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MULTIPLE MODELS IN THE MULTI-ATTRIBUTE CONCEPT DESIGN OF FAST FERRIES

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1. Introduction

A motivation for this work stems from the need for efficient solution of the inter-island traffic in the Adriatic Sea. Fast coastal transport in the Croatian part of the Adriatic Sea consists of catamarans (mostly second-hand of Australian or Norwegian origin), monohulls (mostly Italian origin) and hydrofoils (of the former USSR origin). Often selection among different generic ship types must be made before proceeding with the design of the selected type. Typical example of this situation is to reach decision whether a monohull or catamaran is a better choice for a fast ferry.

A multi-attribute procedure is established as an aid in concept design of several generic ship types such as, fast ferries [Grubisic, 1993], catamaran ferries [Grubisic, 2005], as well as for other types of vessels, developed at the University of Zagreb in last 15 years. Thorough visualization of the design space [Grubisic, 2004] helps the designer in decision-making based on relatively large number of Pareto optimal designs.

Each of this generic ship types is defined within a generic concept design model that is structured in advance and calibrated for the ship type in question. It is not practical to develop one universal model that would be able to represent a number of different generic ship types. An alternative may be to formulate ship concept design model via predefined building blocks (functional entities) [Andrews, 1997]. In that case design optimization would be possible by an approach like SOS (Subjective Objective System) as demonstrated in [Ziv-Av, A., Reich, Y., 2003].

Concept design model for a monohull is quite different from the catamaran design model. Different design parameters are used to define respective ship type and different attribute prediction algorithms are used. Decision making among different topologies belongs to the same type of problems and there may be more than two design models included.

General formulation of the design problem is: for given ship design specifications, find a preferred Pareto-optimal design involving multiple generic ship types.

A three step procedure is proposed:

- step 1 find Pareto frontiers of all generic design models involved, respectively
- step 2 find a preferred design on each respective Pareto frontier
- step 3 find the generally preferred design that belongs to one of the models involved

First two steps are described in [Grubisic 1993, 2003, 2005] and will not be repeated here. The third step involves decision making among multiple design models.

2. Decision making in multiple models environment

Decision-making within one generic ship type, as described by its design model, is performed by a search for the Pareto frontier of non-dominated designs. This procedure is objective if the direction of attribute utility increase is decided. Subjective decision-making process, based on weighting factors

applied to each attribute according to the Saaty's pair wise comparison procedure, minimizes the distance from the ideal design (UTOPIA), found by the Chebyshev norm L_∞. The procedure is presented in [Grubisic 1993, 2003, 2005].
Different designs, themselves Pareto optimal within their own kind, are comparable only under certain conditions. Different models are in principle based on different topologies (i.e. monohull and catamaran). Generally, number of attributes, number of parameters and their respective definitions may be different among the models.

2.1 Dimensionality of the design model

Number of attributes determines the dimensionality of the design problem. If dimensionality of two competing generic ship types is different, two approaches are possible:

- First approach: First reduce the number of attributes to the same number for all generic types and then perform search for common Pareto frontier (cross dominance) and the preferred design taking into account global ideal design (Utopia).
- Second approach: Find preferred design on the Pareto-optimal frontier of each generic type, test them for mutual dominance and consecutively decide among them for the generally preferred one.

2.2 First approach

The first approach my be illustrated by comparison of a 3-dimensional and a 2-dimensional case as demonstrated in [Figure 1]:

