Designing the Failure for Successful Design

M. Cavallin, PhD Candidate in Sea Sciences and Technologies - University of Genoa, Italy

3200 slices of pizza per day

96 kg of coffee per day

1286 kg of potatoes per day

810 kg of flour per day

341 kg of bacon per day

8571 eggs per day

964 kg of beef per day

1.811.807 liters of water per day

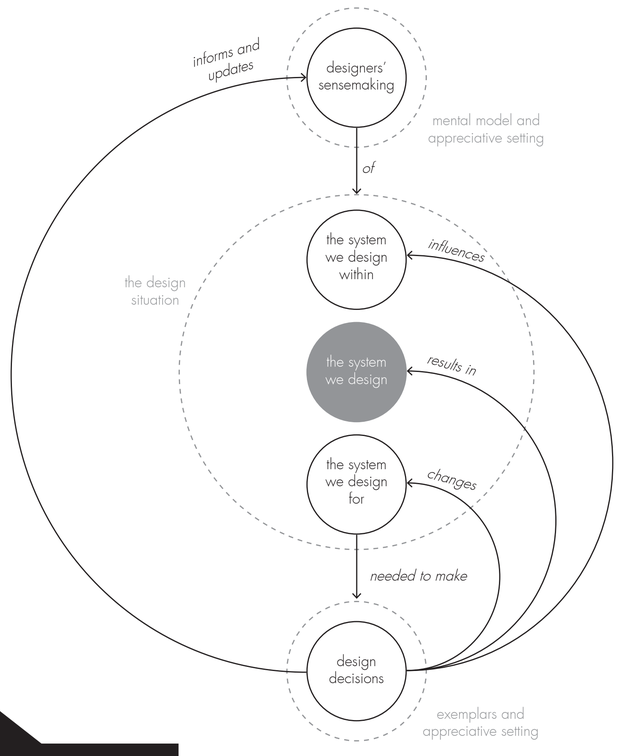
90%
produced onboard

Engineering Tools from a Designer's Perspective

A necessary part of the designer's job is seeing circular economy as a paradigm to design objects or services maximizing environmental and social sustainability while maintaining economical feasibility, specially when the attention to the sustainability issues is mandatory since the beginning of the project. With the multidisciplinary approach being among the most important designer's characteristics, engineering tools such as Failure Mode Evaluation and Analysis, or FMEA for short, can expand the designer's toolkit. While normally used to assess the effects of a part, tangible or intangible, failure on the system of reference, it provides an important tool to foresee potential risks and compare them on a scale giving us the chance to make choices before something happen. The designer can use this evaluation and analysis to assess a particular aspect of the project's material and immaterial components on a numerical scale where each component can be analyzed and compared against the others, sorting out excessively problematic choices in the early state of the project. This concept, applied to the sustainability aspect in the light of circular economy, would therefore give to the designer an idea about how easily a practice or a component can fit among all others not only in the moment of use, but also in a foreseeable future system.

A Systemic Design Model for Complex Systems

Through this systemic model developed by Luras, a design situation can be seen as a system consisting of the system we design, the system we design for, and the system within which we design. The model visualizes the connections between the different systems of the design situation and emphasizes that the development of successful designs depends on an understanding of all these systems, defining the framework conditions of the system we design through the system we design. In this model we should consider the design process as a dynamic system that has to respond and react to each design situation in a flexible and adaptive way. As we gather more data on the systems we design for, we will define the new skills needed for the developing of our design solution. When we learn about the system we design for and the system within which we design, we can expand the boundaries of the system we design and with it expand the scope of our project. With a systemic view of the design situation like this, not only we are able to gain a better understanding of what influences our design, but we can also see how we can influence the world in wider manner than we originally thought through our designs.



(Luras, 2014)

Cruise Daily Pax Consumption

		On land comparison
Energy	10 kWh/d	+213%
Water	280 l/d	+30%
Waste	2,13 kg/d	+1,5%

Cruise ships change their pools' water several times during the day, from 1h to 4h. All this water is taken up by the sea, desalinized and sanitized onboard.

