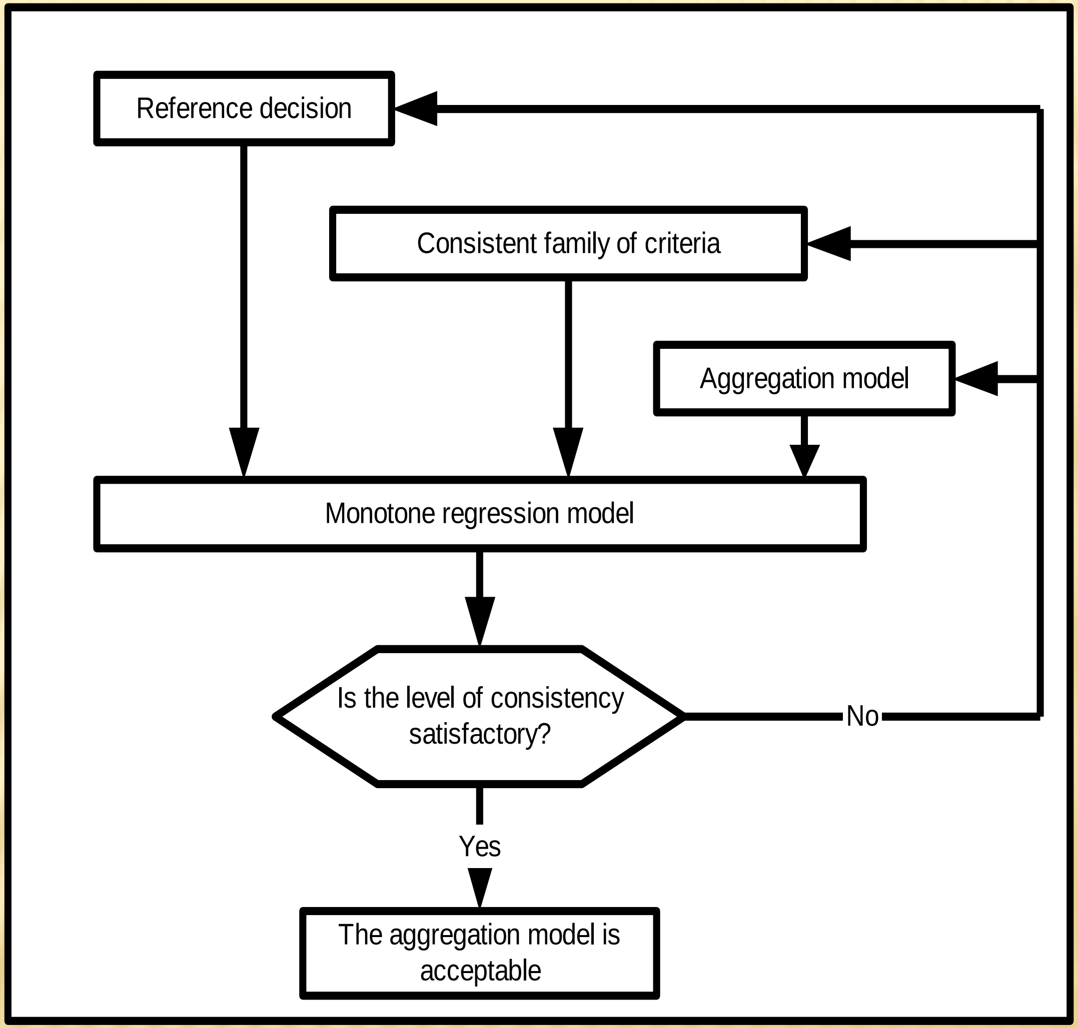
The aggregation - disaggregation approach

The aggregation - disaggregation approach aims to analyze the behavior and the cognitive style of the decision-maker (Hammond *et al.*, 1977; Siskos, 1980; Jacquet-Lagrèze and Siskos, 1982; Siskos and Yannacopoulos, 1983; Siskos, Grigoroudis and Matsatsinis, 2016).

This methodology uses ordinal regression models in an attempt to approach the reasoning of the decision makers through an aggregation-disaggregation procedure.

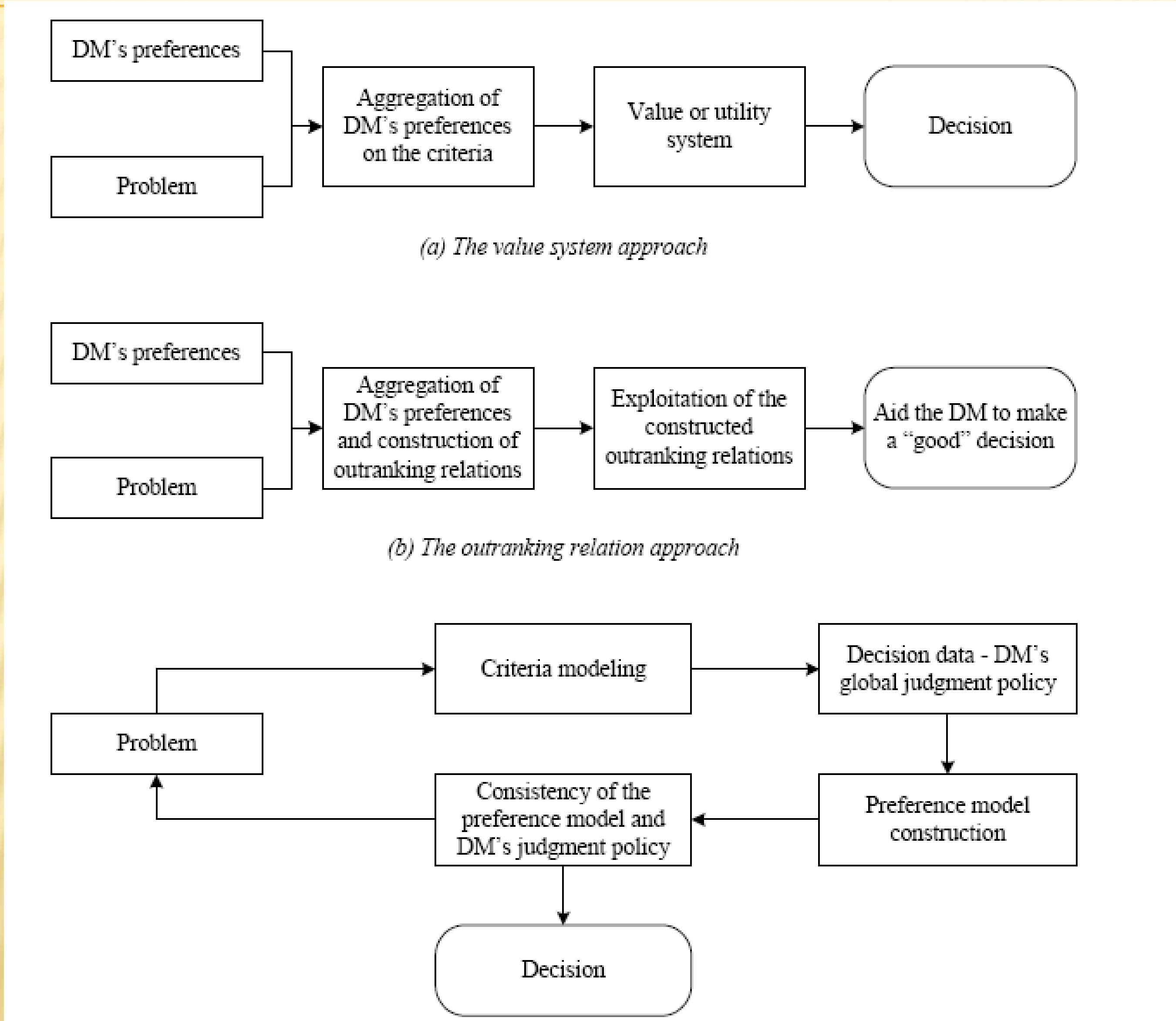


THEORETICAL MULTICRITERIA ANALYSIS APPROACHES



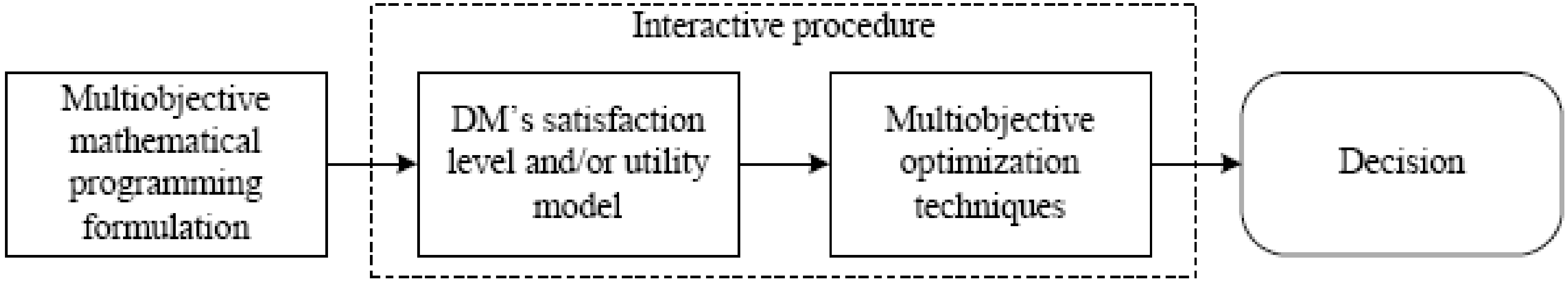
Iterations and interaction between the DM and the model

AGGREGATION-DISAGGREGATION APPROACH VS OTHER MCDA APPROACHES (Siskos and Spyridakos, 1999)



(c) The disaggregation-aggregation approach

AGGREGATION-DISAGGREGATION APPROACH VS OTHER MCDA APPROACHES (Siskos and Spyridakos, 1999)



(d) The multiobjective optimization approach

THE UTA FAMILY METHODS

THE UTA METHOD

UTA (UTilités Additives) methods refer to the philosophy of assessing a set of value or utility functions, assuming the axiomatic basis of MAUT and adopting the preference disaggregation principle.

The UTA method proposed by Jacquet-Lagrèze and Siskos (1982) aims at **inferring one or more additive value functions** from a given ranking on a reference set A_R.

The method uses **linear programming** techniques to assess these functions so that the ranking(s) obtained through these functions on A_R **is (are) as consistent as possible** with the given one (by DM).

THE UTA METHOD

The additive value model

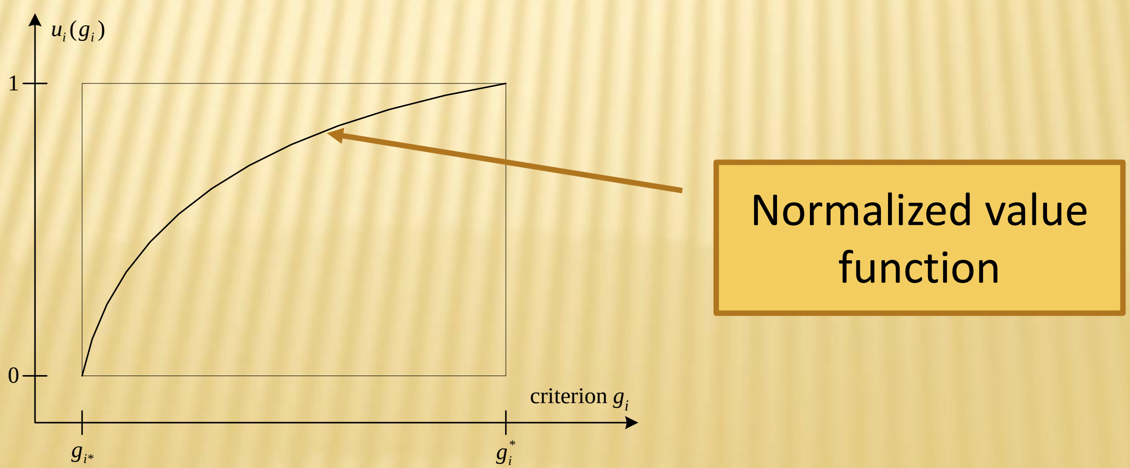
The criteria aggregation model in UTA is assumed to be an additive value function of the following form:

$$u(\mathbf{g}) = \sum_{i=1}^{n} p_i u_i(g_i)$$

subject to normalization constraints:

$$\begin{cases} \sum_{i=1}^{n} p_i = 1 \\ u_i(g_{i*}) = 0, \;\; u_i(g_i^*) = 1 \;\; \forall i = 1, 2, \ldots, n \end{cases}$$

Where: u_i, i = 1, 2, …, n, are non-decreasing real valued functions, named **marginal value or utility functions**, which are normalized between 0 and 1, and **p**$_i$ is the weight of u_i.



THE UTA METHOD

- Both the marginal and the global value functions have the monotonicity property of the true criterion. For instance, in the case of the global value function the following properties hold:

$$\begin{cases} u[\mathrm{g}(a)] > u[\mathrm{g}(b)] \Leftrightarrow a \succ b \ (preference) \\ u[\mathrm{g}(a)] = u[\mathrm{g}(b)] \Leftrightarrow a \sim b \ (\text{indifference}) \end{cases}$$

- The UTA method infers an unweighted equivalent form of the additive value function:

$$u(\mathrm{g}) = \sum_{i=1}^{n} u_i(g_i)$$

THE UTA METHOD

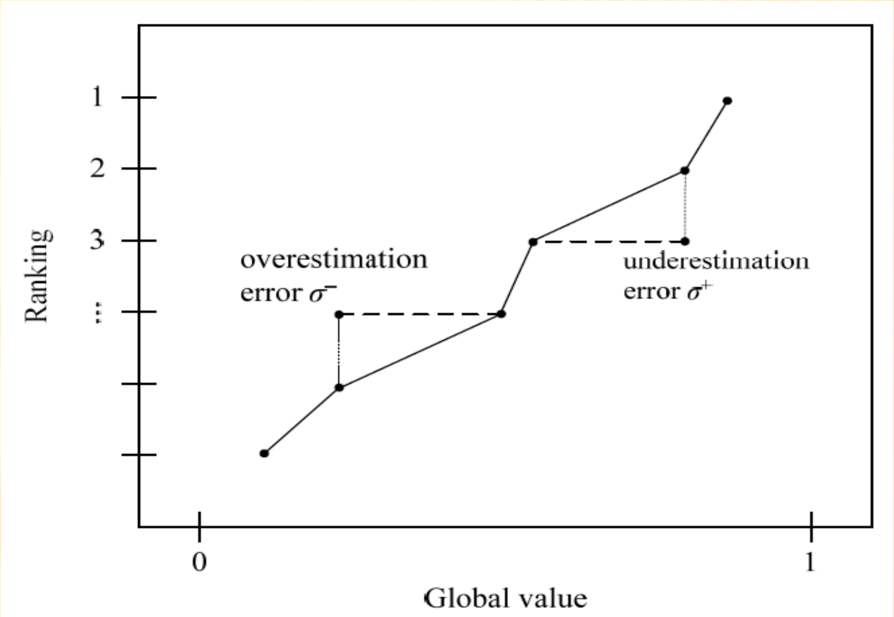
Linear Program (LP):

$$
\begin{cases}
[\min] F = \sum\limits_{a \in A'} \sigma(a) \\
\text{under the constrains:} \\
\sum\limits_{i=1}^{n} \{u_i[g_i(a)] - u_i[g_i(b)]\} + \sigma(a) - \sigma(b) \geq \delta \quad \text{if } a P^* b \\
\sum\limits_{i=1}^{n} \{u_i[g_i(a)] - u_i[g_i(b)]\} + \sigma(a) - \sigma(b) = 0 \quad \text{if } a I^* b \\
u_i\left(g_i^{j+1}\right) - u_i\left(g_i^{j}\right) \geq s_i \qquad \forall i \text{ and } j \\
\sum\limits_{i=1}^{n} u_i\left(g_i^{*}\right) = 1 \\
u_i(g_{i*}) = 0, \quad u_i\left(g_i^{j}\right) \geq 0, \quad \sigma(a) \geq 0 \quad \forall i \text{ and } j, \quad a \in A_R
\end{cases}
$$

THE UTASTAR METHOD

- In the original version of UTA (Jacquet-Lagrèze and Siskos, 1982), for each reference action *$a \in A_R$*, *a* single error *σ(a)* is introduced to be minimized.
- In UTASTAR method, **a double positive error function** is introduced:

$$u'[g(a)] = \sum_{i=1}^{n} u_i[g_i(a)] - \sigma^+(a) + \sigma^-(a) \ \forall \ a \in A_{\mathfrak{R}}$$



Ordinal regression curve (ranking versus global value)

Moreover, another important modification concerns the monotonicity constraints of the criteria, which are taken into account through the transformations:

$$w_{ij} = u_i\left(g_i^{j+1}\right) - u_i\left(g_i^{j}\right) \geq 0 \ \forall \ i = 1,2,\ldots,n \text{ and } j = 1,2,\ldots,a_i - 1$$

THE UTASTAR METHOD

The algorithm

Step 1: Express the global value of reference actions $u[\mathbf{g}(a_k)]$, $k=1,2,\ldots,n$, first in terms of marginal values $u_i(a_i)$, and then in terms of variables w_{ij}, by means of the following expressions:

$$\begin{cases} u_i\left(g_i^1\right) = 0 \ \forall \ i = 1,2,\ldots,n \\ u_i\left(g_i^j\right) = \sum_{t=1}^{j-1} w_{ij} \ \ \forall \ i = 1,2,\ldots,n \text{ and } \mathrm{j} = 2,3,\ldots,\mathrm{a_i} - 1 \end{cases}$$

Step 2: Introduce **two error functions σ^+ and σ^-** on A_R by writing for each pair of consecutive actions in the ranking the analytic expressions:

$$\Delta(a_k, a_{k+1}) = u[\mathrm{g}(a_k)] - \sigma^+(a_k) + \sigma^-(a_k) - u[\mathrm{g}(a_{k+1})] + \sigma^+(a_{k+1}) - \sigma^-(a_{k+1})$$

THE UTASTAR METHOD

The algorithm

Step 3:

- Solve the linear program:

$$\begin{cases} [\min] z = \sum_{k=1}^{m} [\sigma^{+}(a_k) + \sigma^{-}(a_k)] \\ \text{subject to} \\ \left.\begin{array}{l} \Delta(a_k, a_{k+1}) \geq \delta \text{ if } a_k \succ \ a_{k+1} \\ \Delta(a_k, a_{k+1}) = 0 \text{ if } \mathrm{a_k} \sim \mathrm{a_{k+1}} \end{array}\right\} \forall\ k \\ \sum_{i=1}^{n} \sum_{j=1}^{a_i - 1} w_{ij} = 1 \\ w_{ij} \geq 0, \sigma^{+}(a_k) \geq 0, \sigma^{-}(a_k) \geq 0 \ \forall\ i, j \text{ and } k \end{cases}$$

with δ a small positive number

THE UTASTAR METHOD

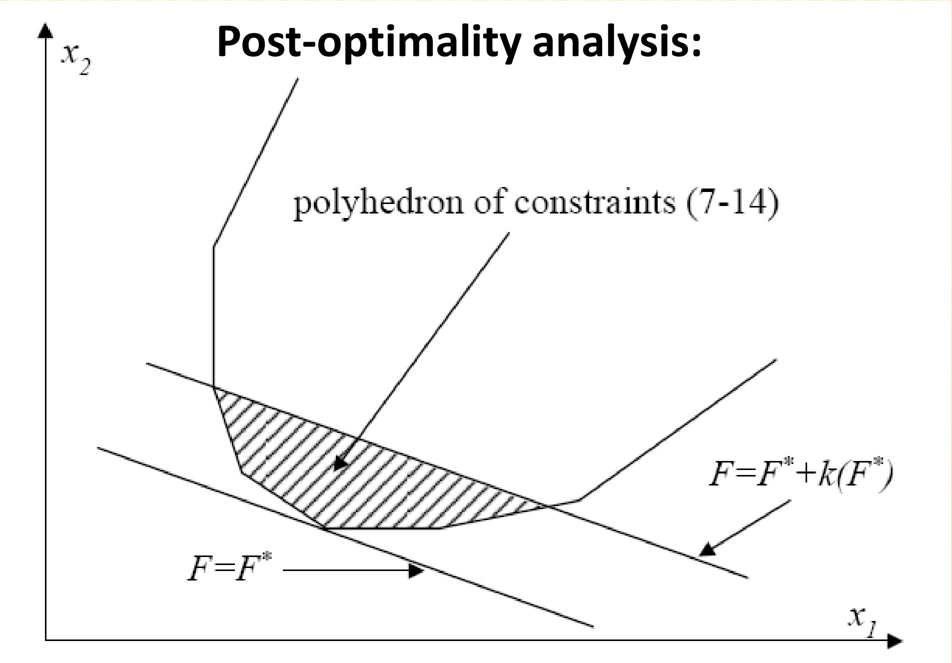
The algorithm

Step 4:

- Test the existence of multiple or near optimal solutions of the linear program (stability/robustness analysis); in case of non uniqueness, find the mean additive value function of those (near) optimal solutions which maximize the objective functions:

$$\sum_{k=1}^{m}[\sigma^{+}(a_k)+\sigma^{-}(a_k)] \leq z^{*}+\varepsilon$$

where: *z** is the optimal value of the LP in step 3 and *ε* a very small positive number.