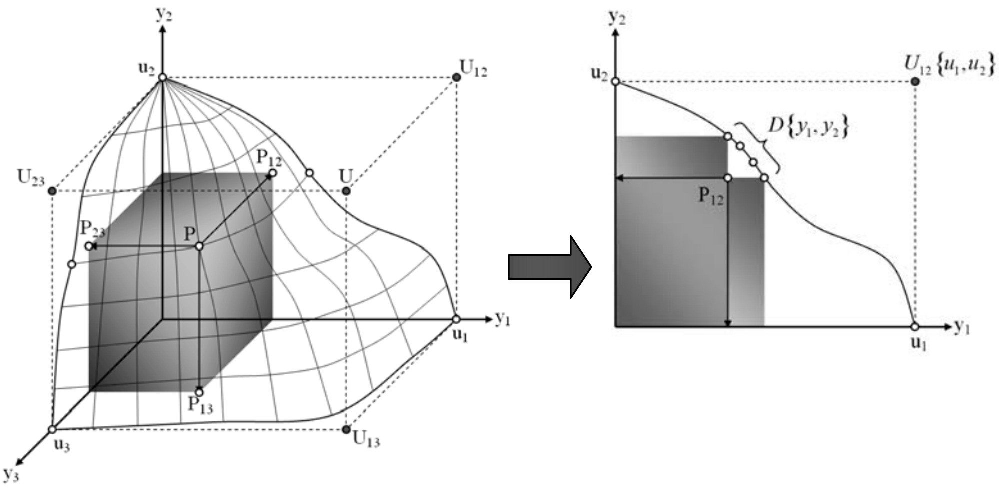


Figure 1. Reducing 3-dimensional attribute space to 2-dimensional

Reducing the dimensionality of the problem from 3D to 2D as shown in [Figure 1] results in a number of previously non-dominated designs to become dominated in the new attribute space with reduced dimension.
For example design $P\{y_1,y_2,y_3\}$ that is on the 3D Pareto-optimal hyper-surface and is non-dominated by definition, becomes dominated in the 2-D Pareto-optimal hyper surface (in this case actually a line of Pareto frontier) by all designs $D\{y_1,y_2\}$. It means that if a set of non-dominated designs was previously generated by a 3-D model (i.e. having 3 attributes) it can not be directly used for cross dominance with a 2-D model because they belong to different spaces. Therefore, it appears that first both models should be set to identical dimensionality and then, as a next step, common Pareto frontier generated by repeating dominance test. If models A and B are involved the procedure may be illustrated as in [Figure 2].

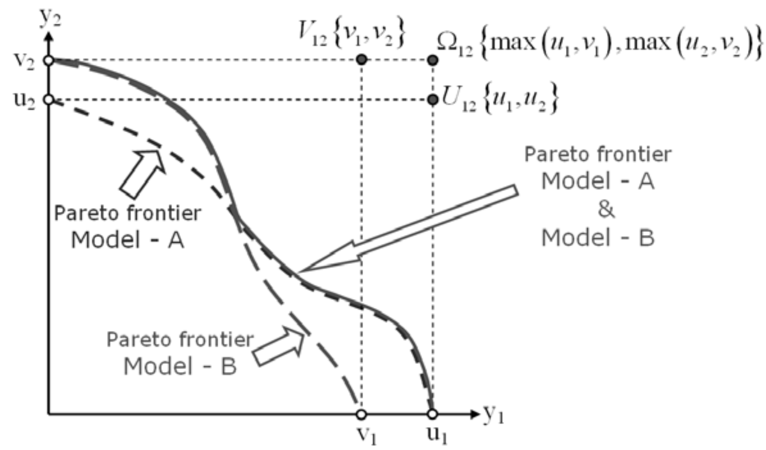


Figure 2. Common Pareto frontier of the two generic models A and B

2.3 Second approach

The second approach deals with preferred designs that are previously decided by multi-attribute objective procedure and subsequently by subjective decision-making procedure. In principle it may be assumed that each generic design model is structured so as to take advantage of most of the available knowledge regarding attribute prediction methods applicable to the respective ship type. Since models are different and the design parameters are different it is to be expected that different attributes may be necessary to define the design. For example constraint dealing with wet deck clearance of the catamaran does not exist in monohull. Since constraints are also attributes of design, it is obvious that different attributes may be included when searching for the preferred design. In that context only preferred designs belonging to different generic models should be mutually compared, since they are defined to the best of the knowledge available for the respective generic model.

Now the procedure becomes quite simple. Only the relations of the preferred designs are checked for dominance. If one is dominated by the other it is eliminated. If both are non-dominated (as it often will be) the decision may not be reached within the knowledge included in the design models. Either subjective decision making with adequate weighting factors must be applied or booth designs be developed further, raising them up from the concept design level to the preliminary design level that includes direct first principle calculations, numerical or model experiments etc.

2.4 Requirements for the applicability of the multiple model decision making procedure

Decisions may be rationally founded only if decision attributes generated by each model are mutually compatible. Each attribute must be defined so as to represent identical physical measure of attainment. It means that, for example, common criteria for passenger comfort level are applied or common cost modelling are applied.

Design requirements must be identical, otherwise the comparison is biased. For example critical requirements for capacity, sailing range or speed must be identical. It makes no sense to directly compare a 250 passenger vessel with a 150 passenger one. This type of comparison may be possible only if special design model dealing with the complete fleet transport problem is developed.

Parameters belonging to different models are in principle different, despite the fact that some of them may refer to the same physical dimension (i.e. length of the monohull is not comparable to the length of catamaran although they both represent ship length) Therefore, it makes no sense to visualize parameter relations belonging to different models. Not even an index in the engine catalogue is necessarily identical, since different catalogues may be used for different models. (e.g. motors for catamarans may be chosen from the single cylinder bank type, while monohull engines may be of the V-type, due to the width limitations).

