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Lifecycle Properties of Stability – beyond Pure Technical Thinking

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ABSTRACT

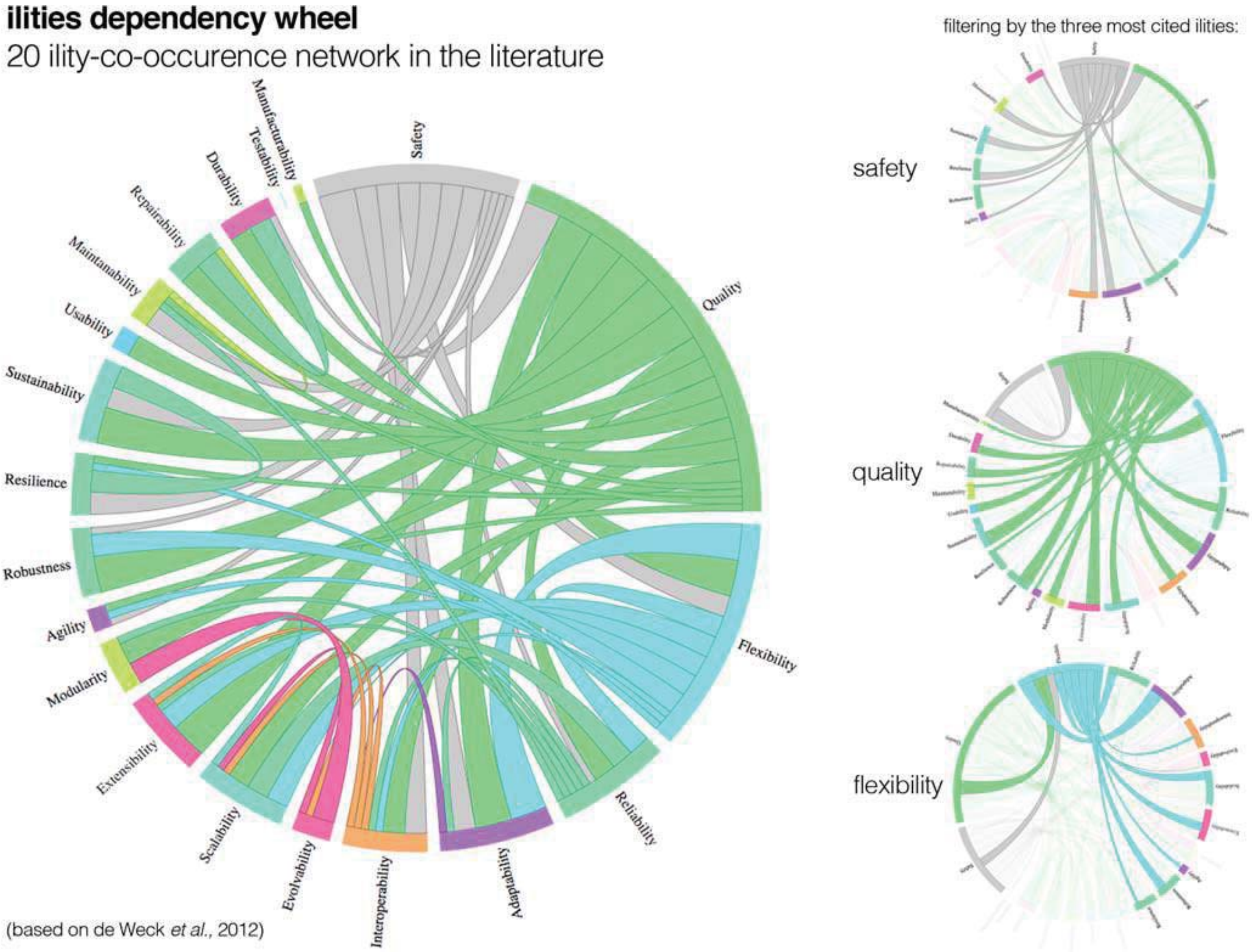
This paper addresses the importance of understanding a stable ship through its lifecycle, which goes beyond purely technical thinking. Not only is it sufficient to address under what circumstances the vessel is operating during its life cycle, but the vessel needs to be stability wise, prepared to handle safely any likely operational condition. Binary decision-making, such as a Ship A complies with the norm, therefore Ship A is stable throughout its life cycle, is only valid for a specific set of scenarios and pre-defined operational conditions, usually involving most advanced and precise engineering methods on the technical aspect, but not necessarily taking into account accurately other important ship-as-a-complex-system aspects being used for different operational scenarios over its life cycle. Our proposition is that stability is, after all, a system lifecycle property, and should be treated as such. How this proposition is observed by a systems engineering classification, both technically and operationally, is discussed in the paper. Stability as a system lifecycle property is observed via change enabled paths, with its agents, effects and mechanisms. The implications for design of five change related lifecycle properties (ilities) are discussed, namely flexibility, adaptability, robustness, scalability and modifiability. We also reflect upon the use of a complex system engineering five-aspect taxonomy. Structural and behavioural aspects are briefly commented based on classical stability formulation, on how internal (e.g. cargo) and external (e.g. environment) stimulus influence the stability. External factors that influence the concept of stability in a certain scenario, such as mission type, location of the mission and market behaviour, are also considered on the contextual aspect. Uncertainties over time, and how it affects the ship stability, are considered from a temporal perspective. The perceptual aspect presents the understanding of stability as a valuable lifecycle property after the ship is put into initial use. A prescriptive semantic basis for stability is proposed as an extension of this work, applying a general change-related ility pattern introduced by recent systems engineering research.