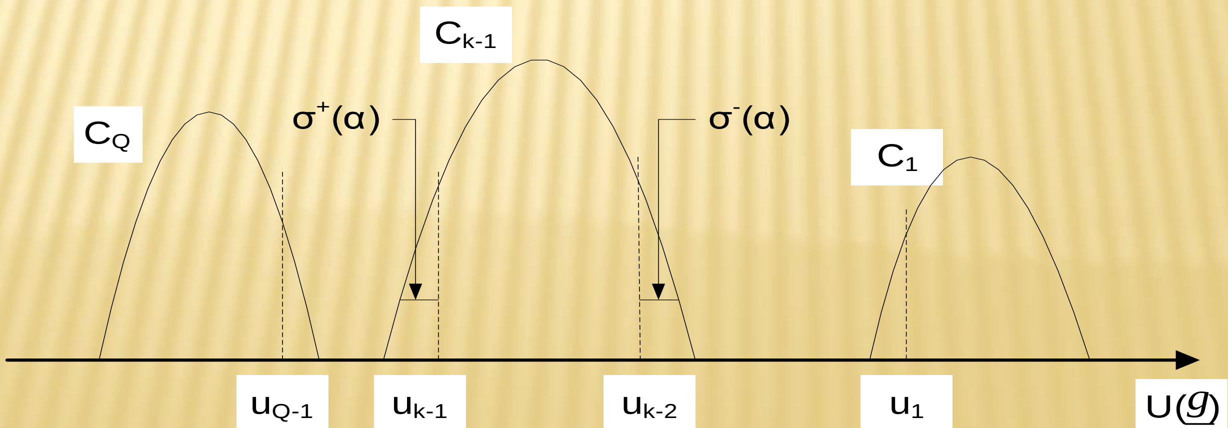


THE UTADIS METHOD

Specifically, the UTADIS method (Utilités Additives DIScriminantes) refers to classification-categorization problems (problematic β), in which we have a set of n alternative actions/choices, A = {α_1, α_2, ..., α_n} which will must be classified into q homogeneous ordered classes-groups C_1, C_2, …, C_q, based on a consistent family of m criteria g_1, g_2, ..., g_m. The class classes are defined a priori as follows:

$$C_1 \; P \; C_2 \; P \; \ldots, C_{q-1} \; P \; C_q;$$

- P denotes the strict Preference relationship between classes



THE UTADIS METHOD

Hence, *u(**g**)* can be estimated by means of the LP:

$$
\begin{cases}
[\min] F = \sum_{a \in A_R} \sigma(a) \\
\text{subject to} \\
\sum_{i=1}^{n} u_i[g_i(a)] - u_0 + \sigma(a) \geq 0 & \forall a \in A_1 \\
\sum_{i=1}^{n} u_i[g_i(a)] - u_0 - \sigma(a) \leq 0 & \forall a \in A_2 \\
u_i\left(g_i^{j+1}\right) - u_i\left(g_i^{j}\right) \geq s_i & \forall i \text{ and } j \\
\sum_{i=1}^{n} u_i(g_i^*) = 1 \\
u_i(g_{i*}) = 0, u_0 \geq 0, u_i(g_i^j) \geq 0, \sigma(a) \geq 0 & \forall a \in A_R, \forall i \text{ and } j
\end{cases}
$$

MARKEX METHODOLOGY & SYSTEM

Matsatsinis, N.F., Y. Siskos (1999), MARKEX: An intelligent decision support system for product development decisions, European Journal of Operational Research, vol. 113, no. 2, pp. 336-354.
Matsatsinis, N.F. and Y. Siskos (2003), Intelligent support systems for marketing decisions, Springer.
This research has been carried out with financial support from the Commission of the European Communities, Agriculture and Fisheries (FAIR) specific RTD programme, CT-095-0844 "Development of an Integrated Knowledge Based Decision Support System for Differentiated Agricultural Products".

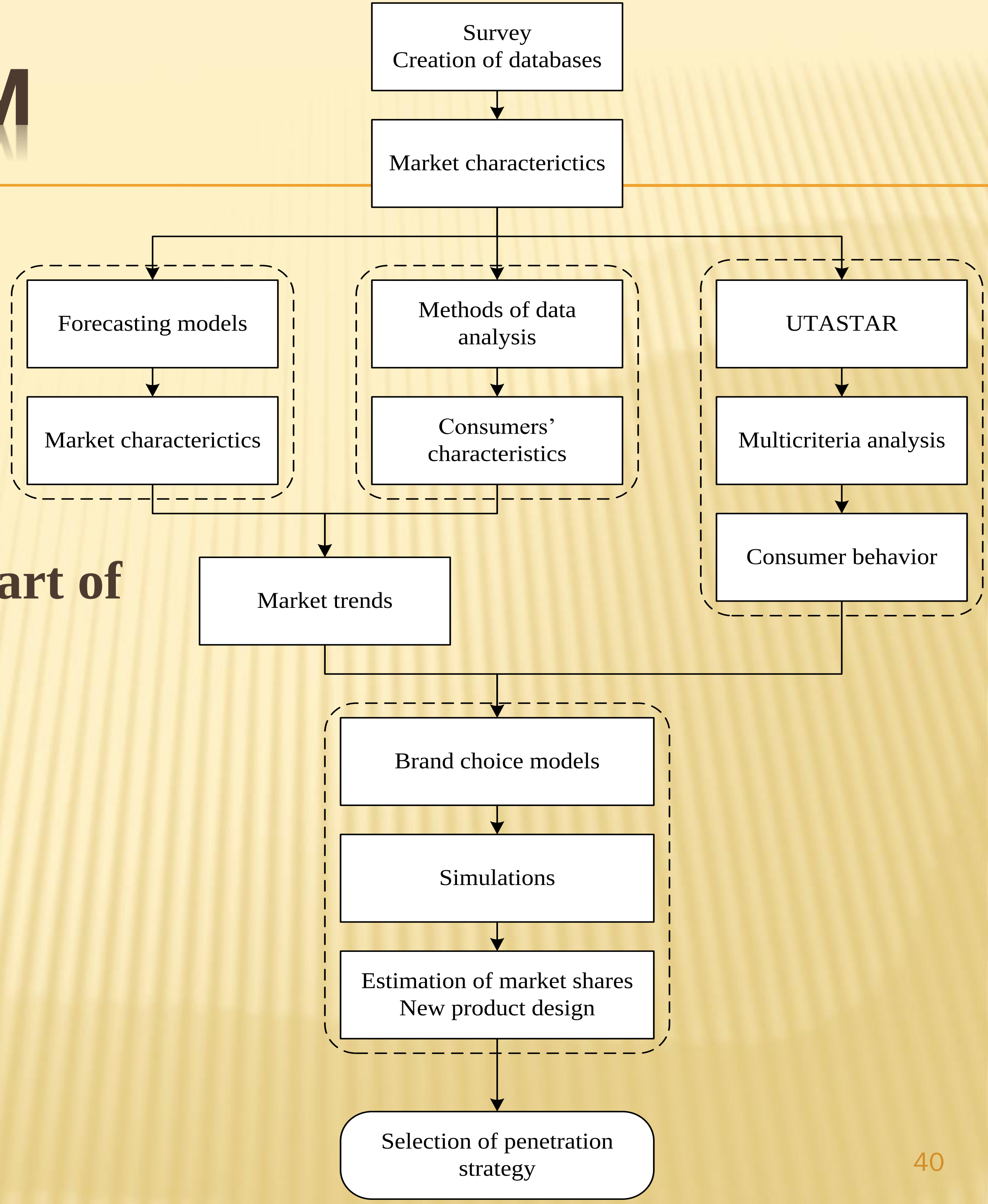
MARKEX SYSTEM

The MARKEX system has been proposed by Matsatsinis, 1995; Siskos and Matsatsinis (1993), Matsatsinis and Siskos (1999), Matsatsinis and Siskos (2003).

The main goal of the system's philosophy is the provision of broad support to the decision maker in the various phases of the new product development process like:

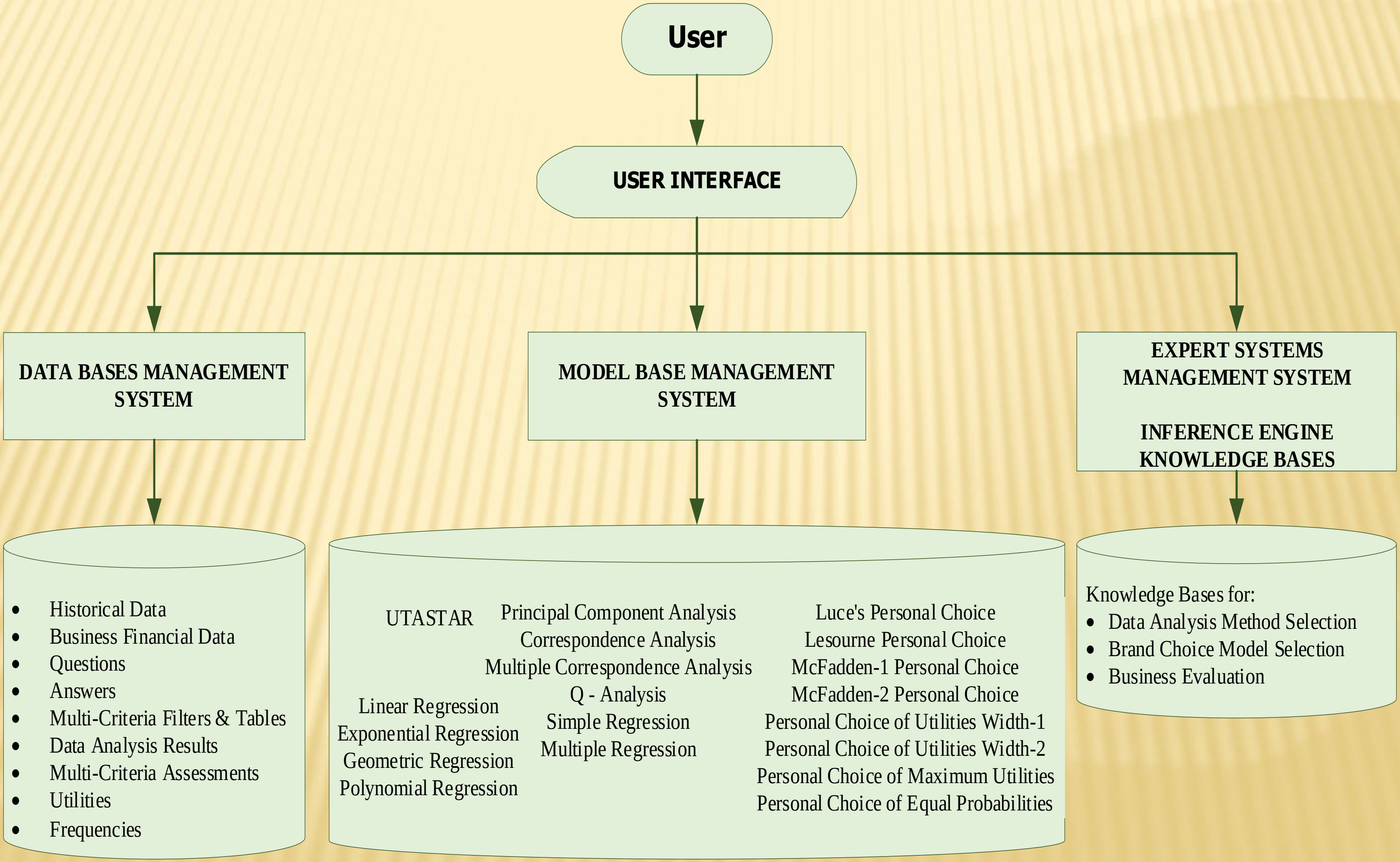
- The processing of data collected by market surveys.
- The analysis of the market and the determination of the market's general characteristics.
- The analysis of the characteristics of the consumers.
- The study of consumer behavior.
- Product and competition analysis.
- The segmentation of the market.
- The design, development, and test of products through the calculation of their purchase probabilities and by the simulation of the market.
- The examination of simple and complex scenarios.
- The selection of the penetration strategy of the product under development through the application of alternative strategies.

MARKEX SYSTEM



Methodological flowchart of MARKEX

STRUCTURE OF MARKEX SYSTEM



MARKEX SYSTEM

CONSUMER PREFERENCE ASSESSMENT

What is your opinion about the following products?

PRODUCT		CARAPELLI	LERIDA	KOLYBARI	HEDIARD	LA JARRE d'OR	PUGET
IMAGE (a)	BAD						
	UNAWARE						
	GOOD						
	VERY GOOD						
COLOUR (b)	UNNATURAL						
	NATURAL						
	ATTRACTIVE						
ODOUR (c)	UNNATURAL						
	NATURAL						
	PLEASANT						
TASTE (d)	UNNATURAL						
	NATURAL						
	DELICIOUS						
PACKAGING (e)	GOOD						
	FAIR						
	GOOD						
	VERY GOOD						

(a) What is your opinion about the quality of..... extra virgin olive oil?
(b) Have you ever heard from others (relatives, friends) about..... extra virgin olive oil?
(c) Which is your opinion about the package of..... extra virgin olive oil?
(d) Which is your opinion about the producing company of..... extra virgin olive oil?

RANKING

Which of the following extra virgin olive oils would you buy?

Repetitive question: If you could not find your oil of choice, which one would you buy?

CARAPELLI	LERIDA	KOLYBARI	HEDIARD	LA JARRE D'OR	PUGET

Multi-Criteria Evaluation Questionnaire

UTASTAR & calculation of utilities.

Questions' File

Question	72	73	74	75	76	77	78	79	80	81	82	83	84	85	....
Answer	3	3	1	3	3	3	2	2	2	2	2	1	1	2	....

Answers' File

Multicriteria matrix filter

	Weak Order	Advertisement	Colour	Flavour	Taste	Package	Price (Fr)
KOLIBARI	112	74	80	86	92	98	106
CARAPELI	110	72	78	84	90	96	104
LERIDA	111	73	79	85	91	97	105
HEDIARD	114	75	81	87	93	99	107
JARRE	115	76	82	88	94	100	108
PUGET		77	83	89	95	101	109

Calculated Utilities

Marginal Utilities

0	0.00996	0.00996	0.15617		
0	0	0.4613			
0	0.00505	0.01995			
0	0.00505	0.00505			
0	0	0	0.30753		
0	0	0.0226	0.0226	0.05	

Post Optimization

0.925	0	0.025	0	0	0.05
0.0024	0.9226	0.025	0	0	0.05
0.0024	0.9226	0.025	0	0	0.05
0.0024	0.9226	0.0149	0.0101	0	0.05
0.0024	0	0.0149	0.0101	0.9226	0.05
0.0024	0	0.0149	0.0101	0.9226	0.05

Marginal Utilities

UTASTAR Model

Mean weights	0.1562	0.4613	0.1197	0.00505	0.3075	0.05
Max weights	0.925	0.9226	0.025	0.0101	0.9226	0.05

Multicriteria preferences of a certain consumer

Multi-Criteria Table for 'Market' products

	Weak Order	Advertisement	Colour	Flavour	Taste	Package	Price (Fr)
KOLIBARI	6	1	2	1	1	3	-20
CARAPELI	4	3	2	1	1	3	-31
LERIDA	5	3	2	2	3	1	-65
HEDIARD	3	3	2	3	2	2	-48
JARRE	2	3	2	3	3	2	-37
PUGET	1	3	1	2	2	3	-18

Average and Maximum Criteria Weights

MARKEX: CRITERIA ANALYSIS

- The study of consumer behavior as well as market segmentation is done with the help of criterion analysis.
- The **decisive role (importance-weight of criteria**) assigned by all consumers to each of the criteria for evaluating the products of the 'Market', is defined by studying the **weights of the criteria** for each consumer, separately.
- The **most important criteria** of consumer behavior are obtained by comparing the weights of the individual criteria with a **significance threshold** (e.g. 0.16).
- Based on the conclusions from the study of consumer behavior analyzes, we can create **market segments** using either different combinations of consumer value system and / or combinations of important criteria.
- After that, we select a market segment and move on to the next stage.

MARKEX: THE MODEL BASE OF THE SYSTEM

Brand Choice Model	Type
Luce (1959; 1977)	$P_{ij}(C) = \frac{U_{ij}}{\sum_{k \in C} U_{ik}}$
Lesourne (1977)	$P_{ij}(C) = \frac{U_{ij}^2}{\sum_{k \in C} U_{ik}^2}$
Multinomial Model McFadden-1 (1970, 1976, 1978; 1980; 1991)	$P_{ij}(C) = \frac{e^{U_{ij}}}{\sum_{k \in C} e^{U_{ik}}}$
Slightly Reinforced McFadden-2	$P_{ij}(C) = \frac{e^{2U_{ij}}}{\sum_{k \in C} e^{2U_{ik}}}$
Width of Utilities-1 (Matsatsinis, 1995)	$P_{ij}(C) = \frac{U_{ij}^{U_{max}-U_{min}}}{\sum_{k \in C} U_{ik}^{U_{max}-U_{min}}}$
Width of Utilities-2 (Matsatsinis, 1995)	$P_{ij}(C) = \frac{U_{ij}^{2(U_{max}-U_{min})}}{\sum_{k \in C} U_{ik}^{2(U_{max}-U_{min})}}$
Maximum of Utilities (Matsatsinis, 1995)	$P_{i,j}(j\|C) = \begin{cases} \frac{1}{m} & if \quad U_{i,max} \geq U_{i,j} \geq U_{i,max} - \varepsilon_i \\ 0 & other \end{cases}$ *Where:* $\varepsilon_i = \frac{\delta_i}{n-1}$; $\delta_i = U_{i,\,max} - U_{i,\,min}$ m: no of alternatives in: $U_{i,\,max}$ έως $U_{i,\,max} - \varepsilon_i$
Equal Possibilities	$P_j = \frac{1}{n}$ if $U_{i,\,max} - U_{i,\,min} \leq 0.1$ Where: n: number of alternatives
Heuristic (Matsatsinis, 1995)	A different model is applied for each decision maker

MARKEX: MARKET SHARES & SIMULATION

The calculation of the market shares of the ‘Market’ products, based on the above models, is done as follows:

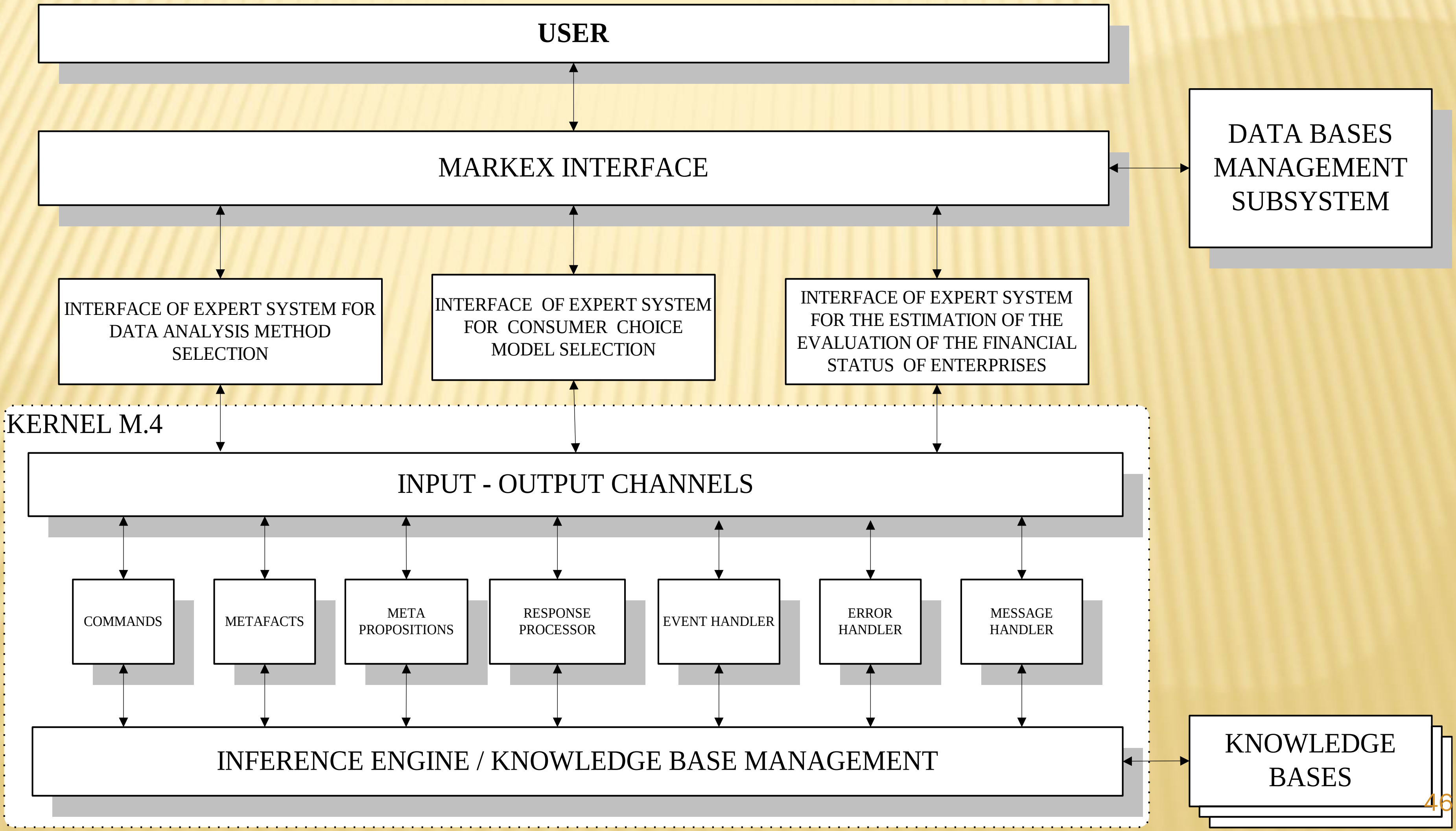
- Let , A={a_1, a_2, …, a_m} the set of ‘Market’ products, for which a set of consumers J={1, 2, …, k} has expressed its preferences.
- Initially, the **probability of purchasing** $P(a_i; A)$ of the a_i product for each consumer is calculated according to the brand choice models (previous table).
- Next, for each consumer j and for each model, a **sales probability vector** is created:

  $[P_j(a_1), P_j(a_2), \ldots, P_j(a_m)]^T$ j=1,2,…,k
- The **global probability of purchasing** each product is then calculated for all consumers:

  $S_i = \sum_{j=1}^{k} P_j(a_i)$ i=1,2,…,m
- Eventually the probabilities are converted into product **market shares** as follows:

  $$MS(a_i) = 100 * \frac{S_i}{\sum_{i=1}^{m} S_i} \%$$
- The selection of the most **suitable model** is based on the criterion of its best approach to real market shares.