3. Case study

To demonstrate the procedure and the problems encountered it is applied to the selection of the preferred design for given design requirements, where monohull or catamaran solutions are possible.

3.1 Design requirements

Assume that a ferry with the following requirements [Table 1] is to be designed:

Table 1. Design requirements of a ferry

REQUIREMENT			value
Number of seated passengers	PAX	-	150
Speed on trials	V_{TRIAL}	knot	30
Range without refueling	R	NM	250
Motor choice	mot	-	1...4
Number of propulsion engines	N_{PR}	-	2

3.2 Propulsion engine choice

Selection of propulsion engines is possible within a catalogue of candidate engines. Here a choice is limited to the following diesel motors including reduction gear [Table 2]. It is assumed that one engine is driving one water jet propulsor. Identical catalogue is used for both design models.

Table 2. Diesel motor catalogue (partial data)

mot	MOTOR MODEL	P_B (kW)	N_E (min^{-1})	W_E (kg)
1	VOLVO D25A MT	605	1800	3150
2	MAN-D2840LE403	722	2300	1867
3	MAN-D2842LE406	882	2300	2058
4	MTU-S60	615	2300	1850

3.3 Design attributes

Attributes are output data generated by the model. Attributes predict values of design characteristics that will subsequently be subject to the process of valuation. Attribute aspiration levels are set in advance in order to measure the attained level [Table 3].

Table 3. Attribute aspiration levels

ATTRIBUTE ASPIRATION LEVEL			value
Service speed	V_{SERV}	knot	30,0
Specific area per passenger	LB/PAX	m^2	0,800
Motion Sickness Incidence	MSI	%	3,0
Cost of the new vessel from yard	C_{NEW}	MU	1,0

3.4 Design parameters

Parameters are input data defining one state of the design model. Designer communicates with the model only through parameters. Design parameters are dependent on the generic model type. Therefore two different sets of parameters are involved [Table 4].

An individual multi-attribute design procedure was applied to both models and presented in the simultaneous view into the design attribute space. Models were structured as described in [Grubisic 1993 and 2005].

Data and information from [Grubisic 2003 and 2005], [Karayannis 1999], [Molland 1995], [Blount 1994], [LR SSC 1996], [Savitsky 1976] was used in structuring both models. Models were calibrated to represent contemporary achievements with monohull and catamaran ferries. Parameters related to the financial environment were kept identical for both cases.

Table 4. Definition of design parameters for two generic models

MONOHULL			CATAMARAN		
Length over planing surface	L_P	m	Length of water line	L_{WL}	m
Max. beam over chines	B_{PX}	m	Beam at max. sect.	B_X	m
Displacement volume	∇	m^3	Draft at max. sect.	T_X	m
Depth at side	D_X	m	Wet deck clearance at max. sec.	G_X	m
Dead rise angle at max. sect.	β_X	deg.	Demi-hull separation (c.l. to c.l.)	S_X	m
Centre of gravity from transom	X_{CG}	m	Transom to max. sect. area ratio	A_T/A_X	-
Propulsor diameter	D_P	m	Prismatic coefficient	C_P	-
Trim tab deflection	δ	deg.	Max. sect. coefficient	C_X	-
Transom to max. sect. area ratio	A_T/A_X	-	Propulsor diameter	D_P	m
Engine catalogue indicator	mot	-	Engine catalogue indicator	mot	-

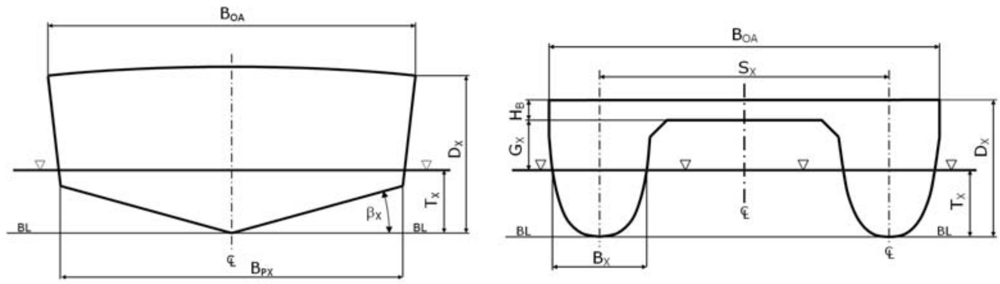
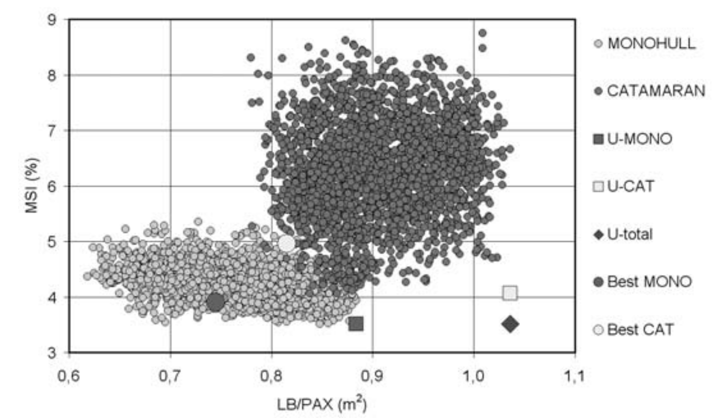