Keywords: *Lifecycle Properties, Stability and Systems Engineering, Ship as a Complex System.*

1. INTRODUCTION – ON THE VALUE OF STABILITY

Stability is such a fundamental property of the vessel that it is inherently connected to every kind of its operation and design approach. Design for safety, for instance, would treat stability as the most uncertain aspect of the vessel design solution to be always feared, with designers being asked right on the first meeting: *What is the worst case scenario that this vessel can operate and yet be considered stable, sound safe?* Design for maximum vessel performance would observe stability as a key constraint for modifications in a current design process, *We could have a bigger crane if the stability criteria did not played such a strong role*, one may say, when designing a new offshore construction vessel. The extension of such an exercise would find stability mentioning in pretty much every X at the Design for X studies (Andrews, 2009; IMDC 2012).

On the other side of the spectre we find new trends on observing qualities of a complex system, such as operability, modularity, maintainability, sustainability and robustness. These new trends and drivers are influencing shipowners' businesses a great deal, shifting perception from the delivery of goods by a ship with a size X and power Y to providing service A and B within safety, economic, and environmental constraints. As Bodénes describes (2013), a decade ago, a shipowner would sit with the designer and discuss hull and propulsion; Today, the meetings are steered by factors such as safety, fuel consumption, capability, and reliability, necessitating documenting this kind of information as precisely as possible. There is, however, no consensus on how this precision can be achieved, especially since this required knowledge is not easy to access due to the abstract (one may say humanistic or non-metric) nature of these factors. Given that there is a clear shift from purely technical to knowledge-oriented factors, we can ask how then the traditional idea of stability fits on it? How is stability connected to a conception of value that includes not only immediate economic return, but also robustness toward uncertain lifecycle scenarios?



(based on de Weck *et al.*, 2012)

Figure 1 - ilities co-occurrence in engineering literature (based on de Weck *et al.*, 2012)

This paper observes and discusses the stability as a system lifecycle property (ilities), connecting it to other ilities and its implications for vessel design. Section 2 proposes key ship design ilities categorized in top requirements, constraints and change related properties. Stability as a lifecycle property is investigated in Section 3, with its agents, effects and mechanisms, as well as implication for design. A five-aspect taxonomy is used to understand the factors that influence value (Section 4).

Extension of this work using system engineering prescriptive semantic basis is briefly investigated in Section 5. A discussion on the desire for proper stability and its value during the vessel lifecycle appears in the conclusion (Section 6).

2. KEY SHIP DESIGN ILITIES

The traditional understanding of lifecycle properties relates to the satisfactory performance from a quality perspective, over the full lifespan of the vessel system. They describe some essential property of the system connected (or resulted from) the form and function mapping of the system. Ilities typically relates to qualities above and beyond cost/schedule and performance expectations for the system development and operation. In other words, requirements that are not necessarily part of the fundamental set of requirements or constraints, but that act as a response to uncertain factors, such as threats (perturbations) and constraints (limitations) (Ross, 2008, 2014).