THE MARKEX SYSTEM - SUBSYSTEMS OF EXPERT SYSTEMS



THE MARKEX SYSTEM - EXPERT SYSTEMS

The following knowledge bases were created:

- Selection of data analysis method,
- Selection of brand choice model (heuristic model), and
- Evaluation of the financial status of enterprises

Example:

rule-47: if target-data-anal = 1 and
nb-of-var = NVar and
NVar > 2 and
NVar <= 7 and
type-of-data = 3 and
not (transform =5 or transform =6)
then data-anal = 'Impossible'.

THE MARKEX SYSTEM - EXPERT SYSTEMS

Knowledge base for the selection of data analysis method

- The assumptions required for the correct function of the analysis methods, the different objectives of analyses achieved by each of these methods as well as the ignorance of the functional details of these methods on behalf of the user-decision maker in the field of marketing, led to the decision to develop an expert system for the selection of the most suitable data analysis method for specific cases.

No	Objectives of Analysis	Data Analysis Methods
1	Search of equivalents - differences of variables	PCA; CA, MCA
2	Search of equivalents - differences of consumers	PCA
3	Investigation of relation variables - consumers	PCA
4	Investigation of intensity of variable relations	RA; MRA, PCA_{Corel}; CA_{Corel}; MCA_{Corel}
5	Grouping of variables	Q_{Col}; PCA_{Col}
6	Grouping of consumers	Q_{Row}; PCA_{Row}
7	Determination of sizes	DS

Every objective is approached best by particular methods of data analysis

THE MARKEX SYSTEM - EXPERT SYSTEMS

Table enumerates the requirements for the application of the data analysis methods. The data base determines the type of data to be analyzed, furthermore, the selection of the suitable method is also influenced by the number of variables chosen.

No	D.A. Method	Num of Var	Number of Depend Var	Type of Depend Variab	Number of Indep Var	Type of Indepen Var
1	PCA	>= 2	0	-		Quantity
2	CA	= 2	0	-		Quality Order
3	MCA	> 2	0	-		Quality Order
4	SP	= 2	1	Quantity	= 1	Quantity
5	MP	> 2	1	Quantity	> 1	Quantity
6	Q	> 2	0	-		Binary
7	DS	>= 1	0	-		Quality Order

The knowledge base was constructed based on information from the international bibliography (Bourouche, 1977; Lagarde, 1983; Lebart et al., 1984; SAS, 1990) as well as on the knowledge of experts in the field of data analysis.

It is composed from 165 rules.

rule-28: if target-data-anal = 1 and
nb-of-var = 1 and
type-of-data = 2
then data-anal = 'PCA'.

rule-119: if target-data-anal = 4 and
nb-of-var = NVar and
NVar > 2 and
nb-of-depvar = 1 and
nb-of-indepvar = nb-of-var - 1 and
type-of-data = 3
then data-anal = 'MR'.

THE MARKEX SYSTEM - EXPERT SYSTEMS

Knowledge base for the selection of brand choice model

The idea applied in the selection of the most suitable model for every market segment (or for every consumer) is based on the one hand on the investigation of the width of global utilities ($\delta = U_{max} - U_{min}$) allocated by each consumer of the segment, and on the other hand on the type of distribution of these utilities.

The width and the type of distribution of utilities contains the information on the way in which the consumer confronts this specific market. The study of these leads to the determination of different types of consumer behaviour. For these different types of consumers, different brand choice models are applied.

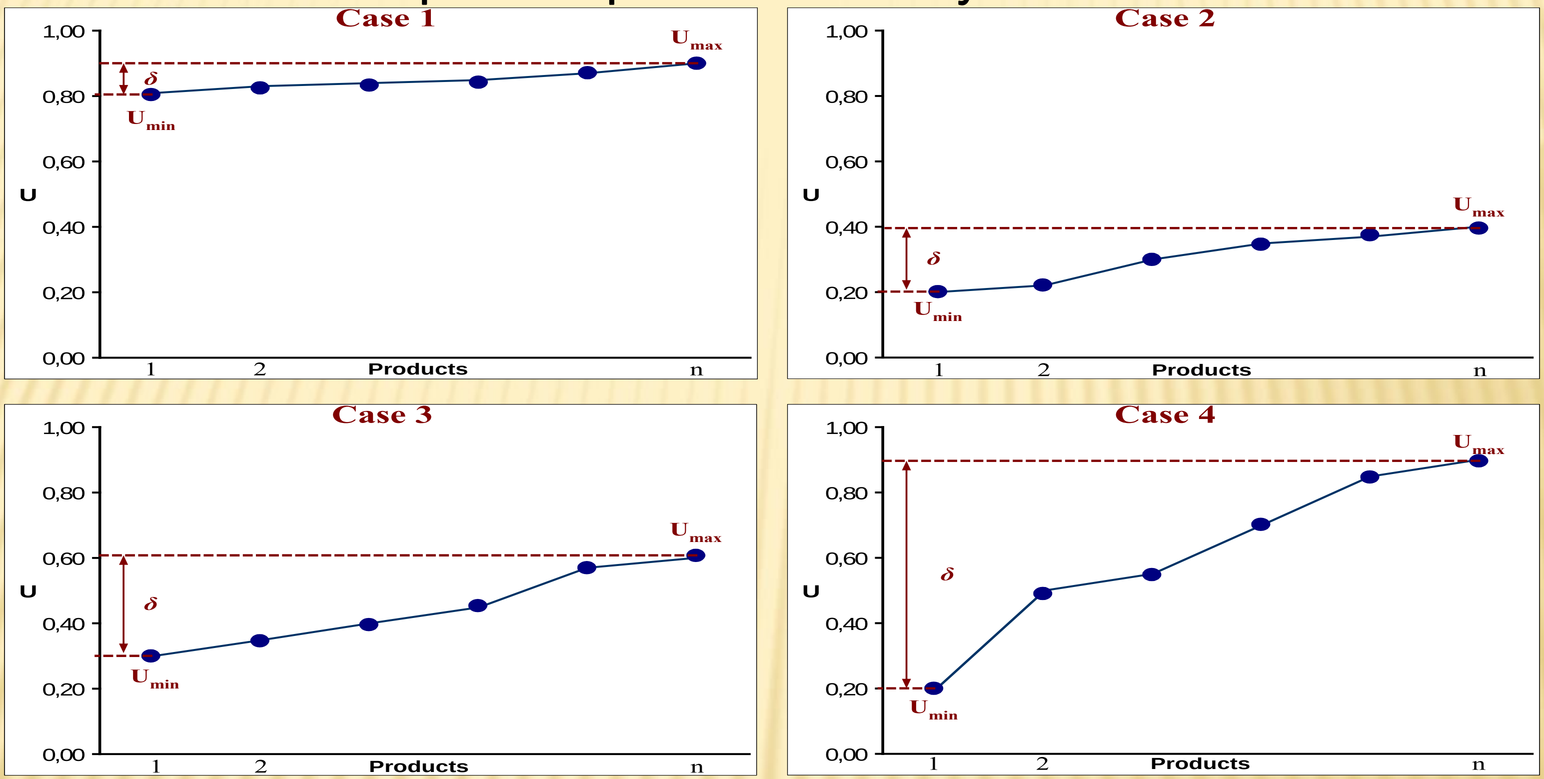
The selection/use of the most suitable model for every case depends on the one hand on the experience acquired from the application of these models for real problems in the field of development of new products and on the other hands on the specific characteristics of the models themselves. It is expressed in the form of rules considering these factors.

The knowledge base of the expert system disposes at present of 35 rules.

Matsatsinis, N.F., A.P. Samaras (2000), Brand Choice Model Selection Based on Consumers' Multicriteria Preferences and Experts' Knowledge, **Computers and Operations Research,** *vol. 27, pp. 689-707*

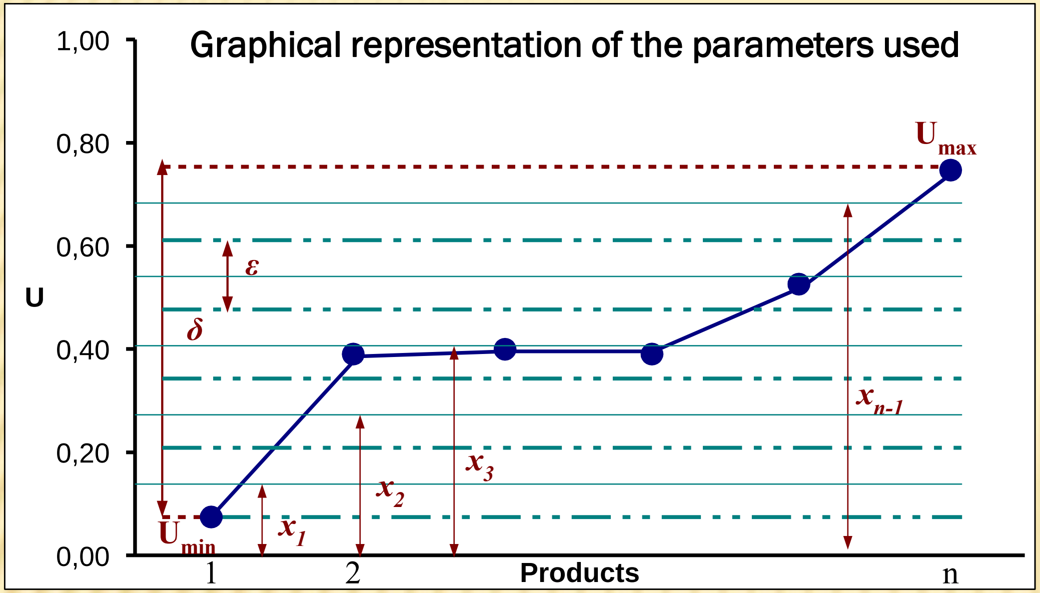
THE MARKEX SYSTEM - EXPERT SYSTEMS

Examples of representative utility functions



Codification of the parameter and corresponding decision-making patterns			
Codification Index	**Value of**	**Segregation capability**	**Consumer's decision making pattern**
1	$0 \leq \delta \leq 0{,}1$	None	Random choice
2	$0{,}1 \leq \delta \leq 0{,}3$	Average	Reluctance
3	$0{,}3 < \delta \leq 0{,}6$	Efficient	Relative reluctance
4	$0{,}6 < \delta \leq 1$	Strong	Brand loyalty

THE MARKEX SYSTEM - EXPERT SYSTEMS



Codification of brand choice models in ascending segregation capability

Code	Brand choice model
1	McFadden-1
2	McFadden-2
3	Width of utilities-1
4	Width of utilities-2
5	Luce
6	Lesourne
7	Maximum of Utilities
8	Equal Probabilities

rule-12: if delta = 3

and symetria = VSym

and VSym <= 0.25

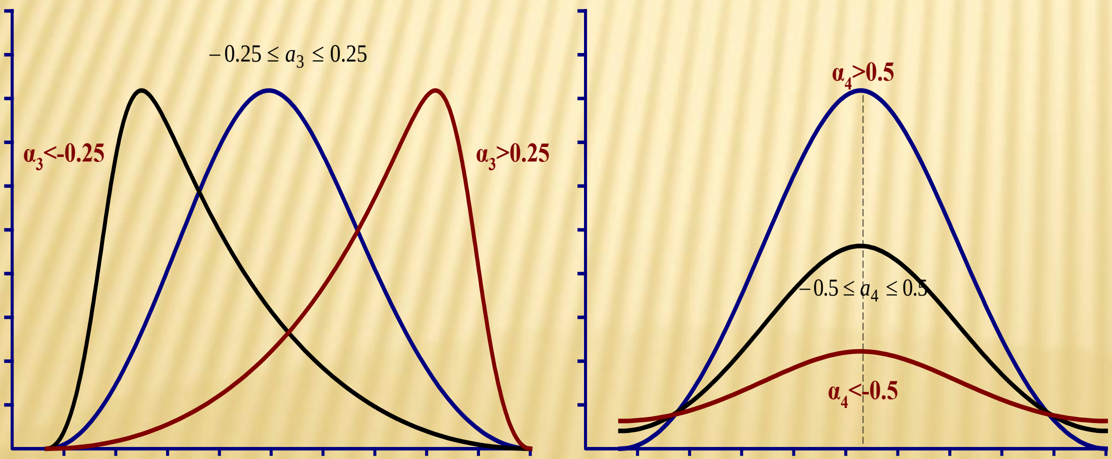
and VSym >= -0.25

and kirtosi = VKirt

and VKirt <= 0.5

and VKirt >= -0.5

then modelsimulation = 4



Shapes of distribution for different values of skewness and kurtosis coefficients

THE MARKEX SYSTEM - EXPERT SYSTEMS

Knowledge base for the evaluation of the financial status of enterprises

- The financial analysis is based on the analysis of indexes and is used by financial analyzers for the estimation of the strong and the weak points of an enterprise. This analysis shows many times the competitive position of the enterprise within its branch and in economy in general. This information is necessary for the determination of the marketing strategy to be followed. However, the estimation of the economic state of enterprises requires special knowledge which the usual user of MARKEX usually does not have.
- We tried to satisfy this need of decision makers in the field of marketing by developing an expert system for the estimation of the financial status of the enterprises.

Matsatsinis, N.F., M. Doumpos, C. Zopounidis (1997), Knowledge acquisition and representation for expert systems in the field of financial analysis, Expert Systems with Applications, vol. 12, no. 2, pp. 247-262
Matsatsinis, N.F., Y. Siskos (1999), MARKEX: An intelligent decision support system for product development decisions, European Journal of Operational Research, vol. 113, no. 2, pp. 336-354.
Matsatsinis, N.F. and Y. Siskos (2003), Intelligent support systems for marketing decisions, Springer.

THE MARKEX SYSTEM - EXPERT SYSTEMS

- In the proposedexpert system, the adopted classification of the indexes is based fundamentally on the methodology developed by Courtis (1978). According to this methodology, the indexes are divided into three basic categories: effectiveness, management proficiency and solvency. Further qualitative criteria for the estimation of enterprises have been added to these indexes (Table).
- In the framework of monitoring the knowledge bases, consisting of totally 1590 rules, repeated comparisons were carried out between the estimations of experts (financial analyzers) and the results given by the system. The estimations of the experts were based on the values calculated by the indexes.

THE MARKEX SYSTEM - EXPERT SYSTEMS

Code Nr.	Indexes of Effectiveness
A1	Profits pro interest rates and taxes / Total of assets
A2	Net profits after taxes / Own capitals
A3	Mixed profits / Total of assets
A4	Net profits / Mixed profits
	Indexes of Solvency
B1	Short term Obligations / Total of liabilities
B2	Total of obligations / Total of Assets
B3	Long term Obligations / (Long term Obligations + Own Capital
B4	Circulating Assets / Short Term Obligations
B5	(Circulating Assets - Stocks) / Short -Term Obligations
B6	Stocks *365 / Cost of Sales
B7	(Customers + bills to be cashed) * 365 / Total of net sales
	Indexes of Management Effectiveness
C1	Financial expenses / Sales
C2	General and administrative expenses / Sales
C3	(Claims)* 365 / Yearly sales
C4	(Accounts to be paid) * 365 / Purchase of raw and secondary material
	Qualitative Criteria
D1	Administrative experience of managers
D2	Position of enterprise in the market
D3	Technological structure of the enterprise
D4	Organization
D5	Specific competitive advantages of the enterprise
D6	Flexibility of the market.

THE MARKEX SYSTEM - EXPERT SYSTEMS

Modelling of the Financial Ratios

If	Then	Is
$A_1 < 10\%$	Industrial profitability	Not satisfactory
$10\% < A_1 \leq 20\%$	Industrial profitability	Medium
$20\% < A_1 \leq 30\%$	Industrial profitability	Satisfactory
$A_1 > 30\%$	Industrial profitability	Very satisfactory
$A_2 \leq 17.5\%$	Financial profitability	Not satisfactory
$17.5\% < A_2 \leq 20\%$	Financial profitability	Medium
$20\% < A_2 \leq 23\%$	Financial profitability	Satisfactory
$23\% < A_2$	Financial profitability	Very satisfactory
$A_3 \leq 0\%$	Gross profit/Total assets	Not satisfactory
$0\% < A_3 \leq 50\%$	Gross profit/Total assets	Medium
$50\% < A_3 \leq 75\%$	Gross profit/Total assets	Satisfactory
$A_3 > 75\%$	Gross profit/Total assets	Very satisfactory
$A_4 \leq 0\%$	Profit margin	Not-satisfactory
$0\% < A_4 \leq 50\%$	Profit margin	Medium
$50\% < A_4 \leq 100\%$	Profit margin	Satisfactory
$A_4 > 100\%$	Profit margin	Very satisfactory
$B_1 < 25\%$	Short-term debt capacity	Very satisfactory
$25\% < B_1 \leq 50\%$	Short-term debt capacity	Satisfactory
$50\% < B_1 \leq 75\%$	Short-term debt capacity	Medium
$75\% < B_1 \leq 100\%$	Short-term debt capacity	Not satisfactory
$B_2 > 80\%$	Global debt capacity	Not satisfactory
$60\% < B_2 \leq 80\%$	Global debt capacity	Medium
$40\% < B_2 \leq 60\%$	Global debt capacity	Satisfactory
$B_2 \leq 40\%$	Global debt capacity	Very satisfactory
$B_3 \leq 0.5$	Long-term debt capacity	Satisfactory
$B_3 > 0.5$	Long-term debt capacity	Not satisfactory
$B_4 \geq 2$	General liquidity	Satisfactory
$B_4 < 2$	General liquidity	Not satisfactory
$B_5 \leq 1$	Direct liquidity	Not satisfactory
$1 < B_5 < 1.5$	Direct liquidity	Satisfactory
$B_5 \geq 1.5$	Direct liquidity	Very satisfactory
$C_1 > 5\%$	Financial expenses	Not satisfactory
$3\% < C_1 \leq 5\%$	Financial expenses	Medium
$2\% < C_1 \leq 3\%$	Financial expenses	Satisfactory
$C_1 \leq 2\%$	Financial expenses	Very satisfactory
$C_2 > 8\%$	General and administrative expenses	Not satisfactory
$6\% < C_2 \leq 8\%$	General and administrative expenses	Medium
$4\% < C_2 \leq 6\%$	General and administrative expenses	Satisfactory
$2\% < C_2 \leq 4\%$	General and administrative expenses	Very satisfactory
$C_2 \leq 2\%$	General and administrative expenses	Perfect
$C_3 > C_4$	Receiving period of accounts receivable	Not satisfactory
$C_3 \leq C_4$	Receiving period of accounts receivable	Satisfactory
C_5 increasing	Circulation of inventories	Not satisfactory
C_5 reducing or stable	Circulation of inventories	Satisfactory
$C_6 \leq C_7$	Circulation of customers and notes receivable	Satisfactory
$C_6 > C_7$	Circulation of customers and notes receivable	Not satisfactory

Modelling of the Qualitative Criteria

If	Is	Then
Managers' work experience	Negative experience	Not satisfactory
	No experience	Medium
	Positive experience up to 5 years	Satisfactory
	Positive experience 5–10 years	Very satisfactory
	Positive experience more than 10 years	Perfect
Firm's market niche/position	Strong competition, firm's weak position	Not satisfactory
	Strong competition, established and competitive firm	Medium
	Moderate competition, firm's strong position	Satisfactory
	Weak competition, firm's leadership position	Very satisfactory
	Single position, monopoly	Perfect
Technical structure-facilities	Old and inappropriate equipment, outdated production methods	Not satisfactory
	Moderate technical structure, non-competitive production cost	Medium
	Relatively modernized equipment	Satisfactory
	Sound technical structure, full modernization scheme under way	Very satisfactory
	Excellent structure, modern production methods	Perfect
Organisation-personnel	Lack of organisation/staff hiring policy	Not satisfactory
	Moderate organisation/staff hiring policy	Medium
	Moderate organisation/staff hiring policy, willingness to improve	Satisfactory
	Good organisation/staff hiring policy	Very satisfactory
	Excellent organisation/staff hiring policy	Perfect
Firm's special competitive advantages	The firm does not possess expertise for its production methods	Not satisfactory
	The firm possesses a small amount of expertise for its production methods	Medium
	The firm possesses a satisfactory level of expertise for its production methods	Satisfactory
	The firm possesses an exclusive expertise for its production methods	Very satisfactory
Market flexibility	The firm does not follow market trends, produces low-demand products	Not satisfactory
	The firm has a limited flexibility	Medium
	The firm has a satisfactory flexibility	Satisfactory
	The firm follows market trends	Very satisfactory
	The firm is a leader in its production branch activity	Perfect

THE MARKEX SYSTEM - EXPERT SYSTEMS

rule-9: IF financial-profitability = very-satisfactory AND
industrial-profitability = not-satisfactory OR
industrial-profitability = medium
THEN prof-totas-stockeq = satisfactory.

rule-155: IF work-exp = not-satisfactory AND
firm-position = not-satisfactory AND
tech-structure = perfect AND
organisation = very-satisfactory AND
special-adv = medium AND
flex = perfect
THEN quality = satisfactory.