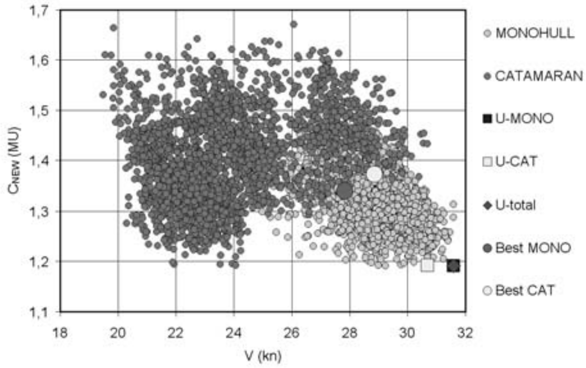
Figure 3. Monohull and catamaran respective cross sections

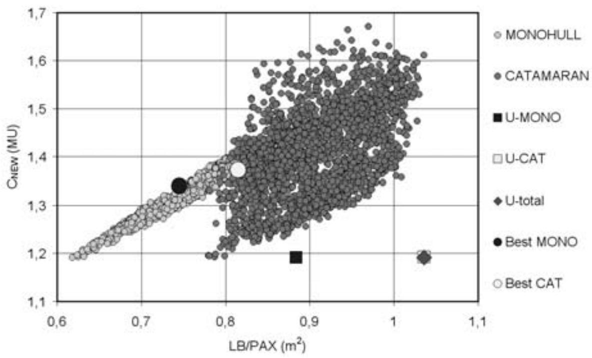
3.5 A two-model projections of the hyper surface of non-dominated designs

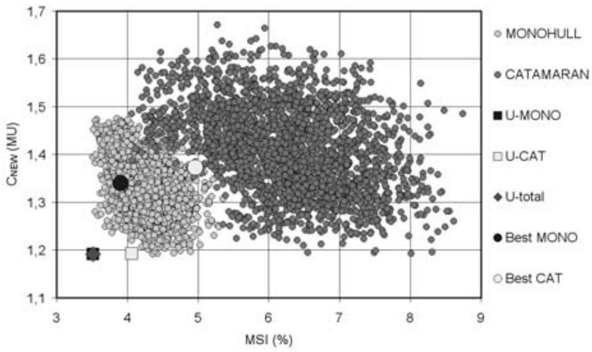
Example of the projection of the hyper surface of non-dominated designs belonging to two models are presented in [Figure 4]. The relation of the averaged motion sickness incidence and the specific passenger space shows two clear groups belonging to the two models. Ideal designs (U-MONO and U-CAT) are shown as well as combined ideal design (U-total).

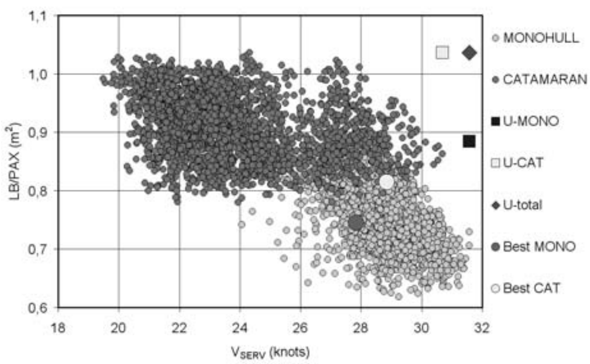
Best (preferred) designs are indicated and they clearly do not dominate one another. It may be concluded that ideal designs are not much apart. Of course, different design requirements and different ponders may have produced different results but it is obvious from the information of the ferry services that both types survive in service with slight prevalence of catamarans.