Many systems engineering authors are giving emphasis to the study of system lifecycle properties in complex systems during the last decade (Hastings *et al.* 2012). *Croud source* approaches, for instance, gathered in 2012 identified more than 80 ilities that can be used to evaluate the performance of a system (Ross and Rhodes, 2015). Descriptive surveys based on occurrence of ilities in written media attempted to illustrate the occurance and dependence of these properties in journal Articles (Figure 1, based on de Weck *et al.*, 2012).

Expressing wishes or expectations for a proper clarification of a property seems essential but, as noted by Rhodes and Ross (2015), tracing and mapping these wishes/expectations remains an ambiguous task. Therefore, selecting and filtering such ilities to the most relevant ones within a specific field is then a necessary challenge.

Table 1 – Key Ship Design Ilities

property	definition	category
QUALITY	The ship is well made to achieve its desired functions (missions) throughout its lifecycle	Top
RELIABILITY	The ship operates throughout its lifecycle without need of unplanned repair or intensive maintenance	Top
SAFETY	The ship operates in a state of acceptable risk, minimizing danger, injury or loss	Top
RESILIENCY	The ship can continue to provide required capabilities in the face of critical failures, such as subsystems malfunctions and environmental challenges	Constraint
AFFORDABILITY	The ship remains delivering value to the stakeholders (e.g. owner, operator, customer) in face of context shifts throughout its lifecycle	Constraint
SURVIVABILITY	The ship minimizes the impact of a finite duration disturbance on overall performance	Constraint
FLEXIBILITY	The ship's dynamic ability to take advantage of external opportunity, mitigating risk by enabling the ship to respond to context shifts in order to retain or increase performance	Change
ADAPTABILITY	The ship's dynamic ability to take advantage of internal opportunity, mitigating risk by enabling the ship to respond to context shifts in order to retain or increase performance	Change
SCALABILITY	A ship parameter can be scaled (e.g. increased/decreased) in order to retain or increase performance	Change
MODIFIABILITY	A ship can modify its form/ essence/ configuration in order to retain or increase performance	Change
ROBUSTNESS	The ship maintains an acceptable level of performance through context shifts with no change in its parameters	Change

(based on Hastings *et al.*, 2012; Ross, 2008; de Weck *et al.*, 2012; Jasionowski and Vassalos, 2010).

Approaching ship design as a complex system problem (Gaspar *et al.*, 2012), we propose in Table 1 eleven key ilities connected to ship design. A general definition is presented, withihn three main categories. *Quality, Reliability* and *Safety* are considered top requirements the "Design for X" concept, meaning that every stakeholder desires a high quality ship (for instance better among peers), with safety (lower risk) and reliable (higher trust). *Resiliency, Affordability* and *Survivability* are considered constraints requirements, defined by price (afford) and how much it can survive disturbances (survivability) and critical failures (resiliency), in which the vessels stops to deliver value if not considered resilient, affordable and survivable at any point of its lifespan.

Change related ilities are connected to the changeability concept presented by Ross (2008), where changes can be considered as the transition over time of a parameter of the ship to an altered state (e.g. of stability). For the rest of this work we will use the terms of this last category to situate and compare stability among other lifecycle properties, pointing out how it influences the perception of an "-able" vessel during its lifecycle (e.g. stable, flexible, affordable, adaptable).

3. STABILITY AS A SYSTEM LIFECYCLE PROPERTY

3.1 Changes in Stability as Enabled Paths

Many lifecycle properties can be understood as how *good* the system reacts to changes in its form and function. Our assumption is thus that stability is a change-related ility (Ross and Rhodes, 2015), and shoud be treated as such, since stability crosses between technical and operational system's metrics. On the initial phases of the value chain, such as concept and basic design, stability is strongly technical, connected to the system form and architecture. It is measured using a structural/behavioural metric, such as criteria for GM, GZ curves and classification society rules.

Later, during operation, changes in the form are not an immediate option, and operational metrics gain in relevance. The performance is then measured based on the mission and environment factors that the ship is subjected to. Operational metrics thus are connected to the relation between stability and other attributes of the ship, such as rolling, pitch and heave acceleration, as well as survivability when perturbed/damaged (Neves *et al.*, 2010).