DEVELOPMENT OF A NEW OLIVE OIL PRODUCT FOR FRENCH MARKET USING MARKEX

The survey was held in Paris by the Technical University of Crete (Greece) with the collaboration of the LAMSADE Laboratory of the University of Paris – Dauphine in 1999

Siskos, Y., N. F. Matsatsinis, G. Baourakis (2001), Multicriteria analysis in agricultural marketing: The case of French olive oil market, European Journal of Operational Research, vol. 130, no. 2, pp. 315-331.

This research has been carried out with financial support from the Commission of the European Communities, Agriculture and Fisheries (FAIR) specific RTD programme, CT-095-0844 "Development of an Integrated Knowledge Based Decision Support System for Differentiated Agricultural Products".

THE MARKET

- 6 competitive products
  - CARAPELLI
  - LERIDA
  - HEDIARD
  - JARRE d'OR
  - PUGET
  - KOLYMVARI

QUESTIONNAIRE:

CONSUMER PREFERENCE ASSESSMENT

What is your opinion about the following products?

PRODUCT		CARAPELLI	LERIDA	KOLYBARI	HEDIARD	LA JARRE d'OR	PUGET
IMAGE (a)	BAD						
	UNAWARE						
	GOOD						
	VERY GOOD						
COLOUR (b)	UNNATURAL						
	NATURAL						
	ATTRACTIVE						
ODOUR (c)	UNNATURAL						
	NATURAL						
	PLEASANT						
TASTE (d)	UNNATURAL						
	NATURAL						
	DELICIOUS						
PACKAGING (e)	GOOD						
	FAIR						
	GOOD						
	VERY GOOD						

(a) What is your opinion about the quality of..... extra virgin olive oil?
(b) Have you ever heard from others (relatives, friends) about..... extra virgin olive oil?
(c) Which is your opinion about the package of...... extra virgin olive oil?
(d) Which is your opinion about the producing company of..... extra virgin olive oil?

RANKING

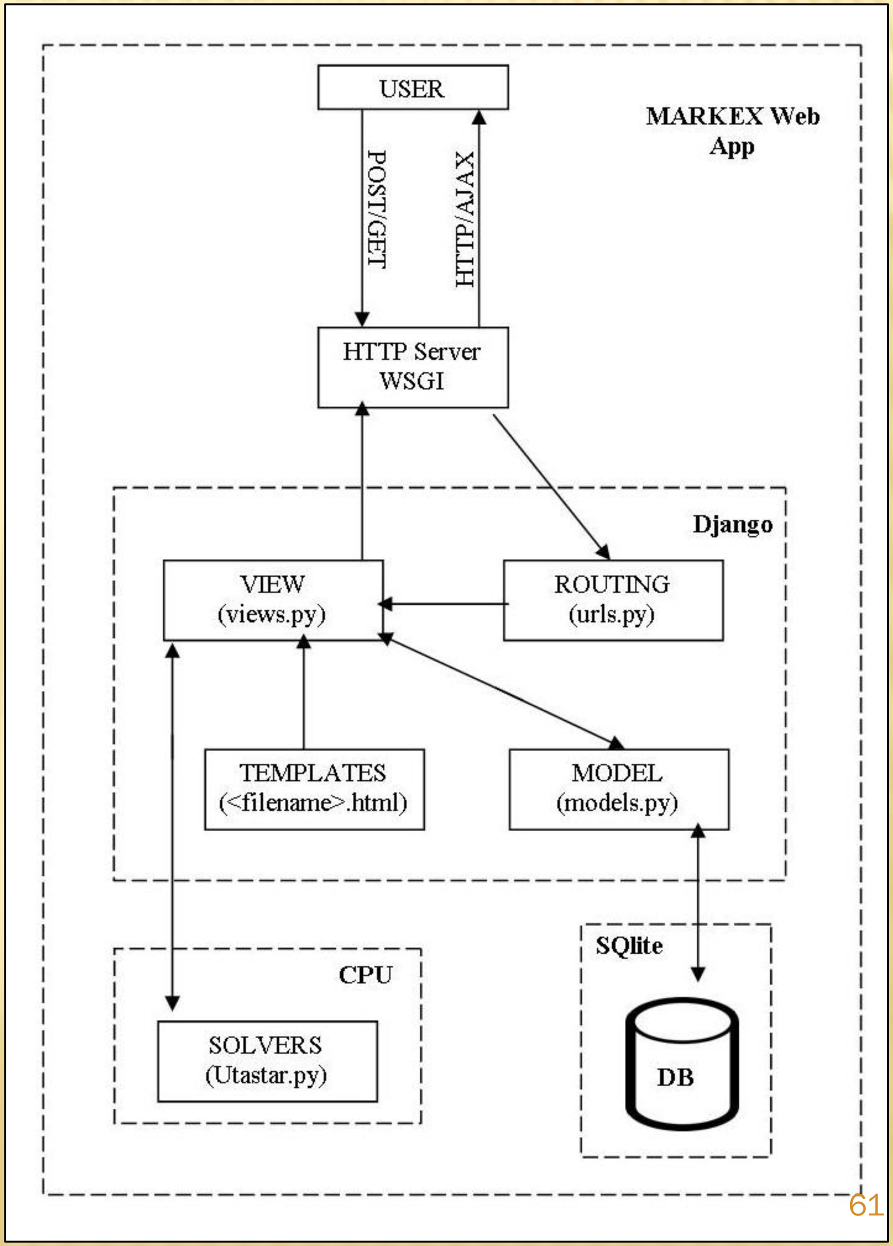
Which of the following extra virgin olive oils would you buy?

Repetitive question: If you could not find your oil of choice, which one would you buy?

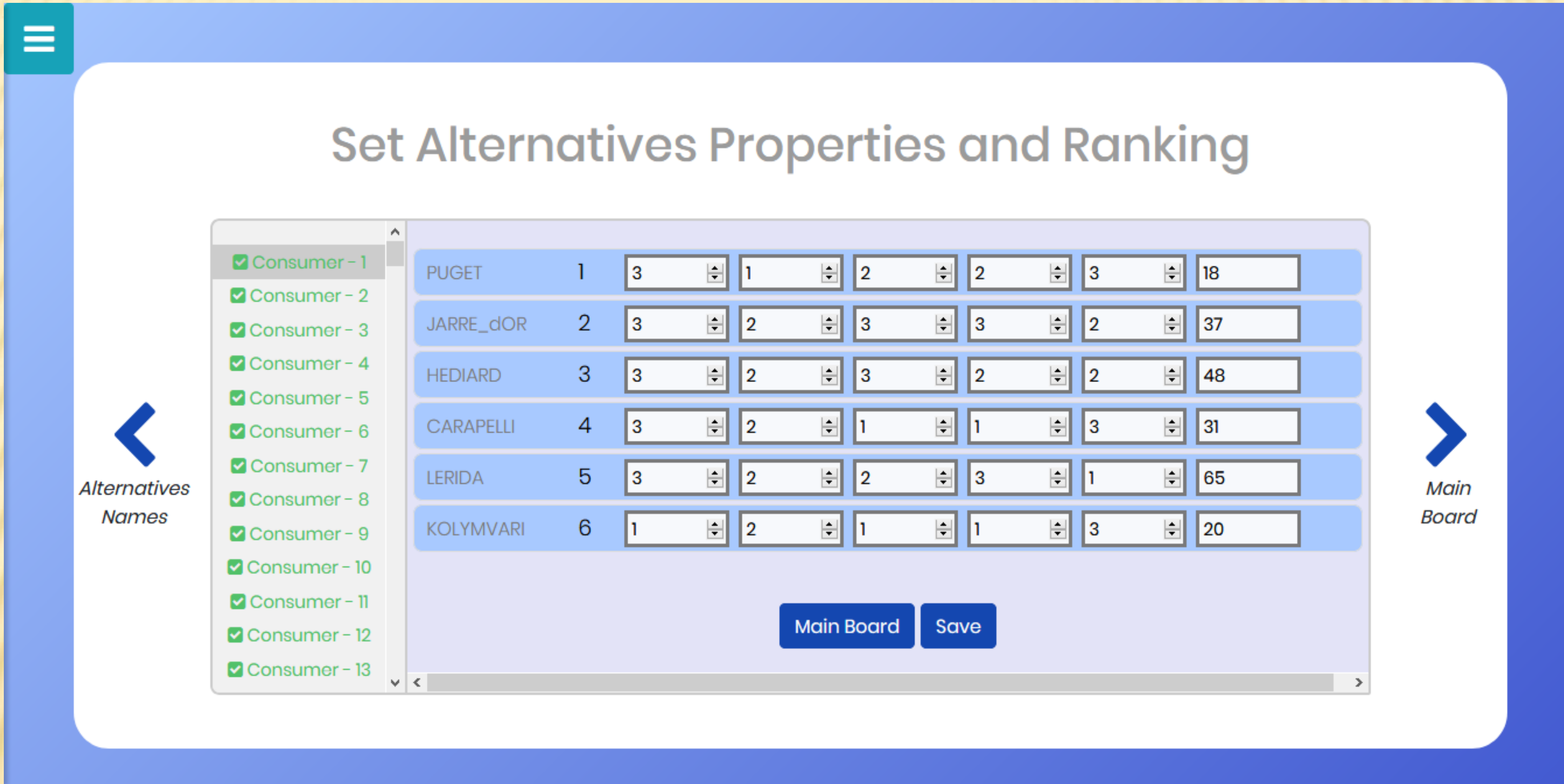
CARAPELLI	LERIDA	KOLYBARI	HEDIARD	LA JARRE D'OR	PUGET

THE CASE OF FRENCH OLIVE OIL MARKET - SYSTEM ARCHITECTURE: DJANGO WEB FRAMEWORK

- It is based on the Python programming language
- It consists of a set of components that help in the rapid development of web applications
- It has tools for managing users, database, content



MARKEX: THE CASE OF FRENCH OLIVE OIL MARKET



Product/Criteria	Image	Colour	Odour	Taste	Packaging	Price
Italian	Unaware	Natural	Natural	Natural	Good	31F
Spanish	Unaware-Good	Natural	Natural	Natural - Delicious	Fair-Good	65F
Cretan	Unaware-Good	Natural	Natural	Natural	Fair	20F
French-1	Good	Natural	Natural	Natural - Delicious	Good	48F
French-2 Organic	Unaware	Unnatural	Natural	Natural	Fair	37F
French-3	Good	Natural	Natural	Natural	Fair-Good	18F

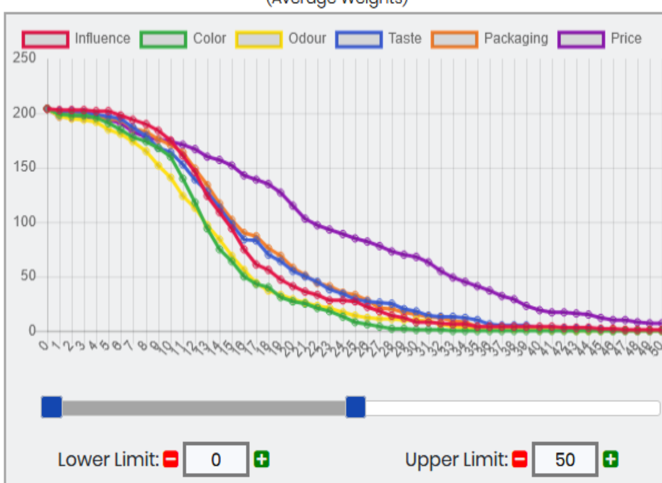
MARKEX: THE CASE OF FRENCH OLIVE OIL MARKET

- Criteria Analysis

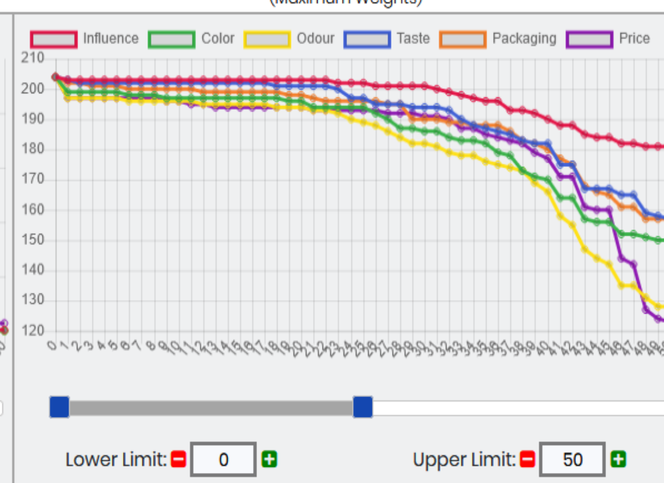
Criteria Significance Analysis

Criterion	Average Weight	Significance Level	Consumers Number (Average Weights)	Consumers Percentage (Average Weights)	Consumers Number (Maximum Weights)	Consumers Percentage (Maximum Weights)
Influence	0.161	0.161	75	36.76%	203	99.51%
Color	0.134	0.134	82	40.20%	197	96.57%
Odour	0.135	0.135	87	42.65%	195	95.59%
Taste	0.166	0.166	84	41.18%	202	99.02%
Packaging	0.168	0.168	87	42.65%	199	97.55%
Price	0.237	0.237	91	44.61%	193	94.61%

Variance of Criteria Weights
(Average Weights)



Variance of Criteria Weights
(Maximum Weights)



MARKEX: SCENARIOS AND SIMULATIONS

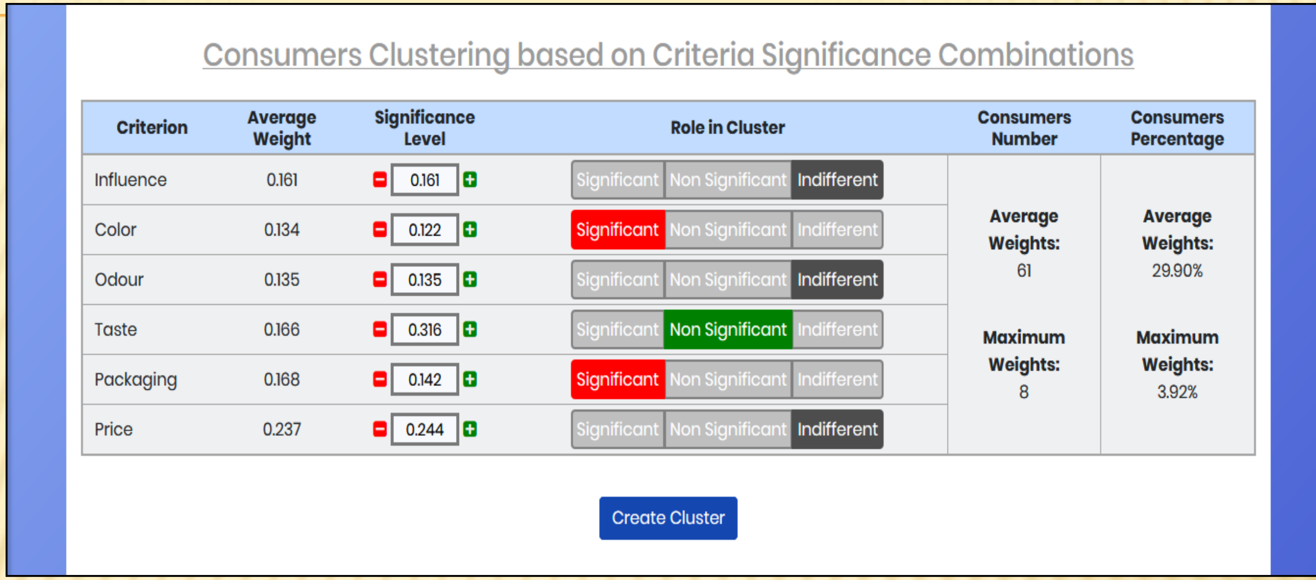
Scenario Selection: Present Market

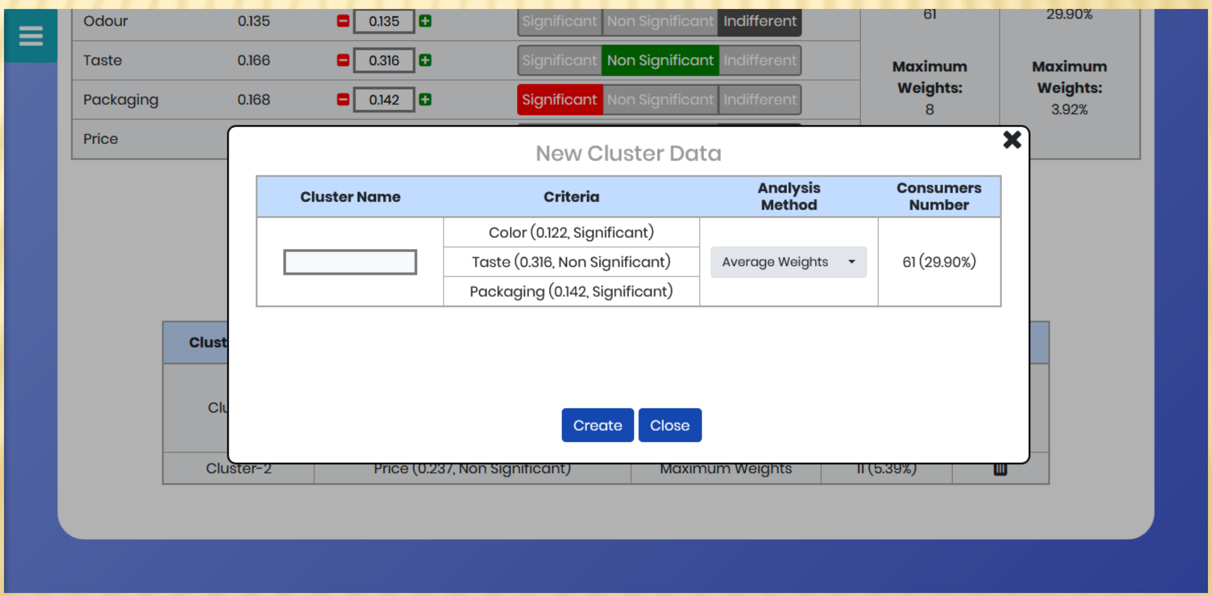
	Product	Influence Level	Color Level	Odour Level	Taste Level	Packaging Level	Price Level
	CARAPELLI	3	2	2	2	3	31
✓	LERIDA	3	2	2	2	3	65
	KOLYMVARI	2	2	2	2	2	20
	HEDIARD	3	2	2	2	3	48
	JARRE_dOR	2	2	2	2	2	37
	PUGET	3	2	2	2	3	18

	Criterion	Range	Mon/ty	Value (From)	Value (To)	Step
	Influence	[1,2,3,4]	Increasing	1	4	1
✓	Color	[1,2,3]	Increasing	1	3	1
	Odour	[1,2,3]	Increasing	1	3	1
	Taste	[1,2,3]	Increasing	1	3	1
	Packaging	[1,2,3,4]	Increasing	1	4	1
✓	Price	[18 - 65]	Decreasing	30	60	15

Calculate

MARKEX: SCENARIOS AND SIMULATIONS





MARKEX: SCENARIOS & SIMULATIONS

Changes in the values of the evaluations of the multi-criteria table:

The corresponding evaluation prices are replaced, for each consumer

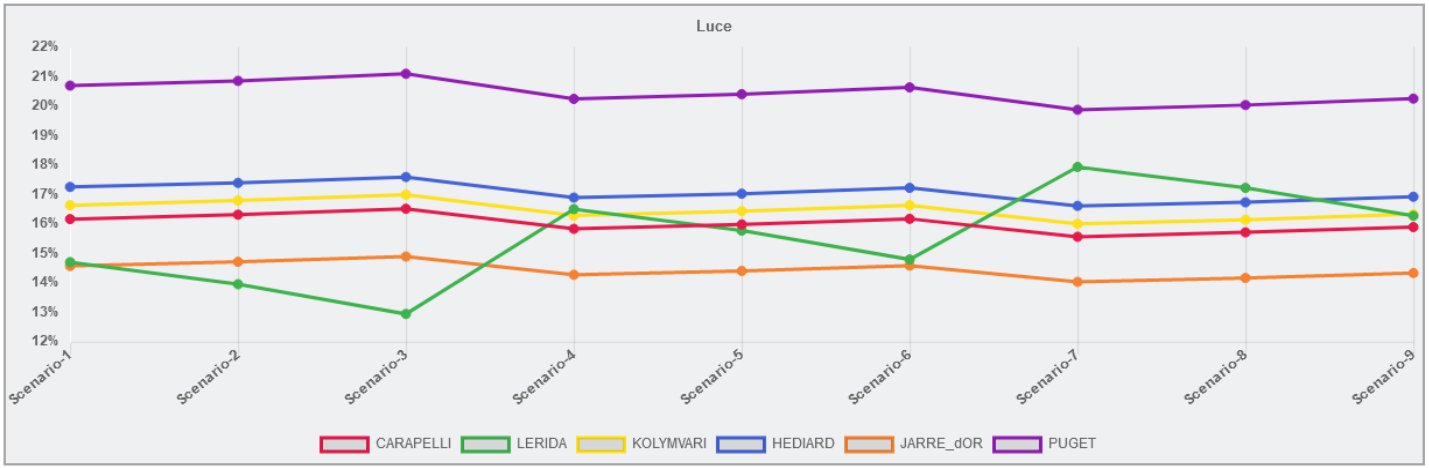
Alternatives/Criteria	Influence	Color	Odour	Taste	Packaging	Price
CARAPELLI	3	2	2	2	3	31
LERIDA	3	2	2	2	3	65
KOLYMVARI	2	2	2	2	2	20
HEDIARD	3	2	2	2	3	48
JARRE_dOR	2	2	2	2	2	37
PUGET	3	2	2	2	3	18