Implementing FMEA in Cruise Ship Design

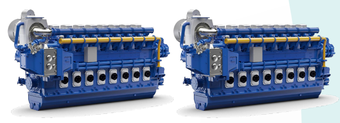
The implementation of concept would be of hepful in the nautical field when designing for a cruise ship that is a complex object containing what can be described as a large community of individuals living in a isolated, heavily controlled environment that routinely interfaces itself with the shore communities where the cruise ship docks. In such environment, the designer is called to provide adequate management and solutions for every resource boarding the ship, tangible or intangible, always with the sustainability in mind. The upsetting chain of events during the COVID-19 pandemic has brought to the surface the profound vulnerabilities of our societies, highlighting the danger they represent: for example, dependence on economic growth, high levels of inequality, and insufficient investment in health systems and scientific research. Defining a new secure, sustainable and prosperous future means supporting a systemic transformation that will require sincere commitment and determination at every level of detail, with companies that can create long-lasting value only by committing to their main collaborators and stakeholders in a mutually beneficial relationship that lasts over time and proactively works towards reaching the objective of a zero-emission cruise industry by the year 2050.
From this point of view, it is important to define accurately the material and energy inflow and outflow, characterized by their quantity and quality, in our scenario of reference using a common language that compares the several options available on a common scale. By applying to those inputs the FMEA methodology within the circular economy framework in a sustainability context, the designer could then highlight the most urgent issues in term of sustainability and begin searching for solution that can have a positive feedback on the overall complex system, the cruise ship, as well as the systems to which the cruise ship connects for the time it is docked.

250 tons of fuel per day
=250.000.000 liters

Heavy fuel oil (HFO) is a category of fuel oils with a tar-like consistency. Also known as bunker fuel, or residual fuel oil, HFO is the result or remnant from the distillation and cracking process of petroleum. For this reason, HFO is contaminated with several different compounds including aromatics, sulfur, and nitrogen, making emissions upon combustion more polluting compared to other fuel oils.

Cruise ship engines and generators

2x Wärtsilä 16V46F



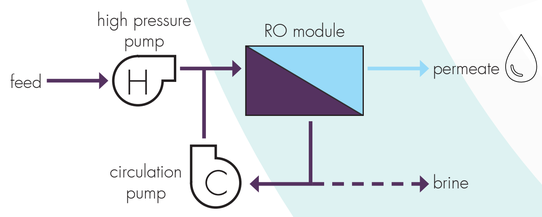
4x Wärtsilä 12V46F

total: 96.000 kW

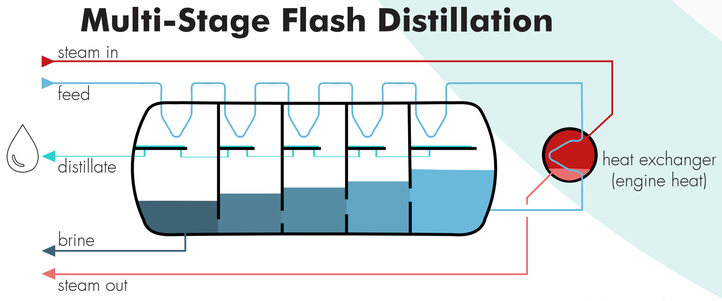
Water onboard

Modern cruise ships are equipped with fresh water production systems that use seawater desalination techniques. Reverse osmosis, a desalination method already widely used ashore, removes impurities and salts by forcing seawater through membranes using pressure created by pumps powered by energy produced on board engines and generators. Another alternative purification process, seawater is evaporated in specially designed evaporators such as multi-stage evaporators which use heat to distill fresh water. The cooling water of engines and generators, which reaches temperatures between 75°C and 95°C, is in this case used as a heat source for the evaporation process, thus functioning in symbiosis with the normal operations of using engines and generators. The resulting condensate has a very low salt concentration. These methods provide a constant supply of fresh water, reducing reliance on coastal connections and allowing vessels to operate in regions with limited infrastructure dedicated to fresh water distribution. However, there is a part of fresh water loaded from the local water network whenever the cruise ship is moored, this practice is called "bunkering" and the water stored in the sterilized boxes on board the ship meets 10% of the water needs on board from port to port.

Reverse Osmosis



Multi-Stage Flash Distillation



Comparison between Onboard and Land use

The major part of cruise ships operating in Europe's exclusive economic zones belong to three large groups: Carnival Corporation and Royal Caribbean and MSC Cruises. In 2017, Carnival cruise ships alone caused ten times more sulfur oxide (SOx) air pollution than all more than 260 million European cars combined, as the fuel used by these ships emits about 2,000 times more SOx than passenger car diesel fuel. Taking into consideration the European scenario, the sum of all cruise ships together also accounts for 15% of the nitrogen oxide (NOx) particles emitted by all European passenger vehicles. In addition, cruise ships release large quantities of carbon dioxide (CO2), phosphorus (P4), soot, heavy metals and other particulates into the atmosphere. The data of the research carried out by the European Federation for Transport and the Environment report that in 2017, 62 kt of sulfur oxides, 155 kt of nitrogen oxides, 10 kt of particulate matter and carbon dioxide in excess of 10 Mt. Sulfur oxide (SOx) emissions form sulphate (SO4) aerosols that contribute to human health risks. Sulfur oxides, fine particles (PM2.5) and nitrogen oxides can accumulate in the tissues of the human body where they come into contact and become the cause of diseases including oncological diseases such as lung cancer, throat cancer, but also chronic bronchopneumopathy obstructive pulmonary disease, cardiovascular diseases and disabling diseases such as childhood asthma, as well as being a cause of acidification of the terrestrial and marine environment.