In this context, it is possible to consider changes in the events of a vessel as paths between different situations/states (Ross, 2014), for instance from *stable* to *unstable* as well as to *more operable due to moderate rolling* to *less operable due to heavy rolling*. This path is affected by external and internal agents, as well as mechanisms to balance/infer the effects of these agents.

To exemplify, consider stability having two essential binary states: stable and unstable. A change event in these conditions can be characterized with three elements: i) the agents of change; ii) the mechanism of change; and iii) the effect of change (Figure 2).

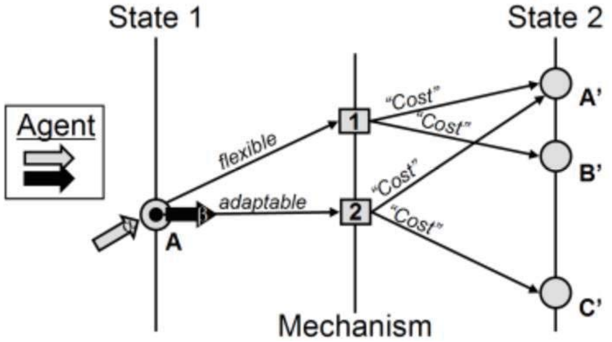


Figure 2 - Changes in stability as paths between states (Ross, 2008)

Consider A the actual state of a ship (for instance stable). An external active change agent α, such as a wave, wind, cargo displacement or damage, acts on the system (ship), affecting its stability. These disturbances accept two paths. First, without any other agent, the system incorporates a certain mechanism (1), such as listing and/or righting arm, leading to a new state, such as more stable, less stable or unstable (A′, B′, C′). Another external change agent (responsive, β) can be incorporated on the system after the initial change occurs, such as intervention from the bridge to reconfigure anti-heeling tanks, leading to the system to adapt to the new situation with another change mechanism (e.g. movement of liquid cargo to counterbalancing heeling, or roll damping tanks). The cost in this model is not necessary connected to a monetary value, but to any value that represents time and/or resources use, such as energy, fuel, reaction and operation time. A summary of the model is listed in Table 2.

3.2 Agents, effects and mechanisms

During vessel design one must consider which technical (hull size, bow shape, tanks division) and operational (accelerations, risk level) metrics should be considered when analysing the vessel’s stability. These choices interfere directly on how the ship will react given a perturbation in its stability state. Our assumption is that change related ilities (Table 1) can be used to define which agents, effects and mechanisms will be used to counteract perturbations in the ship stability (Ross, 2008).

Table 2 – Stability’s elements of change

Element	*Description*	*Term*
Change agent	Element external to the ship, which affects the stability state, such as humans, software or natural phenomena. It can be considered active agents, such as an external force, environmental conditions (wave, current, wind), cargo handling, accidental forces (e.g. winch break, crane failure); as well as responsive agents (external counteractions), such as human decision to manoeuvring, to fill a ballast tank or to retrofit the ship.	**, β**
Change Mechanism	The particular path the ship must take during transition to one prior state (stable) to another post state (more stable, less stable, unstable), such as new heading, tank filling, anchor handling drop, retrofit.	**1, 2**
Change Effects	Effect on the ship after action from agents - more stable, less stable or unstable.	**A’ - A, B’ - A, C’ - A**
Potential Paths	Possible paths when the ship change from one state to another	**α:A-1-A’** **α:A-1-B’** **α,β:A-2-A’** **α,β:A-2-C’**

Stability change agents are divided according to its location. External change agents are considered a flexible-type (e.g. wind heeling the ship, human action to change heading or cargo placement), while internal change agents are considered adaptable-type (e.g. bilge keel or antiroll tanks).

According to this taxonomy, designing for flexibility means facing changes in stability with an external agent, such as the operator at the bridge changing a current parameter of the ship. Designing for adaptability, on the other hand, would tackle changes in the stability state using only internal configurations of the ship-system, such as hull design, automatic antiroll tanks or passive bilge keels.

Effects in stability are considered the difference in states before and after an agent affects the system, indicating that a change in the attribute (e.g. GM value / heeling angle / roll period) has occurred.