Alternatives/Criteria	Influence	Color	Odour	Taste	Packaging	Price
CARAPELLI	3	2	1	1	3	31
LERIDA	3	2	2	3	1	65
KOLYMVARI	1	2	1	1	3	20
HEDIARD	3	2	3	2	2	48
JARRE_dOR	3	1	2	2	3	18
PUGET	3	1	2	2	3	18

The new Global utilities of the alternatives are calculated, for each decision maker (consumer), using the initial marginal utilities of UTASTAR

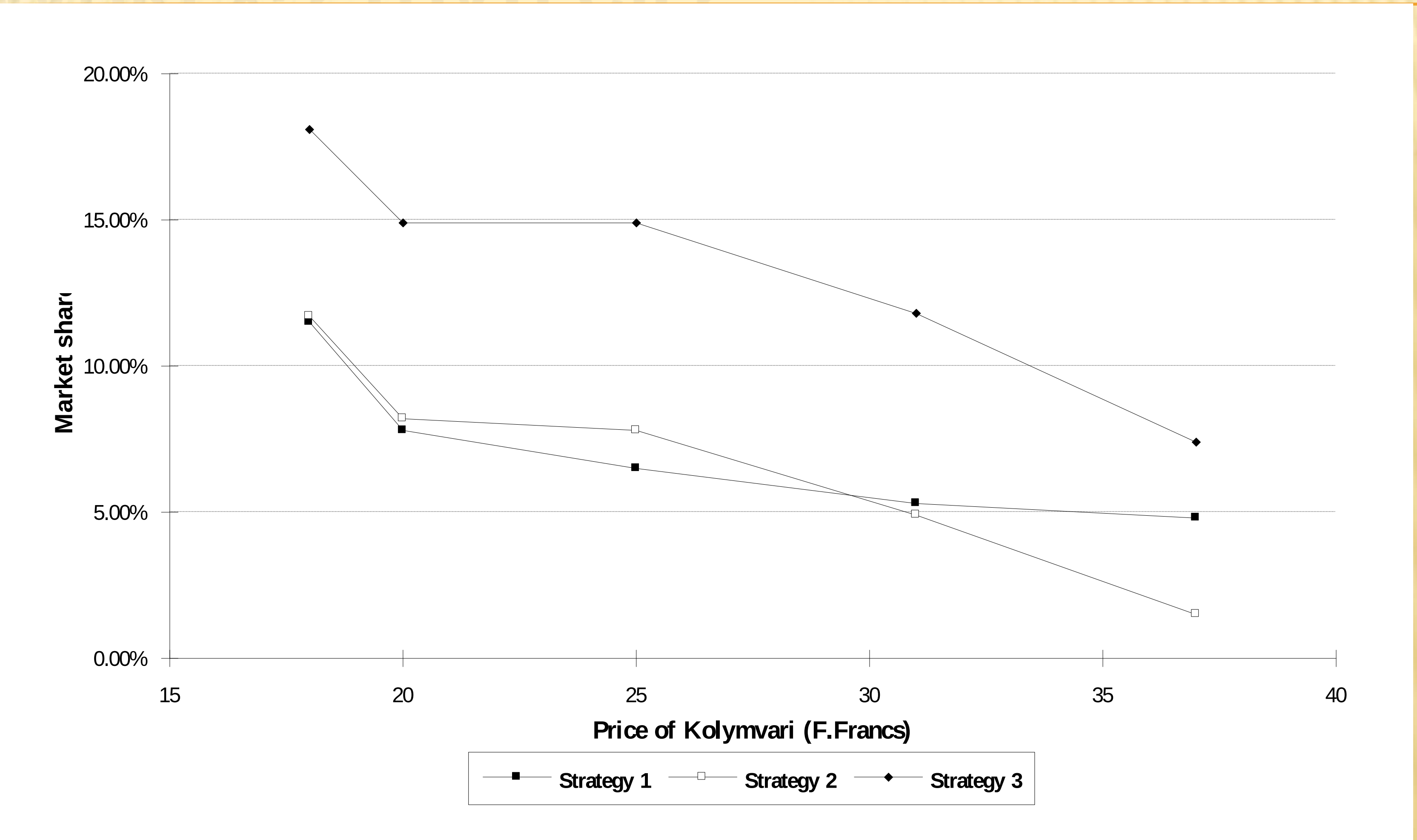
MARKEX: SIMULATIONS

MARKEX: SIMULATIONS



☑	**Scenario - 1**	Color: 1	Price: 30	☑	**Scenario - 2**	Color: 1	Price: 45
☑	**Scenario - 3**	Color: 1	Price: 60	☑	**Scenario - 4**	Color: 2	Price: 30
☑	**Scenario - 5**	Color: 2	Price: 45	☑	**Scenario - 6**	Color: 2	Price: 60
☑	**Scenario - 7**	Color: 3	Price: 30	☑	**Scenario - 8**	Color: 3	Price: 45
☑	**Scenario - 9**	Color: 3	Price: 60				

MARKEX: STRATEGIES



Market shares (sales value) of the Cretan product for the three potential marketing strategies

AN AGENT-BASED SYSTEM FOR PRODUCTS PENETRATION STRATEGY SELECTION

Matsatsinis, N.F., P. Moraïtis, V. Psomatakis, N. Spanoudakis (2003), An Agent-Based System for Products Penetration Strategy Selection, Applied Artificial Intelligence: An International Journal, vol. 17, no. 10, pp. 901-925.

AN AGENT-BASED SYSTEM FOR PRODUCTS PENETRATION STRATEGY SELECTION

Agents are simultaneously considered according to two different levels:

- a functional (task agents, information agents and interface agents), and
- a structural level (elementary agents and complex agents).

METHODOLOGICAL FLOWCHART

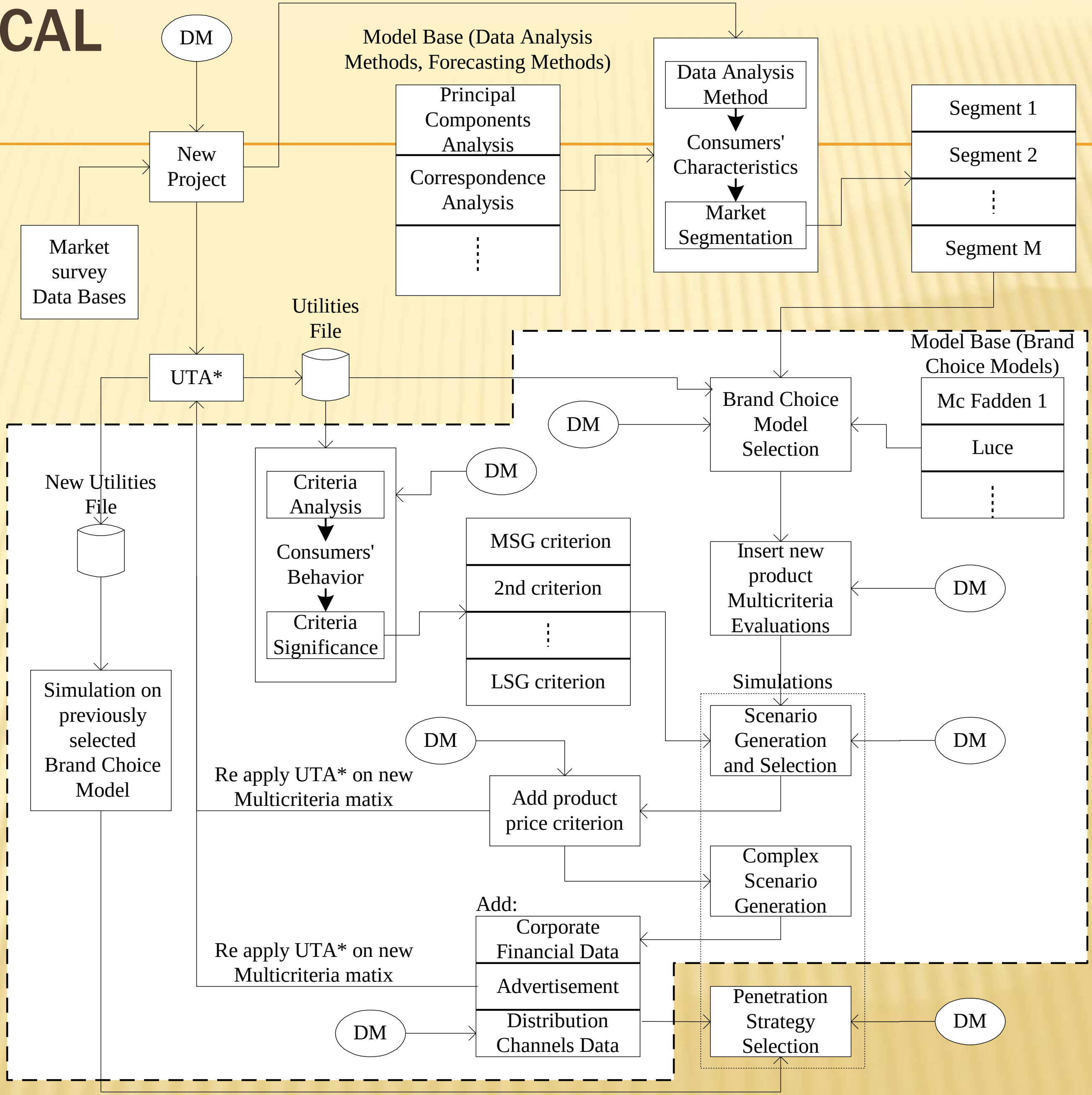


Figure 1. original consumer-based methodology

AGENT BASED ARCHITECTURE

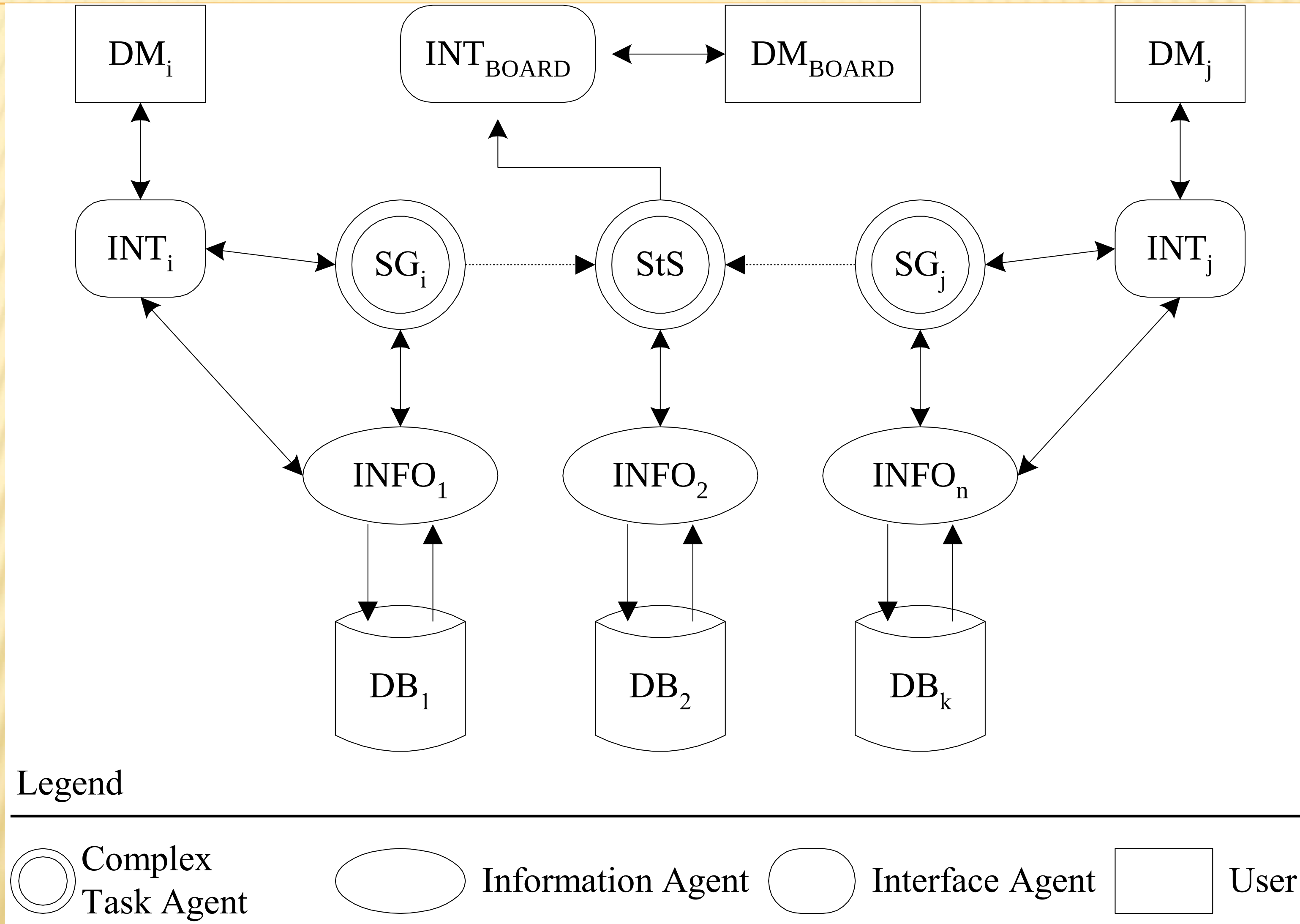
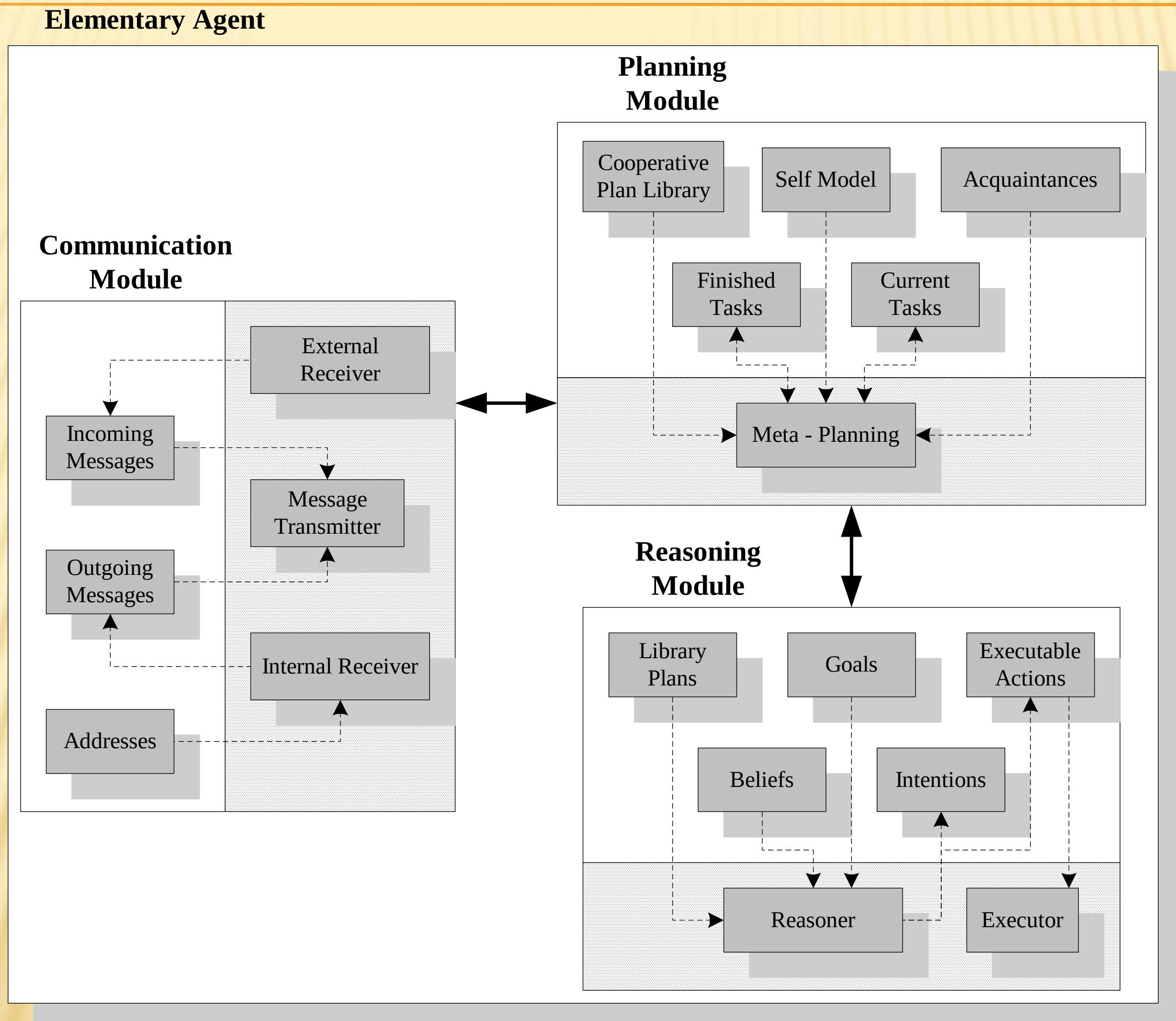


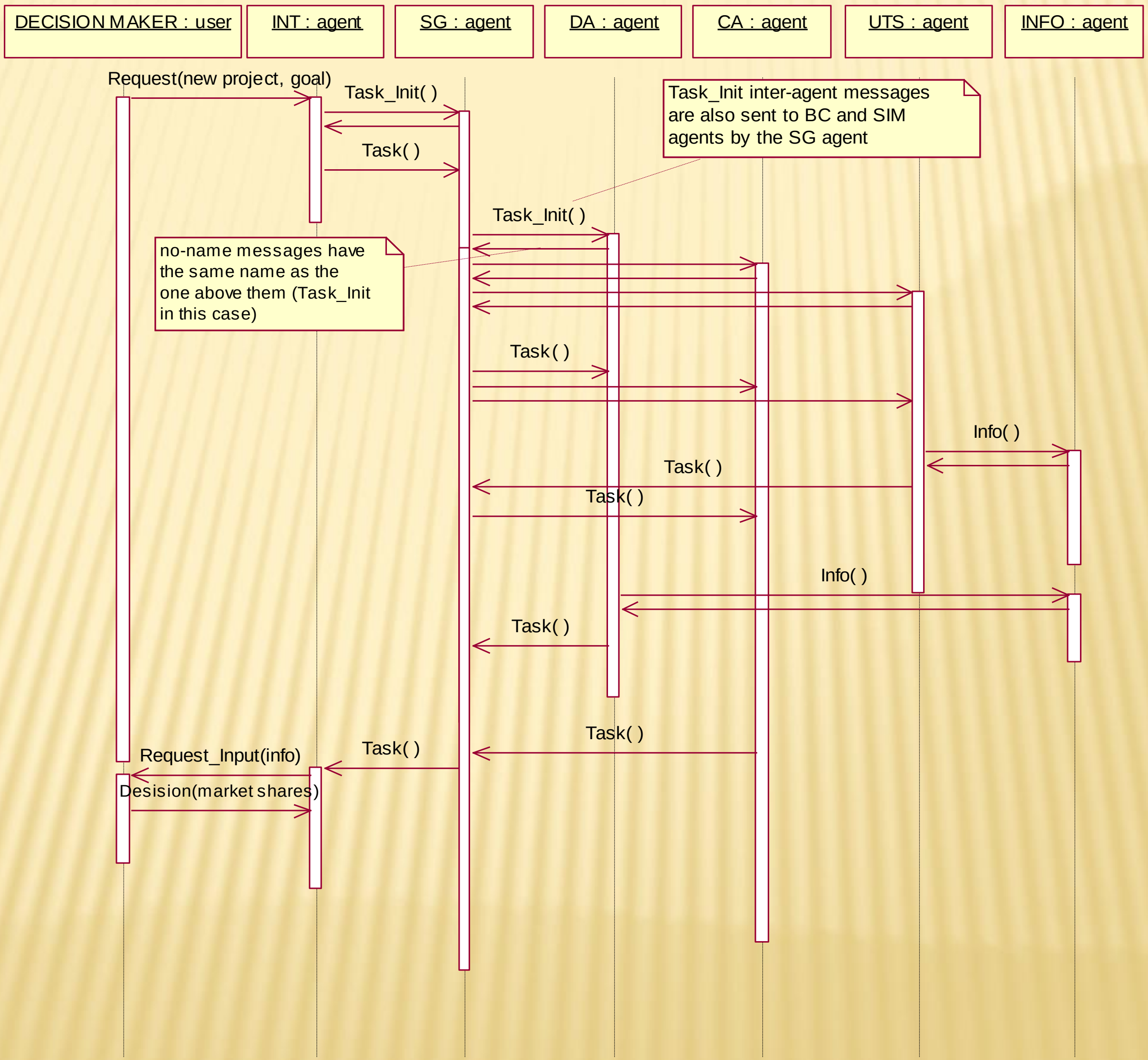
Figure 2

AGENT BASED ARCHITECTURE



Elementary agent architecture view

AGENT BASED ARCHITECTURE



Example, agents' interactions

AGENT ALLOCATOR: AN AGENT-BASED MULTI-CRITERIA DECISION SUPPORT SYSTEM FOR TASK ALLOCATION

- Matsatsinis, N.F., P. Delias (2003), AgentAllocator: An Agent-Based Multi-criteria Decision Support System for Task Allocation, in: V. Marik, D. McFarlane, P. Valckenaers (eds.), Holonic and Multi-agent Systems for Manufacturing, **Lectures Notes in Artificial Intelligence,** vol. 2744, Springer-Verlag Berlin Heidelberg, pp. 225-235.