MONOHULL
CATAMARAN
U-MONO
U-CAT
U-total
Best MONO
Best CAT
C_NEW (MU)
V (kn)


MONOHULL
CATAMARAN
U-MONO
U-CAT
U-total
Best MONO
Best CAT
C_NEW (MU)
LB/PAX (m2)


MONOHULL
CATAMARAN
U-MONO
U-CAT
U-total
Best MONO
Best CAT
C_NEW (MU)
MSI (%)


MONOHULL
CATAMARAN
U-MONO
U-CAT
U-total
Best MONO
Best CAT
LB/PAX (m2)
V_SERV (knots)

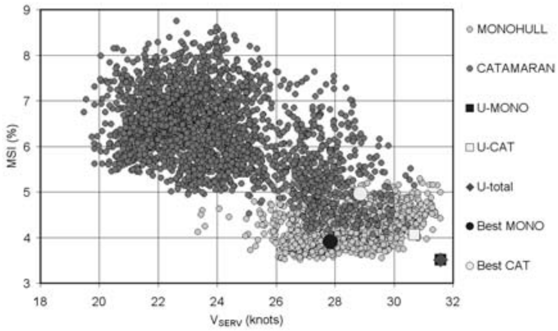


Figure 4. Six views into the hyper surface of non-dominated designs of the monohull and catamaran configurations, respectively

3.6 Attributes of the two preferred designs

From the [Table 5] it is easily decided that both preferred designs are non-dominated according to the four attributes used for decision-making. Monohull is better in cost and motion sickness incidence, while catamaran is better in speed and passenger space.

Table 5. Attributes of the preferred designs

model	V_{SERV}	LB/PAX	MSI	C_{NEW}
	knot	m^2	%	MU
MONOHULL	27,836	0,745	3,908	1,340
CATAMARAN	28,856	0,815	4,964	1,373

It appears that at this level the resolution of the monohull-catamaran dilemma leads to deciding after further development of both designs at a higher level.

3.7 Parameters of the preferred designs

Design parameters for each generic model are given in the [Table 6. a) and b)]. It is noticeable that in both cases the same engines were selected by the objective procedure, but different water jet propulsors. The catamaran is shorter than the monohull as my be expected.

Table 6. a) Design parameters for the preferred monohull design

model	L_P	B_{PX}	∇	D_X	β_X	X_{CG}	D_P	δ	A_T/A_X	mot
	m	m	m^3	m	deg.	m	m	deg.	-	kW
MONOHULL	21,983	4,964	38,934	3,195	22,832	8,996	0,781	9,829	0,806	2x882

Table 6. b) Design parameters for the preferred catamaran design

model	L_{WL}	B_X	T_X	G_X	S_X	A_T/A_X	C_P	C_X	D_P	mot
	m	m	m	m	m	-	-	-	m	kW
CATAMARAN	18,498	1,987	1,148	1,277	4,333	0,918	0,610	0,841	0,688	2x882

3.8 Ideal designs (UTOPIA)

Ideal designs (UTOPIA) of each generic model and a combined ideal design, are given in [Table 7].

Table 7. Attributes of the ideal designs (UTOPIA)

model	V_{SERV}	LB/PAX	MSI	C_{NEW}
	knot	m^2	%	MU
U - monohull	31,580	0,884	3,514	1,192
U - catamaran	30,685	1,036	4,061	1,193
U - combined	31,580	1,036	3,514	1,192

It may be observed that attribute values of the non-dominated designs that maximize certain attributes present objective results and show the limits of the design attributes. With different subjective

weighting it would be possible to select different preferred design in the process of trade off. For example more speed or less cost may be found (but not both), at the expense of passenger comfort regarding space or motion. It would mean that the designer or other decision maker (owner) had changed her/his preferences while developing the design.
The question may be asked, what is the benefit of the proposed approach? It is in the gained insight into the possibilities of trade-off in the multiple model multi-attribute design context and the likely consequences. All possible projections of the hyper surface of non-dominated designs, (in this case study: 3+2+1=6 views of [Figure 4]), enable visualization of the common combined design space, its limitations and they promote clarity of comparison as well.

8. Conclusions

- The search for common Pareto frontier of all models involved, is not necessary.
- Preferred designs, as established by the separate procedures (objective & subjective) applied to each model respectively, use different numbers of attributes pertinent to each respective model.
- Final design decisions are founded on mutual dominance of the preferred designs and using the common set of attributes. At this stage necessary condition for decision-making is common definition and equal number of design attributes.
- Design visualization involving parameters should be performed only within a respective generic model, while only visualization in the attribute space makes sense when dealing with multiple generic models.

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