A robust effect is the ability of the system to remain relatively constant in parameters in spite of system internal and external disturbances (therefore operable). Design for robustness in stability means that the ship will handle the active change agents by itself, maintain itself operable/survivable under an acceptable level of external forces aging upon it.

When parameters need to be changed we are talking about scalability. It means that, for the system to remain stable within the operational range over time, we need to change the scale of one its parameters, such as fill a ballast tank, modify heading or lower the load of a crane.

Modifiability is when the ship requires a modification in its main form/arrangement to remain stable under a certain operation. This requires usually a redesign or retrofit of the vessel to incorporate new structural aspects, such as new antiroll tanks and/or structural reinforcement.

Mechanisms can be understood as the paths that the ship must take to transit between states. It includes elements inherent to the ship design process, such as necessary subsystems, components, resources, conditions and constraints that allows a path between two situations, such as *less stable* to *more stable*, *higher roll acceleration* to *lower roll accelerations*.

For the sake of exemplification, lets consider a crane operation with heavy cargo. The change agent is the crane, and the change effect is the GM value and heeling angle of the ship. Many possible paths (mechanisms) can be taken to minimize heeling angle and keeping safe GM values. The active agent (crane) can modify its arm length and height or even drop the cargo. The ship operator (responsive agent) can turn on dynamic positioning (DP) or roll compensation mechanism. Each action, thus, is connected to a *cost* in terms of time and resources to correct the effect caused by the crane.

When taking these definitions in the initial design process, design for many potential change mechanisms means design for different costs, with potential costs for a given path in a given condition. Over time, not only the cost of a mechanism may change, but also more paths can be added to the ship via new capabilities on board or retrofit of the ship. Table 3 summarizes the Stability's implications for design in terms of flexibility, adaptability robustness, scalability and modularity

Table 3 – Change related properties in Stability

Design for	***Description***
Flexibility	The stability change agent is external to the ship-system. Change mechanisms are possible under external (human, computer) actions
Adaptability	The stability change agent is internal to the ship-system.
Robustness	Design a vessel that keeps stable under conditions' change. Change mechanisms are inherent to the design
Scalability	Design a vessel able to be stable under a set of conditions when its parameters are scalable. For instance activate anti-heeling tanks or move deck cargo.
Modifiability	Vessel is only able to be stable after modifications are incorporated in its form, via re-design or retrofit. It may be the case for a low initial capital cost, with option for a retrofit and more stability in the long-term, if future contracts require it.

3.3 Lifecycle implications for ilities in stability during initial design

Our assumption is that designers should no longer only consider stability properties that meet today's regulations and requirements, but rather consider the implications and consequences of the lifecycle technical, operational and commercial context changes early in the design process (Ulstein and Brett, 2012; 2015), including change related mechanisms into the ship, which allow cost-effective reactions on how it behaves to disturbances in its stability related attributes. In order to explicit address the desire of a shipowner to have flexibility, it is necessary to gather more information about the desired responsive change agent, change effect and mechanisms, as *desiring flexibility alone is an imprecise request.* In this sense, we build on Ross (2008) proposition of analysing and evaluating stability related in five basic steps:

i) Specify the origin of the active change agents (perturbances, disturbances), and in which operational conditions they occur. For instance, finite duration active agents such as wave, wind, short operation loads (hanging, moving) or even chaotic motions; as well as long term shifts (likely to last), such as cargo placement/shift, long operation (towing, crane), damage, free-surface, flooding, collision, grounding should be specified.

ii) Determine the acceptable *cost* threshold, that is, response time and resource uses when disturbed, as well as determining the shipowner willingness to pay for a more stable vessel, such as wider breadth, faster antiroll system, stronger hull or higher dynamic position capability.

iii) Specify if the origin of responsive agent, that is, internal (adaptable and incorporate in the ship as a system) of external (acting on the ship but external to its boundaries).

iv) Consider which effect is expected for each of the responsive agents selected in iii). Robust effects will change no parameter, being inherent to the form/arrangement of the ship. Changes in the level of a vessel parameter creates scalable effects, such as modification of the tension in a towing line, as well as filling up the antiroll tank or activating the DP system. Modifiable effects require changes in the nature of a certain parameter of the ship, such as the installation of a more powerful anti-heeling pump, a new crane or rearrangement of the ship load distribution.