AGENT ALLOCATOR: AN AGENT-BASED MULTI-CRITERIA DECISION SUPPORT SYSTEM FOR TASK ALLOCATION

Basic stages of Multicriteria Methodology:

- *Models a consistent family of criteria (quantitative and qualitative) for evaluating possible allocation combinations.*
- *Identifies an additive function that will be able to consistently attribute the performance of each assignment by ranking alternative assignments hierarchically.*
- *Completes an assignment mechanism that will decide which combination (agent - work) will ultimately be preferred.*

AGENT ALLOCATOR: AN AGENT-BASED MULTI-CRITERIA DECISION SUPPORT SYSTEM FOR TASK ALLOCATION

Multicriteria Methodology: Definitions - Assumptions.

- *Our goal is to assign k tasks to m agents-employees.*
- *The number of tasks can be greater, less than or even equal to the number of agents.*
- *Each task is performed by a single agent, who from the moment a task is assigned to it, is obliged to undertake it.*
- *Agents do not express preferences for any of the tasks.*
- *Tasks are described through a common set of needs - demands.*
- *Agents can be described through a common set of attributes.*
- *The level of evaluation of the agents changes dynamically during the assignment process.*
- *The evaluation criteria are modeled in such a way that they constitute a consistent family of criteria [monotony, exhaustively, and non redundancy].*
- *Each criterion is modeled by a set of subcriteria, which result from combinations of work requirements with the characteristics of the agents, whether it is the work requirement itself or even the characteristics of the agents.*

AGENT ALLOCATOR: AN AGENT-BASED MULTI-CRITERIA DECISION SUPPORT SYSTEM FOR TASK ALLOCATION

- table 1 Agents’ Profiles

Agent’s name	Technical Knowledge	Problem Solving Ability	Reliability	Management Skills	Availability
a1	Basic	Undistinguished	Trustworthy	Clement	High
a2	Expert	Satisfactory	Unproved	Poor	Medium
a3	None	Satisfactory	Unproved	Expert	Medium

- table 2 Tasks' requirements

Task name	Technical Demands	Immediacy	Importance	Social Minded
t1	Basic	Normal	Normal	Normal
t2	Expert	Urgent	Normal	Normal
t3	Average	Urgent	High	Normal
t4	None	Urgent	High	Critical
t5	Basic	Low	High	Critical

- table 3 **Modeling the Criteria**

Speediness	Risk	Functionality
Availability – Immediacy	Problem Solving Ability - Importance	Technical Knowledge-Technical Demands
Problem Solving Ability	Management Skills-Social Minded	Management Skills-Social Minded
	Reliability	

table 4 **Rating Sub-Criteria of Speediness Criterion**

<table>
<tr><td rowspan="8">Speediness Criterion</td><td colspan="5">Availability</td></tr>
<tr><td rowspan="4">Immediacy</td><td></td><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td>Low</td><td>1</td><td>0.6</td><td>0.4</td></tr>
<tr><td>Medium</td><td>0.4</td><td>1</td><td>0.6</td></tr>
<tr><td>Urgent</td><td>0</td><td>0.6</td><td>1</td></tr>
<tr><td colspan="5">Problem Solving Ability</td></tr>
<tr><td colspan="2">Non Satisfactory</td><td colspan="2">Undistinguished</td><td>Satisfactory</td></tr>
<tr><td colspan="2">0</td><td colspan="2">0.4</td><td>1</td></tr>
</table>

MULTI-CRITERIA USER MODELING IN RECOMMENDER SYSTEMS: AN APPLICATION TO MOVIES RECOMMENDATION

Lakiotaki, K., N. Matsatsinis, A. Tsoukias (2011), Multi-Criteria User Profiling in Recommender Systems, ***IEEE Intelligent Systems****, vol. 26, no.2, pp. 64 – 76.*

K. Lakiotaki, P. Delias, V. Sakkalis and N. F. Matsatsinis, "User Profiling based on Multi-criteria Analysis: The role of Utility Functions", *Operational Research: An International Journal*, 9(1),3-16, (2009)

K. Lakiotaki, S. Tsafarakis, N. F. Matsatsinis, "UTA-REC: A Recommender system based on Multiple Criteria Analysis", *ACM Recommender Systems 2008*, October 23-25, Lausanne, Switcherland

MULTICITERIA RECOMMENDER SYSTEMS

Recommender systems are software applications that attempt to reduce information overload. Their goal is to recommend items of interest to the end users based on their preferences. To achieve that, most Recommender Systems exploit the Collaborative Filtering approach.

In parallel, **Multiple Criteria Decision Analysis (MCDA)** is a well established field of Decision Science that aims at analyzing and modeling decision maker's value system, in order to support him/her in the decision making process.

The **proposed methodology** improves the performance of simple Multi-rating Recommender Systems as a result of two main causes; the creation of groups of user profiles prior to the application of Collaborative Filtering algorithm and the fact that these profiles are the result of a user modeling process, which is based on individual user's value system and exploits Multiple Criteria Decision Analysis techniques.

RECOMMENDER SYSTEMS

Basic methodologies

- **Content-based approach:**
  - *is the method of recommend items similar to those a given user has liked in the past based on content information on those items.*
- **Collaborative filtering approach:**
  - *is the method of making automatic predictions (filtering) about the interest of a user by collecting preference information from many users (collaborative).*
- **Hybrid approaches:**
  - *Combine approaches to overcome existing limitations and increase recommendation accuracy.*

RECOMMENDER SYSTEMS

Collaborative Filtering approach

	Item i_1	Item i_2	Item i_3	Item i_4	Item i_5
User u_1	5	7	5	7	?
User u_2	5	7	5	7	9
User u_3	5	7	5	7	9
User u_4	6	6	6	6	5
User u_5	6	6	6	6	5

Target user

Users most similar to the target user

Rating to be predicted

Ratings to be used in prediction

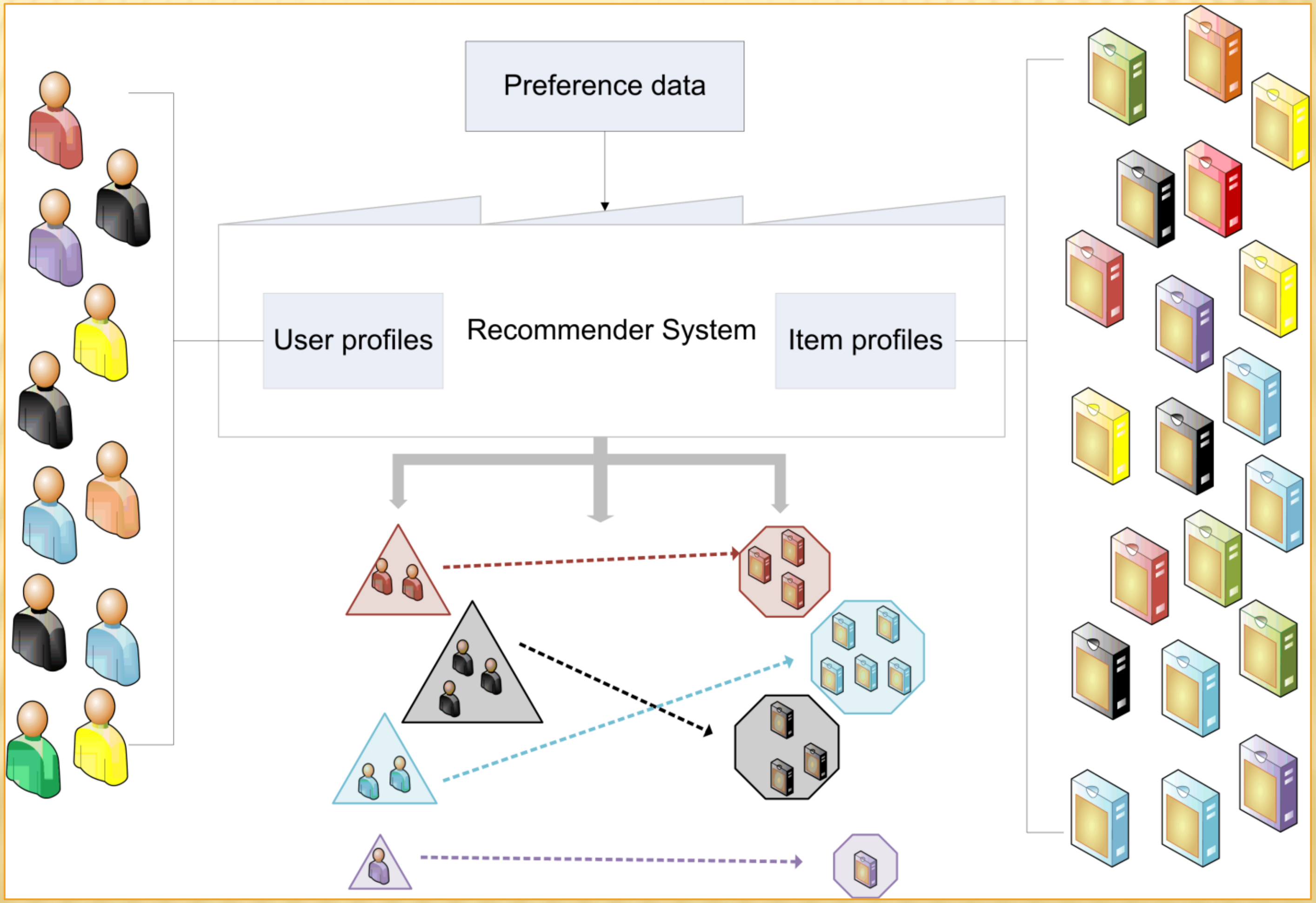
RECOMMENDER SYSTEMS

Why MCDA in RS? Is it a good idea?

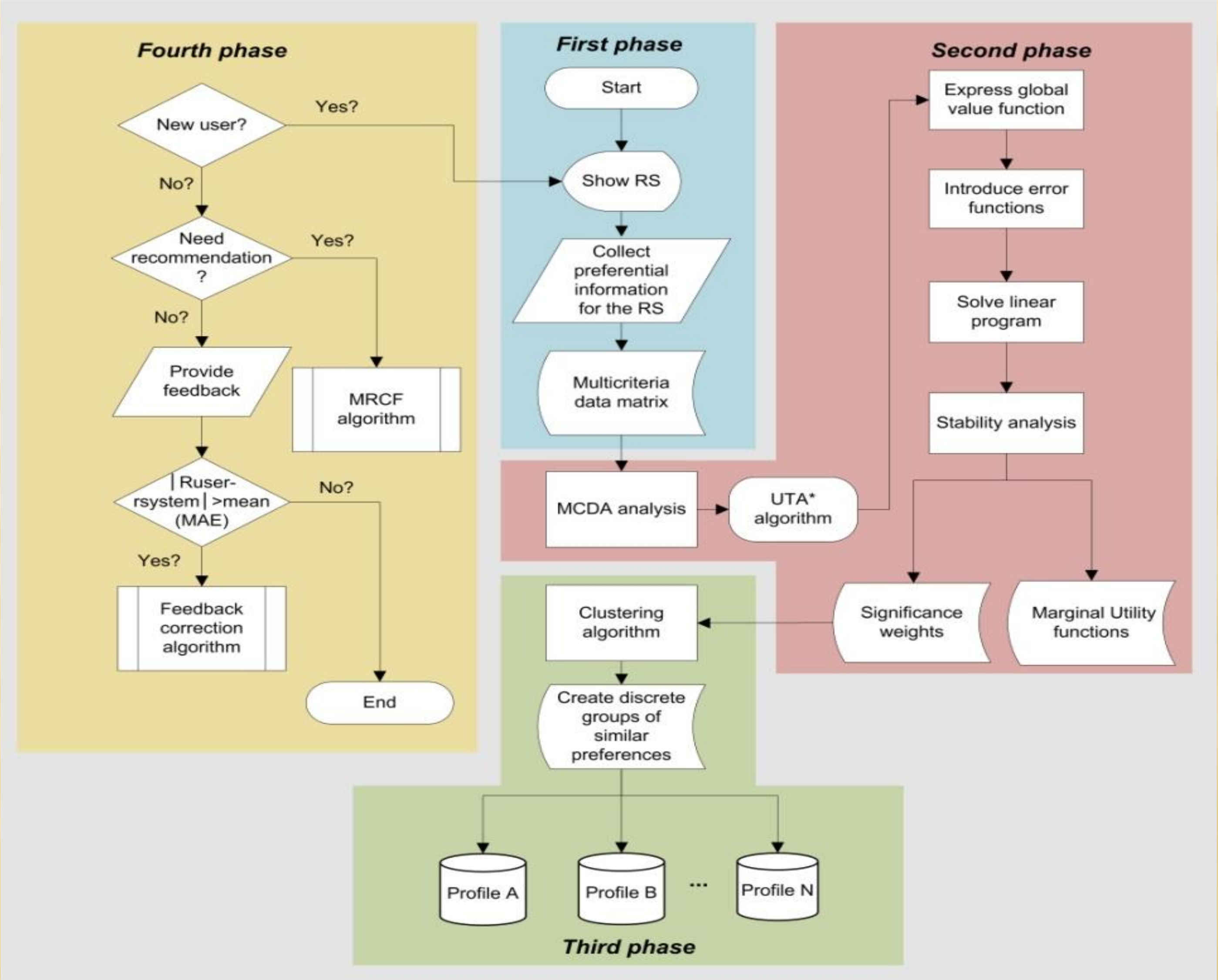
- Most decisions are multi-criteria by nature.
- “Although multi-criteria ratings have not yet been examined in the recommender systems literature, they have been extensively studied in the Operations Research community”*(G. Adomavicius and A. Tuzhilin (2005). "Towards the Next Generation of Recommender Systems: A Survey of the State-of-the-Art and Possible Extensions." IEEE Transactions on Knowledge and Data Engineering, 17, (6): 734-749)*
- Very few multi-criteria Recommender Systems that exploit preference information on several criteria exist in the literature.

MULTICITERIA RECOMMENDER SYSTEMS

Recommender Systems: What are they?

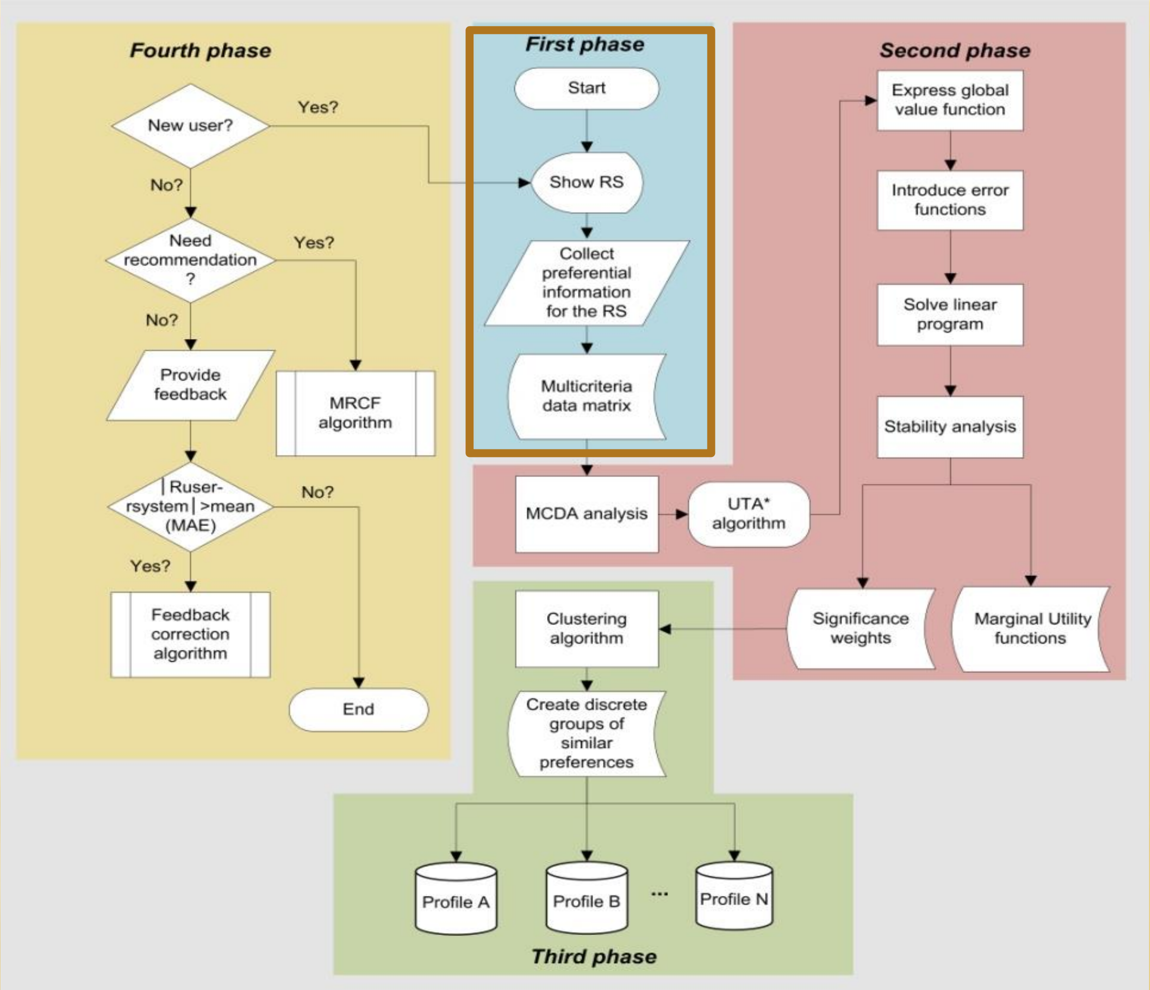


PROPOSED METHODOLOGICAL ARCHITECTURE

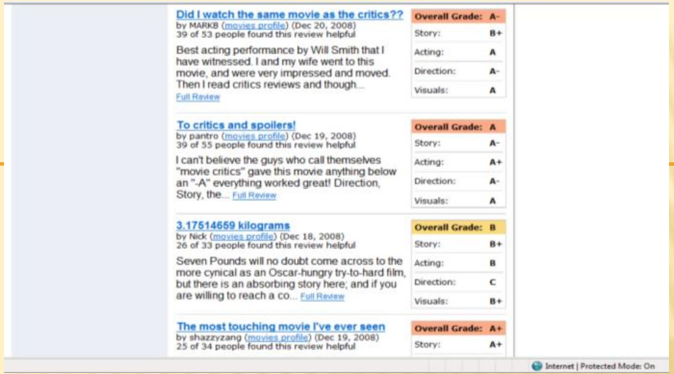


PROPOSED METHODOLOGY

1st phase: Data acquisition



EXPERIMENTAL DATA SET

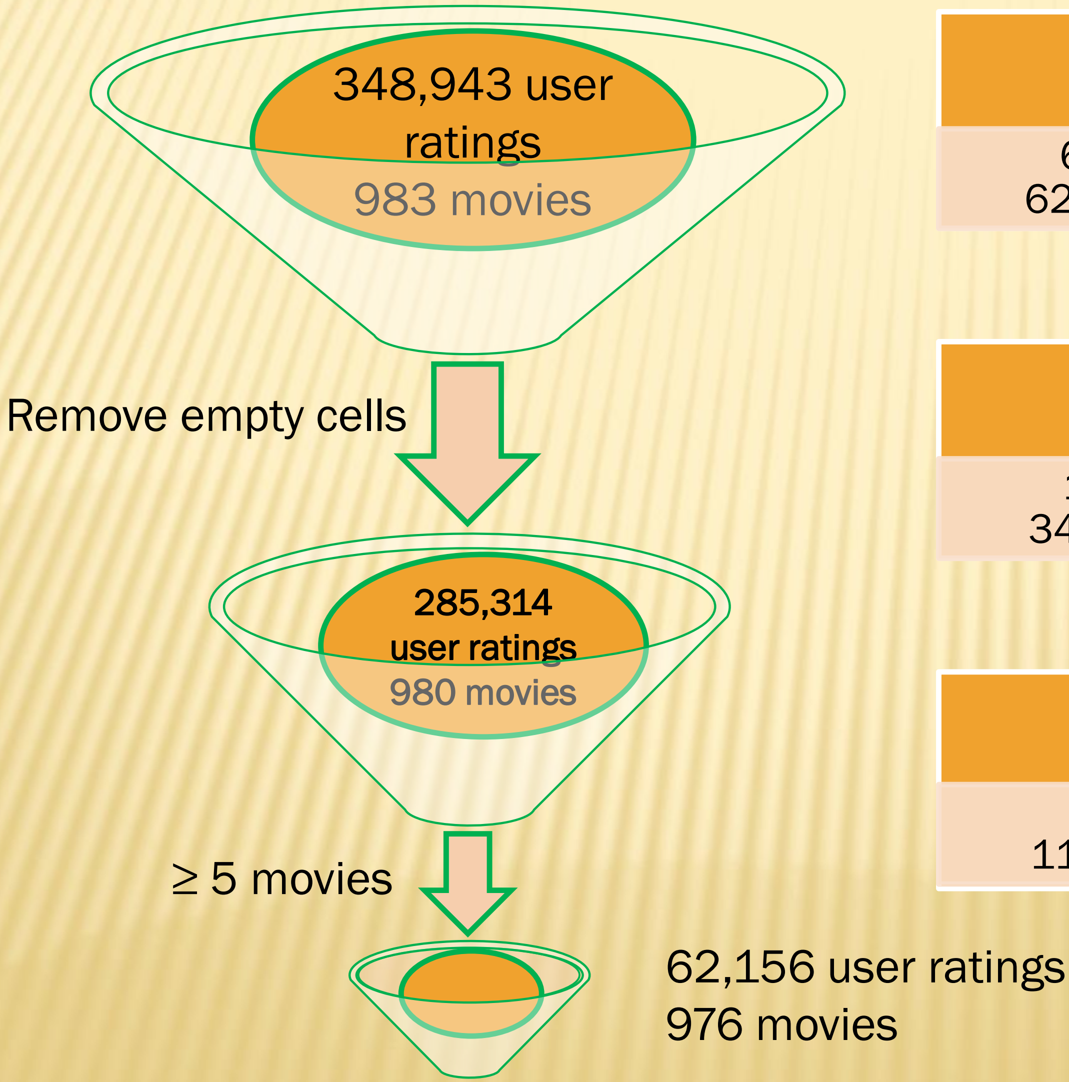


Initial data form							Final data form						
user_id	Overall grade	C_1	C_2	C_3	C_4	movie_id	user_id	Ranking order	C_1	C_2	C_3	C_4	movie_id
1	A+	A+	A	A+	A-	1	1	1	13	12	13	1	1
	B+	B+	A+	B	A+	4		2	10	13	9	1	4
	B	B	A-	B	A+	25		3	9	11	9	1	25
	B-	B+	B+	B	B	23		4	10	10	9	9	23
	C+	C	B	C+	A+	9		5	6	9	7	1	9
2	A	A+	A-	A-	A+	9	2	1	13	11	11	1	9
	B+	B+	B	B	B	18		2	10	9	9	9	18
	B+	A-	A-	A+	B	2		2	11	11	13	9	2
	…	…	…	…	…	…		…	…	…	…	…	…

c_1=story, c_2=acting, c_3=direction and c_4=visuals

A sample of the multicriteria data input matrix before (left side) and after (right side) preparation