17.495 kg of waste per day

32%
discharged at sea (food waste)

only ~12%
disembarked AND recycled

disposable plastic food wrapping can be substituted with paper wrapping that can be processed together with food waste to create a brine that can fuel a biodigestor, producing turquoise hydrogen.

From waste to resource

Brine derived from either water purification process can be stored for a brief period of time and then disembraked on the port of arrival not as a waste, but as additional fuel for biodigestors to produce turquoise hydrogen. It has been demonstrated by companies such as EXXRO, who participated in the study, that food waste can be processed with reverse osmosis after a pulping treatment. The process takes out the residual fraction of water from food waste and produces a brine particularly efficient in biodigestors. This would mean that we could go from 32% to 0% of food waste discharged at sea, diminishing risk of bacteriological contamination of the sea water.
Additionally, the brine can be used to produce various chemical compounds including sodium hydroxide, also known as caustic soda. The sodium hydroxide thus produced from desalination can be used to pre-treat seawater fed into onshore desalination plants. By acting on the acidity of the water, fouling of the membranes used to filter salt water can be prevented, which is one of the main causes of interruptions and failures in reverse osmosis desalination plants. Furthermore, it's possible to use brine to produce another important chemical used by desalination plants and many other industrial processes such as hydrochloric acid, which can be made on site from the waste brine using well known chemical processing methods. The acid produced from this process can be used for cleaning parts of the desalination plant, as well as in several chemical production and as a source of hydrogen.

Waste board, waste offboard

Data gathered from several cruise shipping companies tell us that very day each person on board a cruise ship produces 0.013 cubic meters of waste per day, which in case of a cruise ship capable of carrying a minimum of 6870 and 8200 people between passengers and crew means a production of 89.31 and 106.6 cubic meters of waste per day, equal to values ranging from 14657.42 to 17495.02 kg of waste per day, considering an average weight of municipal solid waste equal to 164.12 kg/m3. The transformation from volume to weight, obtained by following the data reported by the cruise companies' environmental reports, coincides with the data of various national environmental reports, where it is calculated that a person produces approximately 2.2 kg every day. Of the total waste produced on board, a very small fraction equal to 0.66% or from 96.74 to 115.47 kg is incinerated, while 32.09%, from 4703.56 to 5614.15 kg, which represents the compostable part of food waste is discharged into the sea. The remaining 67.25%, which counts from 9857.11 to 11765.4 kg, is solid waste that is unloaded in ports: of these, only 19.01% are recovered and differentiated, which translate into a value ranging from 1873.84 to 2236.6 kg per day, while the remaining 80.99% represents the undifferentiated part which contributes with a value ranging from 7983.28 to 9528.8 kg, from which it can be inferred that the percentage of recyclable waste amounts to only 12.78% of the total.

Less plastic, more paper, more hydrogen

By applying a small change in the system we design for (the cruise ship), we could generate a beneficial effect on the system we design within (the ship operation area) which in turn provide a better operativity on the design situation on the whole.
If we were to apply the MARPOL resolution MEPC.220(63) we would be facing the challenge to reduce the packaging at the source (the port) before being lazy and solve the problem once the garbage is already on the ship. This would mean to remove all primary, secondary and tertiry packages of most items boarding the ship during the regular loading/offloading operation while docked.
If we were to limit this practice to provisions, we would need to substitute all the plastic food wrapping with paper-based ones. This practice would allow us to take a larger quantity of garbage produced on board and treat it so that it becomes fuel for land-based biodigestors and turquise hydrogen fuel plants, that could sell back the hydrogen to the ship, indirectly cooperating to the reduction of pollutants due to the fact that exhaust from hydrogen-based fuels are clean of pollutents. Paper based wraps are available for snaks and even dairy products, as exemplified by companies like Nestlé and Granarolo who use paper wrapping for snacks and yogurts.

Università di Genova | Centro del Mare | PROMOSTUDI CAMPUS UNIVERSITARIO LA SPEZIA | WORLD DESIGN ASSEMBLY TOKYO 2023 DESIGN BEYOND