v) Analysis and evaluation of the vessel design space is done in the last phase, considering, which capabilities should be inherent or installed on board the ship, in terms of disturbances (active agents), reactions (responsive agents), and effects on stability related attributes. For example, if the shipowner requires the ship to be adaptable and robust regarding supply operation in North Sea high wave conditions, while flexible when performing anchor-handling operation in more extreme conditions, then response mechanisms that are able to be flexible and adaptable must be considered when evaluating the design space. In this way, the specific *adaptability* (in terms of low accelerations while supplying) and *flexibility* (in terms of controlling safe GM and low acceleration while anchor-handling in extreme conditions) can be weighed against cost (time/resource) requirements and rules constraints. At the end, we should converge towards a set of quantified lifecycle properties, that is, a value gain versus cost when talking about *robustness* or *scalability.*

4. HANDLING VESSEL STABILITY COMPLEXITY IN A LIFECYCLE CONTEXT VIA A FIVE-ASPECTS TAXONOMY

A systemic approach for defining complexity in ship design is presented by Gaspar *et al.* (2012a, 2012b), where the complexity of a system is captured through five main aspects, namely: Structural (structure and relationships), Behavioural (performance), Contextual (circumstances),Temporal (changes in context and uncertainties) and Perceptual (stakeholders' viewpoint). Here we use these taxonomy to clarify, organize and handle the information necessary to proper identify and build up the elements necessary to understand stability as a lifecycle property.

Structural and behavioural aspects connect to the traditional technical understanding that stability depends on the ship main dimensions, the shape of the submerged hull and tanks/ cargo arrangement, as well as location of unprotected openings such as engine room air intakes and the actual location of centre of gravity KG. Well-known trade-offs analysis, when determining the main dimensions and hull form, should be conducted among some major design disciplines, such as sea keeping, stability, manoeuvrability, sufficient cargo hold volume and payload capacity. Considering a ship with large GM, for instance, where the righting arm developed at small angles of heel is also large. Such a ship is usually considered *stiff* and will resist roll. However, if the metacentric height of this ship is small, with smaller righting arm, the vessel may be considered tender, rolling slowly. Practical offshore support vessel (OSV) design experience shows the necessity of balance between generating stiff or tender design, since they have opposite influences on stability of vessel and convenience of crew during site operation. A *design for safety* thus will be contradictory to a *design for operability.* Therefore, if a shipowner invests in robustness for the reason that his or her vessel may be considered safe for a wide range of conditions, the same investment may lead to a loss in contracts due to limited cargo capacity or smaller crew comfort. What the designer should consider then is the nature of the reaction of the vessel, for instance, by changing one of its change effects, for instance a tank installed in a higher deck (modifiability) that can be filled during site operation (scalability). The initial robust solution is unable to proper consider the extension of the stability complexity, while the modifiable / scalable solution is.

The contextual aspect pertains to the external circumstances to which the vessel is subject to during operation and how its behaviour is affected accordingly. The applied contextual factors in traditional ship design are often dominated by various technical and economic factors during exploration of the technical design space such as meteorological conditions, rules and regulations, supply and demand, breakeven rates and so forth. Such factors will impose a range of requirements and restrictions, the resulting solution space will be significantly delimited, inherently affecting the shape of the vessel and consequently narrowing the diversification of potential stability characteristics. In order to move beyond pure technical thinking, stability as a lifecycle property, which must also be included as input when considering the boundaries of the design space. In other words, stability must be perceived as something more than just metacentric height, a GZ-curve and a characteristic of operational performance. It should also be considered an attribute of value creation across contextual factors, i.e. diversifying the categories of which stability value is commonly quantified by. Exemplifying, a remarkably stable vessel could be considered technically superior, but at the same time, it may also require compensatory investments leading to an increased capital cost. Viewing this in a contextual lifecycle perspective the value of this increased robustness should also be considered in terms of factors such as flexibility, adaptability, and current and presumed market developments.