DATA FILTERING



1st data set

6078 users 62,156 ratings	≥5 movies, 976 movies

2nd data set

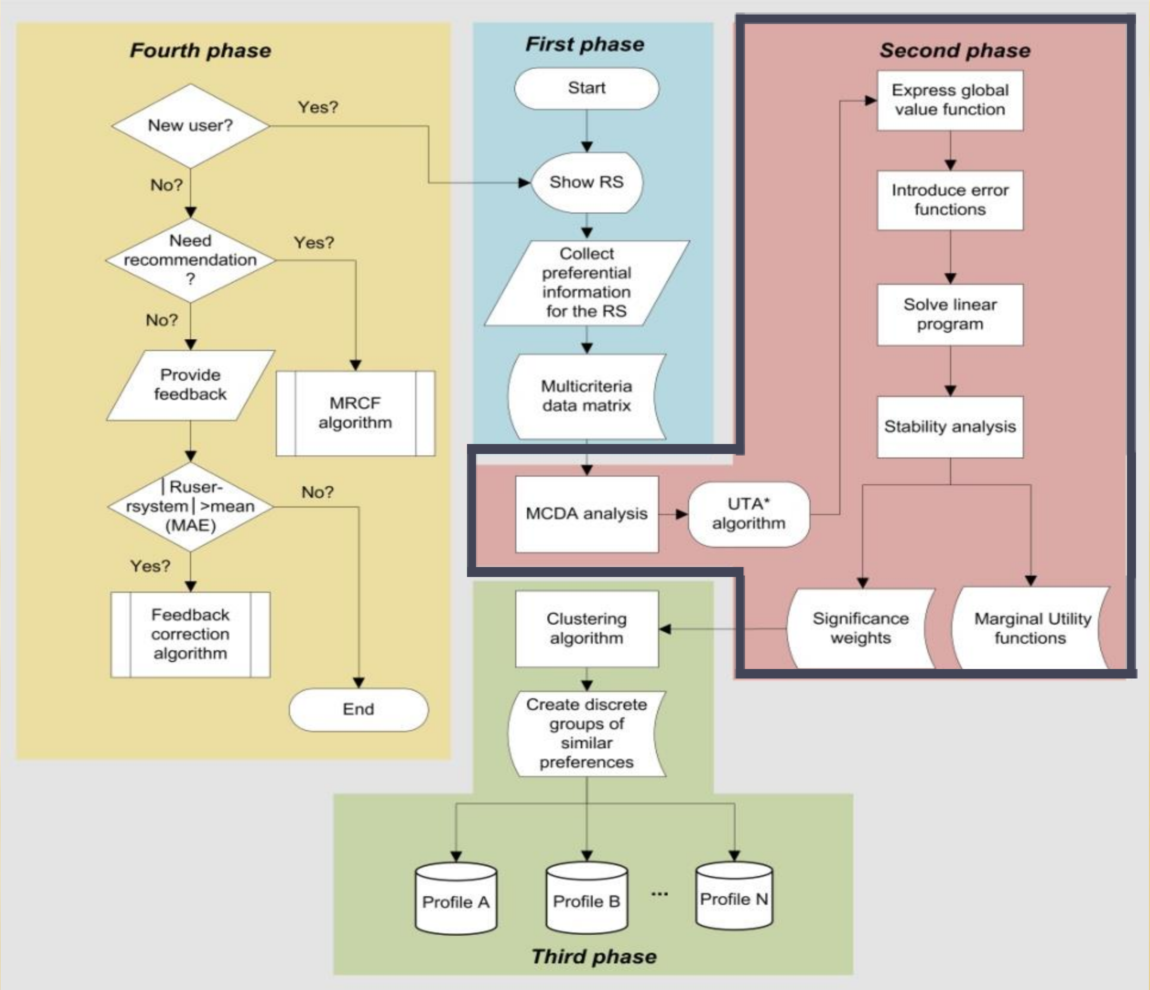
1716 users 34,800 ratings	≥10 movies, 965 movies

3rd data set

191 users 11,757 ratings	≥35 movies, 917 movies

PROPOSED METHODOLOGY

2nd phase: User Modeling



USER MODELING PHASE : THE UTA* ALGORITHM

Reference set

	A_R	g_1	g_2	g_3	g_4	
Alternative	***Ranking order***	***Story***	***Acting***	***Direction***	***Visuals***	
Crash	*1*	*13*	*12*	*13*	*11*	$k=1$
Braveheart	*2*	*10*	*13*	*9*	*13*	$k=2$
Dark Knight	*3*	*9*	*11*	*9*	*13*	$k=3$
Transformers	*4*	*10*	*10*	*9*	*9*	$k=4$
Titanic	*5*	*6*	*9*	*7*	*13*	$k=5$
		$i=1$	$i=2$	$i=3$	$i=4$	

1

$$w_{ij} = u_i(g_i^{j+1}) - u_i(g_i^{j}) \geq 0, \quad \forall i = 1,2,\ldots,n$$
$$and\ j = 1,2,\ldots,a_i - 1$$
$$\begin{cases} u_i(g_i^1) = 0 & \forall i = 1,2,\ldots,n \\ u_i(g_i^j) = \sum_{t=1}^{j-1} w_{it} & \forall i = 1,2,\ldots,n \text{ and } j = 2,3,\ldots,a_{i-1} \end{cases}$$

2

$$\Delta(a_k, a_{k+1}) = u[\mathbf{g}(a_k)] - \sigma^+(\alpha_\kappa) + \sigma^-(\alpha_\kappa) - u[\mathbf{g}(a_{\kappa+1})]$$
$$+\sigma^+(\alpha_{\kappa+1}) - \sigma^-(\alpha_{\kappa+1})$$

3

$$\begin{cases} [\min] z = \sum_{\kappa=1}^{\mu} [\sigma^+(\alpha_k) + \sigma^-(\alpha_k)] \\ \text{subject to} \\ \left.\begin{array}{ll} \Delta(a_k, a_{k+1}) \geq \delta & if\ a_k \succ a_{k+1} \\ \Delta(a_k, a_{k+1}) = 0 & if\ a_k \sim a_{k+1} \end{array}\right\} \forall k \\ \sum_{i=1}^{n} \sum_{j=1}^{a_i - 1} w_{ij} = 1 \\ w_{ij} \geq 0,\ \sigma^+(\alpha_k) \geq 0,\ \sigma^-(\alpha_k) \geq 0 \quad \forall i, j \text{ and } k \end{cases}$$

Marginal value functions

4 Post-optimality analysis

$$u_i(g_i^*) = \sum_{j=1}^{a_i - 1} w_{ij} \quad \forall i = 1,2,\ldots,n$$

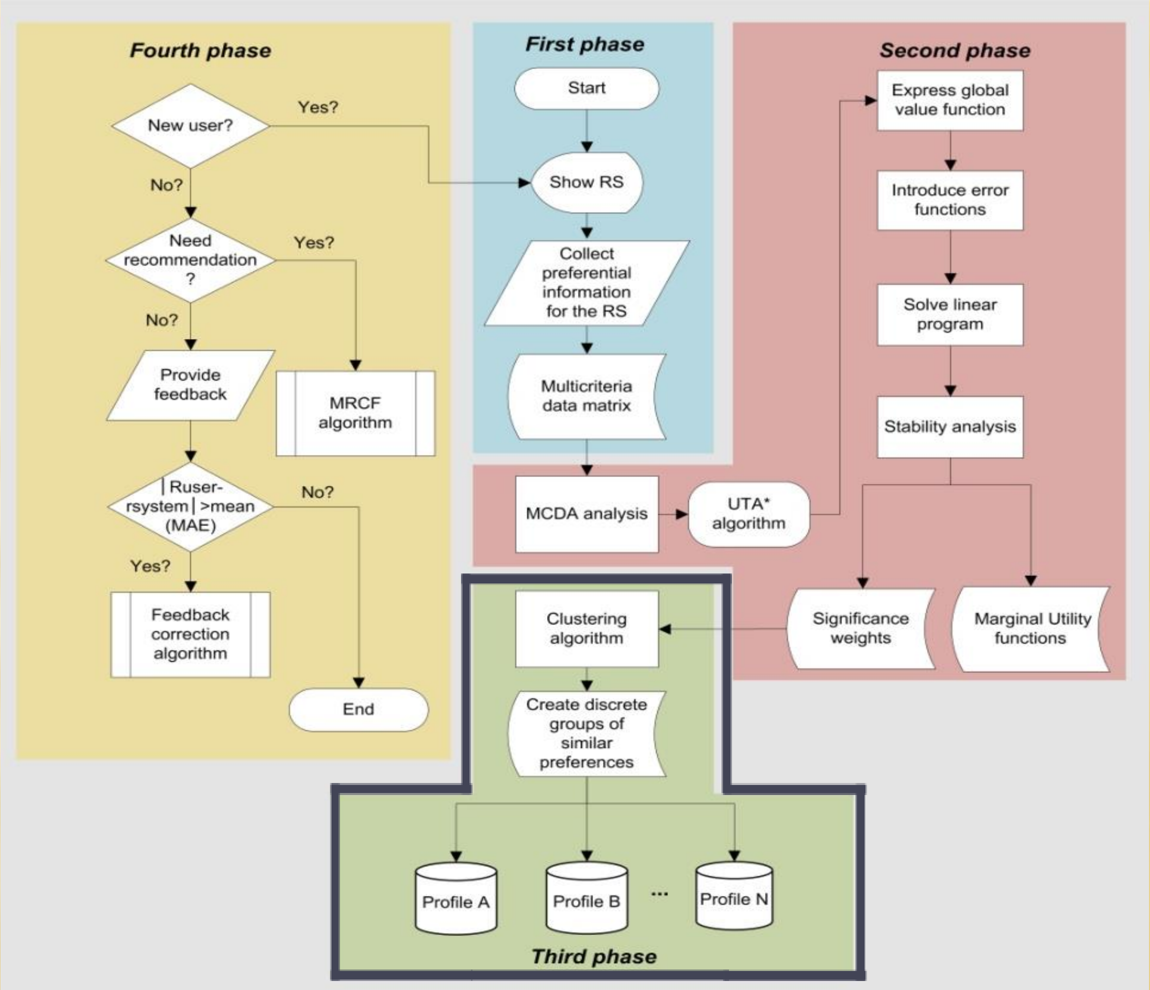
$$\sum_{k=1}^{m} [\sigma^+(a_k) + \sigma^-(a_k)] \leq z^* + \varepsilon$$

USER MODELING PHASE

- Apply UTA* algorithm to each data set individually for every user
- Keep the criteria weights (trade off values) => $u \times k$ vectors
  - Weight matrix dimensions of the first data set: 6078 x 4
  - Weight matrix dimensions of the second data set: 1716 x 4
  - Weight matrix dimensions of the third data set: 191 x 4

PROPOSED METHODOLOGY

3rd phase: Clustering



CLUSTERING PHASE

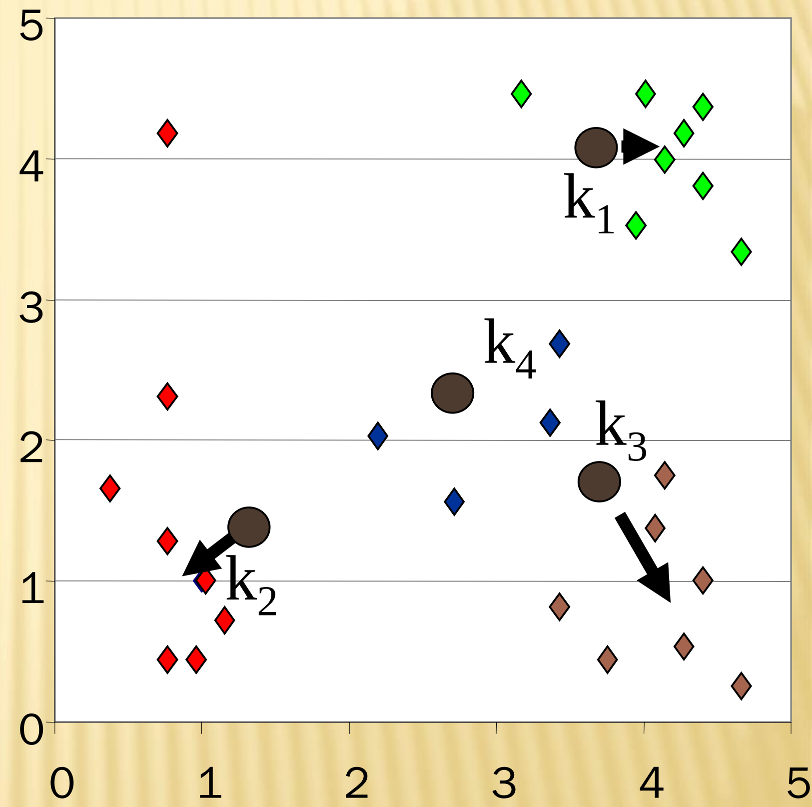
Algorithm Global *k-means*

1. Find optimal k_1 which is the centroid of the data set.

2. Perform N executions of the k-means from k_1 and each data point every time

3. Decide the optimal solution for k=2

4. Repeat above steps until convergence

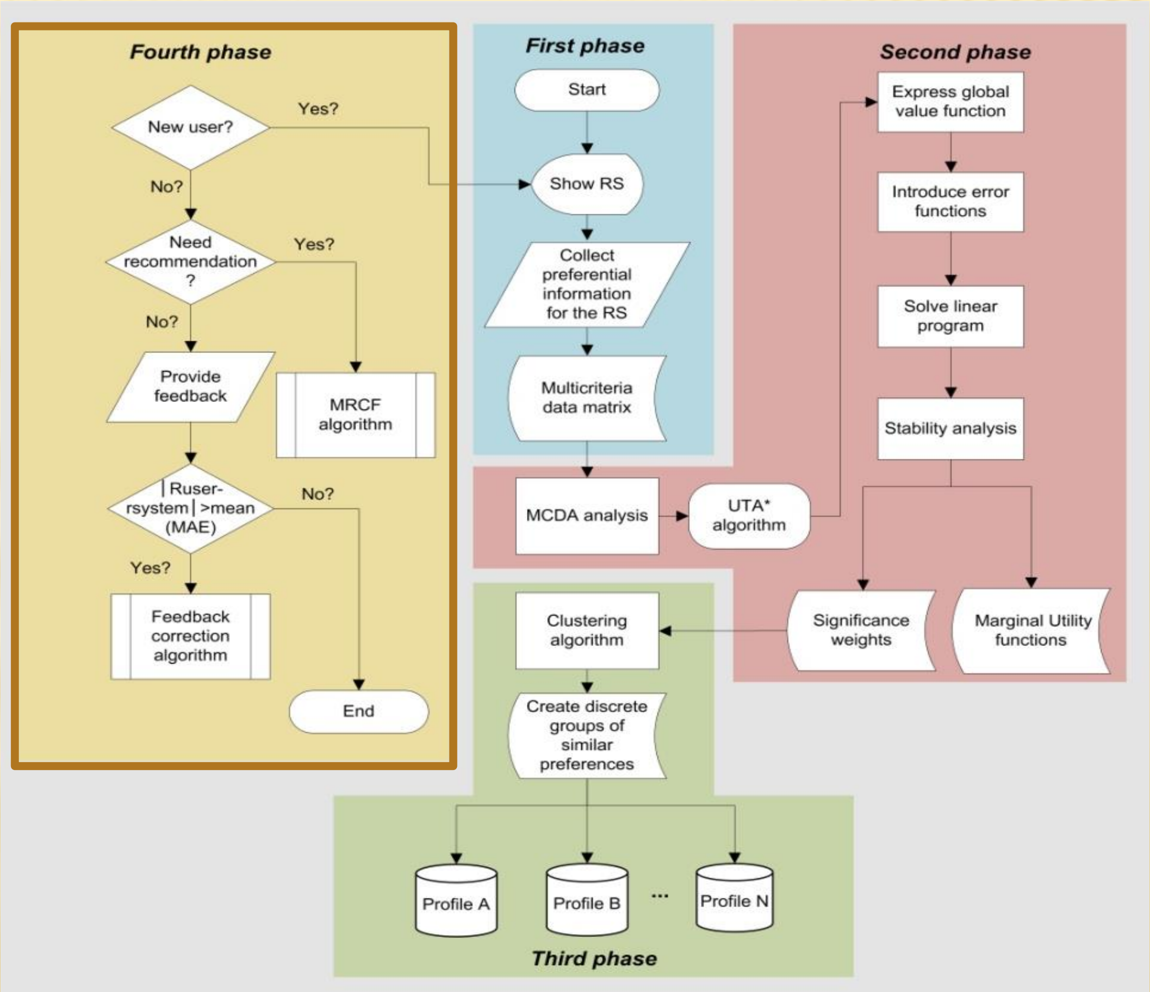


CLUSTERING PHASE

- The **UTA* algorithm** processed the multicriteria data matrix to calculate significance weight vectors w_u , for every user *u*.
- A matrix of 6078 × 4 was formed, which included the weight vectors of all users. All weights were normalized to a range from 0-1.
- **Global k-means algorithm** divided the 6078 weight vectors, resulted from the user modeling phase, into separate clusters. As already stated, global k-means ensures optimality at each clustering step. This means that SSE will continuously decrease over the number of clusters.
- The final **outcome of the third phase** is a collection of disjoint groups of users with similar preferences. These groups constitute the user profile clusters that the system's final step exploits to provide item recommendations. These groups can be updated when required.