When considering a vessel from a temporal perspective, changes in the system's lifespan occurring at disparate points in time, in conjunction with a highly scattered degree of uncertainty, together constitute the fourth taxonomy aspect. When viewing stability as a lifecycle property, a method of quantifying contextual shifts is necessary. The technical perspective would take into account the probable spectre of applicable mission types and operational modes by utilizing a traditional set of analyses, and conclude based on input parameters such as wave height and direction, currents, mass distribution, and hull shape. These types of analyses unquestionably provide excellent sources of information regarding a vessel's stability characteristics; however, they do not take into account contextual variations in an uncertain temporal perspective. One possible method of quantifying such complex information is Epoch Era Analysis (EEA) (Ross and Rhodes, 2008, Gaspar *et al.,* 2012b, Keane *et al.,* 2015), which captures future expectations by encapsulating each factor-variant in a fixed (epoch) and dynamic (era) time-constrained context setting that should be further analysed in terms of probability, optimality, performance, value, and utility, to name a few. This enables the incorporation of multi- values, attributes and assumptions that previously may have been side-lined, generating data for the perceptual aspect.

The overall lifecycle property connected to the perceptual aspect is value robustness, which is used, including but not limited to aspects presented above, to define in multi-perspective a better vessel among a design set. Value robustness is the ability of a system to continue to deliver stakeholder value in face of shifts in context and needs (Ross and Rhodes, 2008). In ship design, this means a ship perceived successful by stakeholders throughout the lifetime of the vessel. Rather than maximizing value delivered by a ship in one situation, we need to maximize it over a range of situations and preferences of the owner (or other constituents). This might reduce the maximum possible reward but also minimize the maximum possible loss, with relevance increasing as uncertainty grows and investors become more risk aware (Gaspar *et al.*, 2015).

In this context, how to perceive stability as a lifecycle property, and make benefit of it to bring more value to the vessel? How to really decompose the multi-perspective perception of what a stakeholder would understand as a valuable ility? Ebrahimi *et al.* (2015) notes that the perception of a better (therefore stable) vessel relies in *a middle term perspective, between the pure satisficing and maximizing the goodness of fit of all stakeholders' expectations*. On one hand, we would like to select the best solution, by creating and analysing all possible risk situations and alternatives, and choose the best. Our limitation as human beings, however, allow us to only compare and contrast a very limited set of variables and alternatives when trying to find the good enough stability. Ulstein and Brett (2015) propose the application of different perspectives to overcome these limitations. *Technical, Operational and Commercial* perspective for instance, links to the vessel skills and level of efficiency needed for a particular operation, while *Smarter, Safer and Greener* perspective connects to a more fashionable idea of effectiveness, increasing the overall effect of the combined technical, operational and commercial performance. The change related ilities are tackled in their approach for *design for efficiency,* where flexibility, agility and robustness are observed in terms of the ability of the vessel to perform different operation, move and upgrading itself quickly and not likely to fail.

5. TOWARDS A PRESCRIPTIVE SEMANTIC BASIS FOR STABILITY

We are aware of the challenges when extending the concept of stability, connecting it to less technical lifecycle properties. While stability is traditionally a well-defined and quantified term in ship design, the informal meaning, ambiguity, synonymy and lack of scientific precision (and therefore standard) for the pre-mentioned ilities raise a yellow flag. This concern does not relate solely to the stability issue, but to the assessment and quantification of all ilities in general. *Flexibility,* for instance, may be connected to the ability *to change* as well as to the ability to *satisfy multiple needs.*

Therefore, to assume that stability can be defined and measured in terms of properties such as flexibility, adaptability, modifiability, scalability and robustness, we need to have a more precise understanding of these terms. Ross and Rhodes (2015) address this issue by proposing a generalization of the change related properties, via a prescriptive semantic basis for these ilities. Starting from the same principle of change agent, effect and mechanism, the authors propose a larger set of twenty categories (elements) for defining a larger set of possible changes in a system. This semantic basis aims to capture the essential difference among change-related ilities, in the following proposed general statement (categories emphasized): "in response to *perturbation* in *context* during *phase*, desire *agent* to make some *nature* impetus to the system *parameter* from *origin(s)* to *destination(s)* in the *aspect* using *mechanism* in order to have an *effect* to the outcome *parameter* from *origin(s)* to *destination(s)* in the *aspect* of the *abstraction* that are valuable with respect to the thresholds in *reaction, span, cost* and *benefit*".

For the illustrative purposes, we can use the aforementioned general pattern to create a statement that intends to capture a more precise meaning to which kind of lifecycle property in stability are we talking about. When talking to *scalability*, for instance, one could state: "In response to a crane failure (*perturbation)* during heavy lift operation (*phase)* in the North Sea (*context*), desire operator (*agent*) to be able to decrease (*nature)* the heeling angle of the ship (*parameter)* from a less stable (*origin*) to more stable (*destination)* position (*aspect)* trough turning on the pumps that feeds the anti-heeling tanks (*mechanism*) in less than ten seconds (*reaction)* that results in the increasing of the volume of the tanks (*effect*), decreasing the heeling angle (*aspect)* to an acceptable value (*destination*) in the ship (*abstraction)* taking less than 30 seconds (*span*), with a energy use (*cost*) inferior than the actual installed system (*benefit*)".

The basis allow then the parsing and decomposition of what one may understand as lifecycle property. When applied to stability, however, this basis can be a bit overwhelming, and simplifications can be done according to phase of the lifecycle studied. When evaluating different mechanisms to overcome unstable conditions, for instance, we may fix the other elements, while leaving the *mechanism* option open, allowing designer to propose and evaluate different alternative paths for meeting the criteria. In this case, considering the example from the last paragraph, rather than proposing the use of anti-heeling tank, one could suggest a second crane to compensate, or adaptations at hull form or at the anti-roll system. In other case, we case vary the causes of failure, investigating which cases of perturbation require robust, scalable and modifiable solutions.

Note also that the concept of *cost* introduced in Section 3.1 is also extended, incorporating common trade-offs that can be used to judge the goodness of a stability performance of a ship, such as *reaction* (timing), *span* (duration), *cost* (resources) and *benefit* (utility).

6. CONCLUDING REMARKS

Much research is currently being developed on the topic of less technical lifecycle properties, and yet many open questions require a more deep study until some consensus is reached as to what this set of agreed upon properties should be like. As for the case described in this paper, our intention was to show that a ship-owner may require a robust vessel system, but in real life situations he or she wants a ship system that can be changed in the future. Market conditions are changing over time and therefore, vessels have to change their capacity and capabilities (internalities) with such externalities. Thus, the way we normally handle the stability of ships from a naval architectural standpoint is not having the process quality of being able to deal with all internalities and externalities to the extent necessary for future flexible/adaptable ship design. Why do people desire higher stability for common initial load cases, while at the same time they know that the vessel over time will be subject to new operational situations not really catered for in the initial design solution space? Stability, may not have a value in and of itself, but rather may represent a significant boundary condition limitation for future adaptability and changeability of the ship at hand. Better prepared for and thought through, in the context of an epoch-era concept framework, stability can be allocated higher value in the future of ship design, than a strict boundary condition, normally,

For the sake of example, let us analyse the main stakeholder and needs of an OSV. It is assumed that the concept of safety considers the protection of human life and environment, and efficiency connects primarily to fuel and the cost (or savings) connected to it. Considering increasingly harsher operating conditions is a necessary precaution in order to reveal adequate stability characteristics when quantifying from a value robustness perspective. The increase of significant wave height, wind speed, and current, all contribute towards a heightened range of loads and motions, consequentially increasing the risk of destabilizing the vessel, minimizing operational windows, and, inherently, depreciating value from a lifecycle perspective. Creating a vessel with sufficient capabilities to counter these effects increases the operational window, but traditionally will also widen the vessel resulting in increased hull resistance and a need for more power to uphold the same speed during transit and on site DP operations. It will also facilitate a higher payload capacity as well as a larger crane capability, again, enabling a wider range of mission profiles. On the extreme case, even if technically and theoretically science and technology are able to design and construct a vessel that does not capsize, such vessel would end up being unfit to operation or, most commonly, unaffordable. Thus, depending on the viewer's perspective regarding the value of stability, certain trade-offs will be virtually inescapable, e.g. payload capacity versus fuel consumption, or level of acceleration (crew comfort) versus operational utilization (up to allowed level of excitation). Using the concept of ilities can then facilitate the understanding and quantification of these stability trade-offs in future vessel design. In other words, a design can be better perceived as more valuable if stability is observed as a lifecycle system property.

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