PROPOSED METHODOLOGY

4th phase: Recommendation



RECOMMENDATION PHASE

Let's assume that each rating **user *u*** gives to **item *i*** consists of an overall rating r_0 and k multi-criteria ratings $r_1, \ldots, r_k$: $\boldsymbol{R(u, i) = (r_0, r_1, \ldots, r_k)}$

$$d_{uu'} = \sqrt{\sum_{n=1}^{k+1} \left(r_{un} - r_{u'n}\right)^2}$$

distance between two users, u and u' for the same item

$$dist(u,u') = \frac{1}{\left|U(u,u')\right|} \sum_{i \in U(u,u')} d_{uu'}$$

overall distance between two users u and u'

$$sim(u,u') = \frac{1}{1 + dist(u,u')}$$

similarity between two users u and u'

$$R(u,i) = \left(\frac{1}{\sum_{u' \in C(u)} sim(u,u')} \right) \cdot \sum_{u' \in C(u)} sim(u,u') \cdot R(u',i)$$

potential rating for an unexplored item i

RECOMMENDATION PHASE

…if *R(u',i)*=[]??

$$sim\_new = sim\left(C(u),C(u')\right) * sim(u,u')$$

new similarity coefficient

$$sim\left(C(u),C(u')\right) = 1/\left(1+dist\left(C(u),C(u')\right)\right)$$

similarity between cluster centers C(u) of user u and C(u') of user u'

$$R(u,i) = \left(\frac{1}{\sum_{u'\in C(u)} sim\_new(u,u')}\right) \cdot \sum_{u'\in C(u)} sim\_new(u,u') \cdot R(u',i)$$

weighted potential rating for an unexplored item i

RECOMMENDATION PHASE

Pseudo-code of the recommendation algorithm

1: Find all users that have rated *i* and belong to *C(u)*

2: if C(u) is empty

3: **repeat**

4: Find closest to C(u) cluster C’ by minimum cluster center distance

5: Apply equation $$R(u,i) = \left(\frac{1}{\sum_{u' \in C(u)} sim(u,u')} \right) \cdot \sum_{u' \in C(u)} sim(u,u') \cdot R(u',i)$$

6: **until non empty C’**

CONCLUSIONS

- The proposed hybrid methodology leads to the design of multi-criteria recommender systems with high recommendation accuracy as a result of:
  - *The incorporation of multiple criteria preference information*
  - *The formation of clusters with common preferences*
  - *The application of a collaborative filtering inspired multi-criteria approach*

- The factors that affect the recommendation accuracy of multi-criteria Recommender Systems designed according to the proposed methodology are proved to be:
  - *The reference set size*
  - *The number of clusters*
  - *The data set size*

A CUMULATIVE UNMANNED AERIAL VEHICLE ROUTING PROBLEM APPROACH FOR HUMANITARIAN COVERAGE PATH PLANNING

Nikolaos A. Kyriakakis, Magdalene Marinaki, Nikolaos Matsatsinis, Yannis Marinakis, Moving peak drone search problem: An online multi-swarm intelligence approach for UAV search operations, Swarm and Evolutionary Computation, Volume 66, 2021, 100956, ISSN 2210-6502, https://doi.org/10.1016/j.swevo.2021.100956.

Nikolaos A. Kyriakakis, Magdalene Marinaki, Nikolaos Matsatsinis, Yannis Marinakis, A cumulative unmanned aerial vehicle routing problem approach for humanitarian coverage path planning, European Journal of Operational Research, 2021, ISSN 0377-2217, https://doi.org/10.1016/j.ejor.2021.09.008.

DRONE SWARMS - USAGE

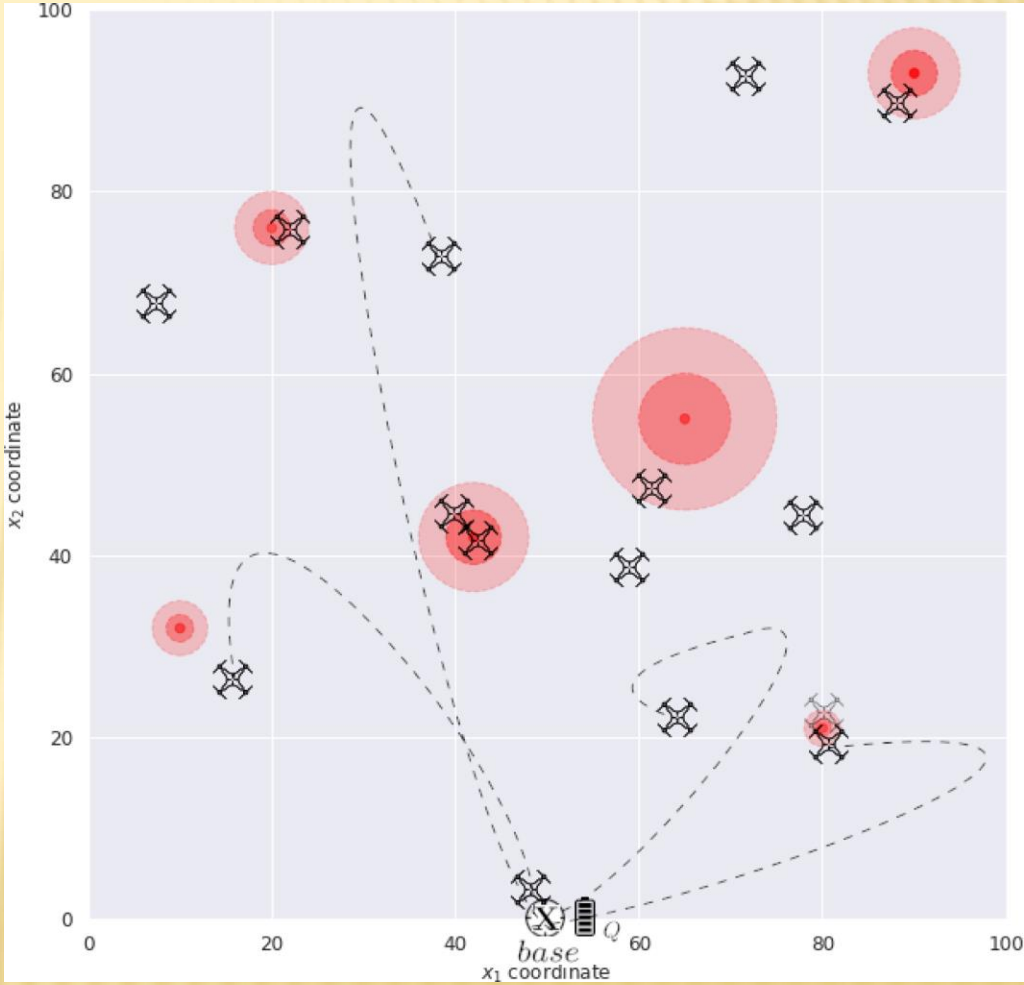
- Military and civilian operations
- Reconnaissance/surveillance, Pick-ups, Deliveries
- Autonomous, agile, adaptive to changes
- No single point of failure
- Expand the capabilities of the operational forces
- Significant advantage over competition/enemy in commercial/military applications

DRONE SWARMS - OR PROBLEMS

- Combination of Decision making, Coordination and Path Planning problems
- Dynamic problems in practice
- A single or multiple objectives simultaneously
- Not just solving but optimizing

DRONE SWARMS - DYNAMIC SEARCH EXAMPLE

- How do we optimally search using a drone swarm in dynamic environments?
- 3-phase process at each time step:
  - **Gather environment data by the agents**
  - **Effectively process data to gain information/ knowledge for the environment**
  - **Determine optimal action for each agent individually**
- Swarm intelligence algorithms to optimize fleet coordination and pathing for the given objective.
- Autonomously adapt to changes
- Fully utilize the available resources



[1] Nikolaos A. Kyriakakis, Magdalene Marinaki, Nikolaos Matsatsinis, Yannis Marinakis, Moving peak drone search problem: An online multi-swarm intelligence approach for UAV search operations, Swarm and Evolutionary Computation, Volume 66, 2021, 100956, ISSN 2210-6502, https://doi.org/10.1016/j.swevo.2021.100956.

DRONE SWARMS - DYNAMIC SEARCH EXAMPLE[1]

- Every location X on the map at time t has an importance value modeled as a cone

$$F_{cone}(\mathbf{x}, t) = \max_{1,\ldots,M}\left(H_i(t) - W_i(t)\sqrt{\sum_{j=1}^{D}(x_j(t) - X_{ij}(t))^2}\right)$$

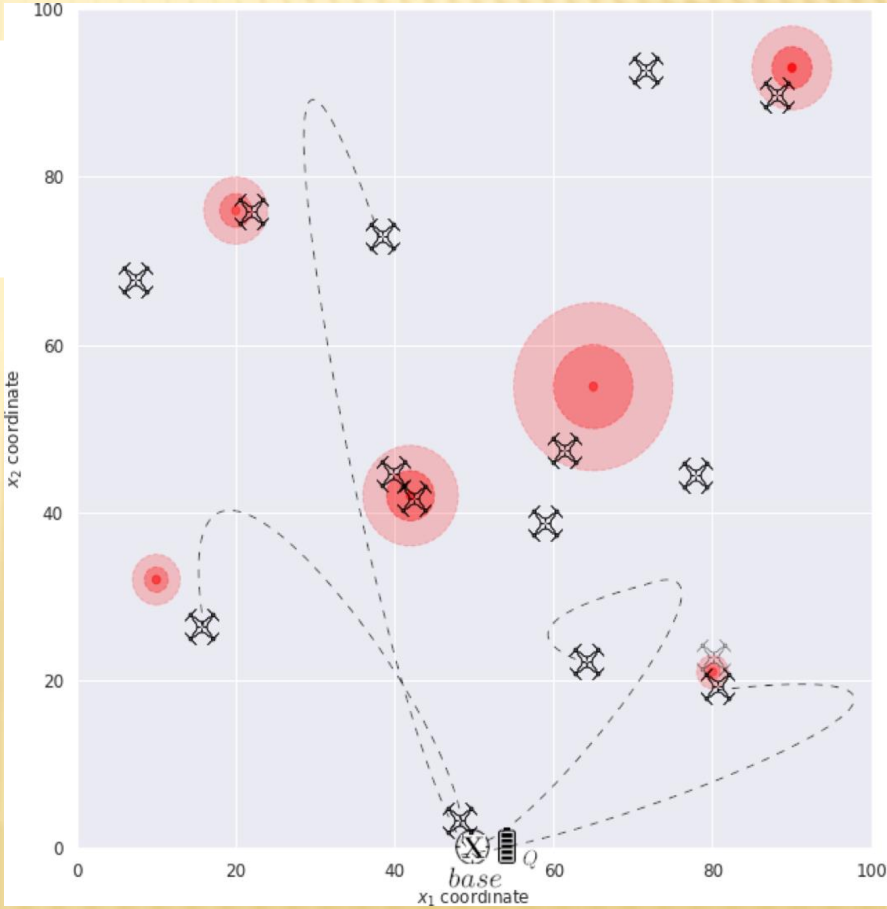
- Changes in sizes and position

$$H_i(t) = H_i(t-1) + height\_severity \times \sigma_h$$

$$W_i(t) = W_i(t-1) + width\_severity \times \sigma_w$$

$$\mathbf{X}_i(t) = \mathbf{X}_i(t-1) + \mathbf{u_i}(t)$$

$$\mathbf{u_i}(t) = \frac{s}{|\mathbf{r} + \mathbf{u_i}(t-1)|}(1-\lambda)\mathbf{r} + \lambda \mathbf{u_i}(t-1)$$

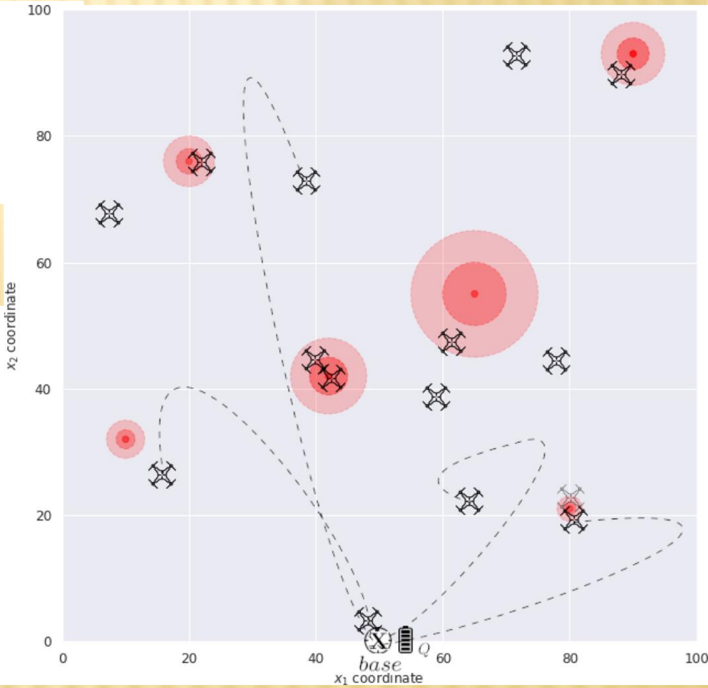


[1] *Nikolaos A. Kyriakakis, Magdalene Marinaki, Nikolaos Matsatsinis, Yannis Marinakis, Moving peak drone search problem: An online multi-swarm intelligence approach for UAV search operations, Swarm and Evolutionary Computation, Volume 66, 2021, 100956, ISSN 2210-6502, https://doi.org/10.1016/j.swevo.2021.100956.*

DRONE SWARMS - DYNAMIC SEARCH EXAMPLE[1]

- Maximize the total importance of the locations found, at every time step, for all duration of operation

$$\underset{\mathbf{x}}{\text{maximize}}\ F(\mathbf{x}) = \sum_{t=1}^{T}\sum_{i=1}^{M} \max_{j=1,\dots,N}\left(\max\left(0, H_i(t) - W_i(t)\|\mathbf{x_j}(t) - \mathbf{X_i}(t)\|\right)\right)$$



- Respecting the drone constraints

$$\mu_j(t) = \sum_{\tau=1}^{\tau=t}\left(1 - \min\left(1, G\|\mathbf{x_j}(\tau) - \mathbf{X}_{base}\|\right)\right), \quad \forall j \in \{1,2,\dots,N\}, \forall t \in \{1,2,\dots,T\}$$

$$\sum_{\tau=2}^{\tau=t}\|\mathbf{x_j}(\tau) - \mathbf{x_j}(\tau-1)\| + \|\mathbf{x_j}(\tau) - \mathbf{X}_{base}\| + 1 \le \mu_j(t)R, \quad \forall j \in \{1,2,\dots,N\}, \forall t \in \{2,3,\dots,T\}$$

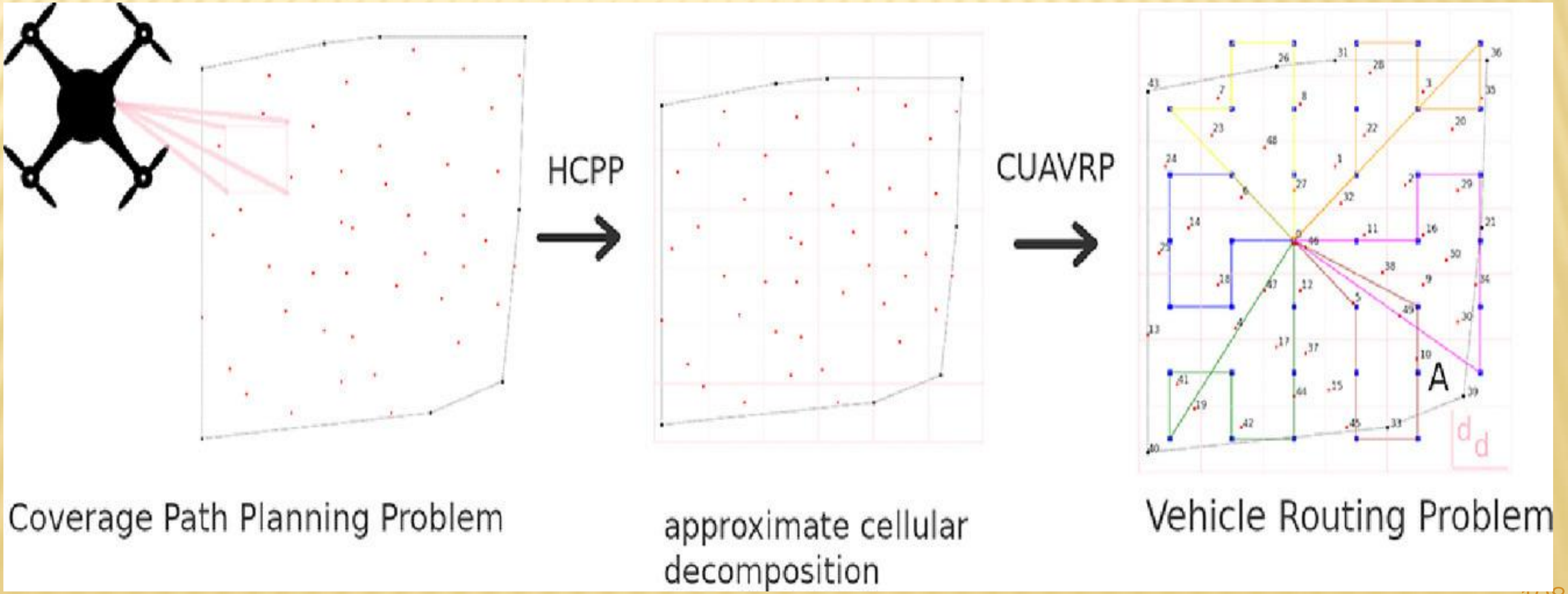
$$\sum_{j=1}^{N}\mu_j(T) = Q$$

$$\mathbf{x_j}(1) = \mathbf{X}_{base}, \quad \forall j \in \{1,2,\dots,N\} \qquad x_{\min} \le \mathbf{x_{j_l}}(t) \le x_{\max}, \forall j \in \{1,2,\dots,N\}, \forall l \in \{1,2\}, \forall t \in \{1,2,\dots,T\}$$

[1] *Nikolaos A. Kyriakakis, Magdalene Marinaki, Nikolaos Matsatsinis, Yannis Marinakis, Moving peak drone search problem: An online multi-swarm intelligence approach for UAV search operations, Swarm and Evolutionary Computation, Volume 66, 2021, 100956, ISSN 2210-6502, https://doi.org/10.1016/j.swevo.2021.100956.*

DRONE SWARMS - COVERAGE EXAMPLE

- How do we optimally cover an area using a drone swarm according to an objective and constraints?
- Problem transformation to leverage on existing optimization tools



DRONE SWARMS - COVERAGE EXAMPLE[2]

- The result of the transformation is the Cumulative Capacitated Vehicle Routing Problem (CCVRP)

$$\min f(X) = \sum_{k=1}^{R} \sum_{i \in V'} t_i^k \quad (1)$$

s.t

$$\sum_{j \in V} x_{ji}^k = \sum_{j \in V} x_{ij}^k, \forall i \in V', \forall k \in \{1, \ldots, R\} \quad (2)$$

$$\sum_{k=1}^{R} \sum_{j \in V} x_{ij}^k = 1, \forall i \in V' \quad (3)$$

$$\sum_{j \in V} x_{0j}^k = 1, \forall k \in \{1, \ldots, R\} \quad (4)$$

$$\sum_{j \in V} x_{j,n+1}^k = 1, \forall k \in \{1, \ldots, R\} \quad (5)$$

$$\sum_{i \in V} \sum_{j \in V} x_{ij}^k u_{ij} \le T, \forall k \in \{1, \ldots, R\} \quad (6)$$

$$t_i^k + u_{ij} - (1 - x_{ij}^k)G \le t_j^k, \forall i \in V \backslash [n+1], \forall j \in V, \forall k \in \{1, \ldots, R\} \quad (7)$$

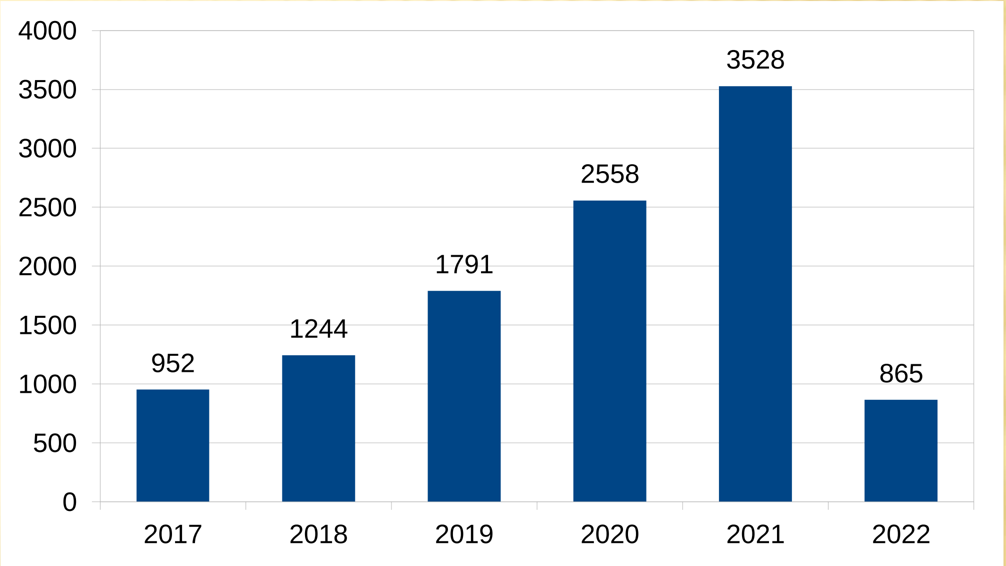
$$t_i^k \ge 0, \forall i \in V, \forall k \in \{1, \ldots, R\} \quad (8)$$

$$x_{ij}^k \in \{0, 1\}, \forall i \in V, \forall j \in V, i \ne j, \forall k \in \{1, \ldots, R\} \quad (9)$$

[2] Nikolaos A. Kyriakakis, Magdalene Marinaki, Nikolaos Matsatsinis, Yannis Marinakis, A cumulative unmanned aerial vehicle routing problem approach for humanitarian coverage path planning, European Journal of Operational Research, 2021, ISSN 0377-2217, https://doi.org/10.1016/j.ejor.2021.09.008.

DRONE SWARMS - FUTURE

- Increasingly popular both in research and in practice
- Regulatory changes required
- Revolutionary potential in military, humanitarian and commercial applications



Number of search results for “drone” in Science Direct

THANK YOU FOR YOUR ATTENTION